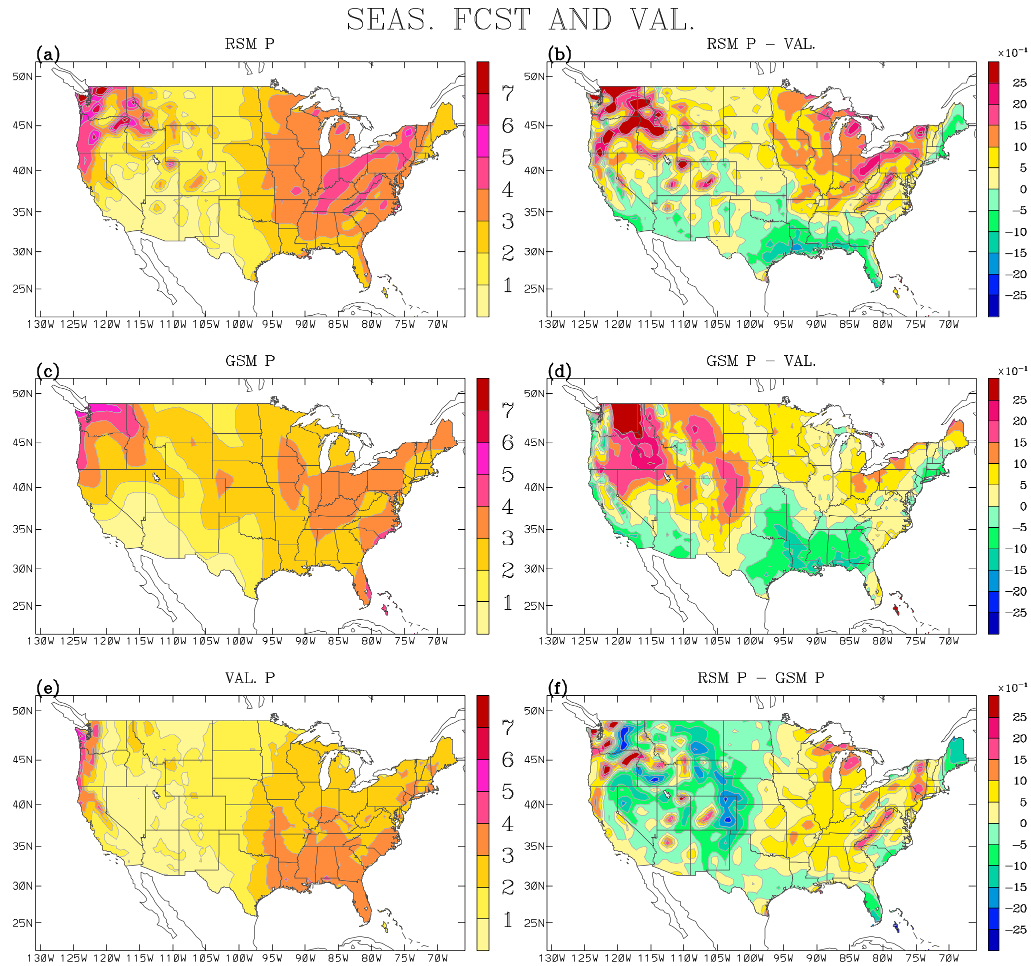

JOINT INSTITUTE FOR MARINE OBSERVATIONS
ANNUAL REPORT
2002-2003



JOINT INSTITUTE FOR MARINE OBSERVATIONS

ANNUAL REPORT

Prepared for the

National Oceanic and Atmospheric Administration

NOAA NA17RJ1231

2002-2003

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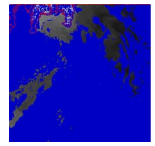
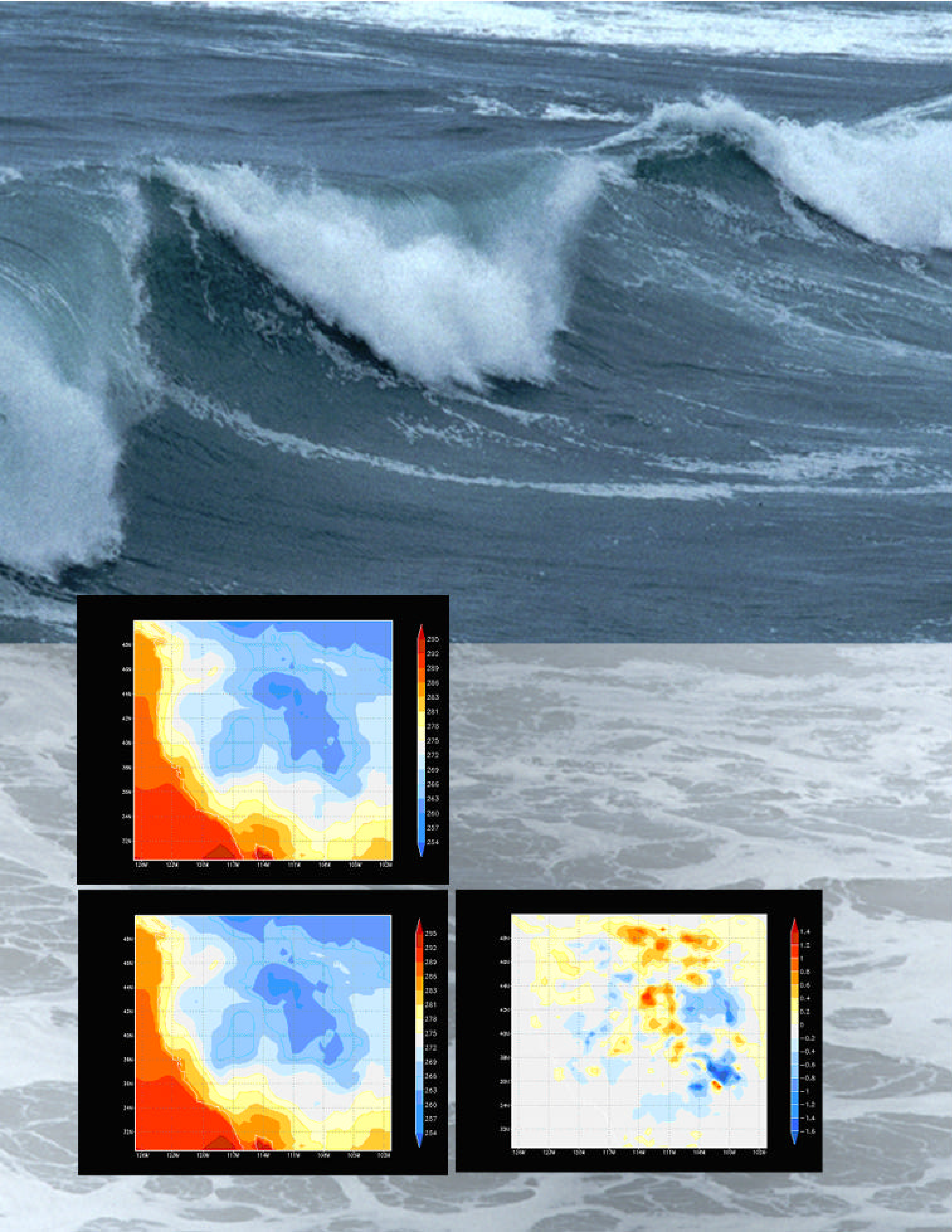


TABLE OF CONTENTS



INTRODUCTION

JIMO research activities of the second year (2002-2003) of the National Oceanic and Atmospheric Administration (NOAA) grant NA17RJ1231 are reviewed in this report. Included are reports from activities of all of the individual and coordinated research projects at the Scripps Institution of Oceanography (SIO) that received NOAA funding. JIMO also manages the NOAA research support, and here reports on, the activities at other University of California (UC) campuses, as well as the CORC/ARCHES program for Lamont–Doherty Earth Observatory of Columbia University (LDEO).

The purpose of JIMO is to provide a framework for enhanced cooperation and collaboration between the SIO and NOAA in oceanic and atmospheric research. Established in 1991, JIMO is one of eleven OAR Joint Institutes within NOAA and is located on the SIO campus of the University of California at San Diego. Comprised of a talented, multidisciplinary scientific and administrative staff, JIMO's experienced leadership is represented by Dr. Peter Niiler who acts as its Director.

JIMO principally serves as a mechanism to bring together the research and infrastructure resources of SIO and NOAA. It also enhances the educational opportunities and breadth of training for students and post-doctoral fellows through close collaboration with the NOAA researchers and by team teaching by SIO, UC Davis, UC Santa Cruz and NOAA scientists at the National Marine Fisheries laboratories. Through these means the next generation of researchers will be trained to understand the special needs of NOAA's mission oriented and operational research methodology.

The specific recognition of the NOAA project support and research collaborators within NOAA are discussed in detail in the reports that follow. During 2001-2002, the NOAA research entities listed below were engaged with SIO in marine, atmospheric, climate, disaster relief and data collection collaborative activities with JIMO:

- Office of Global Programs (OGP)
- Atlantic Oceanographic and Meteorological Laboratory (AOML)
- Pacific Marine Environmental Laboratory (PMEL)
- National Center for Environmental Prediction (NCEP)
- National Weather Service (NWS)
- Climate Data Center (CDC)
- Western Regional Climate Center (WRCC)
- Climate Prediction Center (CPC)
- Southwest Fisheries Science Center (SWSFC/NMFS)

- National Center for Data Collection (NCDC)
- National Marine Fisheries Service (NMFS)
- Pacific Disaster Center (PDC)
- National Weather Service, Alaska Region (NWS)
- National Environmental Satellite Data Service (NESDS)
- Environmental Technology Laboratory (ETL)
- Climate Monitoring and Data Laboratory (CMDL)
- US Antarctic Marine Living Resources (AMLR)
- Forecast Systems Laboratory (FSL)
- Pacific Fisheries Environmental Laboratory (PFEL)
- Climate Diagnostics Center (CDC-CIRES)

RESEARCH HIGHLIGHTS

The research activities of JIMO are summarized by categories of:

A. Climate and Coastal Observations, Analysis and Prediction Research
B. Biological Systems Research
C. Research in Extreme Environments
D. R & D on Observation Systems

Research Highlights of the most recent individual research proposals are summarized in the Tables below and are more fully developed in the body of this report:

A. Climate and Coastal Observations, Analysis and Prediction Research

Consortium on the Ocean's Role in Climate	*Provided sustained measurements of basin-scale surface-temperature and surface-currents with drifters, VOS surface meteorological forcing fields, high-resolution XBT/XCTD sections, and T/S profiling floats. Developed a data-assimilating model of the tropical Pacific and technical improvements of the 'Spray' underwater glider and the Underway CTD.*
Consortium on the Ocean's Role in Climate - Abrupt Climate CHange Studies (ARCHES)	*Provided significant information through modern and paleo observations, modeling of climate changes in the Southern Ocean*

The Argo Project: Global Ocean Observations for Understanding and Prediction of Climate Variability *(A coordinated project)*	*Deployed a global array of 3000 profiling CTD floats, plus a data system that will make all Argo data available to operational and scientific users, in real-time data views of the evolving physical processes that balance the large-scale heat and freshwater budgets of the ocean. Also provided a crucial dataset for initialization and assimilation in seasonal-to-decadal forecast models.*
Global Drifter Program *(A coordinated project)*	*Provided acquisition, technical development, and methods of deployment and distribution of drifter components, sensors and new forms of data in support of the stated tasks of the NOAA Ocean Climate Observing System.*
California Applications Program *(A coordinated project)*	*Developed improved meteorological mesoscale forecasts for fire prevention and management, water resources and hazards, and human health.*
Scripps Experimental Climate Prediction Center *(A coordinated project)*	*Developed an integrated global to regional prediction system by identifying coupled modes of interannual variability and developed and evaluated models capable of predicting these modes. Transferred these prediction methodologies to NCEP, IRI, and Regional Application Centers and applied them to fire danger, hydrologic, and ocean forecast research.*
Mixed Layer Heat Transport in the Tropical Atlantic *(A coordinated project)*	*Maintained an array of 80 drifters in the tropical Atlantic to observe the basin-wide scale tropical velocity and SST fields on time scales of the interannual variations of climate and obtain wind and pressure data within hurricanes.*
Seasonal to Annual Climate Prediction	*Developed seasonal predictability experiments to better understand the role of initial conditions for long-range predictions.*
Measurements of Variations in Atmospheric Oxygen/Nitrogen and Argon/Nitrogen Ratios, and Carbon Dioxide Concentration in Relation to the Carbon Cycle and Climate	*Determined rates of exchange of CO_2 between the atmosphere, oceans, and land biota, and placed constraints on large-scale exchanges of heat between the atmosphere and oceans.*
Evolution of ENSO and Tropical Pacific Climate over the Last Millennium: A Continuous Cross Dated Record From Fossil Corals	*Palmyra Island coral data were analyzed to obtain records to 12th Century.*

Dynamical Forecasting of ENSO: A Contribution of the IRI Network	*Improved operation, usability and evaluation of ENSO forecasting and predictability to forecasting application centers.*
North Pacific Climate Variability and Steller Sea Lion Ecology: A Retrospective and Modeling Analysis	*Examined the potential role that climate change may have played in the decline of Steller Sea Lions in the Gulf of Alaska as modeled by wind stress differences before and after the 1976/1977-climate regime shift in the north Pacific Ocean.*
Project Asian Brown Cloud-Air Pollution in the Asia Pacific Region: Impact on Climate and the Environment-Integration of Science, Impact Assessment, Policymaking and Regional Capacity Building	*Established climate observatories in the Maldives and Nepal.*
The Summertime Atmospheric Hydrologic Cycle over the Southwestern US and Northwestern Mexico	*Developed and analyzed a large archive of regional modeling simulations of daily surface observations of climatological summertime precipitation for the US Southwest. Also, developed a comprehensive water and energy budget synthesis for the Mississippi River Basin*
NCEP Ensemble Seasonal Forecast Verification and Application Project: A Contribution to the ARCS/IRI Network	*Initiated model integrations at SIO to evaluate NCEP seasonal forecasts*
Off-Campus Satellite Data Processing	*Incorporated ocean color data to analysis of AVHRR in small coastal eddies*
Forecasting Climate Changes over North America from Predictions of Ocean Mixed Layer Anomalies in the Tropical and Mid-Latitude Pacific	*Explored the underlying physics of a two-tiered prediction system for climate anomalies over North America for lead times of seasons to years.*

IRI/ARCS Regional Modeling Applications Project	*The applications of regional forecasting have been extended to China and Taiwan*
The Atlantic Ocean: Emerging Tropical Circulation with an Emphasis on Connections to Mid-Latitudes	*Completed the calculation of the time-mean circulation and absolute sea level of the North Atlantic for 1992-2003*
Ensemble Simulations of Observed Climate Variability: Verification Methods and Forecast Simulations	*Researched methodologies of interpretation of forecast ensembles were investigated*
Climate, Water and Water Chemistry -- A Sierra Nevada Observation Program to Understand Important Changes in California Water Resources	*Built and developed a high-density network of hydrological and meteorological stations in Yosemite National Park and in the Santa Margarita Ecological Reserve.*
CLIMAS – CAP Partnership Activities	*Characterized the network of key information flows for decision nodes and calendars, through which strategic planning and economic analysis of climate impacts on fire management and climate information occurs.*
Evaluation of the Use of 20-30 Year Climate Forecasts To Improve Regional Long-Range Energy Master Plans in Southern California: *(A Private Sector/University Effort)*	*Using reality-controlled regional projections of global climate change in energy infrastructure development master plans.*
Travel Support for International RSM Workshop	*The 4th International Regional Spectral Model (RSM) Workshop was hosted by Los Alamos IGPP and SIO-ECPC, IRI and OGP/NOAA, was held at Los Alamos, NM, 7/31-8/02, 2002. Over 25 participants from 12 countries attended*

B. Biological Systems Research

North Pacific Right Whale Acoustic Recording ***and*** **Acoustic Studies of right whales in the Bering Sea** ***and*** **Marine Mammal Acoustic Recording Packages**	*The objective of these projects were to make acoustic recordings of north Pacific right whales (Balaena glacialis) in the Bering Sea region.*
Collection and Analysis of Cetacean Sounds Collected in the Antarctic	*Acoustic recordings of whales and dolphins in the Antarctic were made in collaboration with the Australian Antarctic Division.*
Acoustic Survey of Marine Mammals off Eastern Seaboard Using Two Towed Arrays	*Developed a passive two-dimensional acoustic tracking algorithm for free-ranging dolphins*

Climate-Driven Bottom-Up Processes and Killer Whale Abundance as Factors in Stellar Sea Lion Population Trends in the Aleutian Islands	*As part of a collaborative research project measurements of primary productivity and species composition, abundance and food habits of seabirds in the Aleutian Islands were conducted.*
A Joint Program for Training and Research in Marine Resource Management Modeling	*Improved training of quantitative fishery scientists by establishing a graduate program of study in quantitative marine ecology, resource economics, population dynamics and estimation, and fishery biology.*
Phytoplankton Studies in Support of the U.S. Antarctic Marine Living Resources (AMLR) Program	*Documented the magnitude and quality of the food reservoirs available to grazing zooplankton, and improved the understanding of the interrelationships between the physical, chemical, and optical regimes that maintain these throughout the summer season.*
Marine, Physical, Hydrographical, and Chemical Properties and Phytoplankton of the Antarctic Peninsula: A Time Series 1990-2002	*Collated twelve years of time-series data collected during the Antarctic Marine Living Resources (AMLR) program (1990-2002) into a single unified database. The concern of this project included only data related to phytoplankton dynamics and physical oceanography.*
The Center for Stock Assessment Research (CSTAR)	*Training of undergraduate, graduate, and post-graduate students in the science associated with the problems of assessing the numerical abundance, spatial and size distribution, and reproductive status of commercially important fish species, with the goal of increasing the pool of quantitatively trained scientists for NMFS*
Genetic Population Structure of Central California Coastal Salmonid Populations	*Determined the demographic genetic population structure of extant runs of Coho salmon, Chinook salmon and steelhead in the Central California Coastal region for hatchery operations.*
Ocean Estuarine Physiological Ecology of Salmon	*Determined the relationship between salmon dynamics and environmental factors in San Francisco Estuary for the first 5 years of the study (1995-1999). Growth and energy status positively related to zooplankton biomass and residence time.*
Cooperative Studies of Pacific Coast Salmon NMFS/UCSC	*Conducted research on exploited salmonid stocks in California to better understand their population dynamics, which includes life history characteristics, population estimation, and modeling. This scientific focus enables application of sound management practices.*
Estuarine and Ocean Physiological Ecology of Salmon	*Determined spatial and temporal variability of physiological processes, ecological interactions, and the influences of environmental variables on juvenile salmonids in estuaries and the coastal ocean of California.*

C. Research in Extreme Environments

Operational Volcanic Ash Aviation Hazards: Analysis of Mt. Cleveland and Mt. Hekla Eruptions	*Examined the failure of operational satellite-based airborne volcanic ash detection algorithms in support of both commercial and civil aviation.*

D. R & D on Observation Systems

Joint Project Agreement Concerning CSRC System	*Investigated California's crustal motions that cause unique spatial referencing questions for establishing a modern statewide geodetic control network.*
Implementation of a Real-Time Precipitable Water Capability Using the Global Positioning System	GPS receivers distributed over the continental U.S were used as to estimate precipitable water in the atmosphere for improving numerical weather prediction models. These data also generate quality-controlled, hourly orbital estimates for the GPS satellites at SOPAC in hourly increments below the 25 cm level.

RESEARCH TASKS AND THEMES

RESEARCH TASKS

Under the Joint Institutes cooperative agreement five tasks are defined by NOAA which allow JIMO to group and account for research more easily. The tasks are identified as follows:

Task 1. Administration

Task 1.1 is for administration of the Institute and includes support for the JIMO Director's office and minimal support for the staff. It includes costs associated with annual scientific meetings that are deemed important for the JIMO Director to attend, workshops sponsored by JIMO, web-site development, funding for the Joint Institute Directors and administrative board meetings and formal reviews.

Task 1.2 is to support the post-doctoral fellows and provide a visiting fellows program. It is intended to be a very visible mission of this institute. We envision that each of the themes will support post-doctoral fellows and visiting fellows. They would be allowed the freedom to work with a variety of JIMO scientists on a rotational basis, crossing disciplines. Graduate student support, if appropriate, is provided in individual investigator proposals as funded. The visitors program may invite NOAA scientists to assist in teaching courses to graduate students.

Task 2. Joint NOAA Laboratory/JIMO Programs

The collaborative proposal has NOAA and Scripps working together jointly on research themes. These proposals are broken out by theme and include all research associated funding including the funding of salaries, benefits, as well as instrumentation and computer time.

Task 3. Individual Science Projects

A cooperative research proposal is one which is specific to the JIMO theme areas, but is submitted by individual scientists of JIMO. The distinction here is that there is a loosely bound tie between individuals working on similar themes or topics. It is also seen that this may be a mechanism for developing collaborative proposals in the future, as well as encouraging new areas of research to develop. These proposals are broken out by theme and include all research associated funding including the funding of salaries, benefits, as well as instrumentation and computer time.

Task 4. JIMO Cooperative Research Programs with Other Research Institutions

In support of NOAA's Mission and Strategic Plan, JIMO's Task II was developed to strengthen and coordinate our University of California's multi-campus environment by establishing a regional concept for marine and atmospheric sciences. Proposals would include research conducted at other University of California (UC) campuses, such as UC-Santa Cruz and UC-Santa Barbara, as well as other academic institutions, and non-profit research institutions, when appropriate, in support of JIMO and NOAA research missions, and in meeting NOAA's strategic goal of environmental stewardship. These proposals will include a program development cost (PDC) that will support the Visiting Fellow/Post Doctoral Fellows program at JIMO/SIO (Task 1.2).

Task 5. JIMO Research Infrastructure Proposals

Because proposals relevant to JIMO will be using a variety of observation platforms in order to carry out their research objectives, we have included an infrastructure task by theme area which includes proposals for platform and specialized research facilities. We anticipate that a number of other agencies will be partners in supporting the platform infrastructure.

RESEARCH THEMES

Four thematic areas form the basis for research performed in partnership with NOAA. Each of these areas are relevant to the NOAA mission elements, particularly those of environmental assessment and prediction and environmental stewardship.

(A) Climate and Coastal Observations, Analysis, and Prediction Research

The primary goals for this research theme are to understand the remote forcing functions that control fundamental ocean and atmosphere processes and to utilize this knowledge for prediction. For JIMO the basis of interest is primarily the Pacific, although other areas may be studied as a model or to put the Pacific information in context (e.g., Indian, Arctic). These thrust areas include the following:

Ocean observations will utilize many of the in-place observation systems such as the TAO/TRITON array, drifters, floats, and satellite remote sensing to provide information for models on climate prediction at the ENSO to decadal space and time scales. Defining the ocean's role in governing the climate necessitates the expansion of large-scale, long-term field observation and modeling efforts begun over the past few years in the Pacific to the global system. A networking of these programs in the University California to NOAA research projects is essential to the success of the effort. Deep ocean circulation constitutes another emphasis of this theme area that stresses the fundamental processes governing geochemical pathways. Deep ocean characterization, including deep-water formation and tracking that uses state-of-the-art floats, moorings, as well as unique observations and monitoring techniques, such as chemical or geochemical tracers for signature analysis. In addition, proxy data is used in providing the past climate variability.

Climate prediction and modeling is concerned with the development and evaluation of a wide range of climate models. Of interest are global atmospheric models, regional atmospheric models, global and basin ocean models, land surface models concerned with surface hydrology and fire danger. JIMO goal is to eventually develop coupled atmosphere, ocean and land models that provide greater predictability than is possible with current uncoupled models of these processes. Defining the limits of predictability for these systems requires extensive computational resources and collaborations with NOAA centers that are engaged in similar research efforts.

Coastal ocean assessment and forecasting seeks to measure and define the basic processes in the near shore ocean (eddies, upwelling, currents), and atmosphere (fog, inversions, UV). Research is required to characterize the feedbacks between the coastal ocean and atmosphere and to assess the historical variability. The ultimate goal is to be able to perform short term predictive modeling for such areas as natural hazards (oil spill), navigation and commercial recreation and the recruitment of pelagic stocks. Considerations must be given to mesoscale to small scale processes and temporal scales of hours to decadal. The 70-year, daily SIO pier data and shore stations measurements, in situ moorings, stationary platforms, as well as aircraft and other remote sensing observations will be used to generate the necessary scientific data.

Atmosphere and ocean/atmosphere exchange will continue and strengthen research of mutual interest to SIO and NOAA scientists. These studies include: "teleconnections" and other large-scale meteorological phenomena; air-sea physical and chemical exchange processes; and, global distributions and trends of climate-forcing due to anthropogenic and biogenic atmospheric trace gases and aerosols.

Biogeochemical cycles need to be further defined for their implications for global climate change. These include ocean, atmospheric and terrestrial components of the carbon cycle, oxygen cycle, UV chemistry, and trace metals among others. In addition, proxy data such as ice cores will be used to measure a wide array of paleo-climatologically important physical and chemical parameters such as the CO_2 content and isotopic composition of air recovered from bubbles trapped within the ice.

(B) Biological Systems Research

The population dynamics and physiological ecology of marine ecosystems is a complex research question, which involves finely tuned long-term observation programs. Process oriented research at the system and individual level lead to the fundamental understanding of the physiology and life cycle dynamics of important species. This theme area includes the following four thrust areas:

Fisheries research analyzes long term trends of ecosystems where fisheries are concentrated using data bases such as the four-decade-old CalCOFI program, examines the schooling and behavior of selected species, develops new methods of stock assessment, and forecasts and investigates the effects of fishing activities on the environment. Food chain dynamics is of particular interest in the success of larval populations. Basic studies on the physiology and behavior of such species as sharks are of particular interest. Paleo-oceanographic techniques for the reconstruction of past distributions and abundances are necessary to help decipher the natural variability of the selected commercially important species.

Marine ecosystem monitoring and forecasting examines the distribution and abundance of organisms at all levels of the food chain in relation to their environment, primarily the physical and chemical structure. Ocean currents as transport routes, episodic events as introduction mechanisms, migration routes and impact of climate change on species distributions is featured. Patchiness in the vertical as well as in the horizontal due to mesoscale and small-scale structure is a research topic.

Protected species dynamics focuses upon the refinement of acoustic sensing and tagging methods, the study of population dynamics, habitat utilization, foraging habitats, and diving physiology of marine mammals. In addition, the impact of anthropogenic sound on the migration routes and behavior of these mammals is a study area necessitated by the Marine Mammal

Protection Act and the increase of anthropogenic activity such as shipping, drilling and general development of the near shore zone.

Protected areas and reef systems ecology seeks to do research aimed at protecting marine habitats from anthropogenic change. Reef habitats in particular may harbor clues to past changes in climate in their physical structure. These sensitive systems harbor a diverse community and can represent a historical record of past climate events. In many cases, these habitats are threatened and in need of mitigation.

(C) Research in Extreme Environments

A third theme area for the JIMO is centered on research in extreme environments. In all of the following cases, research necessarily includes the development or rugged sensors, platforms and data transmission devices to perform under adverse conditions. The "adverse conditions" range from ice to high pressure, high temperatures, fog, huricanes, sulfur pools and anoxia to name a few. The theme area is divided into four major thrusts:

Sea-floor processes emphasize the characterization of unexplored environments and subsequent process definition in these newly described habitats. Hydrothermal vent processes continue to be an area of interest for biologists, chemists and geologists. The physiology and physiological ecology of these organisms such as extremophiles and sulfur bacteria are of interest. Vent chemistry and heat transfers into abyssal waters are areas of potential study. Ridge processes and associated crustal dynamics constitute a significant fraction of the proposed research. Methods for the better characterization of these processes or for shelf topography of the seafloor are included.

High-latitude research defines the functional dynamics between Antarctic krill populations, their environment and their predators use bioacoustic and conventional technologies to acquire data for input into pelagic ecosystem models. UV radiation and ozone abundance monitoring and modeling and prediction of health effects will be a major research topic in this thrust area. Cycles and controls of ocean production in high latitudes extending into the southern ocean and characterization of seasonal circulation patterns in the Arctic and Antarctic are included in this topic area.

Strongly forced systems studies focuses on monsoonal dynamics and variability, hurricane prediction and observations and their tracking and modeling, and research in hazard impacted areas.

Toxic environment research takes place at the limits of biological survival. Anoxic waters, sulfur pools heavy metal contaminated sediments present difficult regions for measurement. Most of the extreme conditions are due to chemical or geochemical processes causing noxious conditions.

(D) R&D on Observation Systems

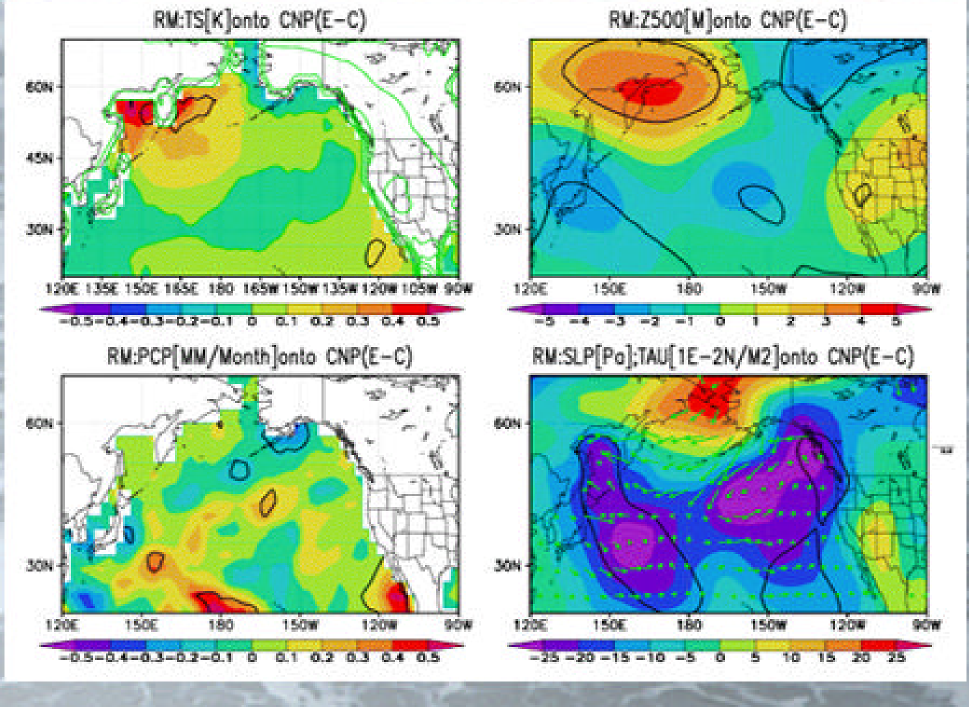
The fourth theme area for research is unique in its cross cutting nature. Observation system development ensures that there is state of the science research and development efforts brought to bear on the scientific problem. Platforms and instrumentation re-engineering, observing system reconfiguration, and data merging and display techniques modification takes place here. This is the engineering component of a smoothly operating research effort.

Extreme technology development focuses on rough weather deployable mooring, low detection optical/chemical sensors, high pressure/heat tolerant probes, optic/acoustic nets/pens for stock assessment, queryable communications, minimal/self tending arrays, non-fouling chemical sensors, aircraft deployable sensors/drifters/buoys. Improved ROVs and submersibles are among the technologies that need to be developed, refined or redesigned. Acquiring enabling technologies and platforms such as the potential addition of new SIO submersibles will significantly expand the research capabilities of the JIMO.

Systems engineering evaluation allows a probing look at the optimal design at the observation system as a system rather than a sum of the components. The goal is to evaluate the existing observing systems and optimize the system at all levels including sensor, instrumentation, platform and sampling design and to reassess the systems architecture at various intervals. Such an ongoing in-depth look at observing systems will ensure the evolution of the systems as the state of the art of science develops.

Information systems management will be in close collaboration with the NOAA units that have direct responsibility for this function. Quality assurance and control of data as well as the dissemination of that data to scientific users is a critical function.

Systems modeling and simulation is an essential part of the information transfer of the research. Here the data is presented to give the most information to the potential user. The scientific models may be coupled with socio-economic or development models for use in policy making. The appropriate simulation and animation techniques can also help in the dissemination of the data for educational purposes to the public or K-12 level.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CONSORTIUM FOR THE OCEAN'S ROLE IN CLIMATE

Russ Davis
Scripps Institution of Oceanography

TASK/THEME: 2A

SUMMARY

The broad objectives of the Consortium on the Ocean's Role in Climate (CORC) are: (1) to maintain critical elements of an ocean climate observing system in the Pacific Ocean, and (2) to develop new observational and data assimilation methods for documenting and diagnosing climate change in the ocean.

Overall CORC progress in this period met expectations. Basin-scale surface-temperature and surface-current measurements by drifter, VOS surface meteorological observations, high-resolution XBT/XCTD sections, and float T/S profiling were carried out at the pace proposed. Development of a data-assimilating model of the tropical Pacific is advancing, as are technical improvements of the 'Spray' underwater glider and the Underway CTD.

RESEARCH ACCOMPLISHMENTS

Sustained Observations

DRIFTER OBSERVATIONS (PEARN N. NIILER)

SVP drifters were ordered from Technocean, Inc. (50) and Clearwater, Inc. (50). These were shipped to AOML and are now being deployed in the tropical Pacific. Sea Bird SEACATs were attached to eight SVP drifters. These were deployed into the East China Sea to follow the Yangtze River flow. One unit, recovered after 31 days at sea, showed that the bio-fouling protection worked well and recalibration showed less than 0.01 psu drift. The objective of this technical development is to provide SSS observations that are stable for more than 300 days from the SVP drifters. SSS observations from the global SVP drifter array will be used for calibration and validation of the AQUARIUS SSS satellite. Testing of the SEACATS is continuing in the East China Sea and the North Pacific.

DRIFTER DATA ANALYSIS (PEARN N. NIILER)

A dynamically balanced absolute sea level field for the global ocean has been calculated (with Nikolai Maximenko of U. Hawaii and Jim McWilliams of UCLA) using the drifter data in a global momentum balance. The sea-level distribution (Figure 1), derived independently from density observations, compares well with dynamic eight relative to 1000 m derived from Levitus, 94. All the recirculation regions associated with the seaward extensions of western boundary currents are clear in the sea-level map. The accuracy of the absolute dynamic height computation is now under investigation.

P. Niiler presented a paper entitled: "The Observed Global Surface Momentum Balance and the Absolute Sea Level" at the EGS/AGU meeting in Nice, France in April 2003. Surface velocity data were transmitted to the CORC data assimilation group each six months and were assimilated into the 1° resolution CORC model of the tropical Pacific.

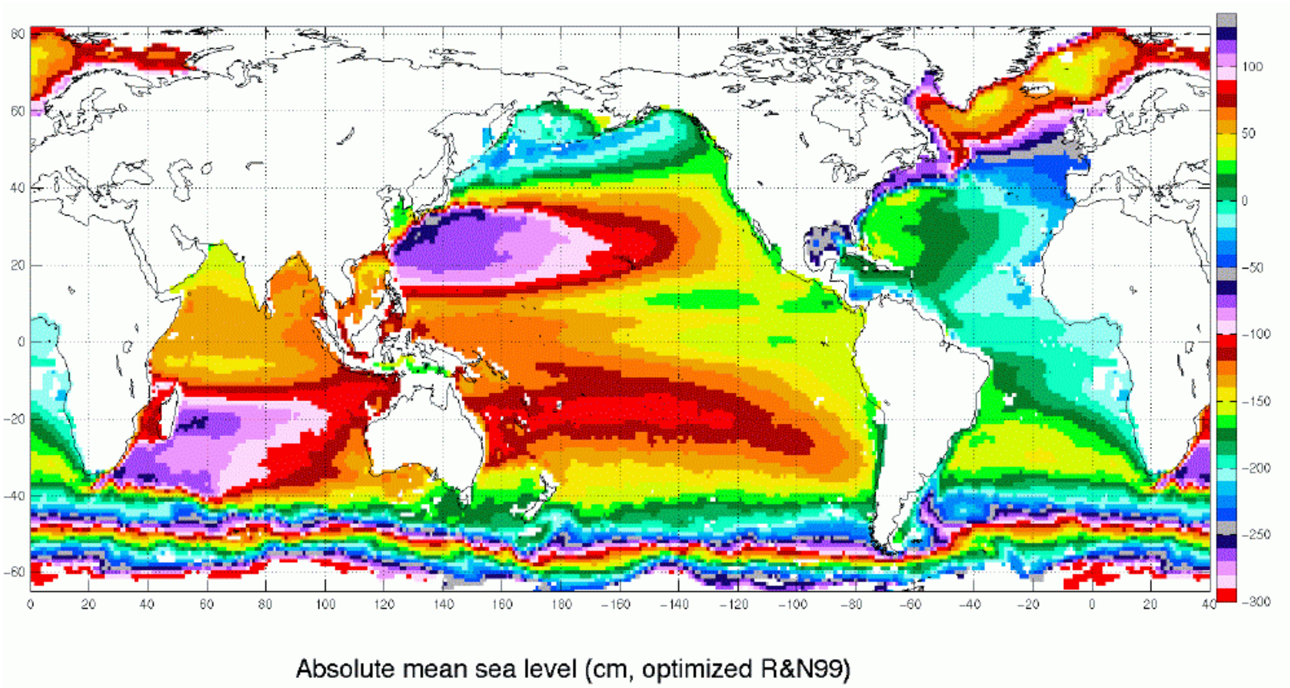

Figure 1. Global absolute 10-year mean sea level computed from the momentum balance and the global drifter observations of time-mean circulation from 1992-2002.

HIGH-RESOLUTION XBT/XCTD OBSERVATIONS (DEAN ROEMMICH)

Quarterly High Resolution XBT/XCTD (HRX) transects have been collected along the basin-spanning routes New Zealand-to-Callao (PX50) and Honolulu-to-Coronel (PX81). Along PX50, transects during the past year were in June, August, and November of 2002, plus January 2003. There is no longer direct shipping between New Zealand and Valparaiso, Chile, so the eastern endpoint of this line was shifted to Callao. Along PX81, transects were in May, July, and October of 2002, plus February 2003.

During each cruise, XBT temperature profiles (0-800 m) are collected at spatial intervals from 10 km near ocean boundaries and the equator, to 40 km in interior regions – resolving boundary currents and interior eddies to enable ocean-spanning integrals of geostrophic transport. Sparse XCTD profiles are obtained to observe large-scale variability of the T/S relation. In addition to the basic XBT/XCTD datasets, we provided technical support for installation and maintenance of CORC VOS meteorological systems (R. Weller, PI), for deployment of Argo and CORC floats, and for testing of new instruments such as the Sippican T-12 XBT (2000 m, research quality). Major software development work is in progress to convert the XBT autolauncher system from MS-DOS/Sippican MK-12 data acquisition to Windows/Sippican MK-21. This conversion is being done collaboratively with NOAA/AOML. HRX data are displayed and made available for download (as complete transects) at http://www-hrx.ucsd.edu/ HRX data are transmitted on the GTS immediately after collection for real-time applications.

We are still in the process of initiating a new HRX line in the Indian Ocean, from Fremantle to Durban, in collaboration with CSIRO Marine Research (Australia). The line is a high priority one in the global HRX network, but it has taken an extended time to identify appropriate shipping and obtain permission for a ship rider. The previous CSIRO principal investigator was promoted to a management position, and a new CSIRO partner, Helen Phillips, has begun work on the project. The first cruise along this route is planned for July 2003.

ANALYSIS OF TEMPERATURE AND SALINITY VARIABILITY (DEAN ROEMMICH)

HRX data are being incorporated into both regional and Pacific basin-wide analyses. Willis *et al* ., (2003) developed a new technique for combining XBT and satellite datasets, and applied it regionally in the southwestern Pacific. This is now being followed up with a study of global interannual heat storage. The following publications have been completed.

Roemmich, D., J. Gilson, and 14 others, 2001. Interannual variability in Pacific Ocean circulation and transport during the 1990s. Abstract, *WOCE Transport Workshop*, Southampton, U.K., July 2001.

Sutton, P. and D. Roemmich, 2001. Ocean temperature climate off north-east New Zealand. *NZ Journal of Marine and Freshwater Research, 35*, 553-565.

Roemmich, D. and W.J. Gould, 2003. The Future of *In Situ* Climate Observations for the Global Ocean. *CLIVAR Exchanges Newsletter* (In press.)

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SURFACE METEOROLOGY FROM VOLUNTEER OBSERVING SHIPS (ROBERT WELLER)

This program seeks to improve the surface meteorological and sea surface temperature observations made by U.S.Volunteer Observing Ships (VOS). During this period we continued to build the surface meteorology program and to collaborate with VOS Expendable Bathythermograph (XBT) investigators on testing and evaluating data from modules developed during the program.

On 22-26 July 2002, instruments were replaced on the Columbus FLORIDA in Long Beach, CA with the support of Carrie Wolfe and Brian Tufts of SCMI (Southern California Marine Institute).

Modules were returned to WHOI for downloading the 1-minute sampled data and calibration. Processed data from February to July 2002 was sent to SIO for review

On 19 – 25 Oct 2002, instruments on the CSX ENTERPRISE were replaced in Oakland, CA by Frank Bahr and Dave Hosom. There was some delay due to the dock strike. The modules were returned to WHOI for data retrieval and calibration, and processed data for the April to October 2002 time was posted on a web site for to SIO for review. Frank Bahr is now responsible for the CORC VOS fieldwork and the data processing at WHOI. The data is at

http://science.whoi.edu/users/seasoar/vos/index.html.

Fabrication of an AutoIMET system for a third Pacific ship was completed in March 2003 and will be installed on the Columbus Florida in June 2003. The ASIMET stand-alone modules on the CSX Enterprise and Columbus Florida will be upgraded to the AutoIMET configuration in 2003. This system costs less than ASIMET and provides the capability to communicate with the NOAA SEAS system for display on the bridge and for automatic insertion of meteorological data into the SEAS reports. The last of the converted systems will be available for installation on the third Pacific ship in 2004 as planned. All of the VOS systems in the Pacific and Atlantic will use the AutoIMET configuration to benefit from commonality of parts and better logistics.

On 13 – 17 Jan 2003, instruments were replaced on the Columbus FLORIDA in Long Beach after the bow mast was damaged at sea. Data for July to November 2002 was posted for SIO for review. On 19 – 23 May 2003 instruments will be turned around on the CSX ENTERPRISE in Oakland. Old modules will be upgraded to the AutoIMET configuration. On 23 – 26 June 2003, instruments will be replaced on the Columbus FLORIDA in Long Beach. Personnel from WHOI and Harris Acoustic Products will install the AutoIMET system including the HullCom (acoustic modem) for near real time SST. The old modules are to be upgraded to AutoIMET.

ANALYSIS OF SURFACE FLUX FORCING OF CLIMATE VARIABILITY (DAN CAYAN)

Typically, monthly-mean turbulent and radiative flux components are estimated using aggregates of bulk formulae calculations over all of the observations each month. To avoid errors in visual sky cover observations and occasional visual sea-state surface wind observations taken after dark, we are recalculating the flux components using only daytime observations. This daytime-based flux dataset begins in 1950 and is updated through 2002. Because other investigators will prefer to apply their own menu of bulk formulae, we are saving the individual weather variables required to calculate each flux component.

Daytime-only observations have some important differences from the nighttime set. A subset of the observations over 165^{0}W-105^{0}W, 15^{0}N-35^{0}N indicates that daytime cloud cover reports (about 3500 to 4500 observations per month, on average) are higher than those observed after dark (about 3200 to 4000 observations per month) in most months (by about 0.4 oktas or about 5%). In most months, daytime wind speeds are higher by about 0.4m/s or about 5%. The air near the sea surface warms and cools diurnally more than does the temperature of the ocean surface, and consequently the daytime sea-surface-temperature minus air-temperature (ΔT) is less than that in the nighttime by 0.4^{0}C to 1.0^{0}C. Specific humidity does not vary much from day to night, but in winter, daytime sea surface saturation specific humidity-minus-air specific humidity (ΔQ) is greater than that in the nighttime by a few tenths of g/Kg. The Table below summarizes the differences of day vs. night for two winter months and two summer months.

Flux Components in 165-105^{0}W, 15-35^{0}N from 1950-2002 COADS data

	Cloud Cover (oktas)		Wind Speed (m/s)		ΔT (^{0}C)		ΔQ (g/Kg)	
	day	night	day	night	day	night	day	night
January	5.1	4.7	7.7	7.3	0.9	1.3	4.1	3.9
February	5.0	4.6	7.5	7.2	0.7	1.2	3.9	3.7
July	5.2	5.3	6.4	6.5	0.0	0.9	4.1	4.3
August	4.9	4.9	6.3	6.3	0.0	1.0	4.5	4.7

Implications for using surface fluxes from the daytime subset, instead of all of the marine weather observations appear to be: (1) lower net (into ocean) shortwave fluxes, (2) greater latent flux, and (3) greater sensible flux heat losses from the ocean. We are working to compute bulk formula fluxes from the daytime and nighttime data, and will then evaluate the variability within this dataset.

SALINITY AND TEMPERATURE PROFILING FLOATS (RUSS DAVIS AND ROBERT SCHMIDT)

The CORC profiling float program was a predecessor to the Argo program. Since Argo is fully operational and beginning to cover the tropical Pacific, this was meant to be the last CORC period for float deployments. Unfortunately, performance of SOLO floats in both CORC and Argo was poor through 2001. During a yearlong hiatus in deployments, SIO carried out a thorough re-design of several SOLO subsystems. Early results indicate the main problems have been solved and SIO Argo and CORC deployments were re-started in late 2002. The thirteen SOLO profiles proposed for construction in 2001-2002 were deployed from a TAO cruise in March 2003. WHOI has ordered 20 Sea Bird CTDs to compensate SIO for CTDs borrowed for earlier deployments. These have been delayed by issues with anodizing the top caps.

WHOI is building, for deployment by SIO, nine floats with FSI CTDs and Orbcomm data communication. Production has been plagued with component supply issues that have been finally overcome. One advantage of the FSI CTD over the Sea Bird is superior dynamic response. This has emerged as a problem with Sea Bird CTDs in the tropical Pacific, where very strong vertical temperature gradients cause salinity spiking. In order to understand and help correct this problem WHOI will be testing the Sea Bird CTD in their dynamic response calibration tank this year.

New Developments

DATA-ASSIMILATING SYSTEM FOR THE TROPICAL PACIFIC (BRUCE CORNUELLE, ART MILLER AND DETLEF STAMMER)

CORC believes that full exploitation of climate observations will depend on developing a data analysis framework that can blend statistical information about scales and variance levels with the dynamical constraints of modern numerical models in order to describe and diagnose climate variability. During the reporting year the assimilation element of CORC expanded its activities aimed at simulating the tropical Pacific circulation during the 1990's. For that purpose, the MIT ocean-GCM was set up in a trans-Pacific strip between $\pm$ 25^0 latitude, with boundaries nested into the global ECCO state estimation effort. Both models were driven by various different forcing products. The model was tested in this configuration with 1/3^0 and 1/6^0 horizontal resolution against CORC XBT sections and drifters data, TAO profiles,

and hydrographic sections. In addition, altimetry and TMI SST fields were used during the comparison. While the $1/3^0$ model seems to do a good job in simulating observed mean and variable upper-ocean current structures, a $1/6^0$ model is required to simulate realistic tropical stratification and intrusion features. Two papers are in preparation showing the resulting model-data comparisons and analyzing the dynamics of tropical instability waves.

Additional efforts went into the preparation of assimilation runs. As a result, we are now prepared to start our first full assimilation runs in the tropical Pacific. The control parameters to be adjusted during assimilation will be the initial conditions, surface forcing, and open boundary conditions. By additionally including ocean-mixing parameters in the control vector, we will be able to estimate horizontal and vertical viscosity and diffusivity as part of the estimation process.

Along the equator, changes in oceanic biology forced by altered physical oceanographic conditions have recently drawn considerable attention as possibly playing an important role in modulating SST through altered absorption of incoming solar radiation and concomitant mixed-layer depth changes. Development and testing of an NPZD-type (nitrogen-phytoplankton-zooplankton-detritus) ecosystem model suitable for the CORC MIT model has commenced. Prototype ecosystem models are now being tested in a physical model of the California Current System that has been shown to mimic observed decadal-scale (1949-2000) changes in temperature, currents, and thermocline depth (Di Lorenzo et al., 2003). Once the wrinkles are ironed out of the prototype ecosystem model, it will be included in MIT-model simulations of the tropical Pacific. A recent CORC-acknowledged paper is

Di Lorenzo, E., A. J. Miller, N. Schneider and J. C. McWilliams, 2003: The warming of the California Current: Dynamics, thermodynamics and ecosystem implications. Journal of Physical Oceanography, sub judice.

UNDERWATER GLIDERS FOR MONITORING OCEAN CLIMATE (RUSS DAVIS)

While profiling floats make feasible the widespread ocean sampling needed to observe climate variability, they do not allow the maintenance of designed observing arrays, because float positions cannot be controlled. Underwater gliders are buoyancy propelled AUVs that can navigate at speeds of 25-50 cm/s with ranges of several thousand kilometers. They are somewhat more complex, and hence expensive, than floats but their controllability may warrant the extra expense in regions, like the equator or along ocean boundaries, where scales are small and currents would sweep floats through rapidly. The CORC glider project aims to perfect glider technology and to evaluate their utility in observing climate variability of localized features like equatorial flows or boundary currents.

The CORC-supported paper

Davis, R.E., C.E. Eriksen and C.P. Jones, 2002. Autonomous buoyancy-driven underwater gliders. *The Technology and Applications of Autonomous Underwater Vehicles.* G. Griffiths, ed, Taylor and Francis, London. 324 pp.

compares the three gliders presently under development. The SIO glider ‘Spray’ is substantially less expensive (~35 k$), has low drag per payload, and a range that exceeds the others. The primary Spray sensor is a PME CTD. Either an optical backscatter or a fluorescence sensor can also be carried. As part of CORC we are working to add an acoustic Doppler current profiler (ADCP) to measure velocity shear and acoustic backscatter at 750 kHz.

Over the last two reporting periods SIO has built one CORC glider and was exercised. An earlier one was built for ONR in local waters. In one operation Spray 02 returned a high resolution CTD section along a CalCOFI line (Figure 2) but the vehicle was lost before returning to San Diego. Based on telemetered data we introduced several improvements to prevent a recurrence and began a sequence of increasing duration sea trials. After several successful trials, Spray 03 was lost at the start of a planned 60-day mission. Fortuitously, a fisherman recovered the hull a month later and the wreckage showed clearly that the Spray had been hit by another vessel that sheared off its two communication antennas and caused a water leak that destroyed all interior parts.

We have redesigned the antennas to have water blocks, so that antennas will not leak when broken, and at the same time switched to Iridium communication. The remaining funds from this period will cover building two additional CORC gliders, less than the four budgeted. This will slow the rate at which glider sampling for climate variability can be evaluated but will not materially affect the scope of the project. We expect to have these two units operational in 2003 and use one to support field tests of the Sontek ADCP, which is in hand.

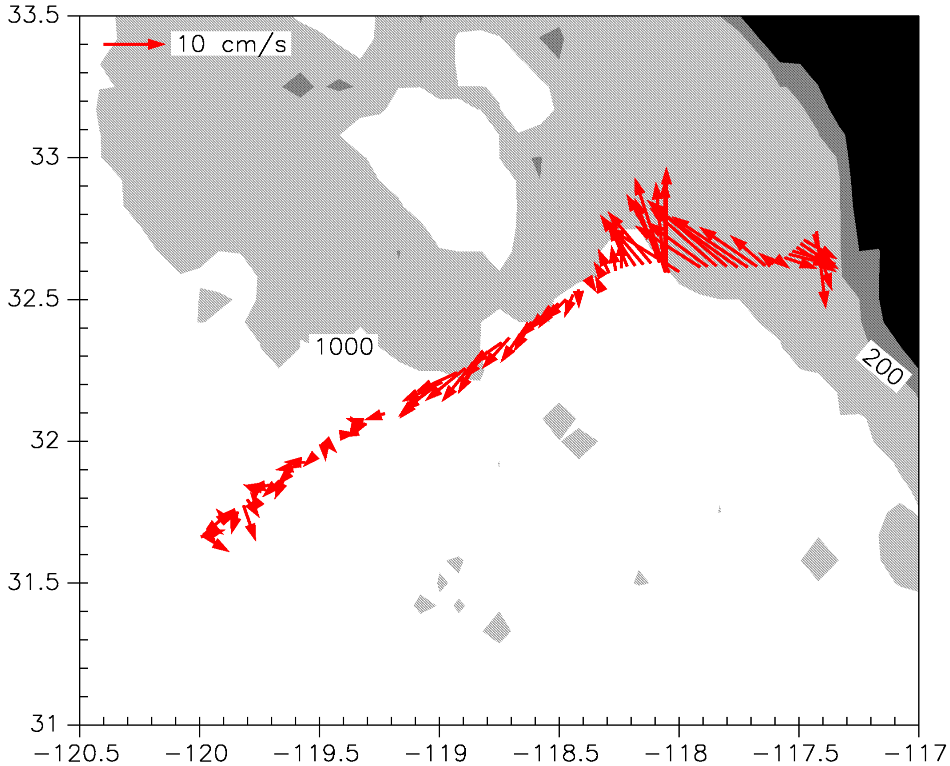

Figure 2. Average velocity over the upper 500 m measured by Spray 02. The associated density section shows a broad northward flow on the inshore side of the Southern California Eddy but discloses nothing of the observed concentrated flow along the 1000 m isobath.

THE UNDERWAY CTD (DAN RUDNICK)

The development of the Underway CTD (UCTD) is motivated by the need for inexpensive profiles of salinity from volunteer observing ships (VOS). While XCTDs do provide the needed salinity profiles at present, cost limits their use. The temperature-salinity (T-S) relationship is most variable in the mixed layer and seasonal thermocline where the ocean is in contact with the atmosphere. Deeper, climatological T-S relationships combined with XBTs are sufficient for observing the hydrographic structure that enters into momentum, heat and salt budgets. Thus, the design goal for UCTD was to obtain profiles deeper than 100 m at 20 knots (typical of a VOS). This goal has been surpassed, as we are able to profile to over 150 m at 20 knots.

The UCTD operates under the same principle as an XBT, spooling tether line from both the probe and a winch aboard ship. The resultant line drag is negligible and probes can go arbitrarily deep. The challenge is to recover the probe because line drag may become large. This has proven possible using a 1.5 mm diameter Spectra line with a breaking strength of 650 lb. Recovery tensions have peaked at 200 lb, so we are working well within the specifications of the line. The UCTD will also be useful on research vessels to increase resolution between conventional CTD stations. At a typical 10-knot speed depths of 400 m should be routine.

Because the UCTD is recovered, rather than being expendable, the cost per profile is decreased. We anticipate a cost of approximately $2000 per probe and at least five profiles per probe, leading to a lower cost per profile than that for an XCTD. Because the probe is recovered, sensors can be post-calibrated and, because the probe carries a pressure sensor, depth is measured rather than being inferred from fall rate. Both these features will improve observation quality over XCTDs.

The conductivity/temperature sensors for the UCTD have been tested acceptably in the lab and in short field operations. Long-term calibration remains an issue that will be resolved as we continue operational use. The first full-scale operations from a research vessel will take place in April 2003 on a CalCOFI cruise. Hourly UCTD casts to 400 m throughout a 5-day leg will be used to address (1) calibration using comparison with concurrent Sea-Bird CTD

casts; (2) operational issues, such as line handling, and ease of use on deck; and (3) utility of the resolution added by UCTD profiles within the coarse CalCOFI grid.

The CORC publication

Rudnick, D. L. and R. E. Davis, 2003: Red noise and regime shifts. *Deep-Sea Res. I***,** in press.

addresses identification of regime shifts such as are often ascribed to transitions in the Pacific Decadal Oscillation. It was shown that a recent composite analysis falsely identifies regime shifts in stationary Gaussian red noise.

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CONSORTIUM ON THE OCEAN'S ROLE IN CLIMATE - ABRUPT CLIMATE CHANGE STUDIES (ARCHES)

Lamont-Doherty Earth Observatory of Columbia University

TASK/THEME: 2A

PALEO RECONSTRUCTIONS

CORC ARCHES: UNDERSTANDING ABRUPT CHANGE AND THE GLACIAL TO INTERGLACIAL CO_2 RECORD (W. S. BROECKER)

SUMMARY

Research interests lies in understanding the record of climate change kept in ice, in marine sediments, in pluvial shorelines, lakes and in mountain moraines. We operated at two levels. First, we ran programs designed to enhance the database. One of these programs involves measuring the weights of size-normalized planktonic shells of a given species of planktonic foraminifera with the goal of determining the extent of weight loss as a proxy for past deep sea carbonate ion concentrations. This constitutes one aspect of the attempt to constrain why it was that the atmosphere's CO_2 content was 80 ppm lower during late glacial time than during the late Holocene. The other program involves the measurement of radiocarbon ages of coexisting benthic and planktic foraminifera in an attempt to reconstruct the rate of ventilation of the glacial deep ocean. Second, we analyzed published data in an attempt to understand the mechanisms behind the abrupt global climate changes which punctuated the last glacial period (i.e., 80,000 to 10,000 years ago). The goal is to evaluate the likelihood that a similar jump from one state of operation to another might be triggered by the ongoing buildup of fossil fuel CO_2.

We also interacted with a wide range of climate scientists. As a member of the NOAA-sponsored Changeling Group, the group meets twice each year to ponder the root cause of abrupt climate change. Broecker is responsible for the primary advisor to Gary Comer's Climate Fellowship Program. So far, twenty-three investigators around the world have been granted three-year funding ($100,000 per year) for support of post-doctoral fellows and advanced graduate students. We ran one or two mini-conferences on hot topics each year. This fall, one will be held on Quaternary sea level reconstruction and in the spring, one will be held on the record in speliothems. Finally, an organized field conferences to more fully understand the timing and pathways of catastrophic releases of water stored in proglacial Lake Agassiz was held. One was held in May and a second is scheduled for September of this year. These field conferences bring together the 10 or so key researchers involved in the history of this lake.

APPROACH, EVALUATION AND METHODOLOGY

The methodology for both my shell weight program and my benthic-planktonic radiocarbon age program have been published. Hence, there is no need to repeat this information here.

During the coming year, we plan to concentrate on establishing the rate of ventilation of the deep Pacific Ocean during glacial time.

Stephen Barker who carried out his Ph.D. research with Harry Elderfield on shell weight studies will join us in January 2004 as a Gary Comer supported post-doctoral fellow. He will continue the carbonate ion proxy research.

Elizabeth Clark will continue to do laboratory work for both Stephen Barker and for me.

RESEARCH ACCOMPLISHMENTS AND RESULTS

Exploratory size-normalized shell weight measurements have been made on planktonic species present in five cores from the South Atlantic Ocean (see Table 1 for locations and water depths). Two of these cores were from Walvis Ridge close to the African continental margin at 23±2°S and three were from the Agulas Ridge at 42°S.

Table 1. Locations and water depths of cores employed for the South Atlantic shell weight study.

Core No.	Latitude	Longitude	Water Depth km	$CO_3^{=}$ μmol/kg
VM22-109	42.0°S	0.3°W	0.77	95
TN057-20	42.0°S	1.0°E	1.34	85
TN057-21	42.5°S	8.0°E	4.90	105
RC13-228	22.3°S	11.2°E	3.20	105
RC13-229	25.5°S	11.3°E	4.19	100

The procedures used are based on those developed by *Lohmann* [1995]. They are described in *Broecker and Clark* [2001]. Briefly, the samples were disaggregated and the greater than 63 micron fraction isolated. This fraction was soaked in water, sonicated for eight seconds and then rinsed and dried. The 300 to 355 micron fraction was then isolated by sieving and up to 50 whole shells of a given planktonic species were picked and weighed. These results are archived on Jean Lynch-Stieglitz's web site under 'Data' at www.ldeo.columbia.edu/~jean.

The results from the two northern cores are summarized in Figure 1. The record from the core from 3.2 km extends back to MIS 6. Weights of five planktonic species (300 to 355 microns) were determined; i.e., *G. bulloides, U. orbulin*a, *G. inflata, G. truncatulanoides*, and *G. ruber*. Only one consistent feature of these results stands out, namely, the weights of all five species undergo dramatic decreases during the course of the Holocene. This weight decrease is similar to that documented in Ontong-Java Plateau cores and in the deep western equatorial Atlantic [*Broecker et al.*, 1999].

The species *G. bulloides* yields the most consistent down-core pattern. It is heavier during glacial stages (i.e., 6 and 4, 3, 2) than during interglacial stages (i.e., 5 and 1). It is absent during the latter part of stage 5e. While the record for *G. truncatulinoides* shows some resemblance to that of *G. bulloides*, the contrast in shell weight between the last interglacial (stage 5) and the last glacial (stages 3, 2, 1) is much smaller. Further, this species appears to have been absent during stage 2. *G. inflata* show an interglacial to glacial shift opposite that seen for *G. bulloides.* For *U. orbulina* no consistent trend is seen over the entire record.

The species *G. ruber* is absent over most of this record appearing only during the early part of stage 5 and during the transition associated with the onset of the Holocene. This distribution through time is consistent with *Charles and Morleys'* [1988] record of the abundance of tropical species in this core which shows peaks spanning Termination II and I. To what extent the absence of *G. ruber* reflects dissolution intensity and to what extent growth abundance is not clear.

The record for core RC13-229 at a water depth of 4.19 km further complicates the picture. Even the trend toward decreasing shell weights during the course of the Holocene so prominently displayed in RC13-228 is evident only for *U. orbulina.* The large weights for the few whole *G. bulloides* shells recovered from the upper three samples in this core are particularly puzzling. As the depth of RC13-229 is one kilometer greater than that of RC13-228 one would expect that its shells experienced greater dissolution-induced weight loss.

At the southern locale only three planktonic species were sufficiently abundant, i.e., *G. bulloides*, *G. inflata*, and *G. truncatulinoides*. The two shallow cores (i.e., 0.77 and 1.34 km) are situated in waters sufficiently supersaturated with respect to calcite that the shell weights should be unaffected by dissolution. Indeed, the weights for Holocene-age shells are greater than those for the two cores from the northern site. Further, there is no convincing evidence for a dissolution-induced decrease in shell weight through the course of the Holocene. For *G. bulloides* and *G. inflata* there is no significant difference between the weights of glacial and Holocene shells. For *G. truncatulinoides* there is a suggestion that the glacial shells are lighter than their Holocene brothers. These results are unexpected because the higher $CO_3^{=}$ concentration in glacial surface waters should have led to larger shell weights [*Barker and Elderfield*, 2002].

The results for the deep core at the southern site largely conform to expectation. Consistent with the expected sea floor dissolution, the shell weights are smaller than those for the shallower cores. Also, a decrease in shell weight through the course of the Holocene is seen. Finally, there is a hint of a shell weight maximum spanning Termination I.

Overall these results are not encouraging. They raise the specter of two potential flaws in the shell weight proxy. First, surface water carbonate ion concentration may not be the only environmental variable influencing size-normalized shell weights. These other impacts may be more important at higher latitudes where seasonally driven changes in water temperature and nutrient availability occur. Second, the offset between pore water and bottom water carbonate ion concentration may be larger and spatially more complex than we had hoped. For example, in environments such as that beneath the productive coastal waters off the African continental margin the offset may be considerably larger than in the tropics. As the offset depends not only on the rate of input of organic particulates but also on the buffering provided by the companion $CaCO_3$, in regions of the ocean where diatoms flourish the ratio of $CaCO_3$ to organic carbon is low promoting a larger pore water offset. It has shown that the pH offset for sediments off the bulge of Africa is considerably larger than those reported by *Hales and Emerson* [1996 and 1997] for Ontong-Java and Ceara Rise pore waters.

CONCLUSIONS AND RECOMMENDATIONS

Shell Weight Program. Questions regarding the factors influencing the initial wall thickness (is surface water carbonate ion concentration the only variable?) and the influence of the respiration CO_2 in sediment pore waters remain to be answered. Stephen Barker will tackle these questions.

Benthic-Planktonic Program. In the studies we have carried out this year, we have encountered disturbing large age differences among the 6 planktonic species we have analyzed. We must come to grips with the source of these differences. To do so, we will have blind duplicates analyzed by two accelerator ^{14}C laboratories.

Radiocarbon Dates on Wood from Glacial Moraines. The spread in radiocarbon ages in wood samples obtained by George Denton and Tom Lowell have failed their attempt to pin down the degree to which the glacial advances of glacial time are synchronous between 40°N and 40°S. Broecker plans to work with them to resolve this problem.

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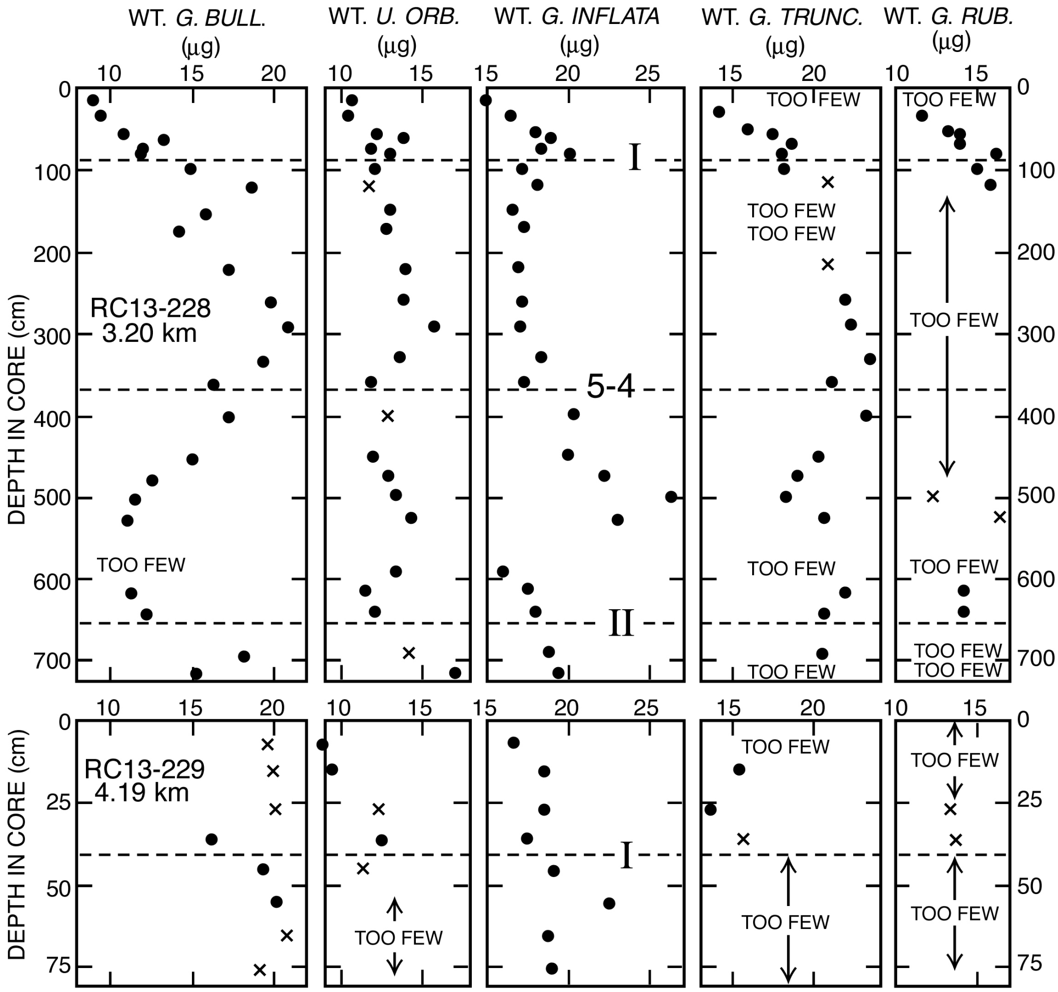

Figure 1. Plots of whole shell weight for five species of foraminifera picked form the 300 to 355 _m size fraction form two cores from 23 ±2°S in Walvis Ridge close to the African margin. The *x* indicates samples for which less than 30 whole shells were found. The dashed lines represent the midpoints of Terminations I and II based on the benthic ^{18}O records for these cores [*Charles and Morley, 1988*].

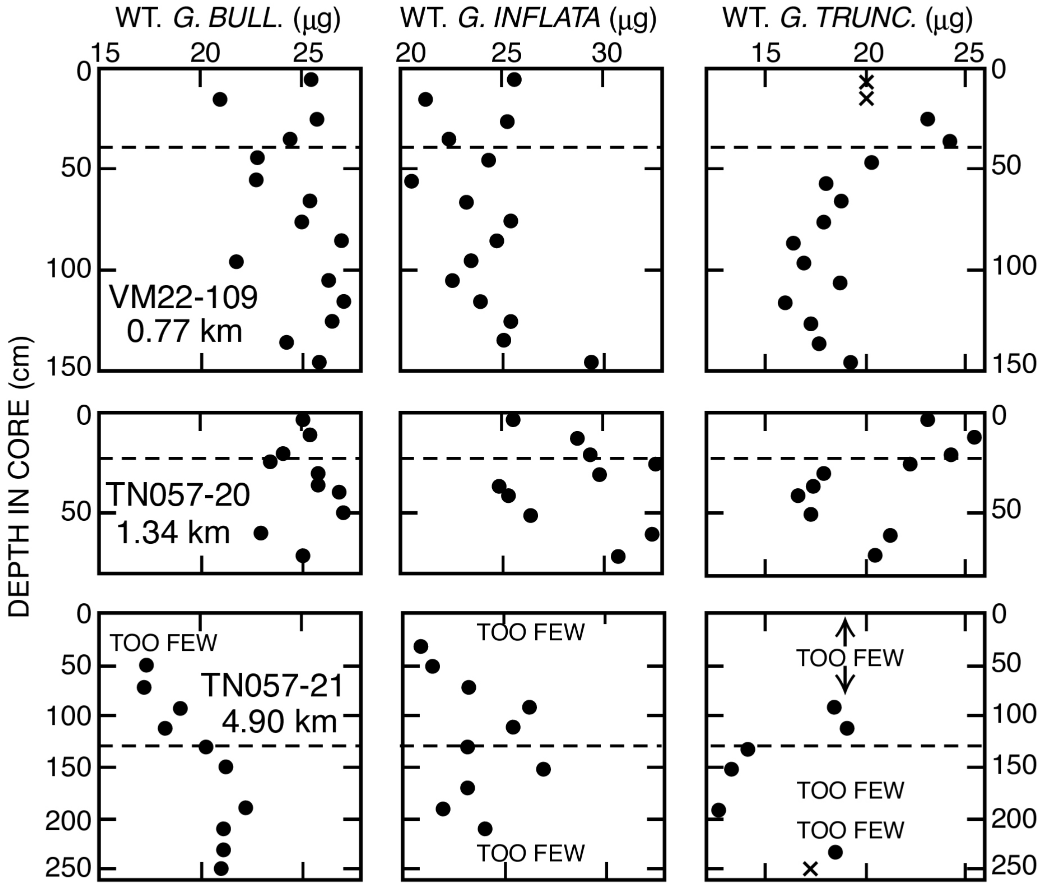

Figure 2. Whole shell weights for *G. bulloides, G. inflata,* and *G. truncatulinoides* from the 300 to 355 _m size fraction in three cores covering a wide range of water depth at 42°S in the Cape Basin. The dashed line represents the midpoint of the glacial to Holocene ^{18}O change (i.e. ~13,000 calendar years).

PATTERNS AND TIMING OF DEGLACIAL CLIMATE CHANGE IN THE EQUATORIAL PACIFIC (JEAN LYNCH-STIEGLITZ)

OBJECTIVES

The aim of this scope is to determine: (1) the reliability of different sea surface temperature (SST) proxies in the Eastern Equatorial Pacific in reproducing the modern surface conditions in this region; (2) examine the spatial distribution of SST in this region for the Last Glacial Maximum and (3) provide a well dated chronology for climate change in this region from the LGM to the present with sufficient time resolution to examine the response of the Eastern Equatorial Pacific through the Younger Dryas climate reversal.

RESEARCH ACCOMPLISHMENTS

At this time, we have complete oxygen isotope records on *G. sacculifer* and *G. ruber* for eight sediment cores in the Eastern Equatorial Pacific. All of these cores have been radiocarbon dated for a more accurate chronology over the deglaciation. For one of these cores, we have developed a down core Mg/Ca based paleo-temperature record over the last 30,000 years. This is the first high-resolution geochemical record of sea surface temperature for the Eastern Equatorial Pacific cold tongue, and is the focus of a paper that was published in *Science*. In this manuscript, we suggest that the existing geochemical records from the tropical pacific, in combination with our new cold tongue data are consistent with an El Nino like pattern (reduced east-west and cross-equatorial SST gradients) during the last glacial maximum. This work is in collaboration with post-doctoral research scientist Tom Marchitto. In addition, we

have developed a downcore alkenone based SST record in another core along with supplemental alkenone data in two more cores. This work was done in collaboration with Julian Sachs at MIT. All of the geochemical paleo-temperature estimates (oxygen isotope, Mg/Ca and alkenone) suggest only a small (<2°C cooling) in the cold tongue region for the last glacial maximum. The oxygen isotope records from the other sediment cores support the pattern of reduced meridional gradients in the Eastern Tropical Pacific, and we have a manuscript which is in press in *Paleoceanography* in the next month on this topic. The work described above was completed by graduate student Athanasios Koutavas who defended his thesis in November, 2002.

We have also completed a compilation of sea surface temperature records for the early Holocene. These records indicate cool tropical SST during this period of high Northern Latitude warm (“Hypsithermal”). This pattern is consistent with that found in a General Circulation Model forced by insolation changes alone and reflects increased upwelling in the tropical Pacific during this time. This work is in collaboration with Zhengyu Liu at University of Wisconsin, and has been published in Paleoceanography.

WORK IN PROGRESS

Athanasios Koutavas is currently pursuing the work with alkenone SST reconstructions on these cores as part of his NOAA Global Change post-doctoral fellowship at MIT under the supervision of Julian Sachs. Here at Lamont we are in the process of developing new Mg/Ca SST records from several of the sediment cores in the Eastern Tropical Pacific. In addition, we are developing initial isotope stratigraphies on shallow cores in the southern subtropical Pacific (near French Polynesia). These will ultimately used to determine the temperature history of this region (for which there is currently no data) since the Last Glacial Maximum, and may be used to examine the strength of the South Equatorial Current. This work is in collaboration with the Sara Harris at Sea Education Association in Woods Hole who has been collecting sediment samples for us.

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CONSTRAINING CHANGES IN WINDS, THE CONVEYOR AND LOCAL CURRENTS DURING PERIODS OF ABRUPT CLIMATE CHANGE
(SIDNEY R. HEMMING AND STEVEN L. GOLDSTEIN)

We are continuing in our goal of characterizing terrigenous sediment sources in the South Atlantic, and have made the following progress during 2002-3:

1. A transect of Sr and Nd isotopes from 16 samples between the 7.5°N and 36.8°S along the South American coast. The results confirmed our expectation of a strong geographic gradient in provenance, reflecting the age of the proximal South American basement, more ancient in the north and younger in the south (Hemming et al., 2002).
2. Sr and Nd isotopes and flux from $^{230}Th_{xs}$ of a set of Holocene and glacial samples along the Mid-Atlantic Ridge (MAR) between 6°N and 45°S. Like the proximal South American sediments, these samples show a strong latitudinal gradient from less ancient sources in the south to more ancient sources in the north. They also show a shift to less ancient sources during the LGM compared to the Holocene. Some of these samples are within the center of the South Atlantic surface circulation gyre, and we expect that they will reflect dominantly eolian sources (Hemming et al., 2002; Franzese et al., 2003a, b).
3. Sr and Nd isotopic measurements on a batch of South Atlantic samples on which grain size distribution and clay mineralogy has been measured (Jones et al., 2002). Hovan has identified an area in the western Cape Basin for which the grain size analyses suggest a dominant eolian source, so we have hopes that these will be good samples to check the changes in eolian contributions to the South Atlantic in the past.

We are also continuing in our goal of constraining changes in the thermohaline conveyor by measuring the Nd isotope composition of the ferromanganese fraction of marine sediments, and have made the following progress:

1. High resolution measurements of Nd isotopes from the deglacial interval (~15-5 ka) from southeast Atlantic core RC11-83 have shown high frequency variations in thermohaline circulation that appear to correlate to significant climate swings in the Greenland ice core records. These results were reported at the Goldschmidt Conference in Davos and a manuscript in review (Piotrowski et al., 2002; 2003; manuscript submitted, Nature).
2. High resolution measurements of Nd isotopes from Stage 3 from nearby core TNO57-21 have shown high frequency variation that correlate to Dansgaard Oeschger events in the Greenland ice core records (Piotrowski et al., 2003), and a high resolution survey is also being conducted across the Stage 5-4 boundary in TNO57-21. The goal is to complete a high resolution record from the present through the last glacial and into interglacial MIS5.
3. A survey of Holocene and glacial Nd compositions from Atlantic cores reveals that not all cores can be used with the methods that we have developed; however, from the cores that work (that is cores where Sr isotope ratios of the ferromanganese fraction is marine) the changes found in the South Atlantic are not consistent with shoaling of NADW but rather indicate a near shutdown (Goldstein et al., 2002). Further development work is underway to determine the best way to screen and process the samples.

CONCLUSIONS AND RECOMMENDATIONS

We intend to continue our mapping of South Atlantic provenance of terrigenous detritus. This is complementary to ongoing work in the circumpolar Atlantic that is funded by NSF Polar Programs, and in the Cape Basin/Mozambique Channel area that is funded by an NSF OCE grant to study changes in the Agulhas Current. We will make further measurements along the Mid-Atlantic Ridge (MAR), which we think offer the best chance of obtaining a pure eolian component. The first batch of samples was taken from the western flank of the MAR, and we have made significant progress in screening for cores to the eastern flank. The stratigraphic work for this search is funded by an OCE grant led by Wally Broecker, to use multiple proxies to understand past changes in the conveyor. Authigenic Nd isotope analyses are part of this project, so the preparation for terrigenous clastic provenance work will be approximately 50% done by this project.

We continue to work toward the goal of creating a map of LGM terrigenous isotope composition for the South Atlantic that is comparable to the Holocene map that exists now (Figure 1). This map is composed of published data, as well as our newly generated data from the Cape Basin, South American margin, western equatorial Atlantic, and MAR.

There are additional data from the survey of Kevin Jones (summer intern, 2002) that are not shown on the map. There are some cores where the position of the LGM is known; however, we expect that a considerable amount of our effort toward this goal will need to be compiling the stratigraphic information from the literature, as well as from primary data that we produce. During the summer of 2003 we are making a vigorous effort using magnetic susceptibility and carbonate analyses to constrain the stratigraphy of South Atlantic cores. We will measure ^{14}C ages to verify the stratigraphy.

A high priority is to produce a down-core record from the Rio Grande Rise, with particular emphasis on Stage 3. The Rio Grande Rise is located conveniently along the provenance gradient and near the present boundary between surface current moving to the north and south along the South American coast (Brazil-Malvinas confluence). We consider this confluence to be analogous to the Agulhas retroflection region. Accordingly, with the demonstrated geographic variation in provenance along the South American margin, we expect to see a significant climate-correlated signal in the provenance variation. It is expected by physical oceanographers that a reduction of Agulhas current contributions in the east, which is implied by our provenance work in the eastern South Atlantic, will be accompanied by an increase in north to south current transportation along the Brazil coast. Thus, in this scenario, we would expect higher ^{87}Sr/^{86}Sr in detritus at the Rio Grande Rise during times when the ^{87}Sr/^{86}Sr is low in RC11-83. In addition to obtaining the isotopic signatures of the terrigenous fraction from this Rio Grande Rise site, we will measure the Sr and Nd isotopes from the ferromanganese fraction. These measurements will be especially interesting in this site due to the strong gradient in deep water compositions in the vicinity of the Rio Grande Rise, and published δ^{13}C and Cd/Ca measurements from benthic foraminifera, both of which also are influenced by changes in the strength of North Atlantic Deep Water, are consistent with this expectation.

**Characterization of the Nd isotope variation of the deep waters of the southeastern Atlantic has provided stunning evidence for rapid variability that appears to be parallel to temperature variations over Greenland during the last 15 k.y. (Figure 2). Piotrowski et al (submitted) have refined the age model for core RC11-83 in this part of the record, with funding from this grant and have created a Nd isotope data set with better time resolution than the δ^{13}C record. This resolution is unparalleled in downcore radiogenic isotope analyses and shows the tremendous potential scope for this tool. Alex Piotrowski is working to extend the record at high resolution into MIS5.

An essential goal of the project is continued method development, both for the authigenic ferromanganese component and for the terrigenous clastic provenance. We have found that not all cores give true marine signals as monitored by the Sr isotope composition of the ferromanganese fraction (Goldstein et al., 2002). We intend to try different extraction methods in order to test if there are ways to fix some of the problem cores. Additionally, we plan to seek further tests for the validity of the data. In the case of the terrigneous clastic compositions, Rutberg et al. (2002) recently found a very strong co-variation between the <2 and <63 micron fractions of the terrigenous component from core TNO57-21 of the Cape Basin. During the summer of 2003, Rutberg supervised undergraduate intern Shastine Van Vugt in a project to determine the silt/clay weight ratios and to prepare the same samples for Sr isotope analyses of the <2 and 2-63 micron fractions. The preparations for the isotope work are underway, and the grain size analyses are quite impressive in their systematic relationship to the downcore Sr isotope variations. We plan to take a range of South Atlantic cores with variable provenance composition and extend the measurements to include the <2 micron fraction. These results should help sort out the eolian vs. current carried components, and it should also provide further background information that will aid our interpretation of down-core results.

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Detrital Sr and Nd isotope ratio provenance studies as indicators of water mass paleo-transports, Agulhas Current, Cape Basin

Workshops

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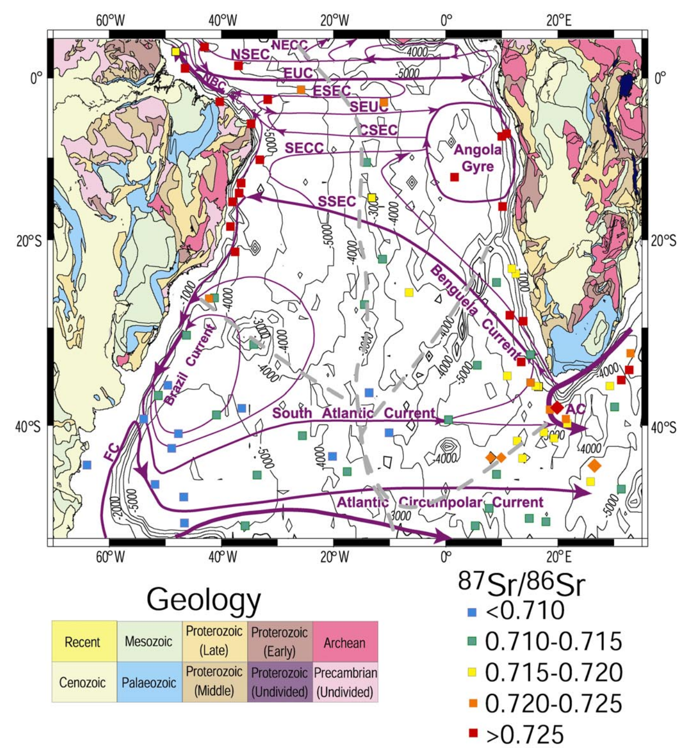

Figure 1. Map of South Atlantic Sr isotope data from terrigenous clastic detritus. Shown for reference are simplified geological provinces of South America and Africa, currents at 100 m and the bathymetry of the South Atlantic Basin.

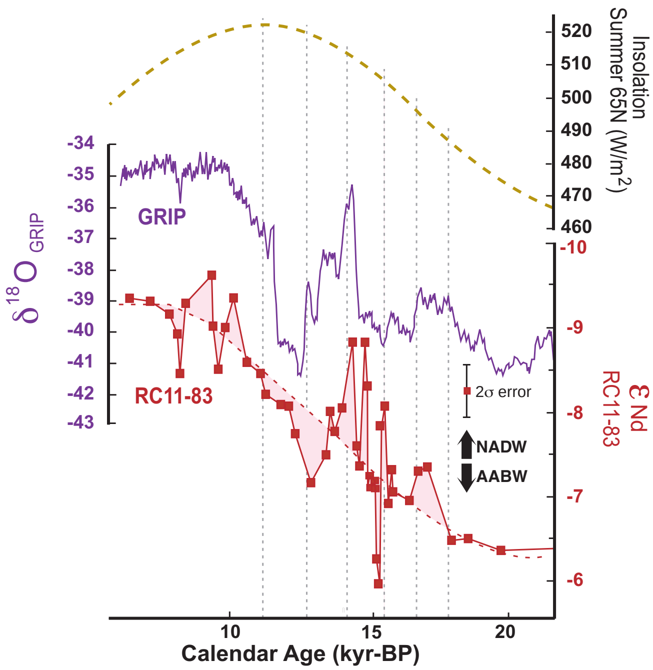

Figure 2. Nd isotopes RC11-83, $\delta^{18}O$ in Greenland Ice, and Northern Hemisphere insolation. The Nd isotope record of the Fe-Mn oxide component of RC11-83 through Termination 1, records a long term gradual strengthening of NADW along with increasing Northern Hemisphere insolation. Some of the millennial oscillations appear to be linked with Northern Hemisphere events like the Bølling warming and the Younger Dryas.

ABRUPT CLIMATE CHANGE DURING INTERGLACIALS (GERARD C. BOND)

SUMMARY

Our research efforts are aimed at understanding the mechanisms underlying millennial climate variability within interglacial climates. This will be done in a suite of North Atlantic sediment cores. I plan to collaborate with GEOTOP's Anne de Vernal, North Carolina State University's William Showers and Duke University's Gary Dwyer.

RESEARCH ACCOMPLISHMENTS AND RESULTS

- My collaborators and I have continued to concentrate on our present interglacial or Holocene interval (0 to 12,000 years ago). We have confirmed our earlier findings that the Holocene records of drift ice match closely proxies of variations in solar irradiance, suggesting a link between Holocene climate shifts and solar output.
- We have documented temperature drops of 2°C to 5°C in the cycles over the several thousands of years in both the western and eastern North Atlantic.
- We documented for the first time that North Atlantic Deep Water Production was reduced during each of the peaks in drift ice and the corresponding solar minima.
- We have confirmed that the glacial's Dansgaard-Oeschger cycles did not end at the termination of the last glaciation, but instead continued in muted form through the entire Holocene.

CONCLUSIONS AND RECOMMENDATIONS

This research is focused on understanding mechanisms of recurring abrupt climate changes that will in all likelihood continue into the future. In that respect our findings will improve our understanding of the potential for adverse future impacts of climate change.   With regard to specific PI's efforts, Bond presented an overview of his research to a visiting group of high school teachers each year of the term of this grant as part of an ongoing Columbia-based program to promote interaction between researchers and teachers. Showers, is a participant in the NCSU Summer Science Mentoring program which brings in minority and disadvantaged high school students to NCSU during the summer period. Results of this project are incorporated in this program.

PUBLICATIONS

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ACCELERATOR MASS SPECTROMETRIC ANALYSES OF RADIOCARBON (John M. Hayes)

SUMMARY

Analyses of radiocarbon for ARCHES investigators in the Paleo Reconstructions.

RESEARCH ACCOMPLISHMENTS AND RESULTS

During the reporting period 1 July 2002 – 30 June 2003 fees totaled $33,277 in support of 117 analyses of radiocarbon for ARCHES investigators (Bond, 68 samples; Denton, 25; Goldstein, 12; Hemming, 12). Of these, 25 were analyses of ^{14}C in organic carbon and 92 were analyses of carbonate minerals. Submissions of samples are continuing. Turnaround times are presently less than two months.

SOUTHERN HEMISPHERE MOUNTAIN SNOWLINES (George H. Denton)

SUMMARY

The research objectives were accomplished as outlined in the original proposal. No changes were made, except for the addition of a pilot radiocarbon dating project on the Puerto Bandera moraines at Lago Argentino. The overall goal of the project for the past year was to reconstruct snowline changes in the Southern Alps of New Zealand during the last glacial cycle. New Zealand is situated in the zone of mid-latitude Southern Hemisphere westerlies in the South Pacific Ocean far from any major continental influences or zones of thermohaline downwelling. Also, New Zealand is on the opposite side of the planet (and with an opposite insolation signal) from the North Atlantic region, which has produced the classic record of abrupt climate changes. The idea is that a comparison of New Zealand snowline variations with the North Atlantic abrupt-change records will point to some of the underlying mechanisms. The major research activities involved field mapping in New Zealand's Southern Alps in January and February, 2002, together with office work during the rest of the year on map digitizing, air-photo interpretation, and snowline reconstruction from field data. The collaborators in the fieldwork were Thomas V. Lowell of the University of Cincinnati, Björn G. Andersen of the University of Oslo, and Christian Schlüchter of the University of Bern. B.G. Andersen also carried out the interpretation of air photographs. David Barrell supervised the digitizing of glacial geological maps at the Institute of Geologic and Nuclear Sciences, Dunedin, New Zealand. Trevor Chinn, National Institute of Water and Atmosphere, Dunedin, New Zealand, is now carrying out the snowline calculations for the Ben Ohau Range of the Southern Alps.

METHODOLOGY

The project this year involved extensive field mapping of glacial geomorphology in the Ben Ohau Range and alongside the Tasman Sea, both sectors of New Zealand's Southern Alps. This mapping was carried out by preliminary analysis of air photographs, followed by field traverses over all the mapped areas. The field information was then digitized into the New Zealand national GIS mapping system. Former glaciers could then be reconstructed from the glacial geomorphic data plotted on this system. From this reconstruction former snowlines could be reconstructed over the entire mountain range. Comparison of modern and former snowlines, together with the radiocarbon chronology of pertinent moraines, permits evaluation of the magnitude of climatic change at selected former time intervals. The photographic analysis was carried out by Björn G. Andersen, the field checking by G.H. Denton and T.V. Lowell, the digitizing by David Barrell, the snowline calculations by Trevor Chinn, and the radiocarbon dating program by G.H. Denton and Christian Schlüchter.

CONCLUSIONS AND RECOMMENDATIONS

First, our results show that the LGM is at least near synchronous in New Zealand, the Chilean Andes and the North Atlantic region. The magnitude of snowline lowering was nearly the same in all three regions. All this occurred despite the fact that the Milankovitch seasonality signal is out-of-phase in middle latitudes of the two polar hemispheres. This means that the role of Milankovitch seasonality forcing was to change the reflectivity and/or trace-gas content of the atmosphere so that snowlines were lowered equally in the two polar hemispheres. Second, only one relatively minor abrupt climate change occurred during the entire 9000-year length of the LGM as now recorded in both polar hemispheres. None of the classic Dansgaard-Oeschger (D-O) events occurred during the LGM. It has already been noted many times that the classic D-O abrupt changes did not occur in interglacial times. Now it is clear that neither did they occur during the entire 9000-year long span of the LGM as recorded at least near synchronously in both polar hemispheres. The implication is that Milankovitch seasonality somehow causes changes in atmospheric trace gases or reflectively in order to drive glacial cycles on a global scale. The classic D-O abrupt changes do not occur when these Milankovitch-driven changes force global climate into a full-glacial value, nor do they occur when the system is driven into full interglacial conditions. Rather the classic D-O abrupt signature is restricted to intermediate conditions of the last glacial cycle. Thus, the D-O abrupt changes are best developed in MIS 3 and during into the last deglaciation (Bölling, Alleröd, Younger Dryas). This observation that only intermediate parts of the last global glacial cycle exhibit D-O events is of paramount importance. It means that the classic abrupt changes occur only during a restricted set of boundary conditions when the climate system is close enough to a bifurcation points that it can be kicked abruptly into alternate modes. During both the full glacial and the full interglacial parts of the cycle, the climate system is driven away from this bifurcation point (s) and D-O events fade out. Thus, the Milankovitch-driven glacial cycle is a crucial element in the generation of the classic abrupt climate jumps, because it pushes the global climate system toward and away from the critical bifurcation point (s).

The bottom line is that from the Southern Hemisphere snowline investigations we can now say that the last glacial cycle is at least near synchronous and of the same magnitude over wide sectors of the planet and that the classic D-O abrupt climate oscillations are restricted to a narrow range of boundary condition within this cycle. The next step is to determine whether the D-O events also have a narrow geographic range confined to the Northern Hemisphere, or whether they are widespread in both hemispheres. Establishment of the geographic pattern may point to the trigger of abrupt climate changes as well as to the components of the climate system involved in propagating these changes. An important item on the list of future objectives is to determine whether a classic Bölling/Alleröd/ Younger Dryas signal occurs in Southern Hemisphere middle latitudes. Our present records are mixed in this regard. From the results of this project, the beginning of the major late glacial readvance is dated to about 11,150 ^{14}C yr B.P. in New Zealand's' Southern Alps and 11,125 ^{14}C yr B.P. in the Argentine Andes; these dates seem to be about 150 years older than the beginning of the classic Younger Dryas in the Northern Hemisphere, but their meaning is not yet understood. Increasingly detailed snowline and chironomid studies over a wider geographic area in the Southern Hemisphere are needed to solve the overall issue of late-glacial abrupt changes.

PUBLICATIONS

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MODERN OBSERVATIONS

SOUTHERN OCEAN MODERN OBSERVATIONS (MARTIN VISBECK AND ARNOLD L. GORDON)

SUMMARY

Maintain the now well established Western Weddell Time Series Station, which consists of a small near bottom moored array and a repeated hydrographic section south of the South Orkney Islands. The mooring sites and CTD/tracer section have been revisited on average every 12 to 18 months. As we rely on opportunistic scheduling of vessel time provided by a variety of sources, timing is approximate, and we will take advantage of opportunities to revisit the sites more frequently, while planning for the eventuality of a 2-year deployment. The observed oceanographic data are analyzed in conjunction with atmospheric forcing data with regards to climate variability and the possibility of abrupt changes.

APPROACH

Depending on availability of ships we have planned to visit the area every 1-2 years to repeat the CTD section and recover and redeploy the moored array.

We continue to use the mooring design developed and proven successful during the first phases of CORC/Arches. The design is flexible enough to allow the addition of sensors or sampling equipment such as an autonomous water sampler.

RESEARCH ACCOMPLISHMENTS

During spring of 2003, the Office of Polar Programs at NSF has generously offered us ship time on cruise LMG03-04 from 5 April to 7 May. We were allocated 10 days to service the mooring sites and conduct CTD/tracer stations. However, sea ice conditions were very extreme this season and the *L. M. Gould* was unable to come even close to our mooring sites. Thus, we used the available ship time for a resurvey of several previous CTD sections to the north of the ice in the Scotia Sea. The data from this region are also of interest and can be compared to our visit during the Dovetail program from August1997.

Figure 1 shows the work area together with the originally planned (green dots) and actually measured (black dots) CTD locations. The mooring locations are indicated by the red dots. The cruise track is displayed as a magenta line and reveals the unsuccessful attempts to reach locations along the previous CTD section. During the cruise we had support by GIS personnel at Palmer Station providing us with up to date satellite images of the sea ice. In Figure 1 the area of dense ice cover (concentration higher than about 70%) is shown as light blue hatched area.

Instead of the intended mooring and CTD work we had to replan leading to a program of 23 CTD stations. Two of these stations were located on the normal CTD section, while the rest constitutes three sections to the east and north of the South Orkney plateau (the black lines in Figure 1 denote water depths of 500, 1000, 2000, and 3000 m). The central of these three sections had been occupied in 1997 and will allow the evaluation of changes over the past six years. The sites of the other two sections were chosen to track the outflow of Weddell Sea Deep Water (WSDP) around the South Orkney plateau. The measurements showed a slowly warming core of flowing westward along the northern slope of the plateau.

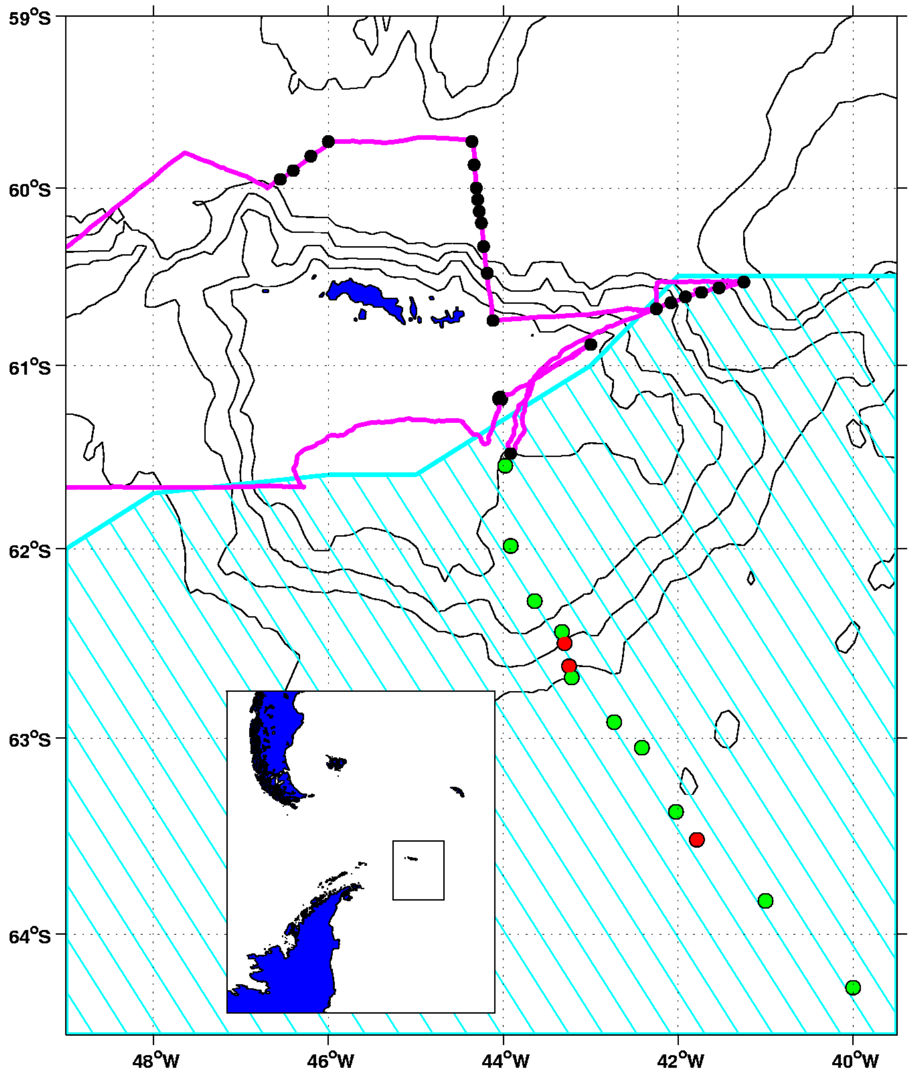

Figure 1. Map of the work area. The cruise track of LMG03-04 is shown in magenta. The planned CTD stations and the mooring locations are denoted by the green and red dots, respectively. The black dots mark the actually measured CTD stations. The light blue hatched area shows the dense ice cover.

Analysis and processing of the time series data already collected is continuing and a paper summarizing the data collected so far is in preparation. The analysis conducted so far has suggested the need for an additional mooring site and we are exploring options to make this happen within the existing funding level.

We are working with NSF to schedule a recovery cruise for the next season to tend to moorings. This has extremely high priority since some of the releases will have reached their battery life time and the WHOI mooring M1 is nominally past their battery life time.

Analysis of Historical Data/data Management: We have assembled and inspected all historical hydrographic data from the regions of deep and bottom water formation in the Southern Ocean and will make them available to the wider community. Preliminary data from the CTD sections and moored time series will be made available first to the CORC/Arches community and then to the public at appropriate times via a project web site, to be developed during this performance period. We are currently exploring several data base structures to accomplish this task.

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TRACERS
(PETER SCHLOSSER)

SUMMARY

The goals for this funding period included participation in monitoring cruises of the WSBW along a short section in the northern Weddell Sea, sample collection of Denmark Strait and Scotland/Iceland overflows, as well as measurement and evaluation of data collected during previous expeditions, including the 1994 WOCE section completed by the Aurora Australis and the Australian Amisor II cruise.

APPROACH AND METHODOLOGY

Sample Collection

Weddell Sea section: We collected ca. 100 tritium, helium isotope and oxygen isotope samples on the cruise to the northern Weddell Sea in spring of 2003. The samples are being prepared for mass spectrometric measurement and will be measured during the next budget period.

North Atlantic time series: We continued sampling along a section within and south of Denmark Strait. This program is part of our overall goal to study the deep branch of the meridional overturning circulation. This water mass is freshening according to Dickson et al. (2002). The samples were collected by colleagues from Iceland (Iceland Marne Science Institute).

Sample Preparation and Measurements

We prepared several hundred samples from several cruises to the Southern Ocean for mass spectrometric helium isotope and tritium measurement

We performed ca. 600 helium isotope measurements from the Aurora Australis cruise 1994. The samples were prepared for mass spectrometric measurement in the laboratory of Dr. John Lupton at NOAA PMEL, Oregon. We also started measurement of the tritium samples from this section. We will begin interpretation of the data once the tritium measurements are complete.

Data Interpretation

We complete interpretation of the data from the section completed along the front of the Ross Ice Shelf. We are presently summarizing the data in a manuscript for publication in Deep-Sea Research.
Reference

Dickson, B., I. Yashayaev, J. Meincke, B. Turrell, S. Dye and J. Holfort. 2002. Rapid freshening of the deep North Atlantic Ocean over the past four decades. Nature 416: 832-837.

TRACERS
(WILLIAM M. SMETHIE, JR.)

SUMMARY

The overall long-term objective of this project is to better understand mechanisms of deep and bottom water formation, deep mixing, and thermohaline circulation and to improve representation and parameterization of these processes in ocean circulation models. The specific objectives are:

1. Investigate the current state of the ocean's thermohaline circulation with particular emphasis on documenting interannual variability in water mass formation at major sites in the Southern Ocean and the coupled North Atlantic/Nordic Seas/Arctic Ocean system.
2. Maintain and optimize the boundary current observing system in the Weddell Gyre outflow region in collaboration with the international community.
3. Interpret the new data in the context of historical data sets.
4. Provide observations that can be used to improve the representation of deep water formation processes in state of the art climate (ocean) models.

Meeting these objectives requires a multi-year observational and data synthesis effort. The results and activities presented in this progress report are for only the one-year period from July 2002 to June 2003.

The major activities for the past year include publication of a paper on the total input of Antarctic waters into the deep ocean based on CFC observations, preparation of a manuscript on basal ice shelf melting and Ice Shelf Water formation in the Ross Sea based on evolving CFC and salinity fields, collection of CFC samples from the repeat hydrographic/tracer line crossing the deep outflow from the Weddell Sea, collection of CFC samples from the Denmark Strait Overflow region, and completing CFC data reduction for measurements made on a recent cruise to the Antarctic continental shelf between 140 and 150°E. Major collaborators are S. Jacobs of LDEO, A. Orsi of Texas A&M University, J.L. Bullister of PMEL/NOAA, and J. Olafsson of the University of Iceland and the Iceland Marine Research Institute.

APPROACH/EVALUATION/METHODOLOGY

The basic approach of this project is to make measurements in regions where deep and bottom water form and in regions where these dense waters enter the deep ocean circulation. The particular measurements my component of this research focuses on are chlorofluorocarbons. Other ARCHES Principal Investigarors provide measurements of temperature, salinity, tritium, helium isotopes, oxygen isotopes, current velocities and moored hydrographic observations at select sites. Temperature and salinity control the density of seawater and dictate whether a water parcel will sink or remain at the surface. The anthropogenic chlorofluorocarbons, CFC-11, CFC-12 and CFC-113, have well known atmospheric time histories and enter the ocean only at the surface. They provide information on the location and age of newly formed deep and bottom water, the extent that this water interacts with the atmosphere prior to sinking, and entrainment of older subsurface waters during the sinking process. The primary regions where deep and bottom water form are the northern North Atlantic and around the Antarctic continent. The ARCHES Modern Observations program places more emphasis on the regions around Antarctica where the least is known. Here we have two observational strategies: 1) monitor the deep and bottom water outflow from the Weddell Sea with a hydrographic/tracer line occupied annually to document and investigate its annual to decadal variability; and 2) make tracer measurements on ships of opportunity to sparsely sampled shelf regions of the Antarctic continent to investigate deep and bottom water formation in these regions. We also maintain a database of earlier data from the Antarctic shelf and coastal seas for comparison with our new data and to examine for temporal trends. For the North Atlantic, we augment on-going time series programs in regions of deep water formation with tracer observations. The tracer data provide information on rates and pathways of deep and bottom water formation, but just as importantly they also provide observations to test and refine ocean circulation models.

The research activities for the July 2002 – June 2003 year are listed below.

1. Published paper entitled "On the total input of Antarctic waters to the deep ocean: A preliminary estimate from chlorofluorocarbon measurements". Smethie collaborated with A.H. Orsi of Texas A&M University and J.L. Bullister of PMEL, NOAA on this paper and H.Lee of LDEO did much of the data analysis used in the paper.

2. Prepared a manuscript entitled “Circulation and melting under the Ross Ice Shelf: Estimates from evolving chlorofluorocarbon and salinity fields in the Ross Sea”. Smethie collaborated with S. Jacobs of LDEO on this manuscript and H. Lee of LDEO helped with the data analysis and preparation of figures. Smethie anticipates that this manuscript will be submitted and published during the next funding year.

3. Collected CFC samples in flame sealed glass ampoules on the LMG03-04 cruise to the mooring site for deep outflow from the Weddell Sea. Due to heavy ice cover, it was not possible to recover the moorings or complete the hydrographic/tracer section. Instead stations were taken in passages in the South Scotia Ridge through which some deep water flows northward from the Weddell Sea. These samples were collected by D. LeBel of LDEO.

4. Collected CFC samples in flame sealed glass ampoules on the 2002 summer and fall and 2003 winter and spring cruises of the Iceland Marine Research Institute in Denmark Strait and north and south of Denmark Strait. These samples were collected by Magnus Danielsen of the Iceland Marine Research Institute. This sampling program was started at the beginning of 2002. Four cruises per year are conducted by the Iceland Marine Research Institute and include CTD/rosette sampling at the stations shown in Figure 1. Stations sampled for CFCs are colored red. This provides time series observations of CFCs in Denmark Strait Overflow Water at its point of entry into the North Atlantic as well as upstream and downstream of this point of entry. The data will be used to investigate seasonal and interannual variability in the formation and input of Denmark Strait Overflow into the North Atlantic. This work is being done in collaboration with Jon Olafsson of the University of Iceland and the Iceland Marine Research Institute.

5. Analysis of CFC samples collected from the 2002 winter and spring cruises of the Iceland Marine Research Institute. These samples were measured at LDEO by E. Gorman and C. Mento (an undergraduate student).

6. Final data reduction and quality control of CFC measurements made on NBP 00-08 cruise to the Antarctic continental shelf between 140 and 150°E in December 2000 – January 2001. This is believed to be an important site of bottom water formation, but prior to this cruise, was sparsely sampled. The work was done by E. Gorman and H. Lee of LDEO. This study is being done in collaboration with S. Jacobs of LDEO.

RESEARCH ACCOMPLISHMENTS AND RESULTS

The deep limbs of the thermohaline circulation are driven by sinking of dense waters in the northern North Atlantic Ocean and around Antarctica. The strength of the input of near surface water to the deep ocean can be estimated from chlorofluorocarbon (CFC) inventories for the past few decades when CFCs have entered the surface ocean from the atmosphere. Initial estimates based on CFC-11 inventories for North Atlantic Deep Water (NADW), the northern source, yielded an input of about 17 Sv (Smethie and Fine, 2001). Initial estimates for AABW based on CFC-11 inventories was about 8 Sv (Orsi et al., 1999), which consisted of 4 Sv of near surface water and 4 Sv of entrained deep water. Thus it appeared that the deep limb of the thermohaline circulation was driven mainly by formation of NADW. However, the AABW is denser than NADW and to properly compare the strength of northern and southern sources, all inputs of near surface water into the same density range need to be considered. This is done in the Orsi et al., (2002) paper. In Figure 2 meridional vertical sections of CFC-11 for the Atlantic and the South Pacific and South Indian oceans show a much higher content of CFC-11 in NADW between the 27.7 and 28.27 neutral density surfaces than for AABW, which is denser than 28.27. The sources for the CFC-11 in NADW are Denmark Strait and Iceland-Scotland Overflow Water with neutral densities between 27.98 and 28.27 and Labrador Sea Water with a neutral density range of 27.7 – 27.98. However there are also southern sources of CFC-11 in these density ranges and the CFC inventory for water with a neutral density greater than 27.7 is about the same for the combined South Atlantic, South Pacific and South Indian oceans as for the North Atlantic Ocean indicating similar inputs of near surface water into the deep ocean in both hemispheres. The southern sources of CFC bearing near surface waters are dense Antarctic shelf waters that flow off the shelf and sink to the bottom to form Antarctic Bottom Water and Antarctic Surface Water that sinks into the Lower Circumpolar Deep Water (27.98 –28.27 neutral density**)** and Upper Circumpolar Deep Water (27.7-27.98 neutral density) layers. The total input of near surface water from southern sources estimated from CFC-11 inventories is about 14 Sv compared to about 17 Sv from North Atlantic sources.

CONCLUSIONS AND RECOMMENDATIONS

This research program consists of several ongoing projects in various stages and results have not been reported for each project. These results will come later as the various projects mature. All are focused on deep and bottom water formation. The results reported above are based mainly on pre-WOCE CFC measurements and include Antarctic Shelf CFC measurements made with NOAA/CORC support. With the WOCE data now available, a much better job

can be done in estimating deep and bottom water formation rates from CFC inventories and this should be done. As we continue to acquire data from the various projects supported by this grant, we will be able to refine estimates of deep and bottom water input into the ocean, document temporal variability in this input and provide data needed to test ocean circulation models.

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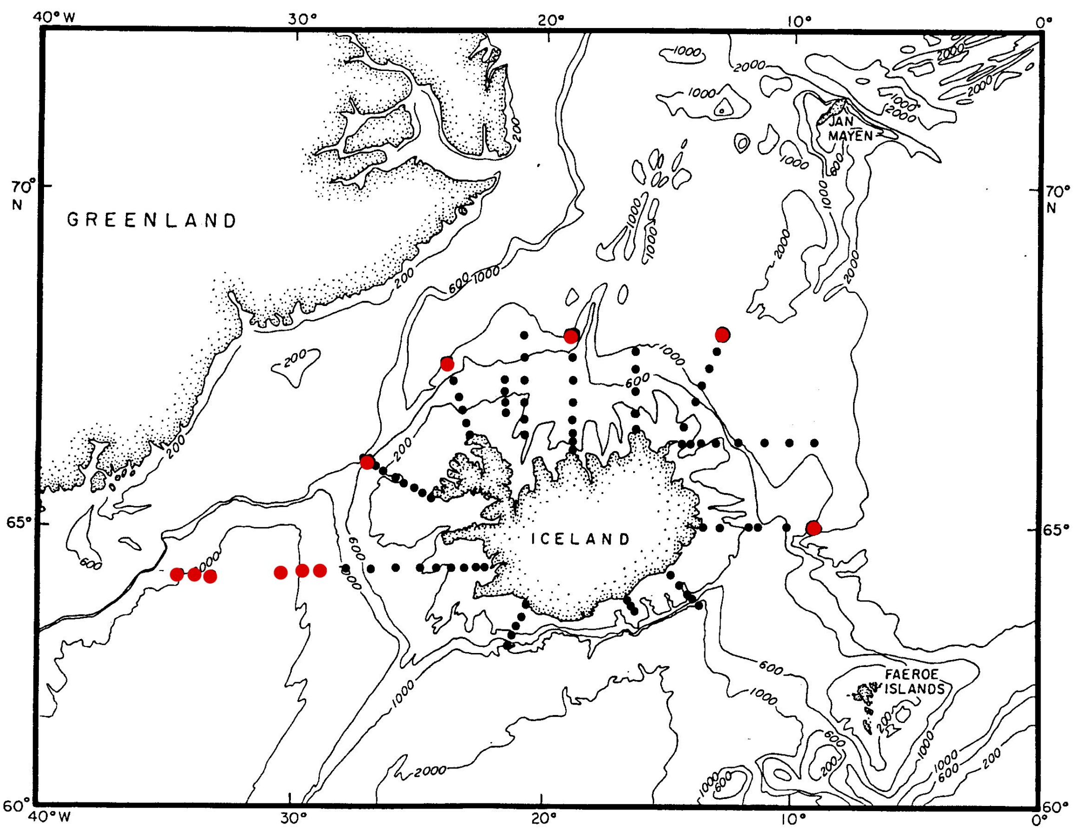
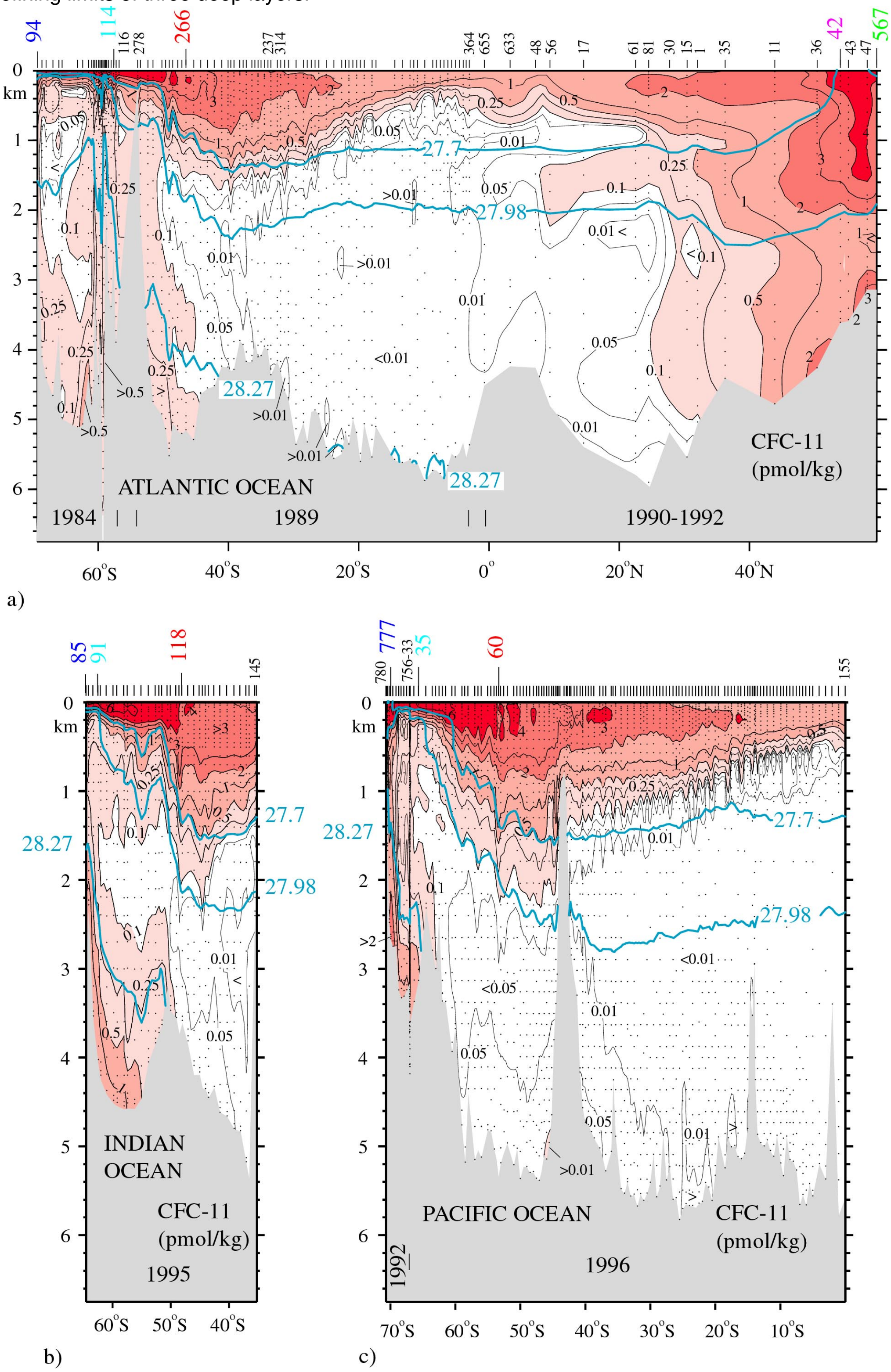


Figure 1. Map of stations occupied four times per year by the Iceland Marine Research Institute. The red dots represent stations where CFC samples are collected.

Figure 2. Vertical distributions of CFC-11 measured along western hydrographic lines in the a) Atlantic Ocean, b) the southern Indian Ocean and c) the South Pacific Ocean. Thick cyan lines indicate neutral density surfaces (kg/m³) defining limits of three deep layers.



OBSERVING THE DEEP WESTERN BOUNDARY CURRENT OF THE WEDDELL SEA (JOHN M. TOOLE)

OBJECTIVES

In collaboration with researchers from the Lamont-Doherty Earth Observatory, an array of instruments has been maintained on the southern flank of the South Orkney Plateau in the Southern Ocean to observe the properties, structure and transport of the deep western boundary current of the Weddell Sea. This current carries waters that have been recently modified by air-sea-ice exchanges adjacent to Antarctica and that ultimately contribute to the bottom waters found throughout the globe. Interannual variations in the transport and/or properties of the deep boundary current may manifest climatic changes in air-sea exchange and in turn, ocean circulation patterns. Our scientific goal for the program is to quantify the nature of the interannual variations to support investigation of their causes and consequences.

SUMMARY

The WHOI contribution to the Weddell Sea program centers around one element of the moored array. With previous support from the CORC program, the NSF and ONR, a new moored instrument has been developed and field-trialed. The new device returns ocean temperature, salinity and velocity information at high vertical resolution over long time. Termed the Moored Profiler, the instrument consists of an autonomous vehicle that mounts on a conventional subsurface mooring and travels up and down the wire carrying sensors through the water column. Profile speed is around 0.3 m/s and the vehicle has a profiling range of around 1 million meters. For the Weddell Sea program, we are instrumenting a site at the 2000 m isobath with a Moored Profiler cycling from the bottom to approximately 300 m depth: an interval spanning the Warm Deep Water Layer down into the newly-formed deep waters. Fellow LDEO researchers completed the array by deploying conventional current meters and acoustic Doppler velocity profilers farther down the slope.

Under prior CORC support, a full year record of temperature, salinity and velocity was obtained for the period April 1999 - April 2000. However, the replacement instrument deployed in April 2000 and recovered in February 2001 failed to log data due to a problem with this particular Profiler's hard disk at cold temperature. A third system, equipped with a hard disk proven to operate to -5C was deployed in February 2001 on a 2-year mission. This system is slated for recovery in April 2003. (Field operations will be carried out by LDEO personnel.)

RESEARCH ACCOMPLISHMENTS

Research has continued in the two main areas discussed in our prior progress report (for the period 7/1/01 - 6/30/02). Analysis of data from the first successful deployment is now also involving Robin Robertson from LDEO. Focus there is on the internal tidal motions. Another point of joint interest is the velocity and temperature fluctuations on several day timescales. We are attempting to establish if these can be characterized as topographic waves or as eddies of anomalous water moving with the boundary current.

We've been reluctant to focus much attention on annual and longer-period motions anticipating the recovery of instrumentation still in the field. Though there's no certainty that those instruments will return useful data, given the possibility of doubling the length of our time series with their recovery, we've concluded that it is sensible to hold off writing up the low-frequency motions until we get a look at those data.

In parallel with the analysis of the moored data, we continue to update and document the software used to reduce and process Moored Profiler data. The software is now available via a web site supported at the Woods Hole Oceanographic Institution. Interested users are asked to contact me (jtoole@whoi.edu) for downloading instructions.

The WHOI contribution to CORC ARCHES is slated to end on December 31, 2002. Responsibility for recovery of the instrumentation now deployed in the Weddell Sea and its return shipment to Woods Hole thus falls to LDEO collaborators. Toole will seek independent funding to process the recovered Moored Profiler data from the period 2001-2003 and work with Visbeck and colleagues on their analysis and scientific publication. Toole will contribute a final project report to the LDEO ARCHES office in 2003 that includes results from the 2001-2003 mooring deployment.

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RESEARCH ON THE MEASUREMENTS OF TWO OCEAN FLUXES OFF S.E. GREENLAND (R. R. DICKSON, FRSE)

SUMMARY

There is growing observational and modelling evidence that the role of the Arctic in Global Change may act through exchange with seas further south. Thus decadal variability may be imposed on the Arctic Ocean through changes in the inputs of heat and salt caused by climatic forcing over Nordic seas. In turn, changes in the heat and freshwater flux from the Arctic to subjacent seas can alter the rate and characteristics of the Atlantic thermohaline circulation (THC), which helps maintain the relative warmth of the climate of NW Europe.

The general objective of this work is to measure the two ocean fluxes [dense water overflow and freshwater flux] off SE Greenland that are essential to identifying and understanding the impact of Arctic change on the Meridional Overturning Circulation of the North Atlantic, to assess the causes of the long term variability in these flows, and to identify the links between that variability and climatic forcing. The specific objectives are: 1) To maintain the present CORC-CEFAS current meter array on the Continental Slope off SE Greenland [in collaboration with IFM Hamburg and IMR Helsinki] to the point where we have recovered decadal/pentadal estimates of the variability in speed & thickness of the cold, dense Denmark Strait Overflow, which drives the THC. 2) To develop and then deploy an array of fixed or profiling moored salinity sensors capable of to measuring the major (and at present totally unmeasured) component of freshwater flux passing south from the Arctic Ocean to the N Atlantic under the ice of the East Greenland shelf south of Denmark Strait.

APPROACH AND METHODOLOGY

The approach adopted is to measure the two main flows in question using moored arrays of instruments appropriate to the task across both the overflow on the East Greenland Slope and the freshwater flux on the shelf nearby, and to identify variability both flows by maintaining these measurements for periods of a few years to a decade. Calibration is achieved by tank test prior to deployment and by standard hydro-sections during mooring service. The work is collaborative between scientists at CEFAS Lowestoft, IFMH University of Hamburg, and IMR Helsinki, and the funding is joint between CORC-ARCHES and the ASOF Programme of EC Framework Programme V. CEFAS takes responsibility for the preparation, deployment, recovery and analysis of moored gear on behalf of the group. Though the instruments moored across the Denmark Strait Overflow are mainly conventional current meters, the freshwater flux array is largely experimental and the rate of its expansion across the shelf and hence the breadth of the freshwater stream covered depends on the progress in trials. Hitherto we have depended on 35-45m long 'tube' moorings to carry the salinity sensors up to the ice-base (Figure 1) but though these have been successful, resulting in a growing recovery of long salinity records (Figure 2) we intend to achieve better vertical resolution of salinity distribution by introducing a number of vertically-profiling HOMER systems as they are proved in trials [HOMER is being developed by staff from Scottish Association for Marine Science, Oban and Proudman Oceanographic Laboratory, Liverpool, UK under a small business research grant from the NERC RAPID thematic programme. The first long deep sea trial of HOMER was deployed off SE Greenland as part of our main overflow array in July 2003; (Figure 3].

Figure 1. A 45M 'tube mooring' carrying 3 SBE Microcat salinity sensors on the deck of FS METEOR before deployment on the East Greenland shelf in June 2002.

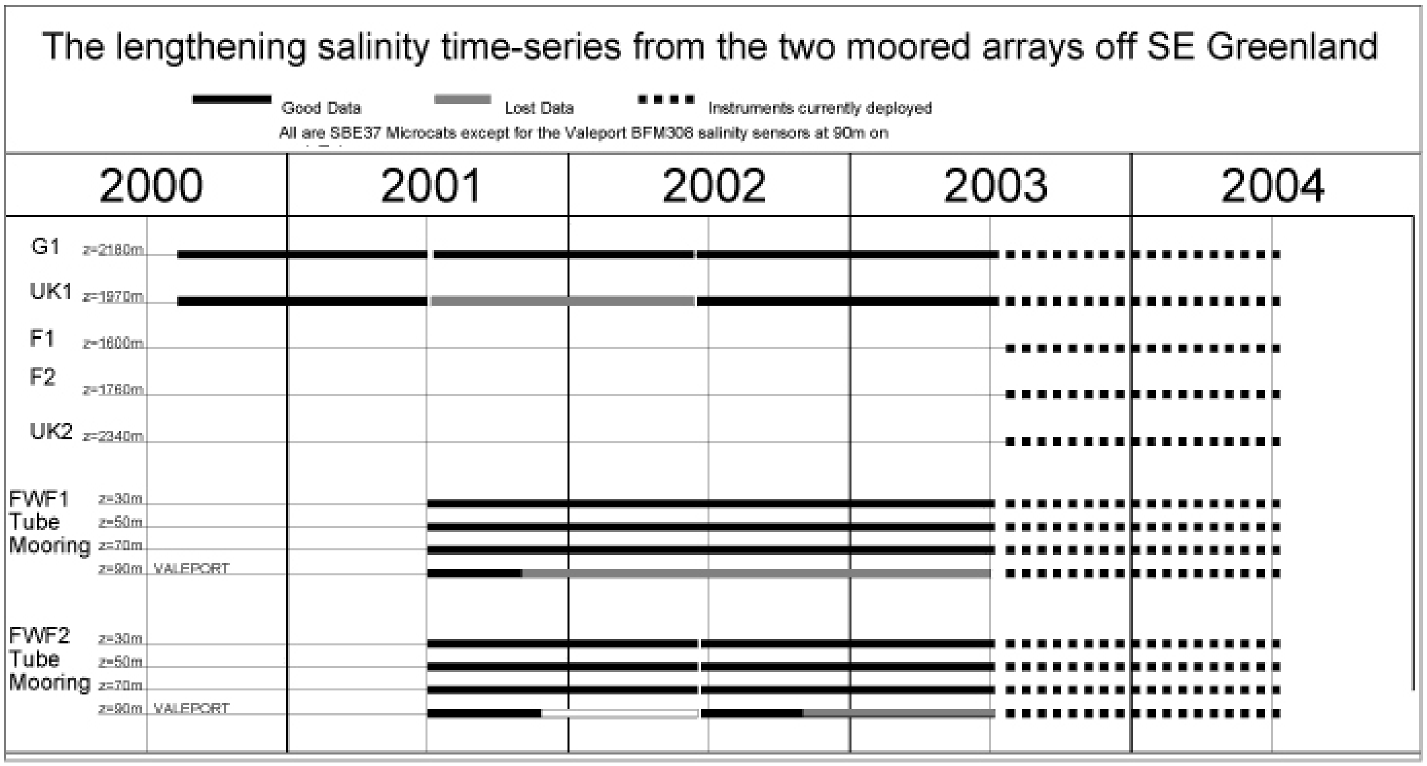

Figure 2. The growing recovery of long salinity records from both experimental arrays off SE Greenland, 2000-2003.

Figure 3. First 1-year deployment of the HOMER CTD profiler in the overflow array off SE Greenland, July 2003.

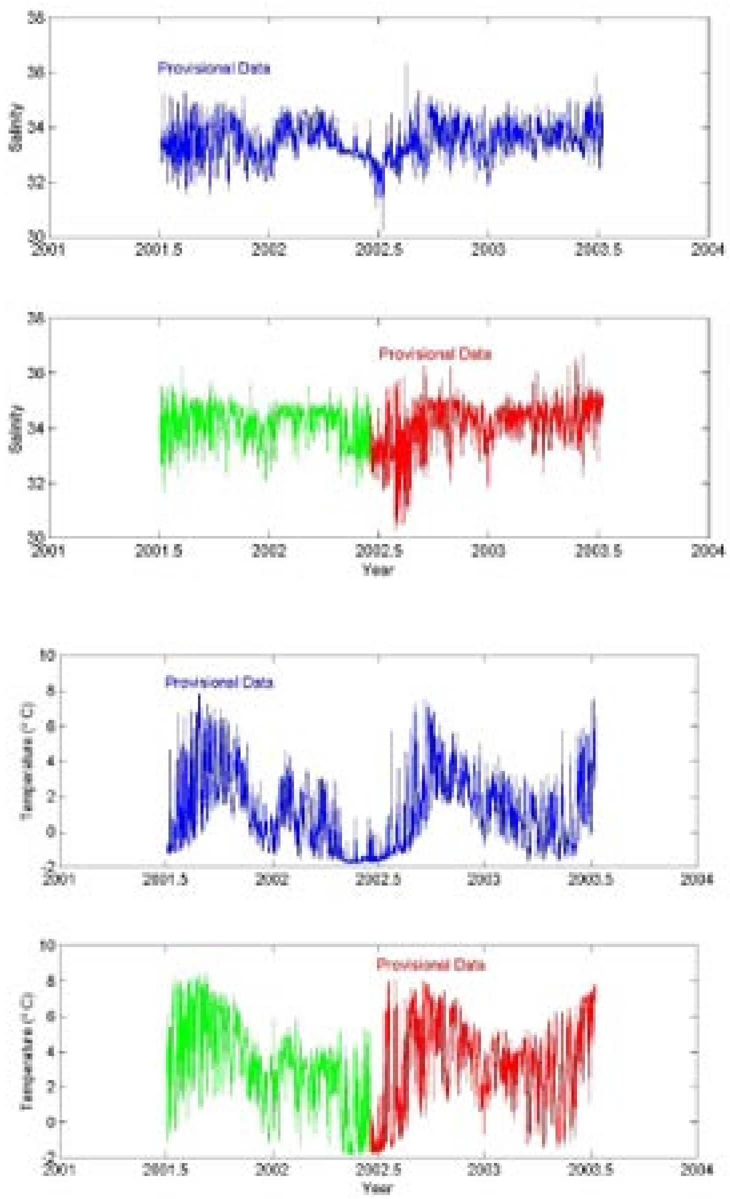

Figure 4. First two-year records of salinity and temperature from the top Microcat sensors (z = 30m) on two tube moorings set 18 km apart under the ice of the E Greenland shelf between June 2001 and July 2003 (provisional data).

During the year under review, in October 2002, we formally sought permission to change the use of the pre-existing budget line-item 'Mooring Costs' into 'Staff Costs for the Analysis and Interpretation of Salinity Records' by a research specialist. The justification is that gear losses had reduced to the point where they could be covered from CEFAS funding while the successful recovery of salinity records from both arrays meant that the current urgent need was for additional staff time for the specialized analysis and interpretation of these records. The analyst in question was currently employed at CEFAS. The planned acceleration of moored deployments for the freshwater flux array on the East Greenland Shelf means that this need is likely to be maintained to the end of this project. Our change-proposal was accepted and is now in practice.

RESEARCH ACCOMPLISHMENTS AND RESULTS

All the principal project aims remain on target.

Denmark Strait Overflow Array

The 8-mooring Denmark Strait Overflow Array was recovered by F/S POSEIDON during 4-26 June 2002 after a 1-year deployment. This array consisted of 7 current meter moorings with 22 instruments, of which 5 moorings are now stretched to cover the bottom 350m of the watercolumn thus resolving the overflow plume thickness. Two SBE-37 Microcat salinity-temperature recorders were included in the array. The remaining mooring comprised an Inverted Echo Sounder (IES) in its bottom-mounted frame, intended to provide a direct acoustic measure of overflow layer thickness. All instruments were safely recovered with a good data return from the current meters of 95%.

A 9-mooring array, this time including 7 c/m moorings carrying 21 current meters and 2 Microcats, was re-deployed for recovery by F/S METEOR in July 2003. The remaining two moorings carried bottom mounted ADCP and IES respectively. [The recovery took place before the writing of this report: 6 of 7 c/m moorings were safely recovered by METEOR yielding complete records from their 18 instruments. Three instruments were lost on the remaining mooring. Of the bottom-mounted instruments, the IES was recovered, to be replaced by the prototype HOMER on trial].

Freshwater Flux Array

The prototype CORC-CEFAS-IFMH freshwater flux array deployed in summer 2001 under the ice on the East Greenland Shelf had consisted of a two polyethylene 'pipe-moorings' designed to encourage temporary knock down rather than removal of the mooring by passing ice. Each carried 3 Microcat salinity sensors (one with pressure sensor) and one Valeport current meter equipped to measure T, S and D. One tube mooring was recovered by F/S POSEIDON in June 2002 with full salinity records from its three instruments and this mooring was replaced. The other tube mooring could not be reached in June 2002 due to ice. [Immediately prior to the writing of this report, both tube moorings were safely recovered by METEOR in July 2003, the one from the 2001 deployment with full 2-year Microcat records on all sensors, and the one from the 2002 launch with full 1-year records. Figure 2 provides a bar chart detailing the expanding return of Microcat recoveries from both arrays to date. Figure 4 provides the first (still provisional) 2-year salinity and temperature time series from the SE Greenland shelf, 2001-2003, showing a similar time-dependence on both 'tube' moorings, set ≈18 km apart). The Valeport c/m's gave short records of around 6 months from both deployments. Of the 3 successful 6-month records, the mean flow was to the southwest with a mean scalar speed of 19 cm $^{s-1}$ and a max of 46 cm $^{s-1}$].

Results from both arrays, and from the larger-scale analysis of hydro data, are of two types, a) those which continue to confirm the pre-existing working hypothesis, and b) those which provide new insights into local, regional or larger scale variability. They are itemised as follows:

- There continues to be little evidence of any systematic seasonal or interannual change in the speed or transport of the Denmark Strait overflow, in contrast to that through the Faroe-Bank Channel which appears (proxy evidence) to be slowing.
- The temperature of the Denmark Strait overflow off SE Greenland appears to be determined by NAO forcing of the upper ocean in the Fram Strait, some 2500km upstream and 3 years earlier (Dickson, Curry and Yashayaev, in press, 2003)
- The hydrographic character of the deepening overflow off SE Greenland determines the density at abyssal depths in the Labrador Sea one year later (Dickson, Curry and Yashayaev, op cit)

- There is clear, if indirect (proxy) evidence of a 40-year increasing trend in the amount of fresh near-surface waters passing south from the subarctic around the western margins of the Labrador Sea (Dickson, Curry and Yashayaev, op cit)
- The progressive 4-decade freshening of the entire system of overflow and entrainment that ventilates the deep Atlantic has continued. (Dickson et al 2002)
- The freshening of the watercolumn of the NW Atlantic is among the largest changes ever observed in oceanography. (Dickson et al 2002)
- The freshening observed in the northern North Atlantic over the past four decades appears to be part of a circumpolar freshening of the World Ocean in both hemispheres. Coupled with an increase in upper ocean salinities throughout the subtropics, this large-scale and long-term redistribution of ocean salinity is suggested to be the 'telltale' of an accelerating water cycle, long anticipated as a result of global warming. (Curry, Dickson and Yashayaev, in review, 2003
- Based on pentad- and decade- mean changes in the trans-ocean gradients of steric height (depth- integrated density), there is no convincing evidence yet of any significant, concerted slowdown in the Atlantic overturning circulation (Dickson, Curry and Yashayaev, op cit)
- With German and Finnish partners, progress has been made in extending a new freshwater flux array across the SE Greenland shelf.
- Despite early promise, attempts to measure overflow plume thickness by acoustic means proved unsuccessful and were abandoned in favour of HOMER profiling.
- Despite the harsh and remote fieldwork site off SE Greenland, the above results have been underpinned by a high recovery–rate of gear during the contract period, including a 95% good data return from current meters.
- The international ASOF study has been advanced to the point of implementation (see http://asof.npolar.no).
- "The Role of the Polar Oceans in the Global Water Cycle" has been submitted as one of the theme questions which could mobilize and motivate global science in a 4th International Polar Year (IPY-4), now being planned for 2007-8 (Dickson, 2003).

CONCLUSIONS AND RECOMMENDATIONS

The flows which form the subject of this proposal are of central importance to the Earth's climate system. The cold, dense overflow whose characteristics and variability are being measured by the Slope array drives the abyssal limb of the Atlantic meridional overturning circulation. The freshwater flows from the Arctic either side of Greenland are implicated in model experiments with slowing that circulation down. Since developing an understanding of the longer-term variability of both flows will be critical to the continued development of climate models, and since the measurements of both are advancing strongly under this project, ---------lengthening to decade-scale in the case of the overflow array, extending progressively across the shelf in the case of the freshwater array-----------it is our strong conclusion and recommendation that the measurement program supported by CORC–ARCHES should continue and ideally accelerate, in conjunction with other funding sources. Since the hydrographic changes observed appear to reflect larger-than-regional scales of variability, we should continue to set the changes we observe into that larger scale context by participation in the current international ASOF effort and ultimately in the global study of the role of the polar/subpolar oceans in climate that will animate the 4th International Polar Year in 2007-8.

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MODELING

MECHANISMS OF ABRUPT CLIMATE CHANGE, THE MODELING COMPONENT OF ARCHES (RICHARD SEAGER , M. CANE, Y. KUSHNIR, ET AL.)

SUMMARY

In this year we have continued our studies of abrupt climate change and the fundamental physical processes within the climate system that are involved. Our work has proceeded along two lines. First, we have examined the role in climate of the thermohaline circulation, variations in which remain a leading contender for causing abrupt change. Secondly we have pursued the idea that, instead, the tropics are an active player in abrupt climate change.

The idea that the tropics are an active player follows from extensive work on interannual and decadal climate variability that shows that tropical climate changes have global impacts and also can cause impressive hemispheric symmetry. Although it is still a matter of debate as to the extent to which this is generally true, many past climate changes (e.g. the Little Ice Age) did contain a hemispherically symmetric component. Our research has shown, using numerical models, that the El Nino Southern Oscillation has varied dramatically over the last 20,000 years. Many of these hypothesized changes have subsequently been confirmed by observational work, some of which was also funded by other components of the ARCHES program.

Currently, we are investigating the global consequences of abrupt changes in the tropics. Continuing the fruitful methodology of mining the recent period of intensive climate observations for analogues of abrupt climate changes, we have uncovered a mechanism whereby tropical climate changes can cause global climate change that is both zonally and hemispherically symmetric. This mechanism, which involves complex interactions between the Hadley Cell and transient eddies, can coordinate climate changes between the Cascade Mountains and the New Zealand Alps.

Turning our attention to the thermohaline circulation we have finally debunked the myth that the Gulf Stream is responsible for Europe's mild winters. Instead we have shown that the forcing of stationary waves by the Rocky Mountains plays a much larger role in explaining the winter frigidity of eastern North America and the mildness of Western Europe. This work has led to an overdue reassessment of the relative roles of the atmosphere and ocean in determining the regional climates around the North Atlantic Ocean.

The tropical warm pools are fundamental regulators of the Earth's climate. They are the place on the planet with the largest water vapor greenhouse trapping. Variations in warm pool size would impact the global mean temperature.

Despite this importance there is no defensible theory for why the warm pools exist and how they might vary. In this last year we have developed a theory for the existence of warm pools that places their genesis in the tropical ocean heat transport and its coupling to the atmosphere heat transport. This work is a fundamental advance in our understanding of tropical climate dynamics.

APPROACH/EVALUATION/METHODOLOGY

Our approach has been to analyze the observational climate record and to use a hierarchy of numerical models to formulate and test hypotheses. The models range from the almost conceptual to fully complex state-of-the-art coupled general circulation models.

RESEARCH ACCOMPLISHMENTS AND RESULTS

The following is a list of our accomplishments and result for this year.

The Role of the Gulf Stream in Climate

It is widely believed that heat transport by the Gulf Stream is the reason why Europe’s winters are so mild. This belief undergirds many theories of climate change that rely on variations in North Atlantic Ocean heat transport. By removing the ocean heat transport in global atmosphere-ocean models it was shown that, actually, ocean heat transport causes a modest warming across the North Atlantic region and no preferential impact over Europe. However, Europe's mild winters are not simply explained by a simple maritime-continental climate distinction. Advection within atmospheric stationary waves forced by mountains greatly cools eastern North America and warms Western Europe, explaining the large contrast in winter climates (Seager et al. 2002). Accordingly it is expected that more dramatic climate change can occur in the North Atlantic sector due to abrupt changes in atmosphere circulation than due to changes in ocean circulation.

Mechanisms of Hemispherically Symmetric Climate Change

Much of the record of past climate change shows hemispheric symmetry and is suggestive of changes in the latitudes of the tropospheric jet streams. We examined variations of the latitudes of the subtropical jet streams and found that hemispherically symmetric latitude shifts are controlled by ENSO. During warm events the jets shift equatorward. At the same time, due to interactions between the altered Hadley Cell and mid-latitude transient eddies, tropical warming associated with El Nino is accompanied by cooling in mid-latitudes. The opposite occurs during La Nina events. Over Canada east of the Rockies, El Nino is associated with warmth in DJF and cool temperatures in the remainder of the year, a change in the seasonal cycle that should presumably favor snow accumulation, supporting the contention in the previous section. This mechanism provides a means in addition to teleconnections whereby the tropics can influence extratropical climate.

An important part of this work is the demonstration that the net effect of transient eddies (i.e. the eddy heat transport plus the heat transport by the eddy-driven mean meridional circulation) is to amplify changes in the tropics to mid-latitudes temperature gradients caused by ENSO. Transient eddies do not always damp temperature gradient anomalies contrary to frequent heuristic arguments presented in simple theories of climate change. This result has important consequences for the global response to past tropical climate variations.

Tropical Ocean Heat Transport and Climate

The mechanisms governing tropical ocean heat transport (OHT) have been studied together with the means whereby it might vary. We have shown in models how reducing tropical OHT, and increasing tropical atmosphere heat transport, causes a cooling of the planet due to interactions between the atmospheric circulation and water vapor (Clement: Sager, 1999}. We have shown that tropical OHT varies little in response to persistent El Nino or La Nina forcing due to compensation between changes in the poleward heat transport by the wind-driven mean meridional overturning and equatorward heat transport by the equatorial gyres. However, extratropical forcing can, over a few decades, cause changes in tropical ocean heat transport (Hazeleger et al. 2003).

We have also examined the origin of the tropical warm pools which are the regions of the greatest greenhouse trapping by water vapor on the planet. We have shown that the warm pools arise through coupled dynamical interactions between the ocean and atmosphere and that the movement of heat by the ocean is a fundamental necessity. Oddly enough this had been overlooked in previous work on the topic. The warm pools arise through a complex interplay between the atmospheric circulation, which seeks to erode the warm pools, and the atmospheric driving of the ocean circulation, which seeks to extend the warm pools. There is potential within this coupling for modulating climate change. This work has been reported in Sager et al. (2003c) and Clement et al. (2003).

The Summer Subtropical Anticyclones in the Climate System

Over the eastern subtropical oceans extensive low cloud cover and low levels of atmospheric water vapor cause regulate local and global temperatures. It is being investigated how these areas are involved in climate change. Our work has conclusively linked the atmosphere circulation, cloud cover, water vapor and SSTs in these regions to remote forcing by the summer monsoons. While the monsoon forcing directly causes weak summer anticyclones over the ocean positive atmosphere-ocean feedbacks, of both thermodynamical and dynamical nature, are required to strengthen the anticyclones and to create the extensive low cloud cover and bone dry free troposphere (Seager et al. 2003a). It is hypothesized that as monsoons vary in strength due to external forcing so too will the summer anticyclones, thus changing the global mean temperature.

The Thermohaline Circulation and Climate

The reason why no deep water is formed in the North Pacific has been reanalyzed with modern data. Contrary to prior explanations our results point to the importance of atmospheric moisture transport and, in particular, the transport within the Asian monsoon (Emile-Geay et al. 2003). Martinson and Pitman (2003) have developed a hypothesis whereby the glacial terminations and other climate perturbations (e.g., possibly Heinrich events) are dependent upon Arctic Ocean overturning and onset of the THC.

Stratosphere influences on Tropospheric Circulation and Climate

In the last decade there has been a growth in observational and model studies that suggest that variations in the stratospheric mean state caused by natural variability and external forcing might have a significant effect on the tropospheric climate through the dynamic link between the two atmospheric layers. It has even been suggested in recent years that dramatic climate changes in the past, e.g. the coldest parts of the Little Ice Age in Europe, were forced by solar variations with changes in stratosphere circulation being the link to surface climate. This work makes it imperative to better understand whether it is truly possible for the stratosphere to exert this strong an influence in the troposphere.

The fundamental dynamic mechanism coupling the two layers is the upward propagation of planetary waves. Motivated by studies that suggest the polar night jet can assume a structure which reflects the waves back down we have used statistical and dynamic diagnostics to study the possibility of a downward effect on the flow in the troposphere. It was found that downward reflection of waves has a significant effect on the tropospheric wave structure a few days later, during January to March, of about half of the years of the observational record.

Further analysis indicates that reflection causes the planetary scale wave pattern in the troposphere to shift in longitude, which may have implications for climate change. This work strongly suggests that external forcing of the stratosphere - by solar radiation or greenhouse gases - can indeed have an impact in the troposphere.

The Northern Hemisphere Midlatitude Storm Tracks

The mid-latitude storm tracks effect regional and global climate in many ways. They are the regions of massive poleward transport of heat and moisture from the subtropics to the extratropics and are also the regions of most extensive low-level cloud cover, the albedo effect of which, significantly cools the planet. Any change in their strength and location will have significant global climate impacts but it is unclear what the controls are.

It is well know that they exhibit substantial variability in location and intensity on interannual and decadal time scales, which is clearly related to the variability in the midlatitude jet stream. Oddly, and contrary to what simple baroclinic instability models would suggest, the mid-winter Pacific storm track is weaker when the jet is strong. We noted that the Pacific jet is also narrower when it is strong, and examined the effects this would have on the growth of perturbations in simple instability models. These models were able to reproduce the observed decrease of spatial growth rate with shear, only when taking into account the narrowing of the jet. The results support the notion that the jet stream in the Pacific acts as a waveguide for perturbations as they move downstream and amplify over the eastern Pacific.

The next step will be to apply this knowledge to examine what can alter the storm track location and strength on long time scales.

CONCLUSIONS AND RECOMMENDATIONS

The project has led to some significant advances in our understanding of the climate processes that are, or are hypothesized to be, involved in abrupt climate change. The Gulf Stream/ European winters work has sparked an important debate that has focused attention on the importance of the atmosphere circulation to the climate of the

North Atlantic region, an area where in the past climate changes have been notably severe. We have continued to advance the case of tropical driving of climate changes. While our case remains shaky, the ensuing debate between proponents of high latitude driving and proponents of tropical driving has energized the fields of paleoclimate and abrupt change research. Our work has also contributed to the growing linkages between climate modelers and workers deciphering the records of climate change to be found in terrestrial, marine and cryospheric sources.

Our major recommendation is that further collaboration between modelers and those working on paleoclimate proxies is needed. Modelers need to take the paleo proxies seriously and seek to explain (or disprove) them by placing them in dynamical context. Those working on paleo proxies can assist collaboration with modelers by pooling their efforts to provide spatial maps of particular abrupt changes (e.g. the Younger Dryas). Modelers tend to work with maps and the provision of maps will facilitate comparison between modeled and reconstructed abrupt changes, a necessary step in the testing of hypotheses of the causes of abrupt climate change.

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SOUTHERN OCEAN MODELING AND ANALYSIS COMPONENT (D.G. MARTINSON, X. YUAN, B. TREMBLAY, AND W. PITMAN)

SUMMARY AND APPROACH

Our overall objective is to improve the documentation and understanding of how the Southern Ocean polar waters and overlying sea ice fields interact (respond and influence) global climate variability. Specific goals include: (1) establish teleconnections (correlations) between polar and extrapolar climate variables; (2) establish confidence of teleconnections; (3) evaluate the extent to which the robust teleconnections are simulated in the primary global climate models; and (4) determine the model mechanisms of the teleconnections that they do simulate.

ACCOMPLISHMENTS

We have addressed each of the individual goals stated above. Results for the number specific goals are referenced in the following published papers:

1 Paper "b" develops upper ocean polar gyre climate sensitive variables, determines their space-time variability through an EOF analysis, and correlates these variables to various global climate indices (e.g., ENSO, NAO,

PNA, etc.) detrended surface air temperature (SAT*) at 5˚x5˚ intervals throughout the globe based on NCEP/NCAR reanalysis data. This extends our previous work where we correlated sea ice variability to SAT*.

2 Paper "b" also utilizes bootstrap method for determining confidence level (versus that expected if the polar variables were quasi-periodic red noise series). Confidence intervals, labeled in number of standard deviations of confidence (σ) are presented on the correlation (teleconnection) maps. Teleconnections that are significant at greater then 3s are seen, with the strongest teleconnection between the ENSO events and polar variables, though many other robust teleconnections are found as was the case with the sea ice variability teleconnections of Yuan and Martinson, 2000 (J. Climate, V13, 1697-1717).

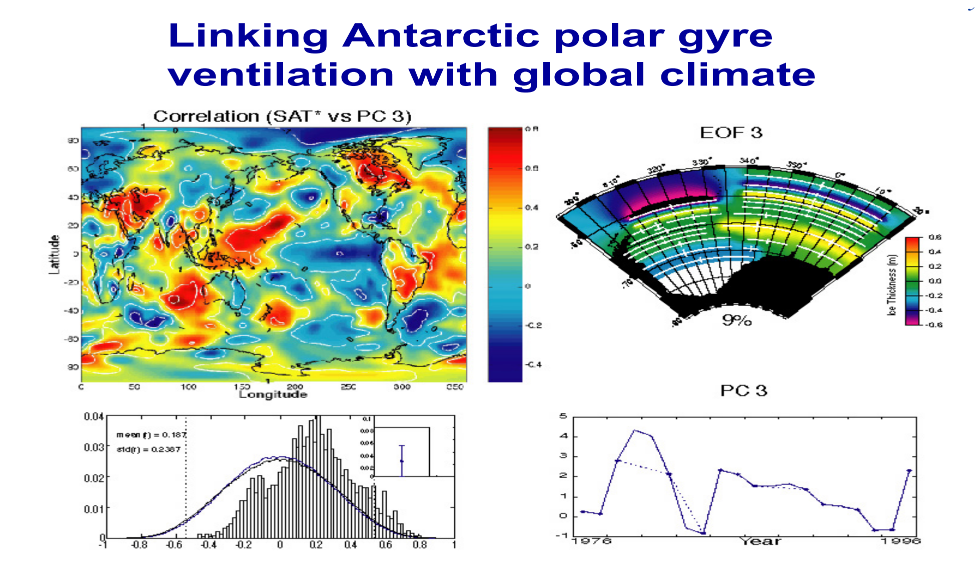

Figure of global teleconnections for mode 2 of Atlantic polar gyre vertical heat flux: Example of extent of global teleconnections of a mode of upper ocean variability of Weddell subpolar gyre against gridded SAT*. Map shows correlation coefficient as function of space with confidence contours (σ). See paper "b" below for details.

3 Paper "d" presents results of examination of 3 (GISS, GFDL, NCAR) primary published global climate model reference simulations to determine which observed (of Goal 2 and produced again in this paper) teleconnections are simulated by the models. Models do poor job of simulating most teleconnections (this is tough model diagnostic because teleconnections are likely driven by a hierarchy of local, regional and global processes which must all be parameterized properly to capture teleconnections). None of the models produce a very convincing El Niño, but a couple of the models do produce a credible ENSO-polar teleconnection.

4 Model teleconnection mechanisms are presented from two different perspectives in papers "a" and "f". Evaluation of GISS model suggests that the change in the equator-pole temperature gradient associated with ENSO events leads to a sequence of atmospheric circulation changes that results in a northward or southward migration of the Southern hemisphere subtropical split jets. This alters cyclogenesis, storminess and polar grye characteristics (in manner consistent with dynamic response suggested from observations in paper 'b").

RECOMMENDATIONS (FUTURE RESEARCH)

We intend to:

- Evaluate the nature of the ocean-ice interaction more carefully to further develop our understanding of the local/regional mechanisms responsible for dominating the polar gyre response. We will do this by coupling the detailed mixing parameterization (KPP) of Large et al. (1997) to the ocean-sea ice model of Martinson (Chen, 1998) and we will run this in combination with the Curchitser ROMS primitive equation ocean model which now has sea ice and the KPP mixing parameterization. From this we hope to determine local scalings, sensitivities, predictions of expected polar change given a forecast change in subpolar climate, and provide some additional clues as to how the polar changes may feedback to influence global climate (which is still not understood or documented).

- Isolate the various subpolar responses to tropical Pacific variability, and from this, project the expected changes that the abrupt ENSO modeling produces, onto the subpolar region. These subpolar changes will then be prescribed in the GCMs and they will be rerun to evaluate the influence of the prescribed subpolar changes on global climate (focusing on the globe, but also paying particular attention to the primary teleconnection regions).

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Martinson, D.G. and W.C. Pitman III, submitted. The Arctic as a Trigger to Glacial Terminations, Paleoceanography.

Presentations

National Research Council/Polar Research Board (4/02)

Role of Southern Ocean in Global Climate Briefing of President's Science Advisor (Dr. John Marburger; 5/03)

Role of Oceans in Global Climate Attended: International Conference on Southern Hemisphere Oceanography and Meteorology (3/03)

THE ARGO PROJECT: GLOBAL OCEAN OBSERVATIONS FOR UNDERSTANDING AND PREDICTION OF CLIMATE VARIABILITY

Dean H. Roemmich and Russ E. Davis
Scripps Institution of Oceanography

TASK/THEME: 2A

SUMMARY

This award is for SIO's participation (Phase 3, Year 2) in U.S. Argo – and thereby in the international Argo Project. By 2005, international Argo will deploy a global array of 3000 profiling CTD floats

(http://www.argo.ucsd.edu),

plus a data system that will make all Argo data available to both operational users of real-time data and to scientific users of a high-quality data stream. The Argo array will provide unprecedented real-time views of the evolving physical state of the ocean, amounting to more than 100,000 temperature/salinity profiles per year. It will reveal the physical processes that balance the large-scale heat and freshwater budgets of the ocean and will provide a crucial dataset for initialization and assimilation in seasonal-to-decadal forecast models. In this report, we review the overall structure and strategy of Argo in the present section and the specific results and accomplishments of SIO-Argo in the next section.

The Argo array is presently more than 25% complete with over 800 floats in all of the world's oceans (Fig 1). Initial float deployments were concentrated in the North Atlantic, North Pacific, and tropical oceans to build effective regional arrays. These are now expanding toward global coverage, as the rate of float deployments is increasing (339 floats deployed in the first half of 2003).

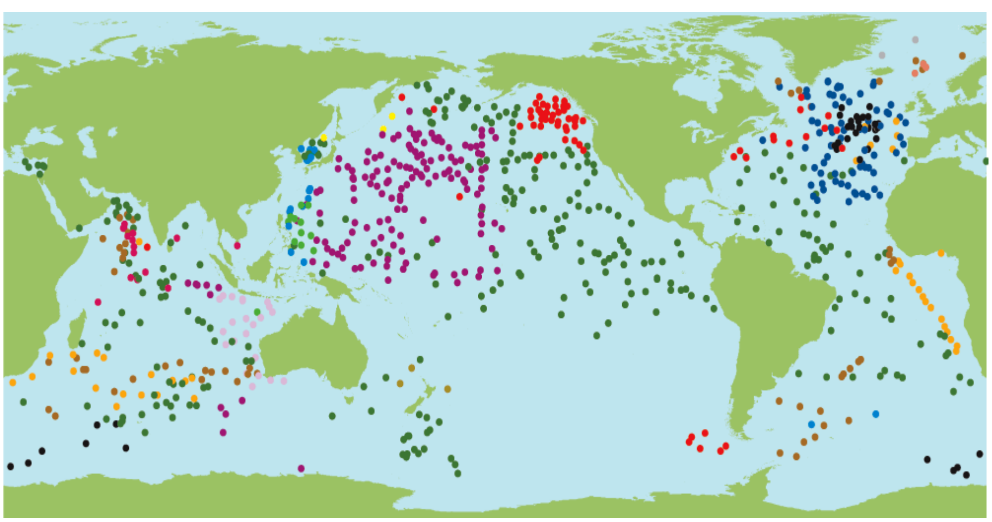

Figure 1. Distribution of 831 active Argo floats as of June 2003. US floats are shown as dark green.

The US strategy for participation in Argo is formulated by the US Argo Advisory Panel, composed of US Argo PIs and major users of Argo data (CLIVAR, GODAE, GOOS, data assimilation centers, fisheries). Present US float deployments are targeted for the tropical Atlantic, Pacific, and Indian Oceans, the northwest Atlantic, northeast Pacific, and Southern Ocean (Figure 2). US Argo is building and deploying about 345 floats with FY03 funding, while scaling up to provide 50% of the global Argo array, or about 410 floats per year on a sustained basis. A major effort aimed at populating the South Pacific with floats is being planned for the coming year. Argo data management activities include a national data assembly center (NOAA/AOML), development of a scientific quality control system for float data (NOAA/PMEL), and maintenance of a global Argo data center (FNMOC).

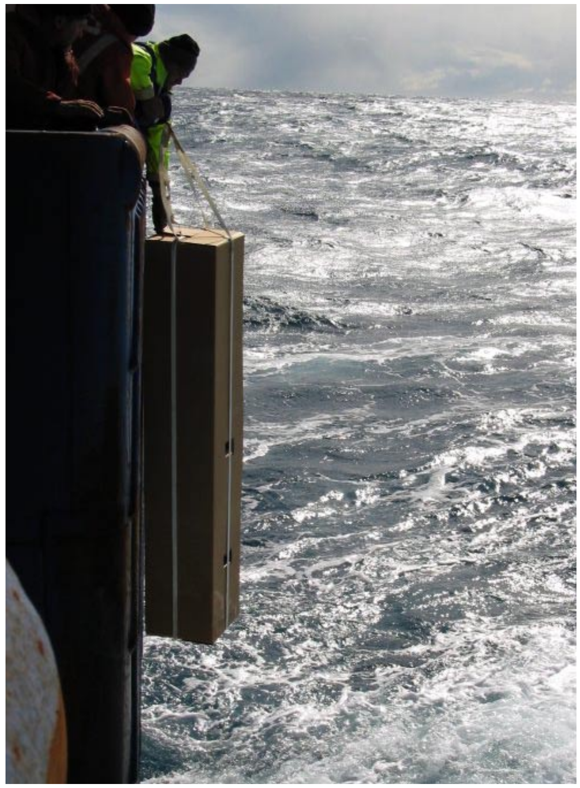

Figure 2: The strong international partnership in Argo is illustrated in this float deployment in the Southern Ocean. A US Argo float (SIO/SOLO) is deployed by Japanese scientists from a New Zealand research vessel, R/V Tangaroa, south of New Zealand.

A major focus of US and international Argo at present is to demonstrate at an early date the scientific and operational value of the Argo dataset. In that regard, the Argo Science Team has made presentations at a number of conferences (e.g. Roemmich et al., 2003, Roemmich, 2003), and the First Argo Science Workshop will be held in Tokyo in November, 2003.

The specific roles of SIO-Argo include:

- Production and deployment of 105 floats per year.
- Technical development and improvement of profiling floats for Argo.
- Participation in the Argo data system through delayed-mode scientific quality control.
- Leadership of international Argo by J. Gould (Argo Director) and D. Roemmich (Chairman, Argo Science Team), and coordination of the U.S. Argo Consortium (SIO, WHOI, UW, NOAA/PMEL, NOAA/AOML).

Results and accomplishments of SIO-Argo are reported in the next section.

RESEARCH ACCOMPLISHMENTS AND RESULTS

Even with less than 30% of the Argo array in place, Argo has already become the dominant source of broad-scale profile data in the ocean observing system. The impact of Argo data on near-real time applications is illustrated by

Figure 3, comparing the Argo and XBT data available in near real-time for May 2003. Not only are there more Argo profiles, but the spatial distribution is broader, as Argo begins to fill in the immense gaps in global sampling that characterize the ship-based networks. In addition to improving on the spatial characteristics of the present networks, Argo also provides better accuracy than XBT temperature and includes salinity in the broad-scale observing system for the first time.

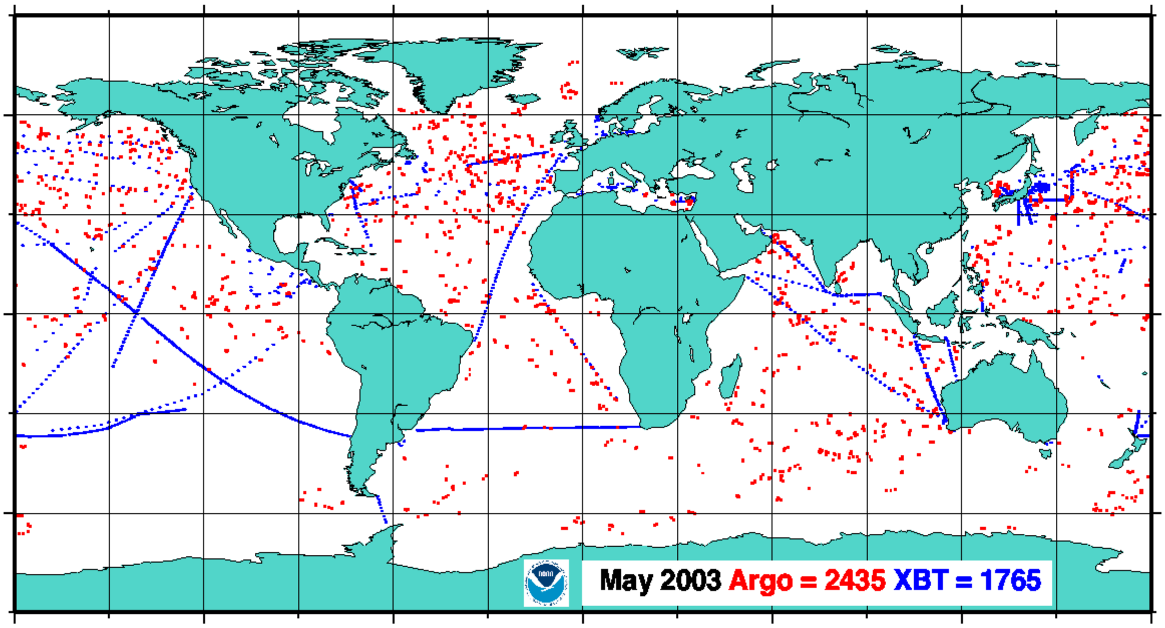

Figure 3. Locations of 2435 Argo T/S profiles and 1765 XBT profiles available in near real-time in May 2003.

During 2002, the major focus of SIO-Argo was technology improvement with the objective of redesigning the SIO-Argo float (SOLO) for improved ruggedness, reliability and lifetime. Major improvements were made in the pumping system and with replacement of the float's controller. There was a hiatus in float deployments while the design improvements were implemented, with small test deployments made in October and December of 2002. Full-scale production and deployment of floats resumed in early 2003. Seventy new generation SIO/SOLO-II floats have been shipped in the first 6 months of 2003, with a similar number planned for the second half of the year. Continuation of this rate of production and deployment through late 2004 will result in all funded floats being deployed, as well as eliminating the backlog of floats that resulted from the 2002 hiatus. The SOLO-II design improvements have also been passed to our partners at WHOI and other SOLO users.

Floats built at SIO this year are targeting the tropical and South Pacific, including the Pacific sector of the Southern Ocean. The present locations of active SIO-Argo floats, as well as recent profiles, are displayed at

http://sio-argo.ucsd.edu.

Plans for deployment of floats in the coming months are at http://www.argo.ucsd.edu/deploypac.html.

SIO participation in Argo data management is through expert examination of all Argo profiles as part of the scientific quality control process. While this process is still being defined by international Argo, J. Gilson of SIO has developed a graphical user interface that allows the user to examine profiles, compare them to regional historical data, implement decisions on salinity recalibration, and rewrite the standard Argo NETCDF files. He has also examined all of the SIO-Argo profiles and worked with A. Wong of NOAA/PMEL to improve the automated salinity adjustment procedures. In the QC process, expert examination of all profiles will be the final QC step, following the automated estimate of salinity adjustment.

Argo program coordination took a major step this year in the creation of an Argo Project Office at SIO, and the hiring of J. Gould as Argo Director. In just a few years, Argo has grown from a small start-up project, loosely coordinated by its participants, into a major international program requiring full-time scientific management. Dr. Gould has come to SIO on a short-term basis (2 years) to define the job of Argo Director, to begin carrying out its tasks, and to help in recruitment of a long-term Director. Major efforts this year have been in preparing for the Argo Science Team Meeting in Hangzhou, China in March, organization of the First Argo Science Workshop to be held in November, and redefinition of the Argo Data Team. D. Roemmich continues in his role as Chairman of the Argo Science Team.

A substantial research result has been the development (Willis *et al.,* 2003a) and application (Willis *et al.,* 2003b) of a new technique for combining satellite altimetric height with Argo and other subsurface data. Willis *et al* (2003b) used this technique to estimate global ocean heat content, and its increase since 1993 by 1.0 W/m^2 (Figure 4). This estimate uses Argo and pre-Argo float data, as well as profile data from other sources. Error bounds on the estimate will decrease as Argo is completed.

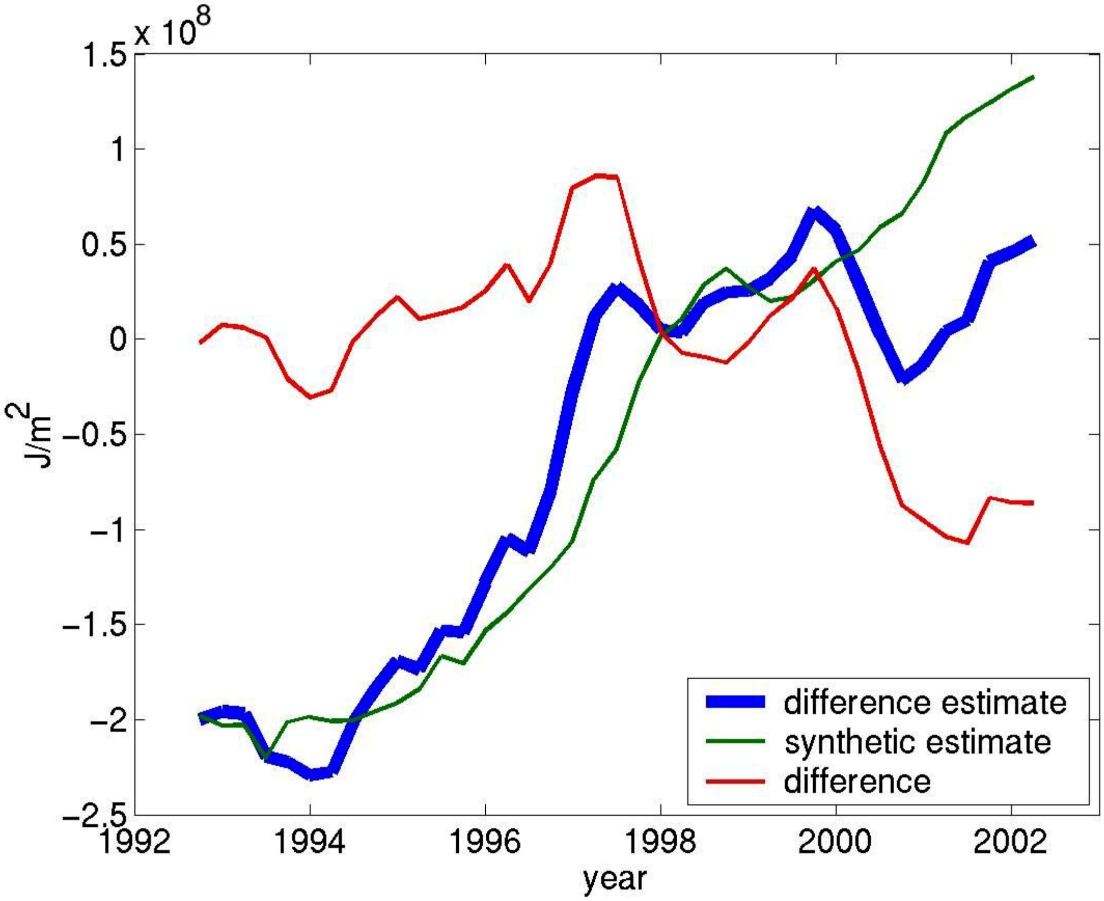

Figure 4. Changes in global ocean heat content (units of 10^8 J/m^2) from Willis et al (2003b), based on altimetric height and subsurface data, including Argo. This combined estimate (labeled difference estimate - blue line) is significantly different from the “synthetic” estimate based only on altimetric height and correlation statistics.

Other SIO-Argo research results have also been reported (Roemmich et al., 2003, Roemmich, 2003), including detection of near-surface and thermocline salinity anomalies in the tropical Pacific, calculation of the contribution of salinity to steric height variability (global), and comparison of surface-layer heat storage from individual floats with air-sea flux estimates.

CONCLUSIONS AND RECOMMENDATIONS

Argo is intrinsically a long-term research effort. It is essential for its success that the full array be implemented and sustained for a period of years in order that the value of global observations can be fully realized. The major challenge for the US and its international Argo partners, will be to sustain the level of effort required to maintain the Argo array long enough to prove its value. This is the fundamental challenge for any sustained ocean observational program – an array that focuses on interannual variability will achieve its full value only after about 10 years. The First Argo Science Workshop (Tokyo, November 2003) will focus attention on the complete range of scientific and operational uses of Argo data, but it must be kept firmly in mind that Argo has only begun. Argo will continue to evolve to more rugged floats, with improved lifetime, communications, and depth capability. Major hurdles of scaling up production, improved salinity stability, and coping with technical failures, have been overcome. Additional challenges lie ahead for this unprecedented global program.

PUBLICATIONS

Refereed Journal Articles

Willis, J., D. Roemmich and B. Cornuelle: Combining altimetric height with broadscale profile data to estimate steric height, heat storage, subsurface temperature and SST variability. *Journal of Geophysical Research* (2003a, in press).

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Roemmich, D.: The Argo Project: Observing the global ocean in real-time. Abstract of invited talk at IUGG General Assembly, Sapporo Japan, June 2003b.

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GLOBAL DRIFTER PROGRAM

Peter Niiler

Scripps Institution of Oceanography

TASK/THEME: 2A

SUMMARY

The “Global Drifter Program” is a scientific project of the Data Buoy Cooperation Panel (DBCP) of WMO and IOC and is part of the Ocean Climate Observing System of NOAA. It is a near-operational ocean-observing network of drifters that, through ARGOS, returns data on ocean currents, SST, atmospheric pressure and winds (and salinity) and provides a data processing system for scientific utilization of that data.

APPROACH

The Scripps Institution of Oceanography (SIO) is responsible for the acquisition of the drifters and for the technical development related to the improvements of performance and the addition of new sensors. The Atlantic Oceanographic and Meteorological Laboratory (AOML) of NOAA is responsible for the drifter deployments and the scientific data processing. Since 1990 the Global Drifter Program, in cooperation with its international and national partners, has maintained an array in excess of 650 drifters in the global ocean. The scientific papers and reports published using data from these drifters can be viewed at the AOML web site:

http://www.aoml.noaa.gov/phod/dac/drifter_bibliography.html

This JIMO task is an ongoing SIO activity to provide drifter acquisition, technical development of drifter components, sensors and methods of deployment and the distribution of new forms of data from drifting buoys in support of the stated tasks of the OAR/NOAA Ocean Climate Observing System: (i) foster ocean research, (ii) provide data for operational analyses and (iii) support international programs. An intimate relationship is maintained with AOML and other US and international scientific programs and members of the DBCP who are responsible for the deployment of drifters of similar hydrodynamic shape and similar sensor quality. In this five-year period of 1999-2004, the focus of the drifter deployments is in the tropical Pacific and Indian Oceans and the Southern Oceans (242 drifters/year). Close coordination is maintained with the “Tropical Atlantic Drifter Program”(78 drifters/year) and the CORC (tropical Pacific enhancements of100 drifters/year), both of which are funded separately by OGP/NOAA. Each year SIO queries and maintains contact with the ocean research programs that use SVP drifters and requests that data be made available to the SIO/AOML data file. In the period 2003-2005 ONR and the Busan National University of Korea will contribute 240 SVP drifters to the sampling of the marginal seas of western sub-tropical Pacific.

RESEARCH ACCOMPLISHMENTS AND RESULTS

Drifter Acquisitions

SIO purchased 276 SVP drifters that were added to the 36 barometers for the Southern Oceans. The drifter acquisitions were distributed equally between Clearwater, Inc. and Technocean, Inc. The barometer additions were all done at Technocean, Inc., because their barometer port assembly was proven superior to others on the market. The SVP drifters without barometers have all been made available to AOML for deployment and the barometer drifters are arriving on schedule. This is an increase of 35 drifters over 2001-2002 purchases for the $540K expended funds due to the re-design of the SVP drifter mechanical and electronic components.

Data Files and Distribution

Additional SVP drifter data files were acquired, processed, corrected for wind-slip and placed into the SIO data file of 220 drifter data files from Phyllis Stabeno at PMEL. The PMEL drifters have drogues centered at 40 m, below the Ekman layer and will be used in the mapping of the geostrophic currents of the North Pacific. Cooperative programs were carried out with Gregg Mitchell of SIO and the Korean National Oceanographic Research Institute. SIO continues to maintain a complete file of all of the historical drifter data that is corrected for wind slip and other biases.

The following investigators asked for and received gridded data files during the past 15 months on velocity and SST:

Lynne Talley	Scripps Institution of Oceanography
Detlef Stammer	Scripps Institution of Oceanography
Meng Zhou	U. of Mass, Boston
Nikolai Maximenko	U. of Hawaii
Sophie Ricci	CERFACS, France

Every year we have updated the file on peer-reviewed publications in the major oceanographic journals that have used drifter data for research results. Figure 1 shows the complete drifter data files that are maintained at JIMO for distribution to the scientific community.

International Planning Activities

Peter Niiler participated and delivered papers at the following international planning activities under the sponsorship of this project: DBCP Meeting Oct. 2002 Martinique, France; AGU/EGS Joint Meeting, April, 2003, Nice, France. NOAA Climate Observation Program Workshop, Silver Spring, May, 2003;

Technical Developments

In 2002-03, the configuration of the SVP drifter was redesigned at SIO by reducing its size by about 40%, but keeping the same water-following capability of 40 drag area ratio, as it was in the past 14 years. In 2002, the SVP price was reduced from $2150 to $1950 and will be reduced further to $1800 in 2003. The following cost savings will have incurred in 2002-03-04 as the low cost drifters are brought on line:

a. Reduction of the size of drifter components by 40% resulted in materials savings in packing material, float, stress relief element and other components.

b. Reduction of the voltage of a redesigned transmitter made by TOYOCOM, Inc.

c. Redesign and change in manufacturing techniques of the drogue, tether and the attachment techniques.

d. Reduction in labor costs in assembly.

e. Total reduction of drifter cost from $2150 to $1700 by 2004 will be brought about gradually as the new assembly methods, new electronics and new size of components and packaging are brought into line. In 2002, an additional 43 drifters were bought with NOAA/OGP funds and in 2003 another 41 will allow the purchase of increase of 84 drifters from 2001. These additional drifters will allow a complete implementation of the North Pacific CLIVAR drifter program in the sub-polar gyre.

CONCLUSIONS AND RECOMMENDATIONS

Drifter Acquisitions

SIO will acquire approximately 264 additional SVP drifters @ $1800/drifter for the ENSO observing network. These drifters will have a drogue centered at 15 m and an SST sensor. These will be purchased on an equal basis from Clearwater Inc., Watertown MA and Technocean, Inc. Cape Coral FL. The policy of acquiring equipment from two US industrial firms on an equal basis allows SIO to maintain a high degree of control over the specification of materials, electronics, power, manufacturing procedures and the deployment containers. An approximate net increase of 24% to the number of drifters acquired in 2001 were bought about over the past two years because of the design work carried out at SIO in full cooperation with all of the manufacturers. In this task, SIO will evaluate the success of these low-cost SVP units that will go to sea for the first time in early 2003. Technocean, Inc. will add barometer sensors to the Southern Ocean drifter array and Pacific Gyre, Inc. will add barometer sensors to the North Pacific array.

Establishing the Pacific Drifter Program with National Data Buoy Center

Under the direction of DBCP a new focused program of drifter deployment has been established in the North Pacific for the purpose of obtaining marine observations for improving marine forecasting along the west coast of North America. The participation of the Global Drifter Program is to make available 50 platforms in 2003 for placement of barometers on the drifters. These platforms are also essential of the CLIVAR implementation. Dr. Paul Moersdorf, the Director of NDBC, has agreed to make funds available to route the data to the NOAA marine forecasters through data links that are operational. It is anticipated that 40 SVP-B drifters will be released in the North Pacific in Fall-Winter, 2003.

Data Distribution and Assimilation

There is a continuing need for the distribution of the wind-corrected, gridded and seasonally averaged data sets on drifter observations of ocean currents for a variety of scientific and operational reasons. While AOML is responsible for the basic scientific processing, SIO is responsible for combining data from disparate sources and distributing "value added" gridded, data sets to the scientific community. We anticipate utilization of these data, which will continue each year, especially in the ocean general circulation modeling and data assimilation communities. There are plans within the NOPP/ONR projects to first, assimilate the ensemble mean circulation observations to be closely followed by assimilation of the near real time drifter velocity. The SST field that relies heavily on drifter observations is already assimilated in a number of operational models.

Technical Issues

There are three technical projects this year. First, is the evaluation of the engineering changes that were made in 2002 to reduce the cost of the drifter. Secondly, we will participate in the evaluation of the addition of a surface salinity sensor, eight of which will be deployed in the East China Sea to track the flood waters of the Yangtze River. It is anticipated that NASA will provide about 200 salinity sensors that will be attached to SVP drifters for verification of their salinity sensing satellite and SIO will be providing platforms and overseeing the sensor integrations with the SVP drifters to the scientific community. Thirdly, we will continue to provide advice and technical support for the processing and evaluation of data from the wind-sensing drifters of several different manufacturers. We will use the NASA QuikSCAT data to evaluate their performance. Evaluation of the direction data from 87 Wind Drifters manufactured by METOCEAN, Inc. of Canada was carried out and a significant number of drifters had biases in excess of 10 degrees. Suggestions for improvements were passed on the METOCEAN during the DBCP meeting in October 2002.

RECOMMENDATIONS

The NOAA Climate Observations plan recommended that full implementation of the global drifter array of 1250 drifters all equipped with barometers be accomplished by 2005. This would require a significant increase of funding of this JIMO task. Some of this increase occurred in the 2003 funding cycle to JIMO and AOML that allowed the purchase of a total of 695 SVP drifters, 116 of which have barometers. The future NOAA requirements will depend upon international contributions that will be discussed at the October 2003 DBCP meeting in Brazil.

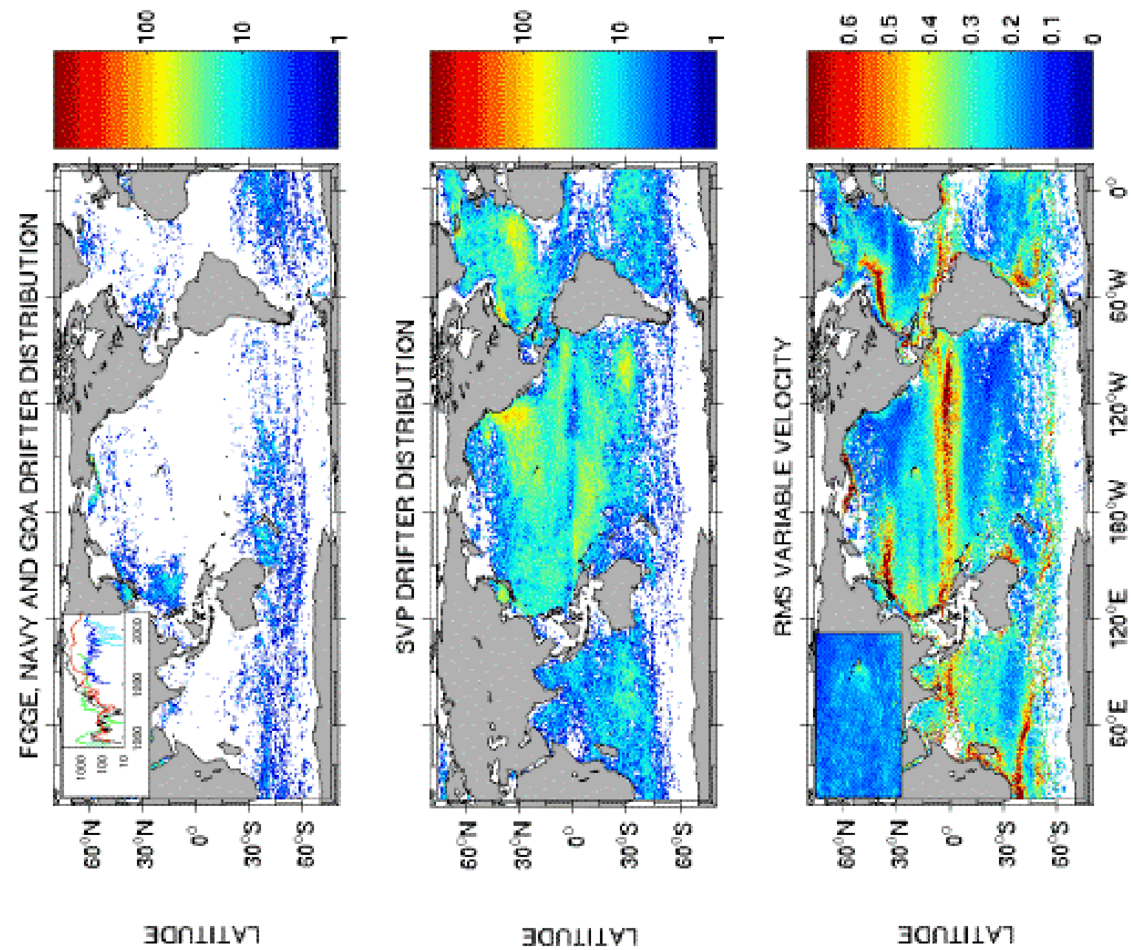
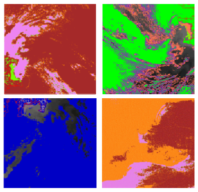


Figure 1.



CALIFORNIA APPLICATIONS PROGRAM (CAP)

D. Cayan, T. Barnett, S. Shyh-Chen, K. Georgakakos, J. Roads, A. Miller, N. Schneider, R. Sommerville, and W. White
Scripps Institution of Oceanography

TASK/THEME: 2A

SUMMARY

The California Applications Program (CAP)

http://meteora.ucsd.edu/cap/,

is a collective of university, federal and private agency scientists studying the impacts of climate variability and attempting to improve climate and extended weather forecasts in the California region. CAP, operating under support by the National Oceanographic and Atmospheric Administration, is working to improve climate information and forecasts that bear on water resources and water hazards, including water resources management, fire prevention and management, and human health. To enhance the utility of this information, the program has identified and is collaborating with a selected set of partners at the federal, state, and local level to address and evaluate the needs of these specific applications.

Progress during the latest project period, calendar year 2002, is described in the following sections, containing narrative, talks and presentations, and publications by CAP researchers.

RESEARCH ACCOMPLISHMENTS

Water Resources

WATER RESOURCES MANAGEMENT, NORTHERN CALIFORNIA WATERS (K. GEORGAKAKOS AND COLLABORATORS)

The focus of this component of CAP is the water resources management of Northern California waters. Evaluating and incorporating hydrologic variability is an essential part of the management of water resources. This takes on greater importance as we face uncertain and potentially straining states of climate. Ensemble streamflow prediction methods (and in some cases operational ensemble flow forecasts) have provided a means of incorporating historical climatic forcing variability and uncertainty in the modeling and forecasting of inflows to reservoir hydrosystems. The incorporation of climate information in these forecasts, the determination of the reliability of the resultant ensemble reservoir inflow forecasts, and the development and testing of methodologies for the effective utilization of such forecasts for the operational management of water resource systems in Northern California, are the primary goals of this research.

The basis of our research and development is an integrated forecast-control methodology for reservoir hydrosystems. It is an end-to-end forecast methodology that incorporates information from Global Climate Models (GCMs), reservoir inflow forecast ensembles, and a decision support system for the reservoir operation and management. The reservoir module includes an assessment system that allows for quantification of management benefits under varying operational plans or inflow forecast scenarios. The integrated methodology was applied to the management of the Folsom Lake reservoir in Northern California. Initial analysis for this reservoir, presented in Carpenter and Georgakakos (2001) and Yao and Georgakakos (2001), indicated significant potential for management benefits with the integrated approach. Their analysis used historical retrospective studies and hypothetical future climate conditions, and compared hydrologic forecasts and management benefits for various forecast scenarios, both with and without the use of climate information from a particular GCM (the coupled CGCM2 model of the Canadian Centre for Climate Modeling and Analysis). These results were extended by introduction of alternative forecast scenarios from a second atmospheric climate model (ECHAM3) running in both an AMIP (using observed SST) and a forecast (using forecast SST) mode.

These results obtained for Folsom by HRC and GWRI along with results obtained earlier for the Midwestern US, led to the formulation of a demonstration initiative, which was jointly funded by various forecast and management agencies. Under the initiative, called INFORM (Integrated Forecast and Reservoir Management), HRC and GWRI Staff in collaboration with operational forecast and management agencies will design, implement and test a prototype end-to-end forecast system coupled to a reservoir decision support system for the improved management of the four large reservoirs in Northern California (Folsom, Oroville, Shasta and Trinity). Although INFORM is now outside the scope of CAP, we provide a brief overview, as we believe that it represents an important product of CAP research.

As a natural extension of our previous single reservoir-site efforts and established collaboration links in Northern California, we initiated a new CAP objective pertaining to regional water resources management in Northern California. During the last year of CAP activities we initiated the development of a regional hydrometeorologic analysis and prediction system for use with decision support systems for regional water resources management in Northern California. The system involves (a) detailed distributed hydrologic models for the tributary basins of the Sacramento River, (b) distributed precipitation ensembles based on downscaled climate and weather model information, and on simplified orographic cloud models, and (c) distributed decision support systems. The INFORM project builds upon an integrated forecast-management methodology (that forms the basis of all of our work in this area of water management) with an effort to entrain users in our research and application efforts. In the following sections, we discuss each of these activities

Supported by funding from CAP as well as by other NOAA Programs and by user agencies over the last five years, HRC and GWRI have shown that the benefits to reservoir management are substantial in California. For Folsom Lake, as discussed previously, retrospective studies using historical data have shown that increases up to 15-18% in annual average energy and decreases of up to 50% in wasteful spillage are possible, without increasing flood damage and with increased water supply made available for agricultural, municipal and environmental uses when integrated systems for forecast (climate and hydrology) and multi-objective management are utilized.

As a result of this, the INFORM demonstration project was designed, proposed and funded by NOAA, CEC, and CALFED, that aims at the implementation of the integrated system in Northern California to serve as the basis for inter-comparisons with present management systems there, and as a test bed of assessing the benefits of using advanced hydroclimatic forecasting methods in reservoir management. Hydroelectric energy production, flood control, water conservation, environmental concerns, and water supply for various uses, are the main operational management objectives of the Northern California system. The project targets Northern California's large reservoirs: Shasta, Oroville, Folsom and Trinity.

A numerical system of the reservoir forecast and management process will be built in close collaboration with the US National Weather Service (NWS), California Nevada River Forecast Center (CNRFC), the US Bureau of Reclamation Central Valley Operations and Planning Division, and the California Department of Water Resources to simulate current operations. Components of the system will run operationally (e.g., climate and hydrologic forecast operation at the CNRFC), while others will run in parallel with actual operational systems for intercomparison purposes (e.g., reservoir release decision models). This decision support system will be built over a period of five years with the first two years devoted to individual reservoirs and the last three years devoted to the interacting four-reservoir system of Folsom, Oroville, Shasta, and Trinity reservoirs. Once the system is in place and the objectives of reservoir management have been defined in collaboration with participating agencies, we will produce an enhanced version of the numerical system that uses an integrated forecast-management approach, developed by the proposers, that is driven by ensemble climate forecasts. We will then use real time database data for selected periods during the five-year project duration to inter-compare various configurations of the built decision support system (including that corresponding to present operations) during periods of different climate regimes (e.g., ENSO, etc.) The analysis will be complemented with retrospective studies using historical data. Economic assessments will be performed by a team of physical scientists and economists from the HRC and GWRI, and from collaborating agencies. Throughout the project period, a sustained mutual technology transfer process will be effected to assure sustainability of new systems and to facilitate reliable interpretation of the integrated system results.

It is noted that INFORM is an implementation and demonstration project, with components built within the operational systems of the collaborating forecast and management agencies and with all the necessary detail in the development of the reservoir management components to depict real operations. Decision makers will have the system trade-off results available in real time for making decisions. Several actual events would form the basis of inter-comparisons. This level of detail is necessary for developing convincing data for consideration by water managers to possibly use

climate information in actual management operations. This INFORM effort is now a separate project outside of the CAP activities.

COASTAL SOUTHERN CALIFORNIA WATERSHEDS
(R. HANSON AND M. DETTINGER)

This study demonstrates the ability to link Global Climate Model (GCM) with regional ground-water flow models (RGWM) through the application of precipitation from the GCM to create inflows for the RGWM. A key factor in ensuring the successful management of ground-water and surface-water resources will require accounting for the link between climatic variability and the cycles of supply and demand that drive the recharge and withdrawal of water resources. Quasi-periodic variations in hydrologic time series that are similar to periodic climatic forcings related to the PDO and ENSO, can have a profound effect on the short-term outcome of variations in hydrologic systems that can play an important role relative to the calibration of the model to historical forcings and to the application of the model to future projections used in water-resource management.

A link was created between three GCM's and the Santa Clara-Calleguas ground-water model that simulates ground-water flow in the coastal aquifers of Ventura, California, using hindcasts of ground-water/surface-water flow for the period 1950-1993. The linkage demonstrates the communication of typical climatic forcings that are related to interannual and interdecadal forcings such as ENSO and PDO. The 1-year lag correlations demonstrate that the ground-water system does respond to the changes driven by the GCM and that these changes are similar to actual historical changes simulated in the ground-water flow system by historical measured precipitation data. In addition, the application of the data to management decisions is exemplified through the use of cumulative probability distributions of "future" ground-water levels, where the ensembles of ground-water levels show similar distribution to the measured and calibrated RGWM water levels.

Consideration of climate variations can be a key factor in ensuring the successful management of ground-water and surface-water resources. This will require accounting for the link between climatic variability and the cycles of supply and demand that drive the recharge and withdrawal of water resources. Quasi-periodic variations in hydrologic time series that are similar to periodic climatic forcings related to the PDO and ENSO. The combined effects of multiple cycles can have a profound effect on the short-term outcome of variations in hydrologic systems. Climatic variability in the simulation of regional ground-water/surface-water systems can play an important role relative to the calibration of the model to historical forcings and to the application of the model to future projections used in water-resource management.

This study demonstrated the ability to link GCM's with regional ground-water flow models through the application of precipitation from the GCM to develop inflows for the ground-water flow model. This linkage required downscaling to maintain the mass balance in the RGWM. The precipitation from ensembles of GCM hindcasts were used to assess the response of the ground-water and surface water systems to climatic variability induced from the GCM derived precipitation. This paper exemplified the linkage by applying a GCM (ECHAM) to the Santa Clara-Calleguas ground-water model that simulates ground-water flow in the coastal aquifers of Ventura, California. The hindcasts were applied to a historical period of ground-water/surface-water flow for the period 1950-1993.

The analysis of the surface-water and ground-water responses demonstrate the communication of typical climatic forcings that are related to interannual and interdecadal forcings such as ENSO and PDO. In addition the analysis indicated that the linkage captures the mean of the changes in the ground-water system, but does not capture the complete variance of the system. This is due, in part, to simplified relations of precipitation to streamflow, other anthropogenic supply and demand factors affecting the ground-water response, and reduced skill from annual discretization of the GCM precipitation to seasonal inflows. The 1-year lag correlations demonstrate that the ground-water system does respond to the changes driven by the GCM and that these changes are similar to actual historical changes simulated in the ground-water flow system by historical measured precipitation data. In addition, the application of the data to management decisions is exemplified through the use of cumulative probability distributions of "future" ground-water levels. The simulated ensembles of ground-water levels show similar distribution to the measured and calibrated RGWM water levels.

The further development of linkages between GCM's and RGWM's will require additional physical and institutional components. The additional physical components required include a complete data network that can capture the actual local inflows to the system that are needed to periodically update a ground-water/surface-water flow model and a self-updating model that can use these data to keep itself current and available for forecasting. Additional development of higher order relations between GCM simulated state variables, such as temperature, relative humidity, and wind data, could also improve the supply and demand linkages between the GCM and RGWM models.

Institutional components would require a means to evaluate the probable future state of the ground-water system subject to physical, monetary, or political constraints and provide water purveyors and water-resource managers with a means to systematically evaluate these outcomes and use these probable changes in hydrologic conditions to guide decision-making.

CLIMATE CHANGE IMPACTS (N. KNOWLES, M. DETTINGER, D. CAYAN; IN COLLABORATION WITH USGS AND THE CALIFORNIA DEPARTMENT OF WATER RESOURCES)

Much of the State's attention in the water sector turned to the threats of climate change this year. In order to maintain and expand collaborations, we spent more time on climate change than on short-term predictions for parts of this year. At their invitation, we organized and held a special Climate Science session at the First CALFED Science conference; four CAP scientists made presentations to that assemblage. As a result, we have been asked to develop a CALFED Climate Science strategy paper for their use in planning future ecosystem-restoration and Bay/Delta management studies and decision making. We have also been invited to make a keynote presentation on this topic at the 5th Biennial State of the (San Francisco Bay) Estuary Conference this October. The CALFED scientists have recently decided (with help) that climate change is only part of their problem and that climate variability should also be a concern. A published paper on paleoclimatic issues facing the Bay/Delta managers in the California interagency newsletter, will appear in the Summer of 2001.

Noah Knowles (Post-doctoral Researcher at SIO), Dan Cayan, Mike Dettinger, and Dave Peterson (USGS, Menlo Park) are investigating the San Francisco Bay-Delta and its upstream watershed using a physically based hydrologic 4 km resolution model of the 140,000 km2 watershed and an advective/diffusion model of the Bay-Delta estuary. This modeling system was used to simulate snowpack and streamflows throughout the watershed under historic and projected future meteorological conditions. Under a "business-as-usual" greenhouse emissions scenario from the NCAP Parallel Climate Model (PCM), which produces average warming of 2.2 deg C by 2060, the total amount of water stored annually as snow in the watershed of the San Francisco Bay-Delta estuary decreases by approximately 50%. This decrease is most severe in the low- to mid-altitude northern Sierra and Cascade ranges, with a regional loss of nearly 70% of the snowpack. This results in a strong decline in the snowmelt portion of the northern headwaters' hydrograph. These losses are also associated with a 25%-50% increase in the magnitude of flood peaks during the rainy season. While impacts are not as severe in the high Southern Sierra, nearly 40% of the snowpack is lost there, resulting in a significant loss of natural freshwater storage throughout the watershed.

With the great attention to California water resources and climate change that has arisen recently, Knowles, Dettinger and Dettinger have participated in the media hubbub over simulation results warning of drastic changes in Sierra Nevada snowcover under recent global-warming simulations. They collaborated with NASA RESAC on hydrologic-response simulations for several Sierra Nevada basins; presented results at PACLIM 2000 and Dec 2000 AFU meeting. Presentations on analyses and simulations of the meteorological and hydrological causes of the largest High Sierran winter floods over the last 85 years were made to the San Francisco Bay/Delta Modeling Forum in February 2001 and to the NCAR Extreme Precipitation

A workshop was held in March 2001. Details of the MRF predictability of such rain-on-snow events in California, with special focus on the most recent one, will be presented at the upcoming Climate Diagnostics Workshop.

The investigators are collaborating with the California Department of Water Resources in communicating these results, and have made several recent presentations to water resources groups around the state as well as providing numerous interviews to local and national news media.

PREDICTING SNOWMELT-DRIVEN STREAMFLOW IN CALIFORNIA'S HIGH ELEVATION WATERSHEDS *(A. GERSHUNOV)*

A. Gershunov is working with Dettinger, Mason and Cayan to test statistical and circulation model-based schemes to forecast various properties of California precipitation and other variables like streamflow, demonstrating that a hybrid GCM/statistical hybrid approach has strong merit. This builds upon a series of useful studies by these authors, including the consideration of ENSO + PDO as a seasonal predictor. A canonical correlation technique that mates ensemble (AMIP) ENSO "forecast" output w western US streamflow patterns shows some promise at producing useful anomalous spring summer runoff forecasts, at differing levels of skill, over the domain.   In a separate, purely statistical effort, Dettinger and others have produced an experimental forecast of spring-summer 2000 US streamflow

and more recently of spring-summer 2001. This forecast uses the historical (1948-recent) record of flow at hundreds of USGS stream gage sites and develops probabilities of daily extremes and seasonal accumulations conditioned upon tropical Pacific (ENSO) and North Pacific (PDO) conditions. The 2000 forecast was published in the January Long Lead Forecast Bulletin. The 2001 forecast was issued last December; these forecasts were verified, revealing modest to weak skill for these recent cases. Dettinger also analyzed the relative roles of ENSO and PDO indices for western April 1 snowpack skill; a resulting paper is in press. Dave Peterson (USGS), Mike Dettinger and others have produced a new experimental forecast of maximum daily snowmelt flow peak using April 1 snow accumulation, or snow depth (whichever is available). Somewhat surprising is how well this seems to work--quite linear and pretty uniformly hi (>.8) correlations over several (~10) rivers across w US. Jessica Lundquist (SIO graduate student), Mike Dettinger and Dan Cayan are exploring streamflow data at hourly intervals to examine the diurnal cycle and how it can be used to understand the dynamics of snowmelt and other processes in western watersheds.

SEASONAL PREDICTION
(A. GERSHUNOV)

A. Gershunov's CAP-relevant work has been largely motivated by our interest in understanding and predicting seasonal anomalies of daily weather statistics (e.g. precipitation, temperature), especially the frequencies of daily extremes.

Following our previous work on the quantification of ENSO signals in seasonal probability density functions (PDFs) of daily precipitation and temperature, especially in the tails of these PDFs, results of Gershunov et al. (1999) uncover the role of midlatitude North Pacific multi-decadal variability in modulating the tropical interannual influence on North American climate. Climate is considered to be the statistics of weather and we showed the climatic influences of interannual - interdecadal modes of variability (e.g. ENSO and the North Pacific Oscillation) on intraseasonal weather extremes – frequencies of heavy daily precipitation events in the contiguous United States. Using canonical correlation analysis (CCA), a powerful technique to diagnose and quantify climatic relationships, local and remote, Gershunov and Cayan (2002) showed that the north Pacific SST variability exerts strong forcing on southwestern US precipitation even in the absence of ENSO extremes.

Our experimental forecasting work during the last three 3-4 years was motivated by our previous discovery that although, state-of-the-art atmospheric general circulation models (GCMs) reproduce realistic large-scale seasonal circulation anomalies, they are unable to correctly simulate the observed signals in the seasonal probability density functions (PDFs) of daily precipitation and temperature. These results led logically to the development of two approaches for seasonal forecasting of daily weather statistics: (1) a statistical approach trained solely on observations of the past and (2) a hybrid dynamical-statistical approach which uses a GCM forecast of the large-scale circulation and statistically downscales it to weather statistics at the station level. Both these approaches use powerful optimal pattern-to-pattern statistical matching methodology and are useful for climate forecasting in different conditions depending on the prediction region, climatic forcing, season and predictand. Gershunov et al. (2000) considered ENSO-related predictability of daily precipiation frequency, intensity, as well as seasonal total and compared the statistical, hybrid and fully dynamical prediction results in California. Gershunov and Cayan (2002) have further shown that non-ENSO-related hydrologic predictability exists, most notably in the southwestern U.S. during winter and spring due to the influences of non-ENSO-related North Pacific variability.

FIELD INSTRUMENTATION
(D. CAYAN, M. DETTINGER, K. REDMOND, IN COLLABORATION WITH THE NATIONAL PARK SERVICE, USGS, AND CALIFORNIA DEPARTMENT OF WATER RESOURCES)

Observations are fundamental to understanding regional climate variability and change and to making informed decisions. In California and other parts of the western United States, there are critical areas, such as mountain snowfed watersheds and the coastal zone that lack the hydrological and meteorological detail needed by resource managers, ecologists, planners and other stakeholders. Thus, we have concluded that a crucial component of the CAP is to better articulate the status of regional climate observations and also work to build this up for present and future needs.

We have begun an effort to provide a set of hydrological and meteorological stations in Yosemite National Park and the close by environs. California's water resources depend vitally upon runoff from its high elevations, including rainfall-dominated coast ranges or the snowmelt-dominated Sierra Nevada. These watersheds are also conduits that carry sediment, nutrients and pollutants and also act as vital arteries in the regional airshed. Climate variability is high however, and annual precipitation and runoff fluctuate from under 50% to over 200% of climatological averages. In Yosemite National Park, we are working on our second field season of installing small portable sensors along three transects: the Highway 120 (Tioga Road) trans-Sierra road corridor and the Tuolumne River and Merced River watersheds. Collaborators include the California Department of Water Resources, the U.S. Geological Survey, the Desert Research Institute and the Western Regional Climate Center (WRCC), and the National Park Service. In the Santa Margarita Ecological Reserve (SMER), operated by SDSU and featuring communications link to HPWREN, we are building an array of meteorological and hydrological observation stations. Our vision is to develop a set of microclimate and hydrologic time series observations to characterize the variability of water and weather in this coastal Southern California watershed.

During the last two years, we have begun to implement these new observational transects and are making arrangements for formal archives of the data at WRCC. Besides the seed funding from OGP and incremental funding from NSF, a new source of funding for our wilderness monitoring efforts has been identified from the California Energy Commission.

WILDFIRE APPLICATIONS

CEFA: THE PROGRAM FOR CLIMATE, ECOSYSTEM AND FIRE APPLICATIONS *(T. BROWN, DRI)*

CEFA, under the direction of T. Brown at the Desert Research Institute (DRI), has been working with CAP on applications of climate and weather information for wildland fire managers and fire weather forecasters in California. CEFA has developed a partnership with the California Firescope Weather Working Group, comprised several state and federal agencies including the California Interagency Fire and Forecast Warning Units (IFFWU), California Department of Forestry and Fire Protection (CDF), U.S. Forest Service (USFS), National Park Service (NPS), Bureau of Land Management (BLM), and Los Angeles and Orange county fire departments.

CEFA has also established a partnership with the University of Arizona Institute for Studies of Planet Earth (ISPE) and Climate Assessment for the Southwest (CLIMAS) to jointly develop annual workshops for climate and fire. These workshops have provided climate training for fire management, knowledge exchange between climatologists and fire specialists, and seasonal climate forecasts for fire management. This activity, among others, has enhanced the collaboration between the CAP and CLIMAS RISA's.

The value of CAP for CEFA has been to: (1) further enhance California fire agency partnerships; (2) build a constituency of users of fire and climate information; 3) allow for product and applications development of fire and climate information and decision-support tools with the California fire agencies.

A summary of individual projects related to and partially supported by CAP is provided below. Information about these and other activities can be found at the CEFA web site - http://cefa.dri.edu.

QUALITY CONTROL OF CALIFORNIA HISTORICAL RAWS DATA *(T. BROWN, DRI)*

The scope of this project was to perform quality control on historical data for approximately 240 Remote Automatic Weather Station (RAWS) sites in California. These improved data can then be used to perform fire danger rating analyses and determine RAWS climatological characteristics across the state. The project was collaborative between CEFA, the California wildfire agencies and the Western Regional Climate Center. The updated data set was provided to the California agencies via CD media in 2002.

DEVELOPMENT OF A PROTOTYPE OPERATIONAL FIRE DANGER MAP FOR CALIFORNIA *(T. BROWN, DRI)*

Currently, once daily (1300 local time) weather observations are used to calculate actual and predicted fire danger for approximately 200 fire danger rating areas across California. However, fire danger can change substantially during a 24-hour period; in some instances fire danger can be higher at night than during the maximum heating time of the day. Thus, it is desirable to produce hourly fire danger maps in an attempt to identify those situations where fire danger rapidly rises or decreases during the late night or early morning hours. The primary objective of this project was to develop a prototype system for producing operational hourly fire danger maps for each fire danger rating area in the state using components of the National Fire Danger Rating System (NFDRS) and hourly Remote Automatic

Weather Station (RAWS) data. Development work was completed in early 2002, and the California wildfire agencies are currently evaluating the product.

CEFA EXPERIMENTAL NCEP ETA FORECASTS
(T. BROWN, DRI)

CEFA produces twice daily forecasts of mixing height and planetary boundary layer transport wind for the U.S. Six-hourly forecasts out to 48-hours are produced at 00 and 12 UTC. A special set of 12 UTC forecasts are produced and emailed daily to the California Interagency Fire and Forecast Warning Units. These forecasts comprise guidance information for each of the California air basins. At the southern California operations center, a clickable web map of air basins has been developed for access to the forecast information.

UTILIZATION AND EVALUATION OF CLIMATE INFORMATION AND FORECASTS FOR FIRE MANAGEMENT

The two primary objectives are: (1) provide monitoring of near real-time climate anomalies of relevance for fire specialists and management, and 2) develop and evaluate weekly to seasonal climate forecasts of fire climate and fire danger elements. Two sets of climate monitoring products were developed for the western U.S. and specifically for the southwest monsoon region. The products include 10- and 30-day anomalies of RAWS maximum/minimum temperature and relative humidity, National Lightning Detection Network lightning strikes, and geopotential height and relative humidity pressure level anomalies using NCEP/NCAR reanalysis grids. Weekly to seasonal climate forecasts are currently being produced at the Scripps Experimental Climate Prediction Center (ECPC). Along with the relevant fire weather elements of temperature, relative humidity, wind speed and precipitation, forecasts of National Fire Danger Rating System elements are also being produced. All of these forecast elements are currently being evaluated using historical RAWS data and several classical forecast verification methods. In addition to ECPC forecasts, the International Research Institute for Climate Prediction also provides CEFA with global monthly forecasts from several different climate models, including their ensembles. CEFA produces U.S. forecast maps of temperature and precipitation anomalies along with associated probabilistic forecasts of these elements, and makes these available to fire weather meteorologists and fire management via the CEFA web site.

AN OPERATIONAL MESOSCALE METEOROLOGY FORECAST FACILITY FOR SMOKE AND FIRE MANAGEMENT: CEFA OPERATIONAL FORECAST FACILITY (COFF)
(T. BROWN, DRI)

The expansion of the wildland/urban interface and increased emphasis on air quality by regulatory agencies in California (e.g., Title 17) has generated a need for improved weather forecast products for both fire and smoke management. In order for the California wildfire and air quality agencies to meet this need, interest grew during the past three years in developing a consortium of users that would fund and support an operational mesoscale meteorology facility. In 2002 a consortium was formed and named the California and Nevada Smoke and Air Consortium (CANSAC), comprised of 13 federal, state, county and local agencies. With various interactions with California agencies already in place, CEFA was asked develop and implement an operational facility to serve the real-time forecast needs of the agencies. The CEFA Operational Forecast Facility (COFF) is currently being developed to produce spatial high-resolution forecasts and value-added products for fire and smoke management for California and Nevada agencies. Products generated from this facility will enhance and improve forecasts for smoke dispersion and transport, fire danger and fire behavior. A collaborative research effort between the U.S. Forest Service Riverside Fire Laboratory and CEFA is being established as part of the consortium. Both personnel and hardware funds from the consortium have become available to begin developing COFF. Product implementation is anticipated during summer 2003.

FIRE AND CLIMATE WORKSHOPS
(T. BROWN, DRI)

CEFA has developed a partnership with ISPE/CLIMAS that has direct benefit to fire agencies in California. For the past three years CLIMAS has organized fire and climate workshops with the intent to provide fire specialists and management with training in aspects of climate, provide a forum for knowledge exchange between climatologists and fire specialists, and recently to produce a national seasonal climate forecast relevant to fire management. CEFA was a co-organizer of the 2001 and 2002 workshops. Fire weather meteorologists from California attended these workshops and indicated value in the information content received. Future workshops are planned with continued emphasis on producing national seasonal climate and fire forecasts.

SEASONAL WILDFIRE FORECASTS (A. WESTERLING, A. GERSHUNOV, D. CAYAN AND T. BARNETT)

We have constructed experimental statistical seasonal forecast models for wildfire area burned and number of fires. Forecasts from our models of area burned have been circulated within the wildfire management and academic communities over the past two years via papers, posters, presentations at professional meetings and at fire management agencies, by email, and via the web. These models have been quite successful at depicting seasonal area burned in the Sierra Nevada, Rocky Mountains, and Intermountain West, and have generated interest and useful feedback from the fire management community.

DETECTING DECADAL SCALE CLIMATE SIGNALS IN WILDFIRE, AND CROSS-VALIDATING STATISTICAL WILDFIRE MODELS WITH PALEO WILDFIRE RECONSTRUCTIONS (A. WESTERLING AND T. SWETNAM)

Using gridded Palmer Drought Severity Indices reconstructed from dendrochronologies, we have estimated a statistical model of annual wildfire activity by state for the western U.S. based on observed fire histories of the 20th century compiled from Forest Service publications starting in 1916, and used it to reconstruct annual area burned from 1701 to 1995. ENSO and decadal climate signals were apparent in some of our data, but could not be confirmed given the relatively short time series and the confounding effects of management in the modern era. We were able to resolve these signals in our reconstruction, and comparing our reconstruction with paleo wildfire reconstructions derived from fire scar chronologies showed strong agreement between both models. This work provides a strong link between paleoclimatologies of wildfire in the western U.S. and our observed records from an era of pervasive, active wildfire management. It also builds confidence in the ability of our statistical modeling techniques to accurately represent climate influences on wildfire in the present era.

CLIMATE CHANGE, WILDFIRE AREA BURNED AND SUPPRESSION COSTS (T. BROWN, B. HALL, A. WESTERLING AND N. KNOWLES)

We constructed statistical models of monthly area burned and wildfire suppression costs in the Sierra Nevada using maximum temperatures and soil moistures modeled from the Bay-Delta Watershed Model for recent decades and applied them to temperatures and soil moistures modeled under a climate change scenario. While this model indicated a marked increase in area burned and suppression costs, it did not well characterize the peak month of the Sierra Nevada fire season, July, and we are trying a different approach. Working with soil moistures from the VIC model, we find a stronger relationship between soil moisture values and wildfire than we did with the Bay-Delta Watershed Model, and with the added benefit that the VIC models' broader coverage should allow us to model wildfire over the entire western U.S.

We have also analyzed the relationship between energy release components (ERC), a metric of fire danger, and fire size and suppression costs for observed data and for a climate change scenario for the western U.S. The largest and most expensive fires were associated with a large ERC threshold value of 60, and most of the west was projected to see an increase in the number of days this value occurred by as much as two to three weeks per year by 2089.

DECISION CALENDARS FOR WILDFIRE AND FUELS MANAGEMENT (A. WESTERLING, B. MOREHOUSE, AND T. CORRINGHAM)

To assess the current and potential role of climate research and forecasts in wildfire management, we began a project to construct decision calendars for fire suppression, prescribed fire, and mechanical fuels reductions. We have conducted in depth interviews with a couple of dozen of fire management personnel and predictive services personnel at the National Interagency Fire Center in Boise, Idaho, the Northwest Coordinating Center in Portland, Oregon, and the governing board of the Joint Fire Sciences Program. These interviews will provide the basis that will allow us to design a survey and questions for follow up interviews that will allow us to construct the planned decision calendars. They have also given us new insight into other mechanisms for the application of climate information to fire and fuels management through long-term forest and range management plans.

HUMAN HEALTH

MOSQUITO ABUNDANCE AND ENCEPHALITUS (D. CAYAN, M. DETTINGER, H. DIAZ, IN COLLABORATION WITH UC DAVIS)

Cayan and Dettinger along with Henry Diaz of NOAA CDC, are collaborating with UC Davis arbovirus expert Bill Reisen and epidemiological colleagues to examine ability to predict potential outbreak of encephalitis in the Central and Imperial Valleys of California. There has been a longstanding (20+yr) network of mosquito sampling sites throughout California, that provide unique time series to test the response of mosquitoes to climate variability.

Monthly time series of mosquito abundance (Tarsalis females, normalized counts mosquitos/trap day) were assembled from several mosquito traps that have been maintained for several years in Kern County in the southern San Joaquin Valley. There are several mosquito species and both male and female genders present in these data sets, but we have chosen Tarsalis because of its involvement in the encephalitis life cycle. The data set considered here covers the period 1973-2000. 28 of the 54 mosquito trap records had 10 or more years of data, so we initially focus on these in testing for possible links to climate variables. Inspection of the Tarsalis abundance series reveals large interannual variability and in many cases, a remarkable trend over the duration of the sampling period. Most of these trends show decreasing abundances with time, perhaps because environmental conditions and light levels at the trap sites has changed. Because of this, the linear trend was removed to yield detrended residual anomalies, from which the initial set of climate analyses was conducted.

The analysis with climate variables has only recently begun, but we have investigated a series of correlations of Tarsalis abundance correlated with the Palmer Drought Severity Index (PDSI), snow accumulation, air temperature, and precipitation. The snow, PDSI and precipitation correlations generally proved to be largest, while temperature correlations were relatively weak (see for drier conditions, as indicated by the positive correlation coefficients). For temperature, higher temperatures in winter had some tendency to associate with higher AMJ Tarsalis abundances.

Further work is planned in which other regional variables (streamflow, soil moisture) and broader scale climate measures (atmospheric circulation and sea surface temperature) will be related to will be tested for links to Tarsalis abundances. Other mosquito species will also be examined. Pedictive capabilities will be examined. More mosquito trap data will eventually be assembled, 3rd and 5th plots will also be examined in comparison to 4th set). Early season (AMJ) Tarsalis abundance correlated with PDSI and precipitation at a higher level than did JASO Tarsalis abundances. Both winter (January or DJF) and spring (April or MAM) PDSI and precipitation exhibited relatively high correlations with Tarsalis abundances, especially with those in the early season (AMJ). In general moister conditions (positive PDSI and positive precipitation anomalies) associate with higher mosquito abundances and vice versa for drier conditions, as indicated by the positive correlation coefficients. For temperature, higher temperatures in winter had some tendency to associate with higher AMJ Tarsalis abundances.

Further work is planned in which other regional variables (streamflow, soil moisture) and broader scale climate measures (atmospheric circulation and sea surface temperature) will be related and will be tested for links to Tarsalis abundances. Other mosquito species will also be examined. Pedictive capabilities will be examined. More mosquito trap data will eventually be assembled, so these will also be examined

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Talks, Presentations, Abstracts

(T. Brown)

Fall 2000 - National Wildfire Coordinating Group Fire Danger Working Team; California Firescope Weather Working Group fall meeting; national Intelligence Coordinators annual meeting.

Spring 2001 - CLIMAS Fire and Climate workshop; organized weather and climate training for the national Intelligence Coordinators; Western Water Assessment invited presentation; CLIMAS Fire and Climate in the Southwest workshop; California Firescope Weather Working Group spring meeting.

Fall 2001 - California and Nevada Smoke and Air Consortium; Climate Diagnostics Workshop; California Firescope Weather Working Group fall meeting; Geographic Area Coordination Center meteorologist fall meeting; American Meteorological Society Fourth Symposium on Fire and Forest Meteorology.

Spring 2002 - National Wildfire Coordinating Group Fire Danger Working Team; California Firescope Weather Working Group spring meeting; lecture at national Advanced Fire Danger Rating System course; CLIMAS Fire and Climate Workshop; California and Nevada Smoke and Air Consortium; Geographic Area Coordination Center meteorologist spring meeting.

(Cayan)

2/07/02	CalEPA Colloquium	Sacramento, CA
2/11/02	ISPE Seminar, Campus-wide Talk	Tucson, AZ
	Climate Variability: Impacts on low level temperature inversions and air quality in the Western U.S.	
2/14/02	Mosquito Vector Control Dist, Dettinger & Cayan attended	Corona, CA
3/03-06/02	PACLIM	Pacific Grove, CA
3/07-08/02	Earth System (CSES) Adv Com, Chairperson program review	Seattle, WA
3/13-16/02	US Geological Survey Retreat, San Francisco Bay Ecosystems	Menlo Park, CA
3/18/02	ROADnet group meeting	La Jolla, CA
3/21/02	98th AAG Annual Meeting. Invited talk, Changes in runoff in Western N.A.	Los Angeles, CA
3/22-23/02	Desert Tortoise Council. Invited talk, Climate Variability	Palm Springs, CA
4/05-02	California Energy Commission	La Jolla, CA
4/09/02	ROADnet group meeting	La Jolla, CA
4/23-25/02	NPS Vital Signs Workshop, Yosemite National Park. Invited participant	Mariposa, CA
4/27/02	San Diego Yacht Club, ARCS Foundations. Talk, Climate Change.	San Diego, CA
5/16/02	San Diego County Watershed Planning	La Jolla, CA
5/17/02	Vice Chair of State Water Resources Board & Secretary of Resources Visit	La Jolla, CA
5/18/02	HPWREN Users Meeting	Mt Laguna, CA
6/05/02	NOAA OGP Harvey Hill, Kelly Redmond Visit	La Jolla, CA
6/09-15/02	Yosemite National Park Fieldwork	Yosemite National Park, CA
6/28/02	SMER Watershed Workshop	Santa Margarita, CA
7/10-11/02	USGS Place-Based Scientist Workshop	Menlo Park, CA
7/23-24/02	Dept of Water Resources, Frank Gerhke, G. Bardini visit	La Jolla, CA
8/21/02	Discussion w/ California Energy Commission & California Climate Center	Sacramento, CA
9/04-08/02	Yosemite National Park Fieldwork	Yosemite National Park, CA
9/29-30/02	Yosemite National park Planning Workshop	Yosemite National Park, CA
	Cayan, Dettinger, Lundquist, Redmond, USGS & NPS	
9/30/02	ROADnet Poster Session	La Jolla, CA
10/07-09/02	Sierra Nevada Science Symposium. Poster Session	Kings Beach, CA
10/10/02	Squaw Valley. Invited talk, Regional Council of Rural Counties	Squaw Valley, CA
10/16-18/02	Reisen *et al* Program Review, climate, mosquitoes and encephalitis	Bakersfield, CA
11/04-05/02	Climate Change Data& Detection CCDD Panel	Washington, DC
11/08/02	Annual Water Resources Conference.	San Bernardino, CA
	Invited talk, Global Change and California Water Resources	
11/20/02	Larry Carlson, Dept. of Water Resources	Camp Pendleton
	Marine Base, CA	
11/21/02	California Water Association Conference	Anaheim, CA

	Panel member, Global Change & California Water	
12/02-05/02	US Climate Change Science Planning Workshop	Washington, DC
	Panel member, Climate Modeling	

(Dettinger)

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Westerling, A.L., Knowles, N., Cayan, D., and Dettinger, M., 2001, Modeling Sierra Nevada wildfire season severity and suppression costs under a climate change scenario: Eos, AGU Fall Mtg Supplement, 82(47), GC31A-0203.

- California Snow Cooperative Survey Workshops, Novembers 1997 thru 2001
- National Water Resources Forum, January 1998
- Briefing, Yosemite National Park Senior Staff, on Predictability of Major Floods, January 1998.
- Third National Conference of the National Hydrologic Warning Council, Dana Point, CA, March 1999 (keynote address)
- National Park Service Pacific West Region Annual Meeting, San Diego 2000

- NASA Earth Sciences Innovations Showcase, Tucson, January 2001
- State of San Francisco Estuary Conference, 2001; Desert Tortoise Council, Palm Springs, March 2002
- Sierra Nevada Science Conference, North Tahoe, October 2002
- San Diego City Sustainability Forum, “Climate Change Impacts and San Diego,” San Diego, October 2002

Special Meetings Coordinated

- Annual Pacific Climate Workshops, 1998 (El Nino 1998)
- 1999 (Climate and Society)
- 2000 (Planning for the 2000s)

  2001 (Decadcal Climate Variations of the Last 1000 Years)
- 2002 (Solar Influences on Climate)
- 2003 (Integrated Mountain Science).
- “Climate and CALFED” Sessions at 1st and 2nd Biennial CALFED Bay-Delta Program Science Conferences, October 2000 and January 2003
- Two special sessions on Natural Variations of Groundwater Systems at Fall AGU Meeting, San Francisco, December 2000.

Other Recent External CAP Activities

- Invited reviewer, Environmental Defense Fund’s “Climate Change and Los Angeles’ Water Supply” report, December 2000.
- Participant, Yosemite National Park Research Planning Workshop, March 2001.
- Panelist, California Department of Water Resources, Forecast Methodology Review, 1999-2002.
- Participant, Central California Environmental Prediction Initiative planning workshop, Monterey, CA, February 2002
- Consult with Mojave Water Agency regarding future climate variability (how to choose among competing climate scenarios for next 25-50 years), San Diego, May 2002.
- Leadership and organization of multi-institutional CALFED team for development of a climate-science white paper to guide future CALFED-funded climate observation and research, including
- Presentation to DWR-motivated “Climate change and California water resources planning” forum, Sacramento, October 2001
- Plenary speech regarding CALFED climate issues, Biennial State of the Estuary Conference, San Francisco, October 2001
- Presentation to CALFED Ecosystem Restoration Program’s Independent Science Board, davis, February 2002
- Organization of “Climate and CALFED” Sessions at 1st and 2nd Biennial CALFED Bay-Delta Program Science Conferences, October 2000 and January 2003

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Georgakakos, K.P., T.M. Carpenter, and J. A. Sperfslage, “Design and Validation of Real-Time Hydrologic Forecasts for the Folsom Lake Watershed,” 2001 California Weather Symposium, Sierra College, Rockland, California, 22 June 2001.

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Carpenter, T.M., Georgakakos, K.P., Graham, N.E., Georgakakos, A.P., and H. Yao, “Incorporating Hydroclimatic Variability in Reservoir Management at Folsom Lake, California,” 83rd AMS Annual Meeting 2003, Long Beach, California, 9-13 February 2003.

Georgakakos, K.P., “Use of Climate Information in Water Resources Management: Path from Research to Operations,” Climate Prediction Assessments Workshop: Research and Applications from Use to Impacts, Alexandria, Virginia, 28-30 October 2002.

(Redmond)

Redmond, K.T., 1997. Persistence of hydrometeorological elements and relationship to Pacific climate variability. 22nd Annual Climate Diagnostics and Prediction Workshop, Lawrence Berkeley National Lab, Berkeley CA, Oct 20-23, (KT Redmond and DR Cayan).

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Redmond, K.T., 1998. ENSO and Western Precipitation Persistence. AGU Fall Meeting, San Francisco, Dec 6-9.

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Redmond, K.T., 1999. ENSO and extreme precipitation events in the western United States, American Society for Photogrammetry and Remote Sensing, Conference, Portland, May 19. (D.R. Cayan, K.T. Redmond, L. Riddle)

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Redmond, K.T., and B. Martin, 1999. Probability distributions of climate elements conditioned on CPC Forecasts. 24th Climate Diagnostics and Prediction Workshop, Tucson, Arizona, Nov 1-5.

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Redmond, K.T., 2000. Climate Data Availability. USGS Western Region Climate Variability Workshop. 9-10 Feb 2000, Radisson Hotel, La Jolla, CA.

Redmond, K.T., 2000. Transboundary access to climate data and information. Symposium on Climate, Water, and Transboundary Challenges in the Americas. Bren School of Management, UC Santa Barbara, Jul 16-19.

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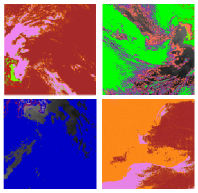


SCRIPPS EXPERIMENTAL CLIMATE PREDICTION CENTER

J. Roads (Director), G. Auad, J. Chen, S. Chen, L. DeHaan, H. Hwang, H. Kanamaru, S. Iacobellis, M. Kanamitsu, A. Miller, A. Nunes, A. Ruane, H. Seo, R. Somerville, T. Nakaega, W. White, E. Yulaeva
Scripps Institution of Oceanography

TASK/THEME: 3A

SUMMARY

There is a major change underway at the Scripps Experimental Climate Prediction Center (ECPC). Previously, the ECPC used the reanalysis I version of the National Centers for Environmental Prediction's (NCEP's) medium range forecast (MRF) model or global spectral model (GSM; Roads et al. 2001a) to make routine experimental global forecasts. These global forecasts (daily out to 7days and weekly out to 16-weeks) start from the NCEP operational 00UTC global analysis and use persisted SST anomalies (+climatology) as a lower boundary condition.

These GSM forecasts (e.g. Roads et al. 2003a) have been augmented recently by an updated version of NCEP's seasonal forecast model (SFM; Kanamitsu et al. 2002a), which is based on updated physics from the NCEP/DOE reanalysis II (Kanamitsu et al. 2002b). The SFM has a nominal (a reduced grid technique is used near the poles) horizontal resolution of T62 (about 2º). There are 28 levels in the vertical sigma coordinate system. ECPC's SFM is run in a different fashion from the GSM. Starting from slightly perturbed initial conditions, and forced with observed SST anomalies, 10 simulations are made up to present. Then, persisted SSTs or forecast SSTs are used to generate a forecast ensemble. The forecast SSTs come from a simplified model for the tropical Pacific and are produced by the IRI. This new SFM is being coupled to an ocean model and sometime in the future we hope to demonstrate that such a coupled system will be demonstrably better than current persisted or forecast SSTs as well as our current ocean forecasts, which use forecast GSM anomalies to drive a Pacific Ocean model (Auad et al. 2003).

A major advantage of the SFM over the GSM is that the computer code of the SFM was completely rewritten to run on multiple platforms with single and/or multiple shared memory machines. The code was improved further to run on massively parallel processor (MPP) machines using Message Passing Interface (MPI) routines. The SFM is now running on the COMPAS cluster at the Scripps Institution of Oceanography. Normally the SFM runs on 64 processors and takes 2 hours to make a 7-month forecast. Depending upon the number of ensemble members, a normal 7-month forecast takes between 1-2 days. During the rest of the month background runs are being made to augment the growing ensemble climatology. In addition, as changes are made in the model new climatologies have to be developed. In fact, there are a few physical parameterization differences between the ECPC SFM and the NCEP SFM. The ECPC SFM has an updated set of land physics state, as well as revised formulation of land surface evaporation. However, it should be noted that the NCEP SFM does start from observed initial conditions unlike the ECPC SFM, which is starting from previous simulations. Ignoring the initial conditions is generally thought to be reasonable when considering long-lead forecasts (greater than a month) although there are certainly times and places when initial conditions can be important even for seasonal forecasts (Reichler and Roads 2003a,b,c,d). Another difference between ECPC SFM and NCEP SFM is the initial condition of the soil moisture. In the NCEP SFM, climatological soil moisture is used while in the ECPC SFM; the simulated soil moisture is used. This may impact the forecast skill particularly in warm seasons.

This SFM is also being used for the international Coordinated Enhanced Observing Period (CEOP). NWP centers have been requested to archive a more complete synoptic gridded output set and there may eventually be corresponding to gridded satellite data. Developing the hydroclimatological output from these data sets will require a special effort and ECPC is now recognized as one of the major NWP centers contributing to CEOP (ECPC, NCEP, NASA DAO, NASA GLDAS, ECMWF, UKMO, BMRC, CPTEC, JMA, Indian NCMRWF). Our goal is to not only provide comprehensive forecasts/analyses with this model, but also with the NCEP/DOE reanalysis II model.

The SFM being used for CEOP is currently being initialized from the NCEP/DOE reanalysis II archive but additional work described below is developing an alternative analysis using the SFM as the basic model. Various data impact studies with this portable version of the reanalysis system are also underway. One objective is to find a way to extend the 3-dimensional analysis of atmosphere in the early years when no upper air observation is available. Preliminary runs with a surface observation only analysis showed significant improvement over AMIP runs, providing a potential for pre-radiosonde era analysis.

The ECPC SFM has not yet fully replaced the ECPC GSM in part because the ECPC GSM is currently tightly linked to a number of additional models and applications. The GSM forces a regional spectral model (RSM; Anderson and Roads 2002, Roads et al. 2003b, c, Roads 2003, Chen and Roads 2003), in order to gain increased spatial resolution (50-25 km resolution) for several selected regions (US, CA, SW, Brazil). The GSM and RSM are based upon the same physics used in the GSM (and SFM) and can, in principle, be updated as the GSM (SFM) is updated. Current output products from the GSM/RSM include a fire weather index and associated variables such as 2m-temperature, relative humidity and 10m-windspeed as well as precipitation and soil moisture. We are attempting to replace the GSM with the SFM, but this process may take some time.

We are investigating a fire danger code describing the USFS National Fire Danger Rating System forced by the RSM and GSM predictions (Roads et al. 2003). The fire danger code depends upon past history and must be integrated continuously, using observations, like land surface and ocean models. These experimental fire danger forecasts are also being displayed at various external, sites as an experimental aid in long range planning. These fire codes are being evaluated in collaboration with the US Forest Service (USFS) and the Center for Fire and Ecological Applications (CEFA) at the Desert Research Institute (http://www.cefa.dri.edu/).

We have begun investigating the Variable Infiltration Capacity (VIC; Maurer et al. 2001) land surface model in collaboration with the NSF Science and Technology Center for *Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA, see* http://www.sahra.arizona.edu/about/index.html) and will eventually be coupling this model to the RSM and GSM. This land surface model is currently being used as part of a national land data assimilation project, and after evaluations we will test the feasibility of having a land surface prediction as part of a coupled land-atmosphere prediction effort. We foresee that some major changes may have to be made in order to make the land surface model more applicable to the Southwest, which is the current major focus. An innovative feature is that we now download precipitation observations in near real time, as part of a continuous land data assimulation, which is used as the starting point for the VIC forecasts.

A single column model (SCM), which was previously used to diagnose cloud and radiation profiles over the ARM sites, is now being used to predict detailed characteristics of the atmospheric vertical structure up to a week in advance. Now that the experimental system has been set up, including routine forecasts for our WWW site, the SCM will be evaluated to determine the quality of these predictions. In particular, we are examining the ECPC GSM and RSM with the aim of improving convective and radiative parameterizations.

The GSM forces a Pacific Basin Ocean Model in order to develop seasonal ocean forecast applications. Like the land surface model, the fire danger model, a past history must be used to initialize the model and in this case we use the reanalysis, augmented by the more recent operational analysis up to the forecast starting point, at which point we use the GSM forecasts.

The new SFM is also being coupled to the MIT ocean model and sometime in the future we hope to demonstrate that such a coupled system is better than current persisted or forecast SSTs, as well as our current ocean forecasts, which does not have the potential for developing an ocean data assimilation system. This coupled system will be used primarily for experimental climate prediction, but could also be used for a wide range of applications, ranging from coastal ocean analysis-forecast problem to global warming studies. Also, an independent and more accurate dynamically coupled forecast will complement NCEP's and IRI's operational seasonal prediction and may eventually result in improved atmospheric and ocean model forecasts and data assimilation.

The combination of the SFM coupled to the MIT ocean model, both with data assimilation, together with the Regional Spectral Model, VIC land surface model, diagnostic USFS fire danger and SCM models, makes the experimental ECPC system a unique climate analysis-forecast system. We are hopeful that our coupled system, will eventually be able to provide useful predictions of inter-annual variations in precipitation, fire danger, streamflow and other variables.

Aspects of our experimental ECPC prediction system have already been made available to various application centers, including the International Research Institute, the California Application Project, National Taiwan University (NTU), Hong Kong Observatory, and Heilongjiang China Weather Bureau. In addition, the ECPC now provides major support for the regional spectral model, including an RSM model master who maintains the RSM home page and updates the RSM as the parent GSM is updated at NCEP. The ECPC also actively collaborates with many regional research centers, such as the USFS fire meteorology project in Riverside, CA, the Center for Fire Ecology in Reno, NV, the Global Fire Monitoring Center in Potsdam, Germany, the National Taiwan University long-range prediction effort in Taipei, Taiwan, as well as a number of other developing regional prediction efforts, including one for the UA STC (SAHRA).

Finally, ECPC is actively collaborating with NCEP and IRI. As discussed above, once a month a 10-member 7-month forecast is now routinely made and submitted to the IRI. The ECPC-SFM forecast has now been accepted as one of the premier members of the multi-model ensemble forecast at IRI. The hindcast scores have been found to be comparable other major models, thus adding a new valuable source of information for the IRI. The products are also sent to NCEP and are regularly used in their operational seasonal forecasts. We are also beginning to evaluate the NCEP reanalysis and seasonal forecasts and attempting to find ways to downscale these forecasts to individual regions. In addition, we are working with a number of other atmospheric models utilized by the IRI, with a special focus on regional downscaling. We have successfully downscaled from the NCAR CCM3 and the NASA NSIPPmodel, as well as the NCEP models and initially helped the IRI to use the RSM in conjunction with the ECHAM model. We have participated and lectured at several IRI training sessions. Finally, with support from IRI and OGP, we have successfully organized four international workshops on the RSM. The 5^{th} workshop will be organized in (2004) in Seoul, Korea. Roads is also the chairman of the scientific advisory committee for regional reanalysis, which is using the NCEP Eta model, and a member of the OGP GAPP science advisory committee and NCEP/GAPP core science advisory committee.

Further details about ECPC progress are provided below and on the ECPC WWW site http://ecpc.ucsd.edu/. References to the most recent ECPC publications are also provided below.

Global Predictions and Analysis

GSM

The Scripps Experimental Climate Prediction Center (ECPC) has been making experimental, near real-time seasonal global forecasts since 00 UTC Sept. 27, 1997 with the NCEP global spectral model used for the reanalysis. Images of these forecasts, at daily to seasonal time scales, are provided on the World Wide Web (WWW) and digital forecast products are provided on the ECPC anonymous ftp site to interested researchers. Roads et al. (2001) previously discussed basic characteristics of the global forecast system for the global and US regions. Other regions (Europe, Mediterranean, and Asia) were examined in collaboration with various international researchers (Roads et al. 2002; Chen et al. 2001). These ECPC global model forecast evaluation efforts have now been compared to corresponding regional model forecast evaluations, described in Section 2.

SFM

As indicated above, the GSM seasonal forecasts have been augmented recently by an updated version of NCEP's seasonal forecast model (SFM; Kanamitsu et al. 2002a), which is based on updated physics from the NCEP/DOE reanalysis II (Kanamitsu et al. 2002b). The SFM has a nominal (a reduced grid technique is used near the poles) horizontal resolution of T62 (about 2^{o}). There are 28 levels in the vertical sigma coordinate system. ECPC's SFM is run in a different fashion from the GSM. Starting from slightly perturbed initial conditions from a previous model run (instead of the operational analysis used for the ECPC GSM), and forced with observed SST anomalies, 10 simulations are made up to present. Then, persisted SSTs or forecast SSTs are used to generate a forecast ensemble. The forecast SSTs come from a simplified model for the tropical Pacific and are produced by the IRI. The current skill of soil moisture in the model is also being assessed. We will also test the sensitivity of the forecast to soil moisture by adding observed soil moisture to the AMIP run spin-up month.

The SFM forecast is run on the local COMPAS Linux cluster using 60 nodes. All 10 members of the forecast, as well as the 10-member spin-up month, can be completed in less than 48 hours of wall clock time on the Linux cluster. The post-processing is done on a separate machine simultaneously. Our computer resources allow us to have the forecast available within approximately 3 days from the time the SSTs are received. Results from the forecast are posted on the ECPC web site (http://ecpc.ucsd.edu/projects/GSM_model.html). In particular, we post seasonal anomalies of standard fields (for example **Figure LDH1)** as well as the spread **(Figure LDH2)** and variance of the ensemble members and the consistency of the forecast from one month to the next **(Figure LDH3)**. Starting in June of 2003, the ECPC forecast was chosen to be included in the IRI multi-model ensemble forecast based on the performance of the model. The skill of the ECPC model compared quite favorably to other models in most areas (Figure LDH4).

Again, these SFM forecasts are currently made once a month out to 7 months, but we are hopeful we will soon be able to replace the previous GSM with this new SFM for the daily to seasonal forecasts needed for the various application models.

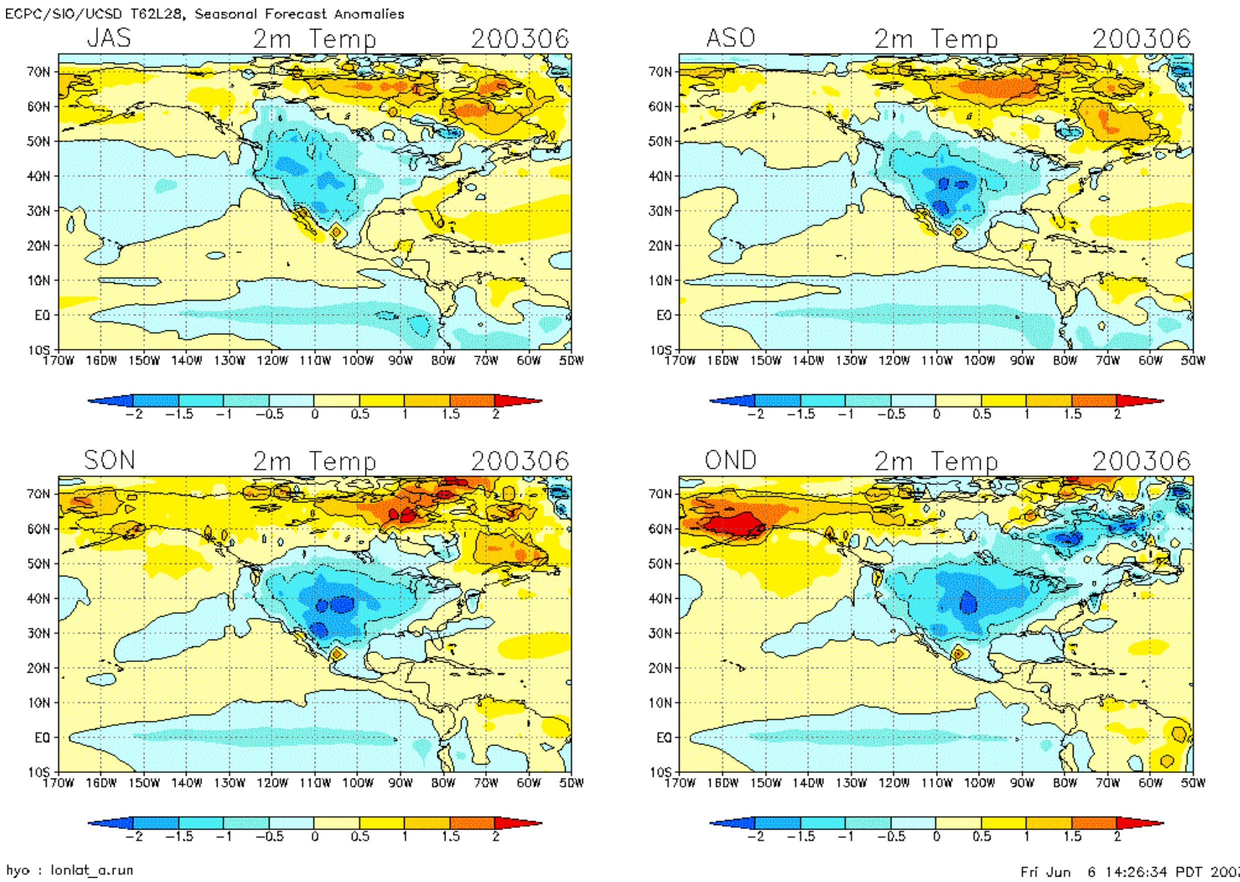


Figure LDH1. Temperature anomaly at 2 meters from the forecast of June 2003 for 4 seasons. Anomaly taken with respect to 50 year AMIP.

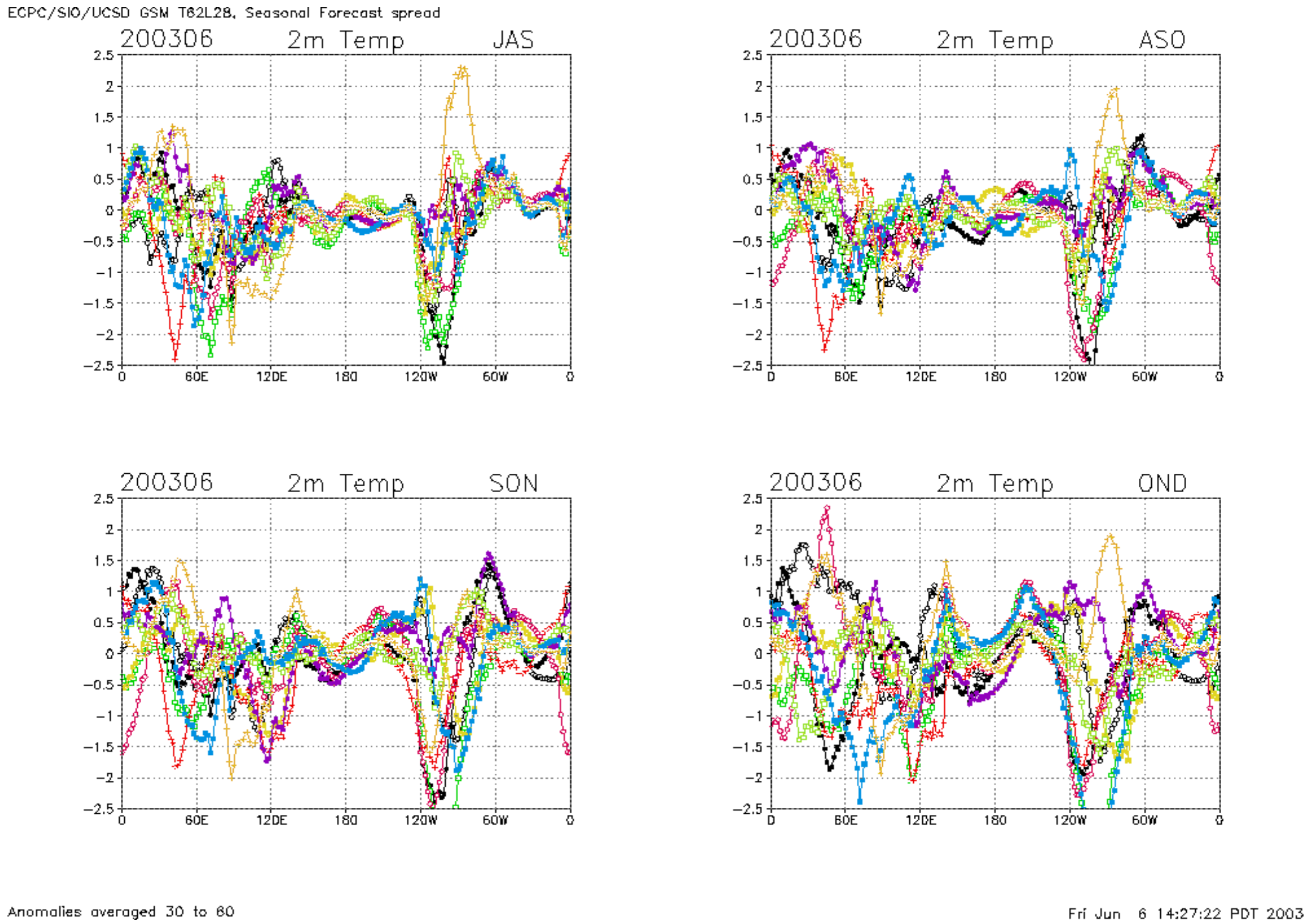


Figure LDH2. Temperature anomaly at 2 meters for each ensemble member averaged from 30N to 60N. Again, from the forecast of June 2003 for 4 seasons using a 50-year AMIP climatology.

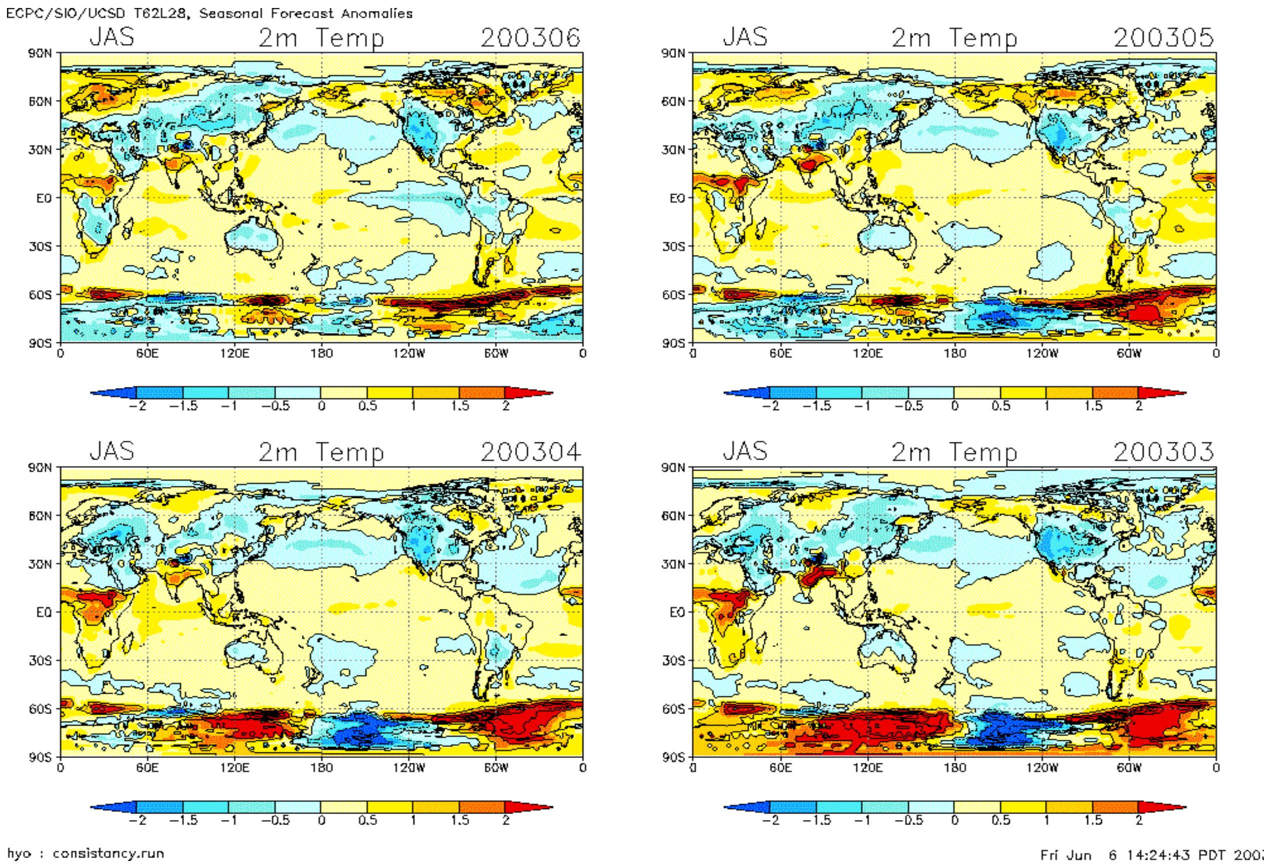


Figure LDH3. Temperature anomaly at 2 meters for July/August/September from the forecasts of June 2003, May 2003, April 2003 and March 2003. Anomaly taken with respect to 50 year AMIP climatology.

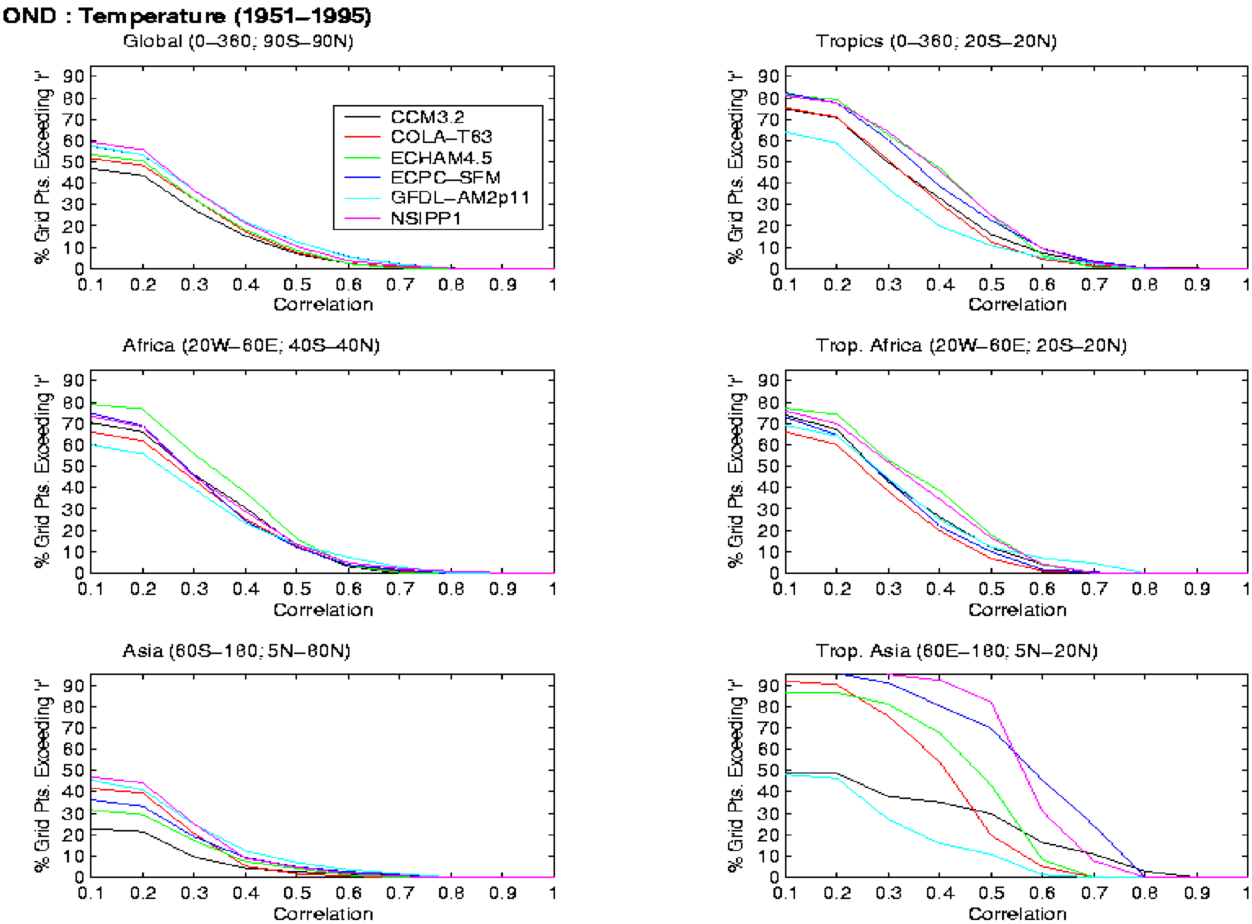


Figure LDH4. Temperature anomaly correlation summaries for 6 global models and 6 regions. (Figure courtesy of IRI.)

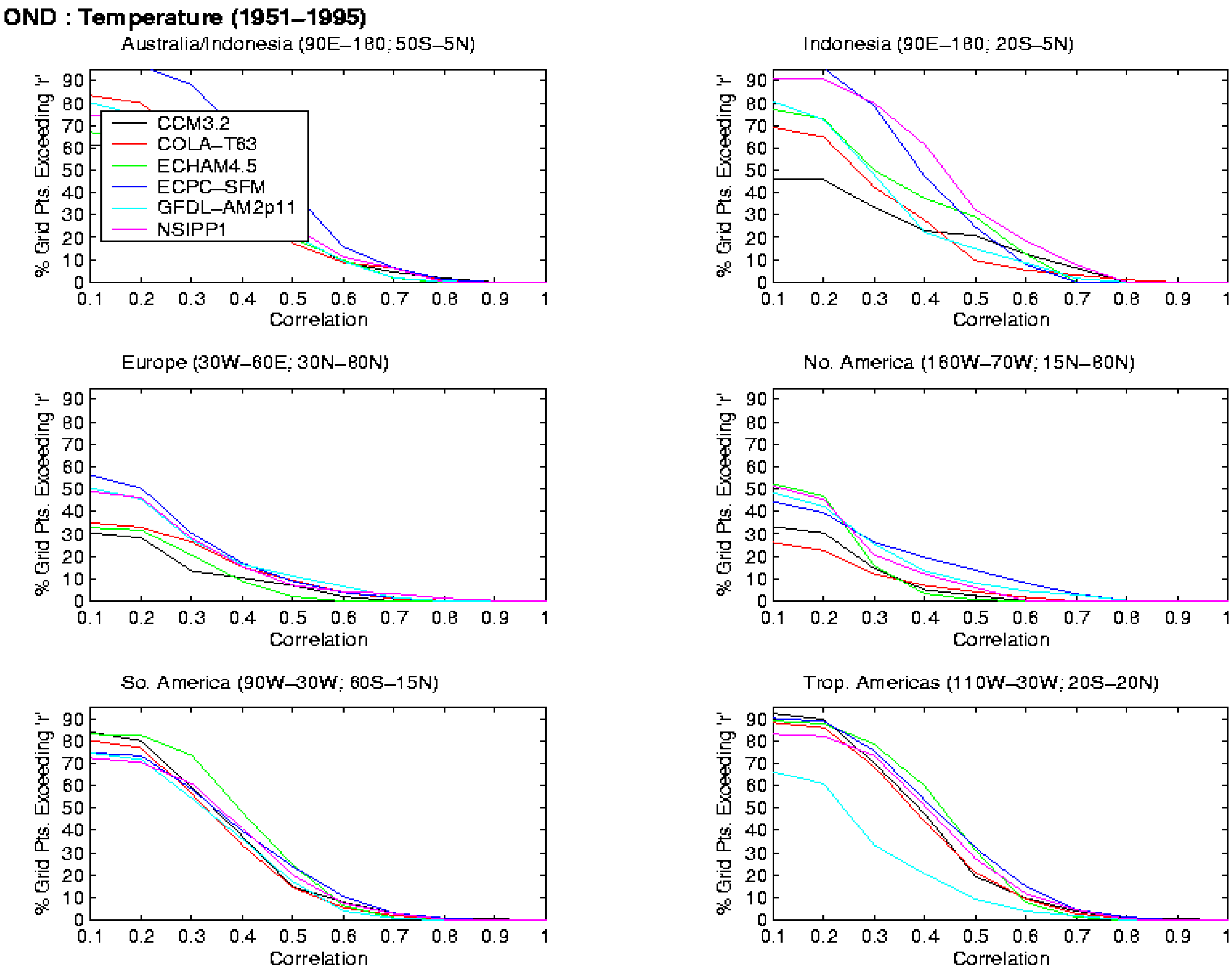


Figure. LDH5. Temperature anomaly correlation summaries for 6 global models and 6 regions. (Figure courtesy of IRI.)

Long-Range Atmospheric Predictability in the Tropics

During the past year, our studies of long-range (2 weeks – 2 months) atmospheric predictability were focused on the tropical regions. In the tropics, the skill of numerical weather prediction models has always tended to lag that in the mid-latitudes. Forecasting tropical variations is not only complicated by the lack of good observations, but also by the relative complexity of tropical dynamics, which are governed by fundamentally different principles than the extratropics. We were interested to find out at what time scale the tropical atmosphere responds to changes in the underlying forcing, and how sensitive tropical forecasts are to uncertainties in the description of the underlying ocean. These questions are not only relevant for coupled forecasting systems, but also for simpler ocean predictions using persisted SSTs. In this context it is important to find out at what lead time and over which regions the added uncertainty introduced by using persisted SSTs weakens the skill of tropical forecasts. Our study of tropical predictability examined two different time scales: First, monthly means were investigated, which cover intraseasonal to interannual time ranges. Second, 30-60 days filtered data were examined to capture the predictability of the Madden-Julian Oscillation (MJO) phenomenon.

Our work was based on experiments with the global spectral model (GSM) developed at the National Centers for Environmental Prediction in T42L28 resolution. It simulates the global atmosphere with a horizontal resolution of approximately 300 km and 28 vertical layers. We performed five idealized experiments using different combinations of initial and boundary conditions. For example, for experiment "ICBC", proper boundary and initial conditions were used. Ocean boundary conditions were derived from the observed history of sea surface temperatures (SSTs) and sea ice, while land boundary conditions were produced internally by the land surface scheme of the model. The initial conditions were derived from a continuous 22 year long integration with the same model that was forced with the same boundary conditions as ICBC. Experiment “IC” was started from identical initial conditions as ICBC, but was forced with the climatological mean seasonal cycle of sea surface temperatures, sea ice, soil moisture and snow cover. For experiment “BC”, we used the same boundary conditions as for ICBC, but initialized the model from an atmospheric state, which was close to its climatological mean. Experiment “ICP” was started from the same initial conditions as ICBC, but used persisted ocean boundary conditions. Each experiment simulated the evolution of the boreal wintertime atmosphere of 22 years (1979-2000). In each of the 22 years, the experiments were started on December 15th and run for 107 days through the end of March of the following year. Since the chaotic nature of the atmosphere requires a probabilistic approach, we repeated each run ten times by starting from slightly perturbed initial conditions but forcing with identical boundary conditions.

Figure TR1 presents monthly mean predictability as a function of lead time in a Hovmöller diagram. Shown is the temporal correlation of the 200 hPa velocity potential (_${}_{200}$) along the equator (10°N to 10°S). The data were low-pass filtered using 30 day running averages before the correlations were calculated. The results for experiment ICBC (left panels) are shown as absolute correlations, and the remaining panels show differences in correlation to ICBC. One can see that at the monthly time scale the effects of both initial and boundary conditions are important. Simulation ICBC, for example, had two predictability maxima over the Pacific and Indian Oceans, which sustained for very long time. One can see from simulation BC, and to some extent also from iBC, over which areas imperfect initial conditions led to reduced predictability at long lead times. The most affected area was the eastern hemisphere, and least sensitive was the region around the date line. Interestingly, the most persistent errors were located over regions which were far away from the date line. Simulation IC had the largest loss in skill over the central Pacific. The loss in skill over the Indian Ocean was smallest, and there the correlations were statistically significant (>0.3) out to 50 days. Thus, to some extent the predictability pattern of IC was just the inverse of BC. Simulation ICP shows that the errors introduced by using persisted boundary conditions evenly affected all regions. The largest error growth occurred over the western Indian Ocean and the Atlantic. In summary, one can say that the tropical atmosphere is rather slow in responding to changes in boundary conditions, particularly in areas, which are far away from the main forcing regions.

Figure TR2 shows a case study of MJO related predictability in phase space. Shown is the evolution of the wavenumber-one Fourier coefficient of 30-60 days filtered _${}_{200}$ in the complex plane, where the magnitude *r* is represented by the distance to the origin, and the phase ⊥ by the angle from the positive x-axis. Time is indicated by different colors. The similarity between trajectories of individual experiments is a measure of predictability. At short lead times (0-20 days, red and orange colors), the trajectories of ICBC, IC, and ICP were quite similar owing to the strong initial condition effect. After that, experiment IC had continuous regular oscillations but the magnitude decreased because of the gradual decorrelation of individual members. The trajectory of ICP was very distorted at longer lead times (green and blue colors) since the coherence between members was lost. Experiment ICBC exhibited a regime shift at about day 30 (yellow color), and then continued with regular oscillations. After the shift, the trajectories of iBC and BC were very similar in phase, as well as in magnitude to ICBC, owing to the strong forced variability in all three experiments. It was found that this boundary forced MJO skill was particularly high during years with large intraseasonal SST activity (not shown), which had a synchronizing effect on the phase of the MJO. The consequence of this high sensitivity to boundary conditions is that fully coupled models are needed for further progress in MJO predictability.

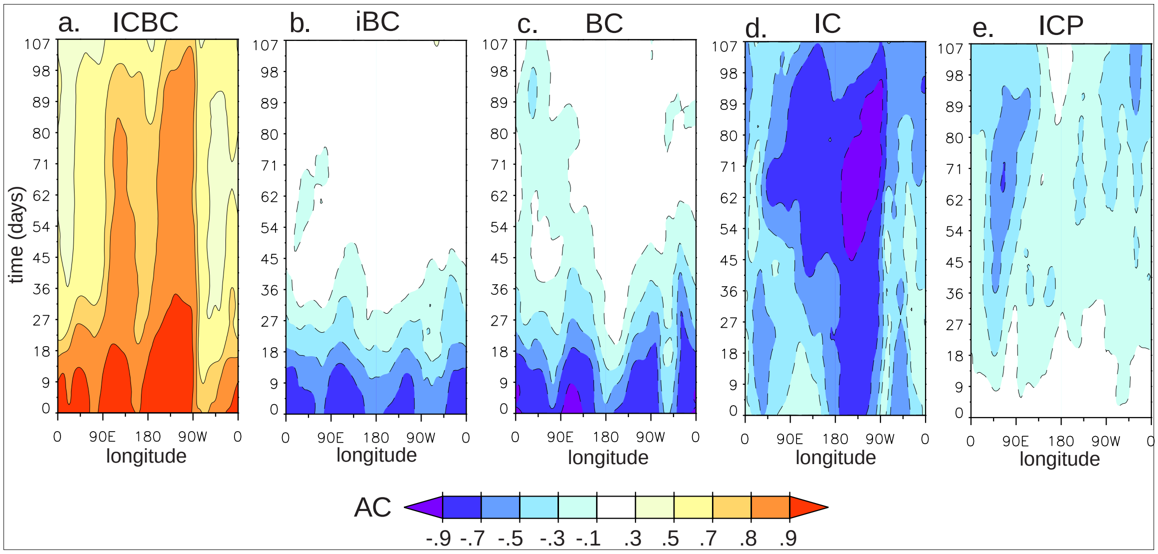


Figure TR1. Hovmöller diagram of temporal anomaly correlation (1979-2000) of monthly mean data along the equator (10°N-10°S) for $_{200}$. ICBC (a) shows absolute correlations, and the other experiments (b)-(e) show differences with respect to ICBC.

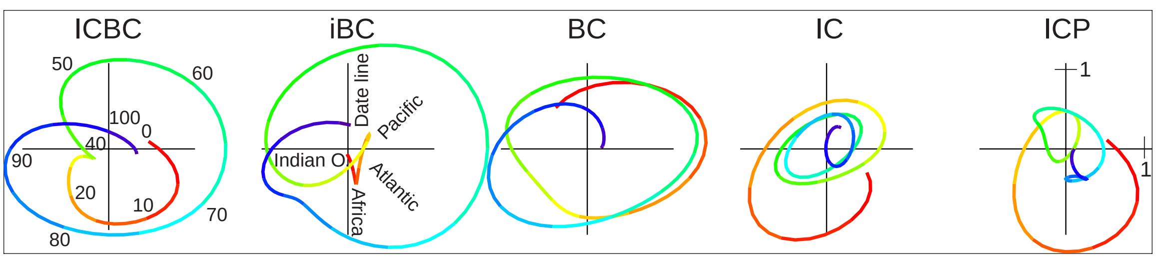


Figure TR2. Trajectory of the MJO in phase space. Shown is the evolution of the complex wavenumber-one coefficient of filtered $_{200}$ during northern winter 1992 for different experiments. Distance from the center denotes magnitude in 10^6 m^2s^1 (see ICP). Angle from the positive x-axis represents phase. Time is shown in colors and by numbers for ICBC. It changes every 5 days, starting with red (day 0-4), and ending with purple (day 105-107). The geographical locations mark the approximate center of maximum convection for a given phase angle.

Interdecadal Forecast Skill Variations

For practical forecasts, it would be useful to know whether forecast skill varies in a predictable manner. We are studying the interdecadal anomaly correlation change in an ensemble AGCM experiment by computing the potential anomaly correlation of the seasonal mean forecast fields from a 52-year SFM ensemble integration. The boundary condition for these forecasts used observed sea surface temperatures (SSTs) and sea ice. These lower boundary conditions were prepared for the ECMWF 40-year Reanalysis. In comparison to other dynamical models, the climatology and interannual variations in our integration have been quite good.

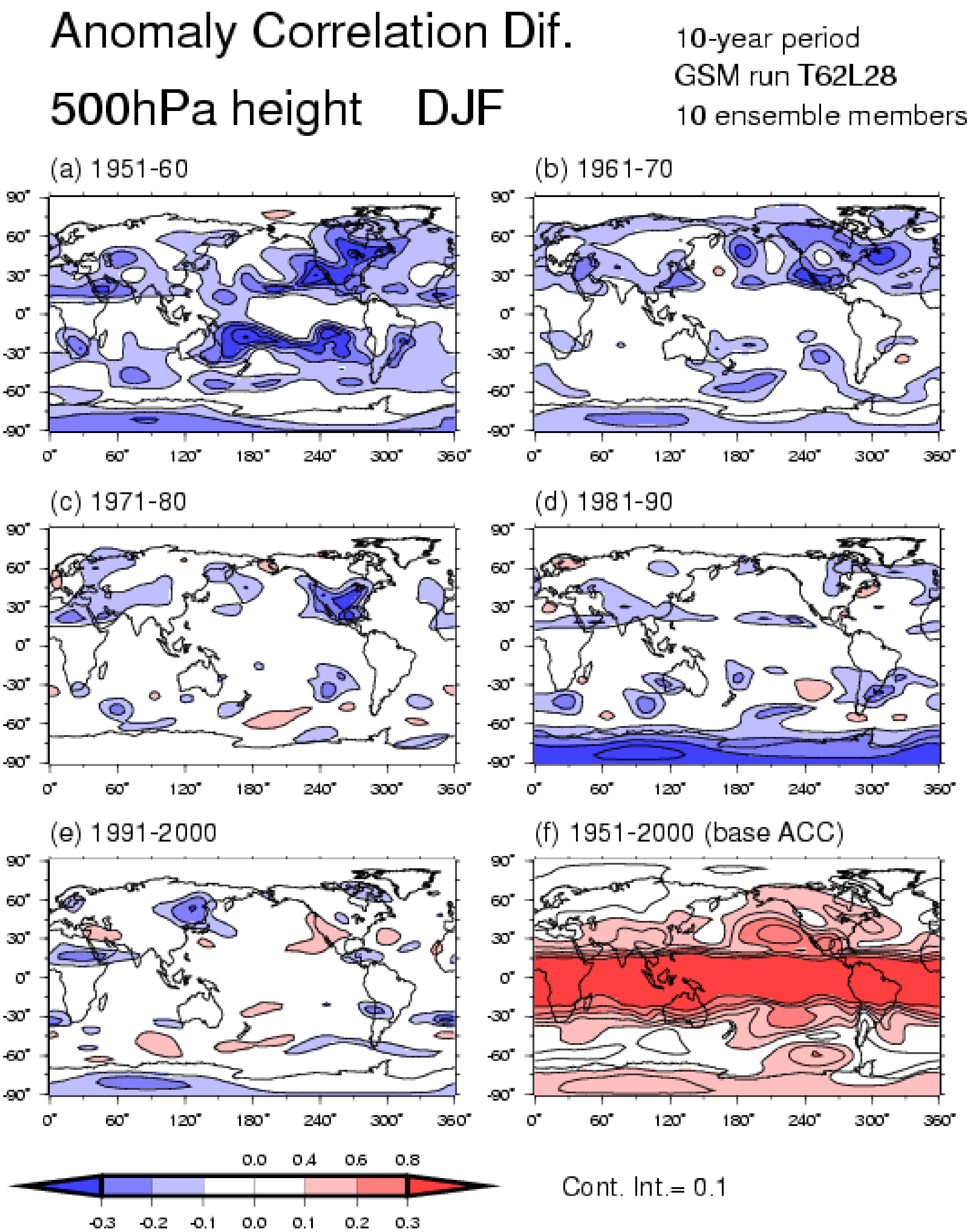


Figure TN1. Geographical distribution of 500-hPa geopotential height potential anomaly coefficient (ACC) difference for DJF for each decade. The difference is obtained by subtracting 1951-2000 ACC from ACC for each decade.

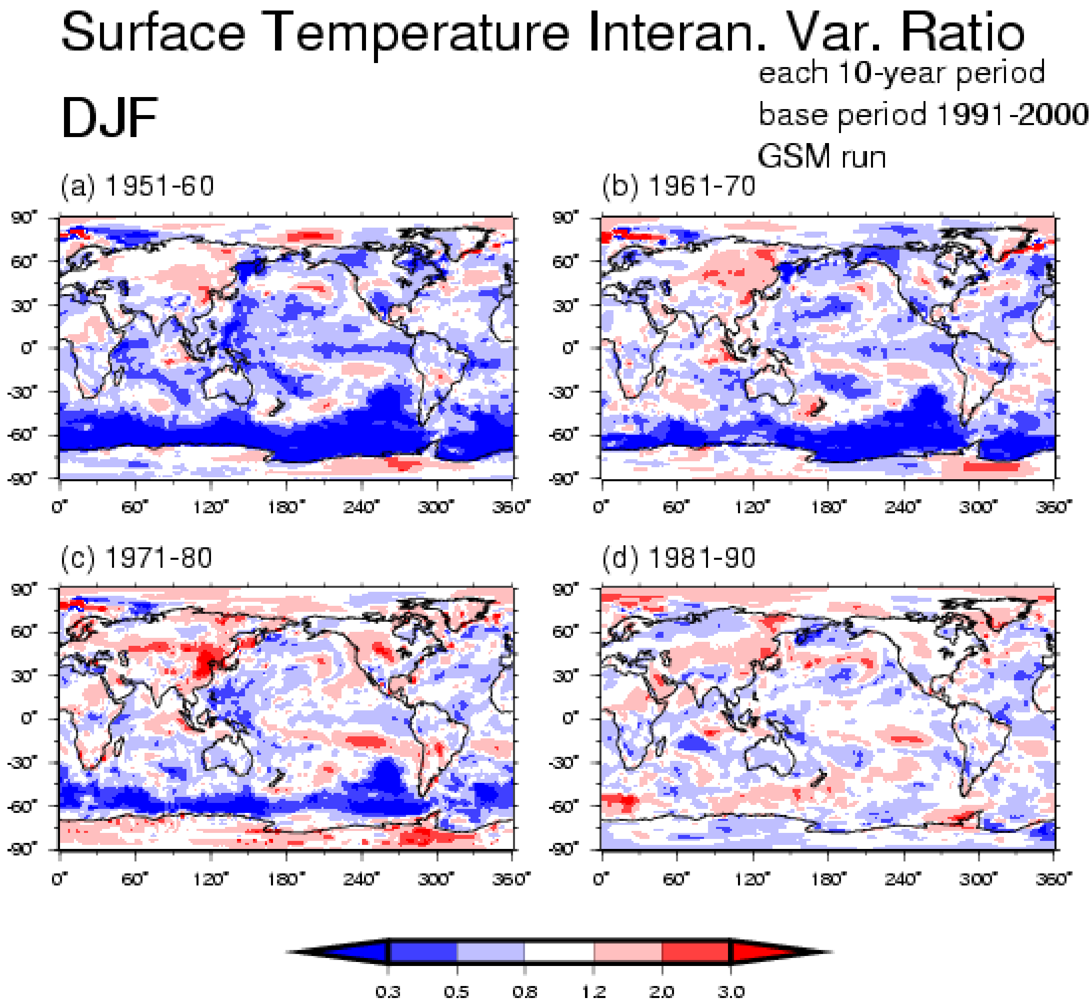


Figure TN2. Geographical distribution of the interannual SST variability ratio. These values are obtained by normalized the variances by those for 1990s.

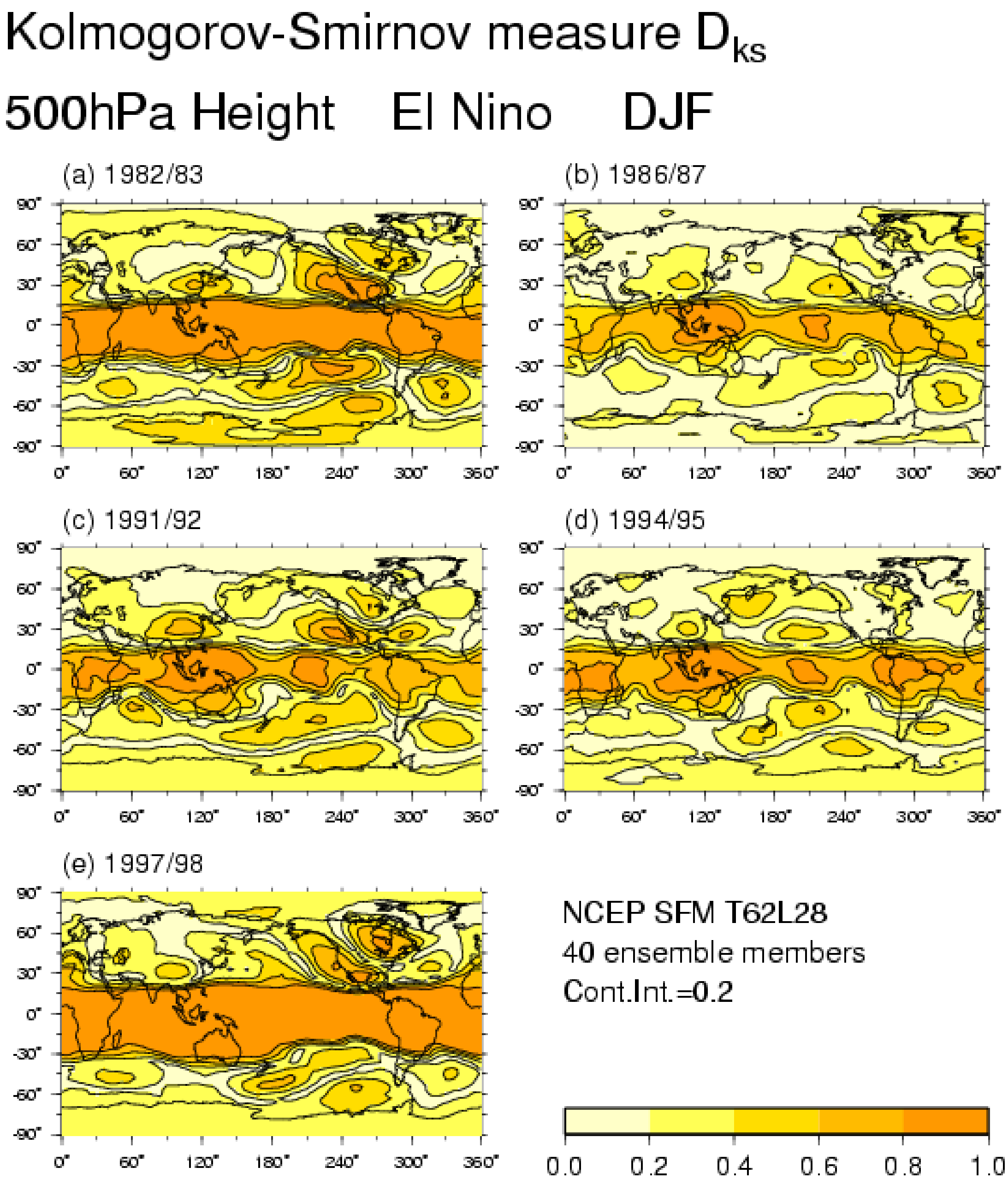


Figure TN3. Geographical distribution of Kolmogorov-Smirnov measure *Dks* of 500hPa geopotential height for different warm episodes (El Nino years).

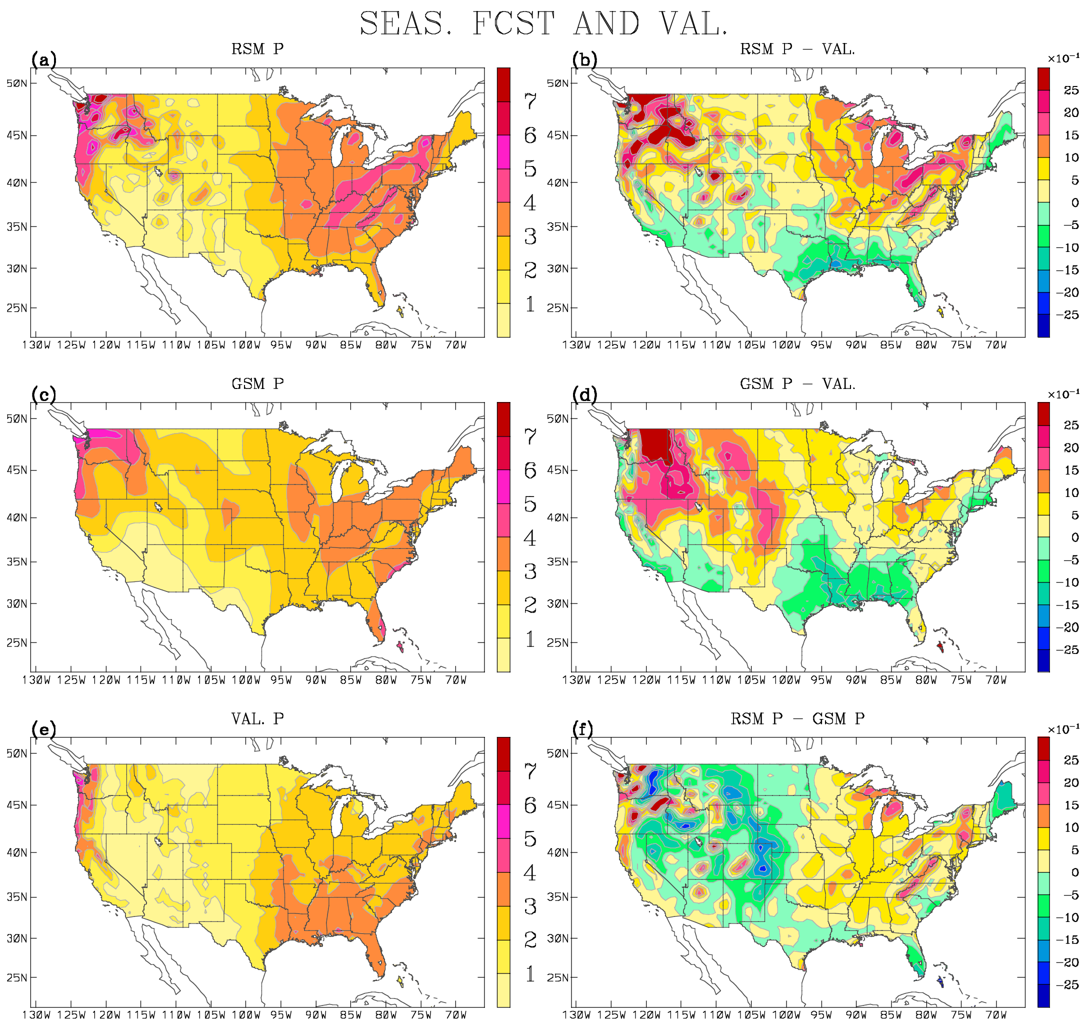


Figure TN3. Geographical distribution of Kolmogorov-Smirnov measure *Dks* of 500hPa geopotential height for different warm episodes (El Nino years).

We computed the potential ACC r based on the Sardeshmukh (2000) formulation as

$r = s^2/[(s^2+1)(s^2+1/n)]^{0.5}$, where $s=(\langle x\rangle\langle x\rangle/\langle x'x'\rangle)^{0.5}$ is the measure of the population mean anomaly relative to the population spread with x the state vector. This is the maximum value that the model can reach under the perfect model assumption. **Figure TN1** shows the geographical distribution of the 500 hPa ACC difference for DJF for each decadal period. The difference was obtained by subtracting 50-year (1951-2000) ACC from each decadal period. The distinct ACC apparently increases as the time goes. This suggests that recent seasonal forecasts are much easier than 1950s or 1960s forecasts. This increasing trend was found in almost variables in our experiment. The difference patters in **Figure TN1** are also similar to those of the streamline functions that we obtain from differences of warm and cold episodes.

We thus infer that the external forcing, SST is a possible cause for the trends. **Figure TN2** shows the geographical distribution of the interannual variability surface temperature for DJF for each decadal period. We used the variances to measure the variability and normalized them by those in 1990s. We found the same trend again in SST. The variability in 1950s is significantly lower than in 1990s. Smith (2000) found an increasing trend in the sea level that may be related to increasing variance in ENSO variations. Xue et al. (2003) found the interdecadal changes of the standard deviation in extended reconstruction of global SST (ERSST) (Smith and Reynolds, 2003). We compared the ERSST with the SST of Hadley center global ice and SST (HadISST) (Rayner et al, 2003) and found the same variance trends in both SSTs. A more detailed description of this study is under preparation and will be submitted for publication.

Probability Distributions

Changes in the probability distributions of seasonal mean forecasts were explored with a 21-year DJF NCEP-SFM operational forecast data set for 1979-1999. Firstly, a set of the data with four different initial conditions was analyzed using a two-way analysis of variance. One factor was the SFM interannual variations and the other was the initial condition. We found that there were no significant differences for the initial conditions sand, therefore, we could combine the four data with the different initial conditions into one data set that consists of forty ensemble members. We chose five normal years based on Nino 3 SST and obtained a normal probability distribution by combining the five-year data set into one. Secondly, we compared the probability distribution of the seasonal forecast data with that of the normal probability distribution.

A nonparametric two-sample Kolmogorov-Smirnov measure *Dks* was used to identify the detectability of the change of the distribution (Sardeshmukh, 2000). **Figure TN3** shows geographical distribution of *Dks* of 500hPa geopotential height for different warm episodes (El Nino years). The values of more than 0.2 are statistically significant. High values over the Tropics were found, especially in the strong warm episodes, 1982/83 and 1997/99. The values over midlatitudes were low in the weak warm episode 1986/87. Similar characteristics were found in the geopotential height and temperature for different levels. We conclude that the NCEP-SFM hindcast four-month composite data can detect changes in probability distributions.

We are extending these analyses to other variables for all seasons. We will further examine the detectability of the extreme events with our SFM hindcasts. Another issue is the robustness of the detectability. Climatological mean and skill score are currently treated as a function of time and ensemble size and we are clarifying how long averaging period and how many ensemble size are required to obtain the best (robust) estimate of the climatological mean and skill score.

CEOP

The World Climate Research Program (WCRP) is developing a Coordinated Enhanced Observing Period (CEOP), which has started and will run for the next few years. As part of CEOP, there are planned to be several global reference sites that provide a number of in situ observations of water and energy budget study (WEBS) variables. Processed satellite data (geophysical variables) will also eventually be available at these sites. Output from several numerical weather prediction models is also potentially available, but like the in situ and satellite data needs to be developed, and will be as part of this proposal. In addition, NWP centers have been requested to archive a more complete synoptic gridded output set and there may eventually be corresponding gridded satellite data. Developing the hydroclimatological output from these data sets will require a special effort and the ECPC is now recognized as one of the major NWP centers contributing to CEOP (ECPC, NCEP, NASA DAO, NASA GLDAS, ECMWF, UKMO, BMRC, CPTEC, JMA, Indian NCMRWF). In particular, the ECPC is providing a comprehensive set of gridded and model output location time series of 93 variables (2-D and 3-D) from short-term forecast/analysis runs initialized from the NCEP RII for the period Jul. 1, 2001-Dec. 31, 2004. As an example of some of the model output and in situ data that will be available, Roads et al. (2003) provided a preliminary comparison between the US National Centers for Environmental Prediction (NCEP) Seasonal Forecasting Model (SFM) being run at the Scripps Experimental Climate Prediction Center (ECPC) for CEOP, the US National Aeronautics and Space Administration (NASA) Data Assimilation Office (DAO) global model, and the NASA Global Land Data Assimilation System (GLD) land surface model with the Canadian Boreal Ecosystem Research and Monitoring Sites (BERMS) in situ observations (OBS). This effort is continuing.

Kanamitsu (2003) has begun to study the precipitation-convergence-evaporation exchange at the CEOP reference sites. For the long term average, Evaporation (E) plus total column moisture Convergence (C) minus Precipitation (P) is equal to zero. This equation also holds for the time variation of the long time mean, such as the seasonal variation and the interannual variations of the seasonal mean as described in the following equation:

-_[P]+_[E]+_[C]=0

where [ ] is the long time average and __ is the difference in the long time averages. This equation can be interpreted as the exchange of three component system, which consists of P, E and C. The equation of these exchanges will be written in the form:

_[P] = { C <=> P } + { E <=> P }

_[E] = { P <=> E } + { C => E }

_[P] = - { C => E } + { P <=> C }

This equation can be illustrated as a triangular exchange diagram shown in **Figure MK1**.

In order to estimate the directions of exchanges from observations, the correlations between the changes in P, C, and E, and the ratio between P and E, and P and C are examined. The former provides relationships among the three parameters while the latter provides “precipitation efficiency”. Reanalysis-2 data (1979-2002) at 40 CEOP station locations was used for the computations . The 6-hourly values of P and E are extracted from diagnostics output, and C is computed from spectral coefficients. The running time mean of 1-, 2-, 6-month, 1-year and 2-year, and the time tendency of the time mean are calculated, and the correlations and precipitation efficiency are obtained for time mean 6-hourly climatology, full fields and anomalies.

Three distinct correlation types were found. They are classified as positive correlation between P and E, positive correlation between P and C and positive correlation between E and C (denoted as type PPP), MPM and PMM. These three types of correlation can be interpreted as the following exchanges among P, C and E (the detailed procedures to arrive at these diagrams are beyond the scope of this report). Type PPP is the most common within the CEOP stations (about 50%) and appears both in tropics and in higher latitudes. It indicates positive feedbacks between P and E through CISC, and P and C through soil moisture and moistening. The input to the system is possible to all the components. The MPM and PMM types are next common and also found in tropics and extra-tropics. Any other types of correlations are not found in the CEOP locations. The MPM type is characterized by the positive feedback between P and C through CISC mechanism, but negative feedback between P and E, most likely from the increase in cloudiness that reduces the evaporation. The input to the system can be both to P and C. The PMM type is more frequently observed in 3- and 6-month averages. It is characterized by the positive feedback between P and E through soil moisture. The negative correlation between C and E is the result of increased E, which results in colder surface temperature and hence decreased moisture convergence. Only possible input to the system is the change in P. This effort is continuing.

Global Reanalysis

The reanalysis-2 data assimilation system has now been successfully ported to Linux and IBM-SP machines and has successfully incorporated the CVS version of the ECPC SFM. The system is fully debugged and is running on both Linux and IBM-SP machines. Some parameters have been added or substituted, and some of the shells and programs have been fixed to be consistent with CVS system. Serial computation have been tested on Linux. OpenMP directives were added in the ssi routine for optimization on IBM-SP, so that shared memory programs in the both ssi and fcst routine were applied. The speed of computation depends strongly on the number of BUFR observation data. As an example, Table SOH1 shows wall-clock time for 1-day data assimilation cycle on 1997110700 run on Linux and IBM-SP machine.

Table. SOH1**. Total wall-clock time and computational rate of major routines for 1-day assimilation cycle.**

Linux	**IBM-SP**
(Total: 55min)	(Total: 31min)
oiqc : 20%	oiqc : 55%
ssi : 64%	ssi : 30%
fcst: 11%	fcst: 7%

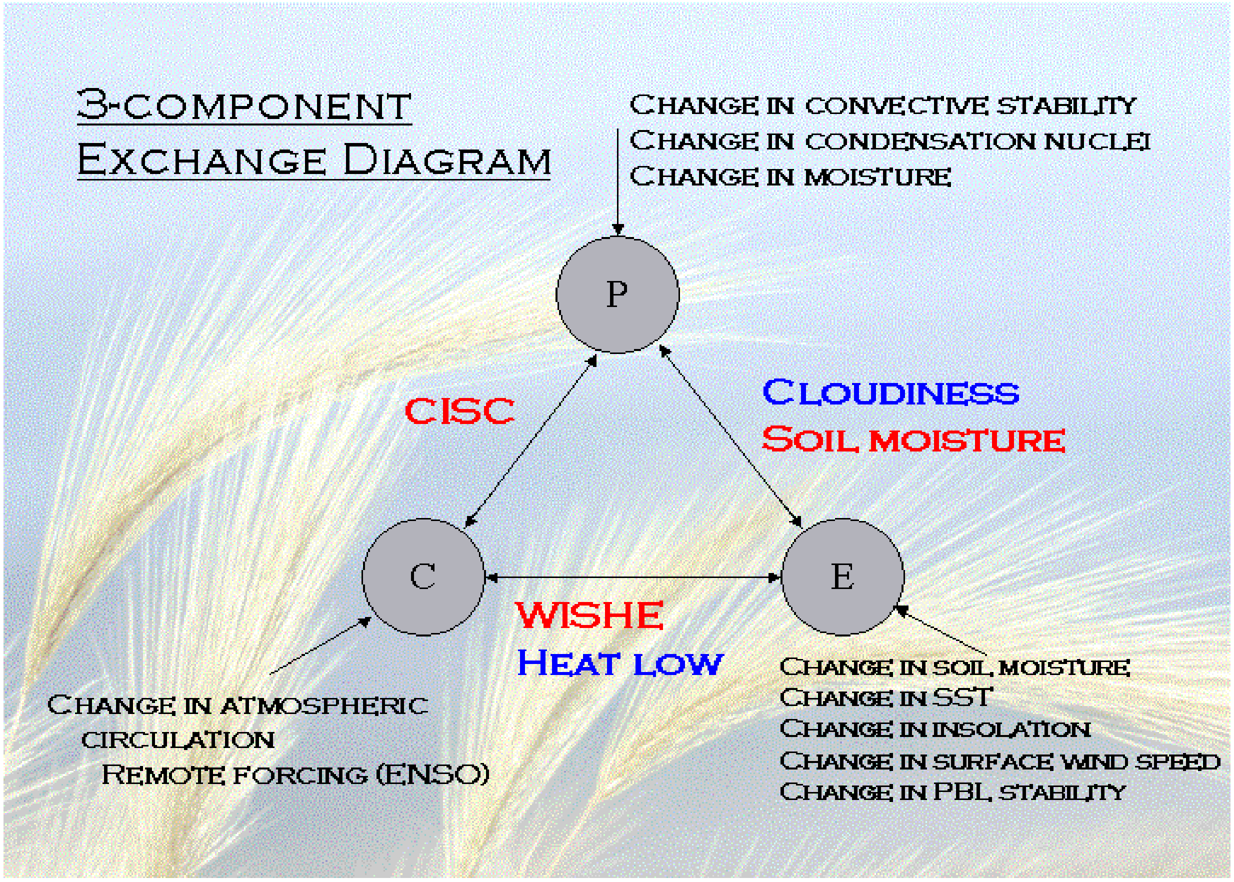
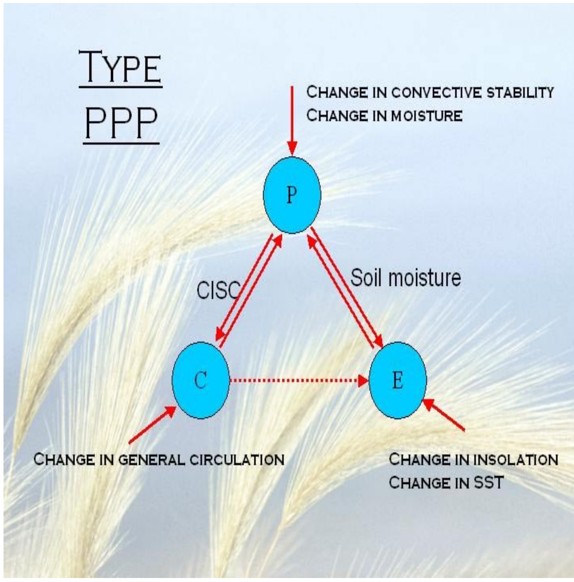
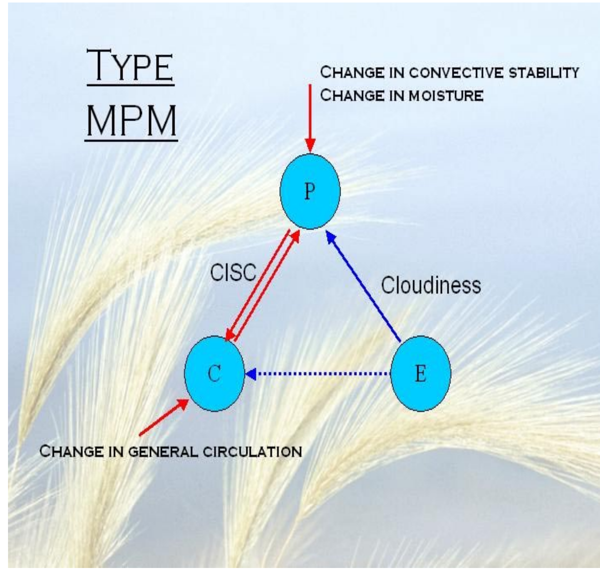


Figure MK1. Illustration of three-component exchange diagram over land. CISC stands for Conditional instability of second kind and WISHE stands for wind induced surface heat exchange. Red character indicates positive feedback while red character indicates negative feedback. The arrows into P, C and E from outside the triangle are the external input to each component caused by the change in season and other remote forcings.





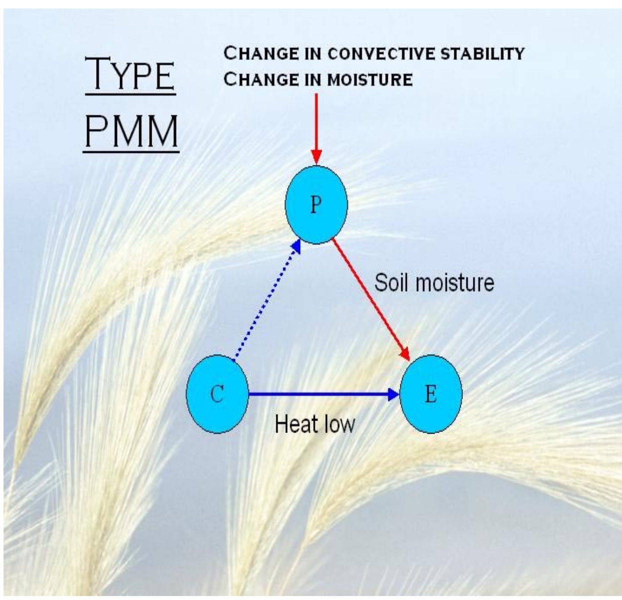


Figure MK2. Exchange diagram for three types of correlations.

The one-month test analyses are compared with the original Reanalysis-2 (R-2). Total 2-month integration from Nov. 1st to Dec. 31st 1997 is performed and monthly mean output of December is analyzed.

The SFM has different long-wave radiation, convective parameterization and land surface physics from those of R-2 SFM. The comparison of the analyses shows, difference in relative humidity and lower tropospheric temperature in equatorial latitude, geopotential height around South Pole and other differences in precipitation. Some of those are given in Figure SOH1. The cause of the difference might be from different physics scheme, computational environments, and so on. Further refinement will be performed. Even when the GDAS is simulated with setting same physics options of SFM as those of R-2, the results also show a little difference.

Since these basic experiments showed that the GDAS system is working, we started our main objective of data extraction experiments. Experiments are designed to find the accuracy of Reanalysis for the data sparse pre-satellite years by looking into the impact of selected variables to the data analysis system. One-month analysis with non-surface data, surface observation only data, without using satellite temperature data, no humidity data, no wind data and no surface pressure data are examined. The data are removed before entering the SSI (Spectral Statistical Interpolation) routine. Experiments without satellite temperature or humidity are most similar with control run, which assimilates all data (Figure SOH2). The analysis with no surface data, no wind data and no surface pressure data followed. Although the experiment using only surface data are more different from control analysis, it showed amazing reduction of error compared to the corresponding AMIP runs (data assimilation without observations) (Figure SOH3). Further examination of the results, particularly the influence of moisture analysis on spin-up/-down is in progress.

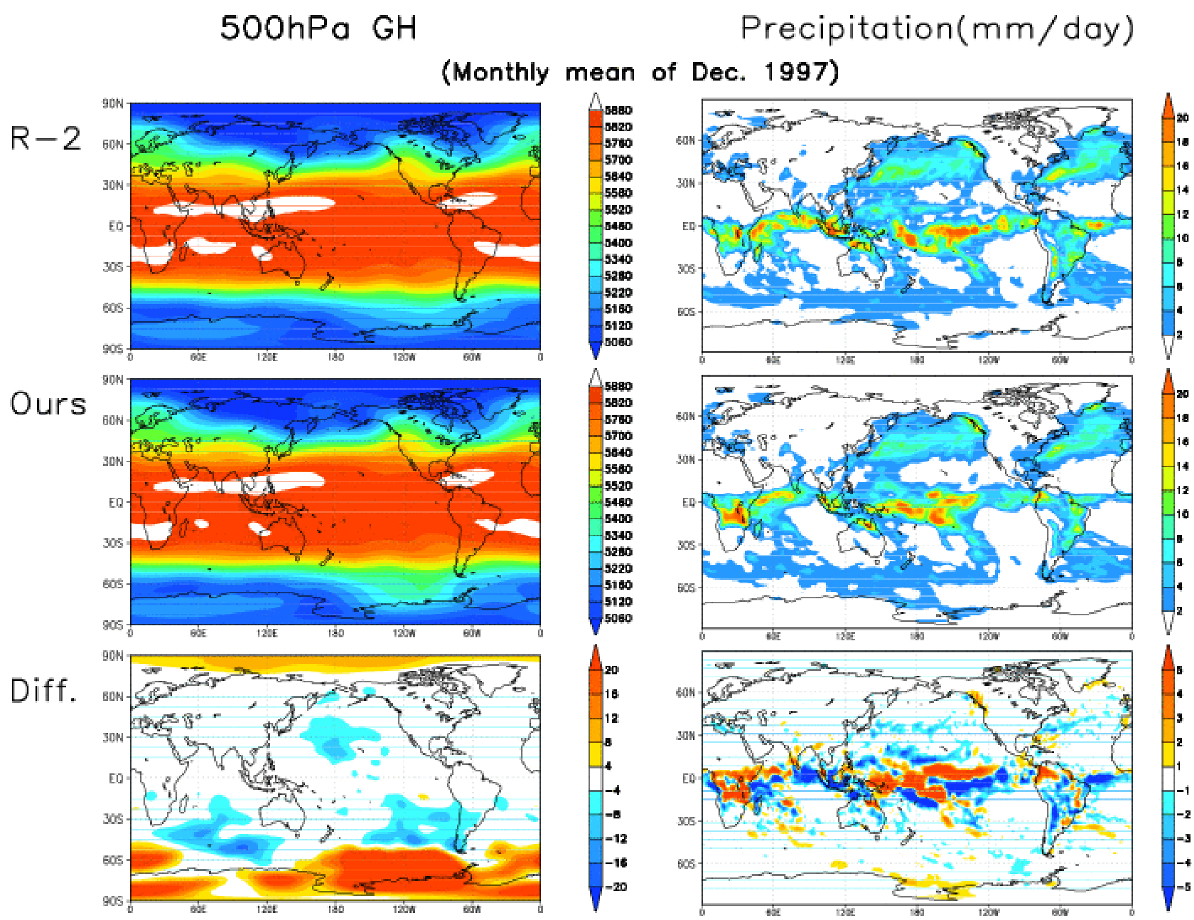


Figure SOH1. Comparison of 500hPa geopotential height and precipitation between Reanalysis-2 and our GDAS.

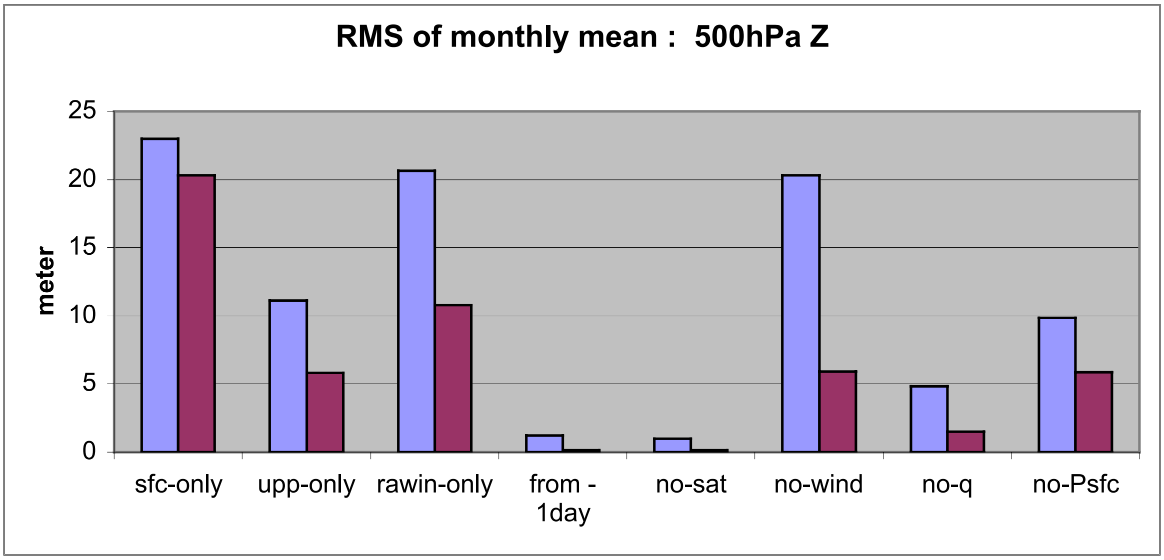


Figure SOH2. RMS errors of monthly mean 500hPa heights over the Southern Hemisphere of –90 ~ -30S (left column) and Northern Hemisphere of 30 ~ 90N (right column) in Dec. 1997 of several data extraction experiments.

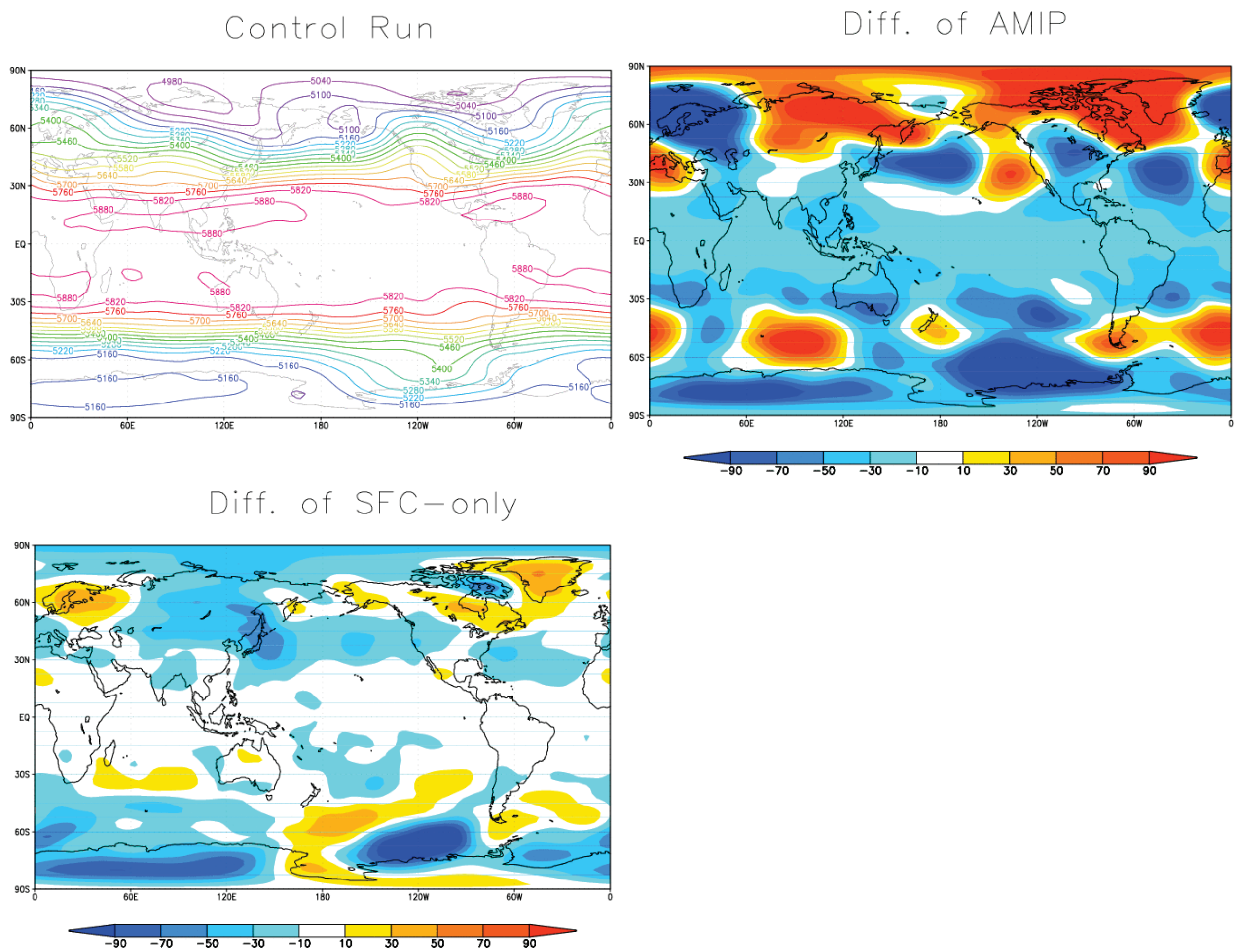


Figure SOH3. 500hPa height of Control Run (left top panel), difference of AMIP from Control Run (right top), and difference of SFC-only experiment from Control (bottom).

EXPERIMENTAL REGIONAL PREDICTIONS AND SIMULATIONS

RSM

The ECPC has now sponsored four international RSM workshops and is planning the 5th (as well as at least 2 future ones at other international sites), which will take place during Jul. 2004 in Seoul, Korea. The ECPC is also still providing a voluntary RSM model master, who responds to international queries about the model, provides training for the model at IRI training workshops, and maintains the RSM home page as part of ECPC's extensive WWW outreach. ECPC is also investigating regional climate predictions to better understand model drifts, biases and potential high-resolution predictability for the entire US (50 km), Brazil (50 kms), California (25 km), US southwest (25 km), Taiwan (15 kms), Routine RSM and GSM forecasts are for these regions are displayed on the WWW. Evaluation of these regional forecasts is underway with various national and international collaborators. A number of papers describing continuous simulations have been published (Anderson and Roads 2003, Chen et al. 2001, Chen 2001; Roads et al. 2002, Roads 2003).

We have begun to investigate a new version of the Regional Spectral Model (RSM) to be managed by Concurrent Versions System (CVS) and controlled by configure files and Makefile system. This new RSM/CVS system is designed to have the same structure as the NCEP's Global Spectral Model (GSM), which is also managed by the

CVS, so that the latest updates of model physics in the GSM/CVS system can be directly incorporated into the RSM/CVS system. The surface fields in the RSM/CVS such as topography, sea surface temperature, surface roughness, and surface albedo are obtained directly from the higher resolution observation or climatological data, rather than interpolated from the lower resolution global analysis or forecast data. The RSM/CVS has a parallel computing capability and the speed-up is about 75% per processor. The RSM/CVS system is an efficient, stable, state-of-the-art atmospheric model designed for regional climate research, currently working on IBM-SP, Origin, and Dec-Alpha machines. The RSM/CVS version was described by Han (2001) and is available from the ECPC RSM web pages (http://ecpc.ucsd.edu/RSM/).

An RSM/CVS user manual (Han 2001) has been developed to provide users with entry-level information for the model system installation, the model library and utility, the model code and input/output structure, and the model integration and run procedure. This manual is composed of five subsections of CVS system, model system structure, model integration road map, model IO, setting-up experiment and model run procedure. Based this manual, we have given lectures to new RSM/CVS users in the IRI (International Research Institute) training sessions on dynamical downscaling for seasonal to interannual climate prediction as well as at the international RSM workshops. This training will continue.

IRI Intercomparison

A regional modeling intercomparison project for Brazil among the: (1) Scripps Experimental Climate Prediction Center regional spectral model (RSM), (2) Florida State Univ. nested regional spectral model (FSUNRSM), (3) Goddard Institute for Space Studies regional climate model (RCM), and (4) IRI regional climate model (RegCm2) was described by Roads et al. (2003). In comparison to Xie and Arkin observations, the regional models had a seasonal systematic precipitation error that was somewhat similar to the driving NCEP/NCAR reanalysis systematic error, although the regional model ensemble mean was somewhat smaller. However, the ensemble mean standard deviation was somewhat less than some of the other models and the observations, indicating that averaging individual model runs will result in reduced variance and does not necessarily provide the smallest RMS error or highest correlation. Threat and bias scores were calculated against a set of raw (cleaned up) station measurements and the regional ensemble mean provided increased skill over the driving NCEP/NCAR reanalysis. However, when the Xie and Arkin data set was used as the basic observation set, the NCEP/NCAR reanalysis was superior to the regional model ensemble mean.

Chen and Roads (2003) further compared regional simulation using the regional spectral model (RSM) with 50-km grid space increment over South America. NCEP/NCAR 28 vertical levels T62 spectral resolution reanalysis were used to initialize and force the regional model for a two-year period. Initially, the RSM had a severe drying trend in the soil moisture that adversely impacted the precipitation. The drying trend was presumably a response to the positive feedback between an imperfect cumulus parameterization scheme and the soil moisture module in the model. This drying trend was corrected by tempering the deep soil moisture in the model during the integration. Two additional experiments were examined. The first experiment prescribed the daily soil moisture in the deep second layer from the driving reanalysis; the second experiment utilized observed precipitation to interactively correct the deep soil moisture during the integration. The regional precipitation simulation was then marginally better than the reanalysis precipitation. Both experiments corrected the reanalysis wet bias precipitation and had better anomalous threat scores (**Figures Sc1a,b**) for the highest monthly precipitation intensities. The interactive correction of the second experiment provided the best simulation. These experiments indicate the potential value of using realistic deep soil moisture for simulating regional South American climates.

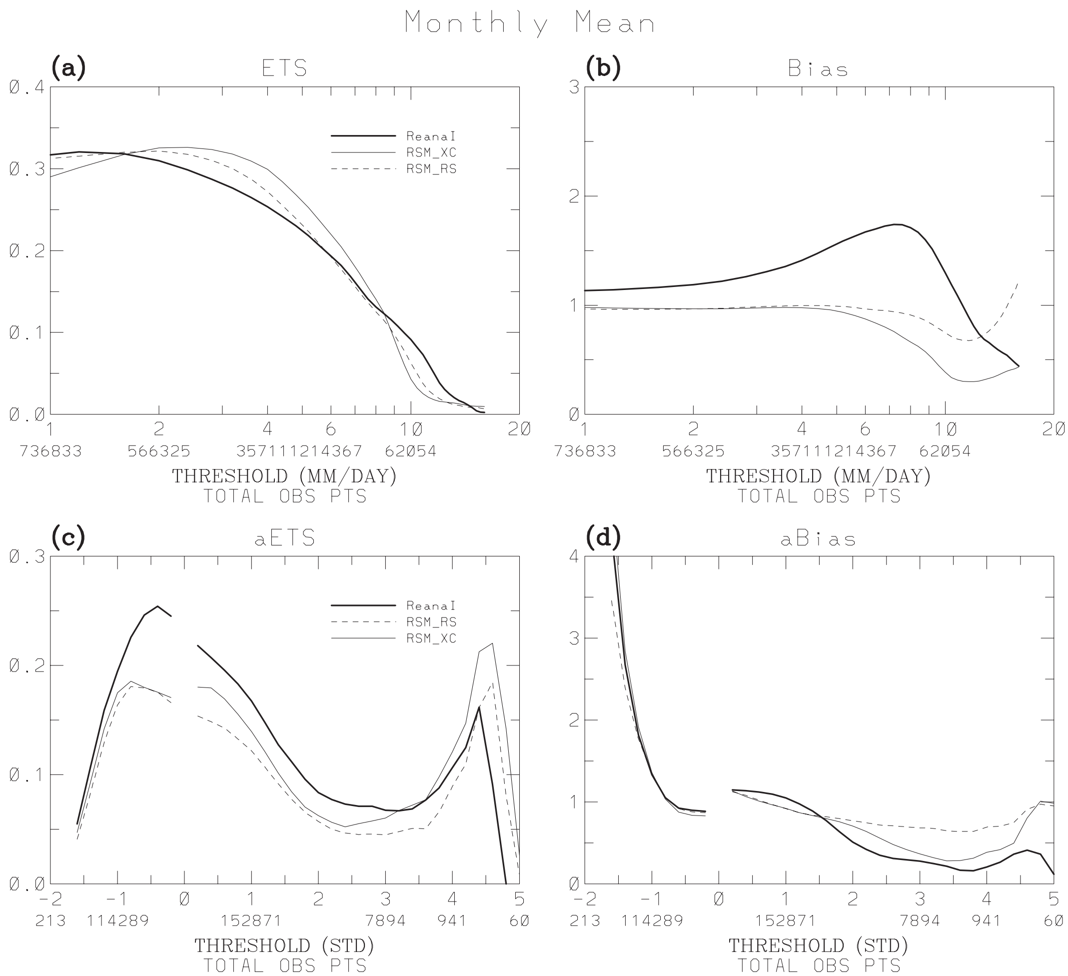


Figure SC1. Equitable threat and bias skill scores for precipitation for Reanalysis I (thick solid lines), RSM_RS (thin dashed lines) and RSM_XC (thin solid lines). The scores for total monthly mean are given at (a) and (b), those for the anomalies after removing seasonal mean are given at (c) and (d).

US Regional Climate Simulations and Seasonal Forecasts

Roads et al. (2002) investigated whether a regional climate model provided a more useful regional climatology than can be obtained from larger-scale global analyses or a better regional forecast than can be obtained by a large-scale seasonal prediction model. US regional spectral model (RSM) climate simulations forced by 1-day global spectral model (GSM) forecasts initialized from the NCEP operational analysis were compared with regional RSM simulations forced by the NASA Seasonal to Interannual Prediction Project general circulation model (GCM). The GCM was continuously forced by observed sea surface temperature variations, but since sea surface temperatures (SSTs) are so persistent, these forced GCM simulations were equivalent to seasonal GCM predictions, which are mainly based upon persistent SSTs anyhow. RSM simulations forced by these two global modes were compared at the same spatial resolution as the global models (200 km) and at higher resolution (50 km). Resolution was important for producing better geographic pictures, but does not currently produce significantly more skillful regional climate simulations or forecasts of the temporal variability, which already have significant skill from the global models. However, regional climate simulations and forecasts better depict the precipitation intensity, especially over the US West. Finally, re-initialized (from the large-scale analysis) one-day RSM forecasts were compared with continuous RSM simulations, and this increased the overall regional skill back to the original GSM skill, which was somewhat degraded in continuous RSM simulations.

Roads (2003) further compared 3 years of GSM and the RSM precipitation forecasts over the US, with special attention to various biases and errors (**Figure JR1**), as well as the significant forecast skill (**Figure JR2**) at weekly to seasonal time scales. While these experimental forecast results suggest that there is precipitation forecast skill, out to

at least a season, to be realized from both global and regional dynamical models, it was disappointing that the RSM did not seem to provide markedly more skillful precipitation forecasts than the GSM (**Figure JR3**). Excessive forecast variance is a major problem with the current RSM. In short, deficiencies in the coarser-scale GSM were overcompensated in the higher resolution RSM, which ultimately led to other problems. Seasonal RSM precipitation was especially high over the northwestern US. The seasonal variations were comparable to these seasonal forecast biases, indicating that they must be removed, either empirically or through the development of better models. Once they were removed, the skill of the RSM and GSM forecasts seemed at least comparable. Thus again, while the RSM demonstrated weekly to seasonal forecast skill, it does not currently produce clearly superior forecasts.

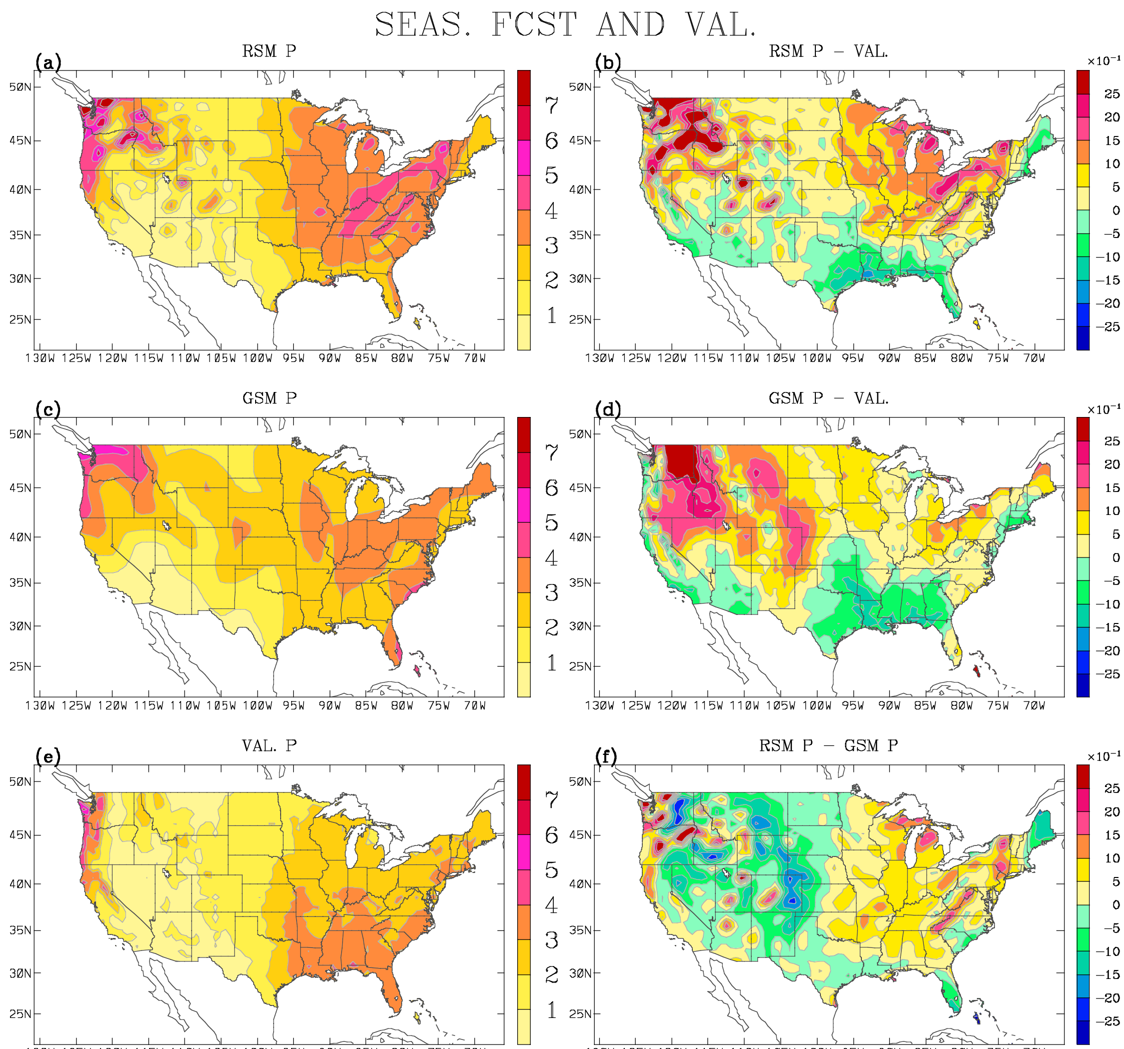


Figure JR1. RSM, GSM, and validation (Higgins 2001) seasonal precipitation forecast means (mm/day): (a) RSM P; (b) RSM P – validation; (c) GSM P; (d) GSM P – validation; (e) validation; (f) RSM P – GSM P.

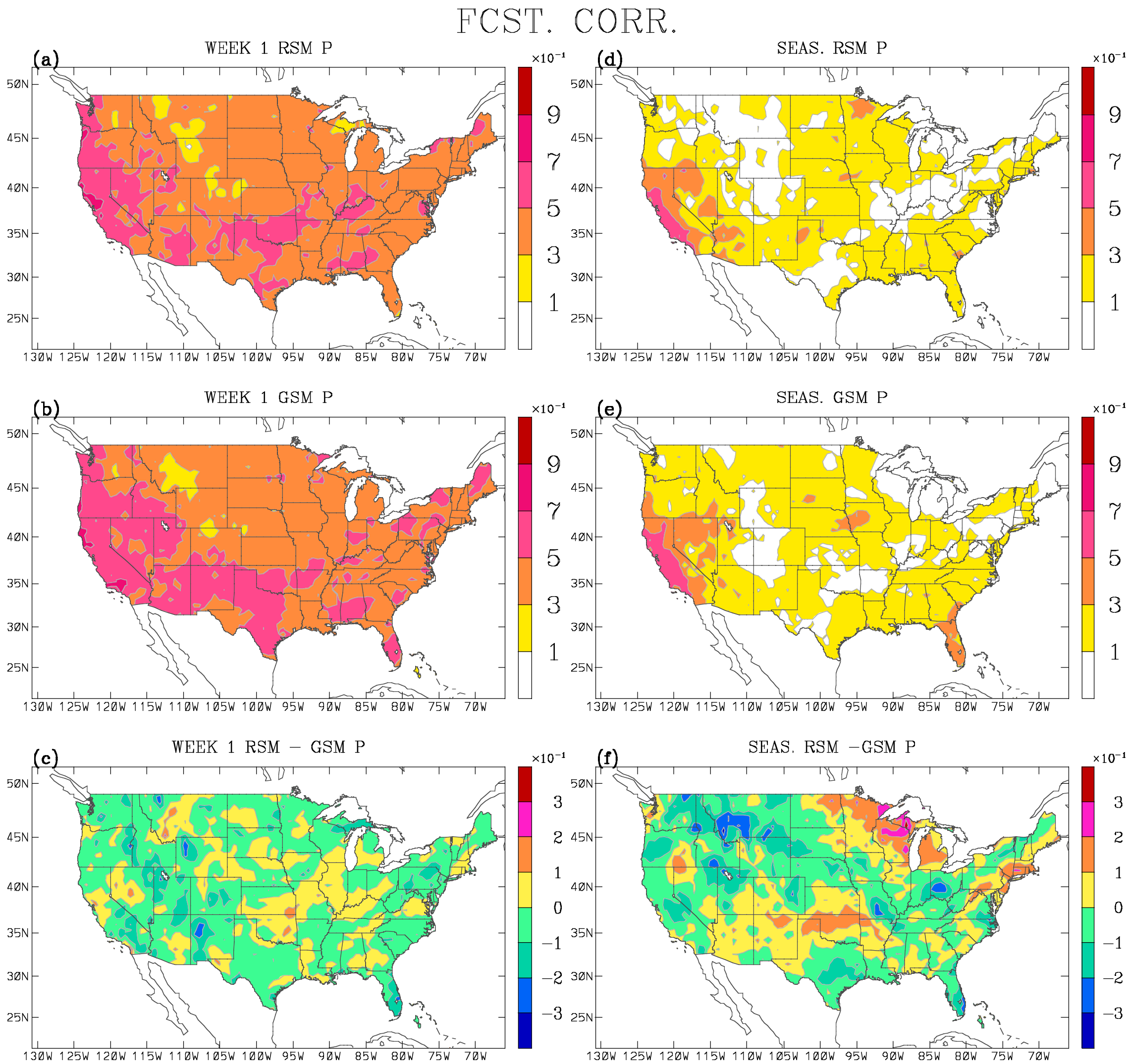


Figure JR2. RSM and GSM seasonal forecast correlations with validating observations: (a) week 1 RSM; (b) seasonal RSM; (c) week 1 GSM; (d) seasonal GSM; (e) week 1 RSM – GSM; (f) seasonal RSM – GSM.

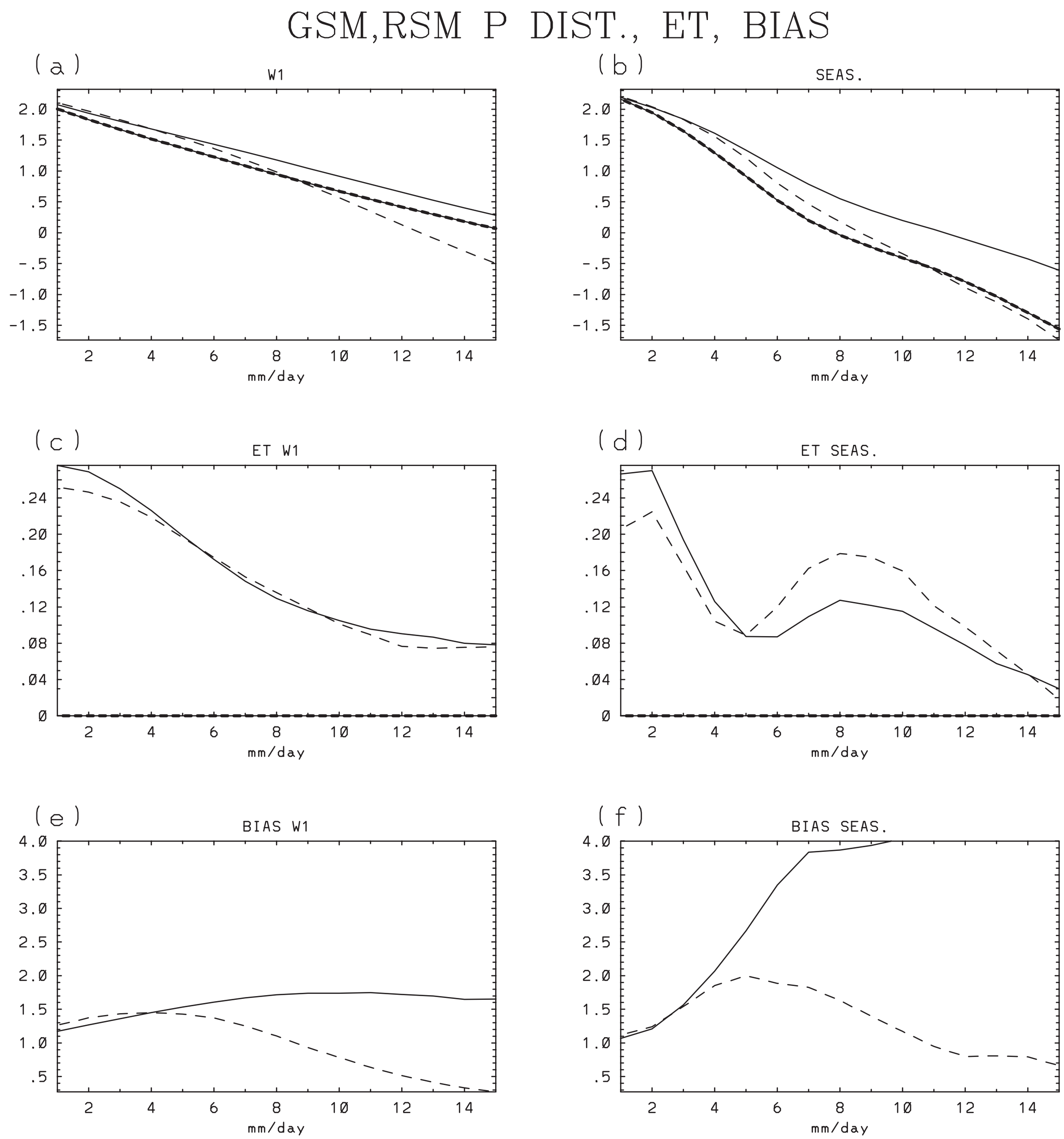


Figure JR3. US RSM (solid line) and GSM (dashed line) week 1 and seasonal precipitation equitable threat skill scores: (a) week 1 O (number of observations above the abscissa limit (thick dashed line), F (number of forecasts above the abscissa limit) in the RSM (thin solid) and GSM (dashed); (b) same as (a) except this is for the seasonal forecasts; (c) week 1 equitable threat scores for the RSM (solid line) and GSM (dashed line); (d) same as (c) except this is for the seasonal forecasts; (e) week 1 bias scores for the RSM (solid line) and GSM (dashed line); (f) same as (e) except this is for the seasonal forecasts.

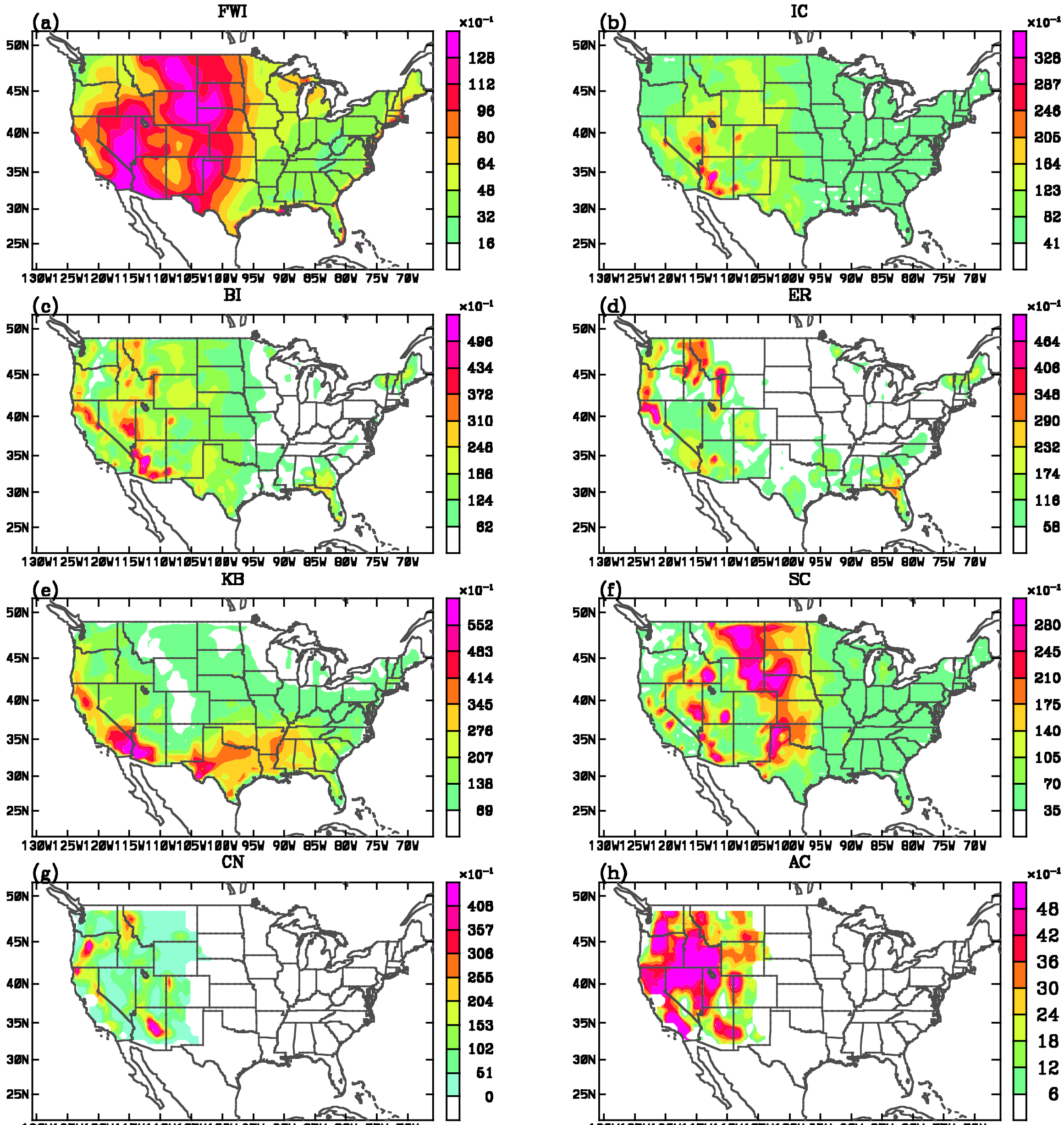


Figure JR4. Summer seasonal mean validation means: (a) FWI; (b) IC; (c) BI; (d) ER; (e) KB; (f) SC; (g) CN; (h) AC.

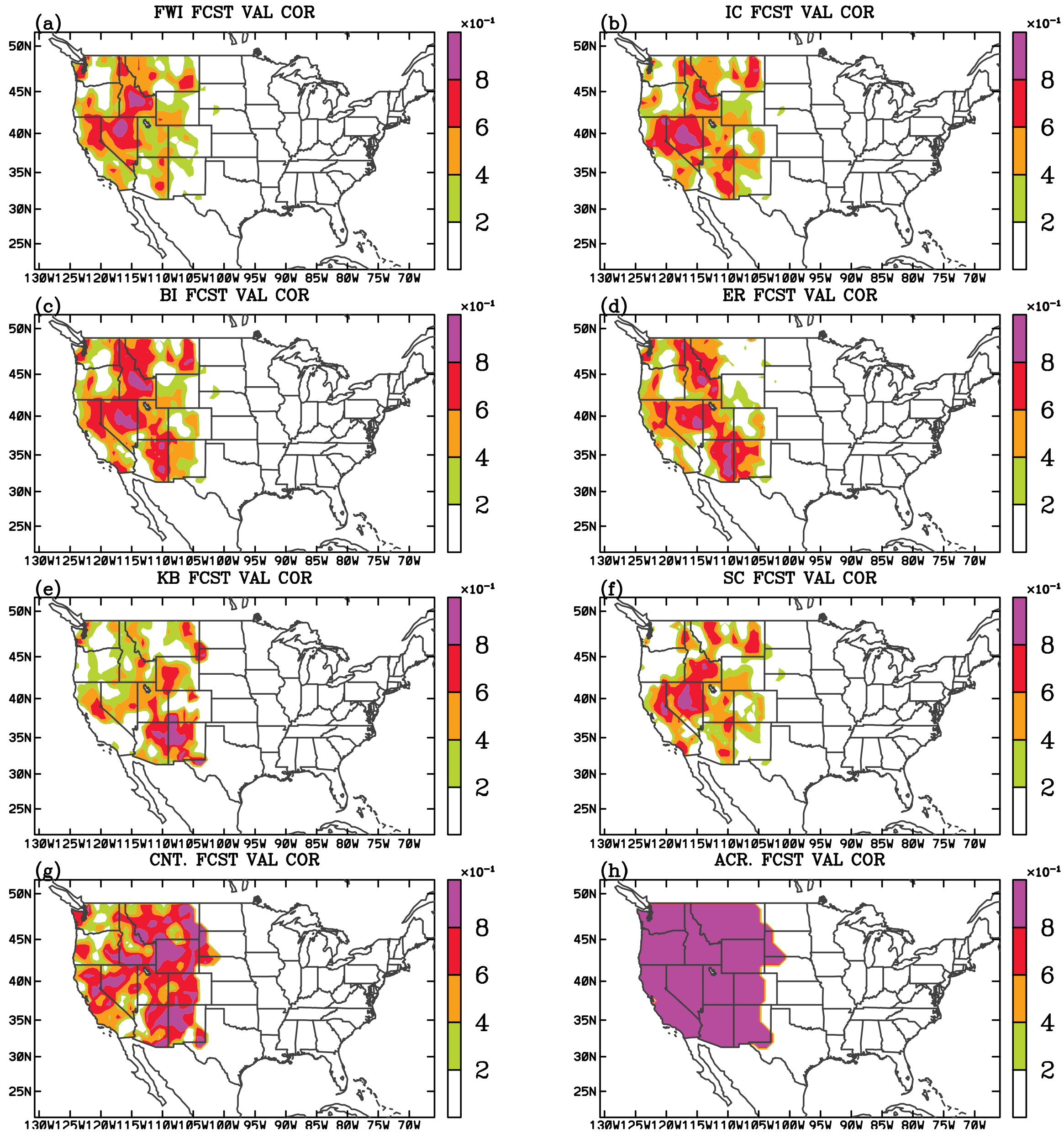


Figure JR5. Summer seasonal mean correlations between validation NFDRS indices, CN and AC, with AC: (a) FWI; (b) IC; (c) BI; (d) ER; (e) KB; (f) SC; (g) CN; (h) AC.

Sensitivity of Model Horizontal Diffusion Schemes

During the past few international RSM workshops co-sponsored by ECPC, many modeling groups have repeatedly complained about the excess rainfall in mountainous regions. After many intensive discussions, it was the consensus in the meetings that the problem may be the artificial horizontal diffusion on sigma coordinates employed in the previous version of RSM. The original design of the horizontal diffusion in the NCAP RSM and mesoscale spectral model (MSM) was for perturbations on sigma-coordinate surfaces. Therefore, the dynamical terms can be expressed as simple as a linear term for implicit and spectral computation. However, the perturbation, which is defined as the difference between outer coarse model terrain and inner NCEP RSM/MSM high-resolution model terrain, can be large over the mountain area as horizontal resolution increases (**Figure. SC2)**. In case of temperature or moisture field, the perturbation value on top of the high terrain from regional model is colder or drier than that from the outer model because it represents the value at higher altitude. The perturbation temperature is warmer or more moist in the regional model at the valley or sides of the mountain, due to lower altitudes. With this pattern of perturbation, the horizontal diffusion of perturbation on sigma surface will reduce the differences between the regional model and outer model; hence warming (moistening) on top of mountain and cooling (drying) over the sides or valley of the mountains, depends on the ambient conditions, such as monotonic decreasing of temperature and moisture with height. Then, the warming and moistening (cooling and drying) will produce convergence and excessive rainfall (divergence and down-slope cold air). This non-negligible error would eventually ruin the forecast and simulation over mountain areas in the high-resolution modeling.

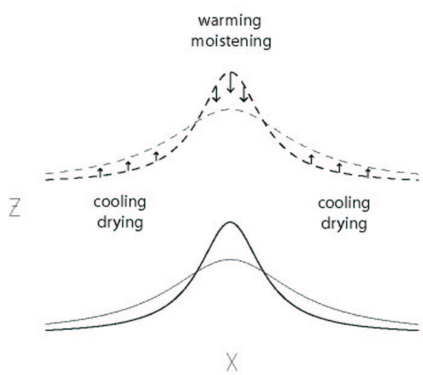


Figure SC2. A schematic plot to show the differences in height of the same sigma layers due to the model terrain differences between the outmost coarse resolution model (heavy solid and dashed curves) and inner fine resolution model (light solid and dashed curves). The solid curves indicate the model terrain heights and the dashed curves indicate the model layer heights. The arrows indicate the tendency of the sigma layer movement after applying horizontal diffusion on sigma surfaces.

To overcome this artificial diffusion problem, a new diffusion scheme is developed for RSM and MSM. A coordinate transform is applied to derive a horizontal diffusion on pressure surface by the variables provided on terrain-following sigma coordinates. Three cases from three institutes are selected to illustrate the impact of the horizontal diffusion on pressure surface, which improves or corrects numerical errors of mesoscale modeling over mountain areas. These cases address concerns from omni-directions, including unstable and stable synoptic conditions, moist and dry atmospheric settings, weather and climate integrations, hydrostatic and non-hydrostatic modeling, and island- and continental-orographies. After implementing the horizontal diffusion on pressure surfaces for temperature and humidity, the results show more reasonable rainfall and flow patterns when compared to the observations. This method corrects the warming, moistening, excessive rainfall and induced convergent flow patterns around high mountains under unstable and moist synoptic conditions, and the cooling, drying, and divergent flow patterns under stable and dry synoptic settings.

Regional Downscaling for NAME

Two RSM regional downscaling simulations were submitted to the NAMAP (NAME Model Assessment Project). We are the only center who submitted three simulations with different downscaling strategies. The first report prepared by Dave Gutzler indicated that the ECPC RSM simulation is comparable to other simulations, with several important differences. The precipitation amount is on larger side (not the largest), the low level southerly along the foothills of the Sierra Madre Occidental is not apparent in the monthly mean, and diurnal peaks occur at noon. Additional experiments are planned to examine the cause of those differences and to further extend the study to the interannual variations, as well as to study the sensitivity of the simulation to physics and other nesting methods.

Regional Downscaling for CA

A 50-year regional downscaling of Reanalysis over California is a project supported in collaboration with the California Energy Commission and the Earth Simulation Center in Japan. Parallelization (MPI version) of the RSM code was completed with the help of SDSC on IBM-SP machines and was subsequently ported to the COMPAS Linux cluster at SIO. The RSM is now running about 25 times faster on Linux cluster machine, and efficiency of the model integration experiments increased significantly. The conversion of the code for the NEC's SX machine is in progress and a test run is being planned for Dec. 2003.

Currently, two improvements for the RSM are under investigation. The first is the use of spectral nudging that makes the downscaling insensitive to the choice of the domain (and to reduce systematic error of the RSM simulation). After a long integration of the model run, a large-scale anomaly from the reanalysis field tends to develop inside the regional model domain. **Figure HK1a** shows the deviations from the reanalysis for 500mb height in the control run for 1997 December (10-day average). It is clear that the control run deviates from the reanalysis with a positive peak in the southeast. The spectral nudging technique conserves the small-scale details yet reduces the large-scale anomaly (Figure. HK1b). The technique adds nudging terms to smaller wave numbers in the spectral domain. Surface skin temperature is changed in the spectral nudging run in the north of the anomaly peak of 500mb height that was reduced (Figure. HK2). Precipitation rate also changes after spectral nudging, but the changes seem to take place randomly over the area (Figure HK3) The technique is being improved for application in a month or longer integration and larger domain sizes.

The second improvement is the application of land use data in the RSM. In collaboration with Guido Franco, additional use of land use data in the downscaling run is being tested. Some of the useful datasets include Weislander vegetation map for California (1945), CALVEG data set from 1977 LANDSAT imagery, GAP analysis from 1990 LANDSAT imagery, and urbanization data from California Department of Forestry. Incorporating long term variation of land use change is expected to improve the regional down scaling.

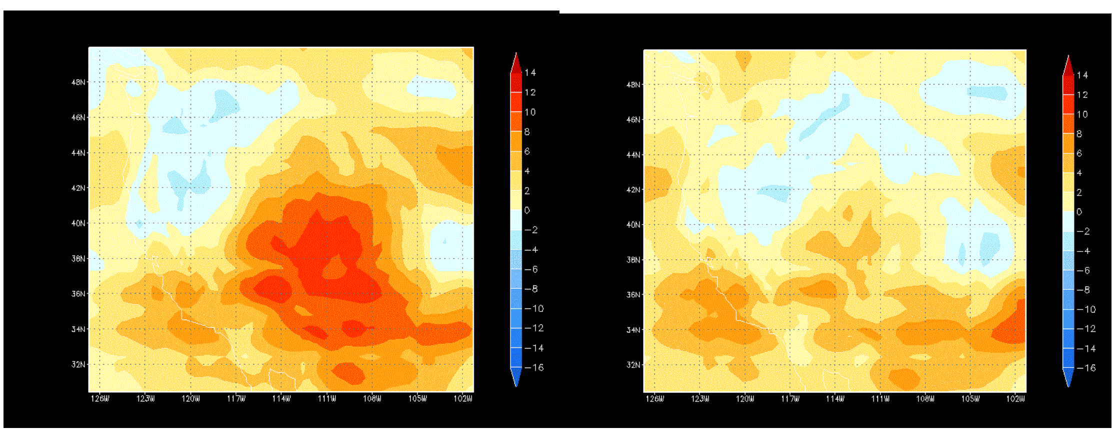


Figure HK1. Deviation of 500 mb height from the reanalysis for the control run (a) and the spectral nudging run (b) in December 1997 (10-day average). The domain covers California and the western United States.

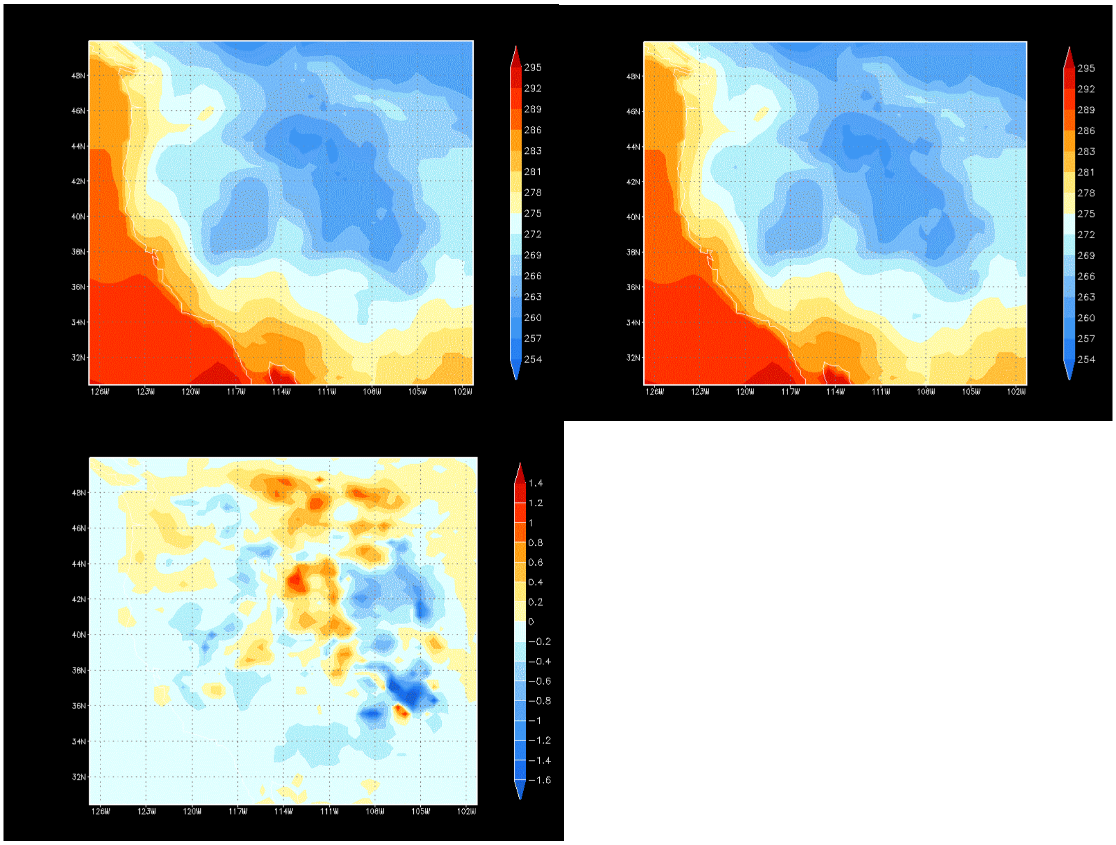


Figure HK2. Surface skin temperature filed from the control run (a) and the spectral nudging run (b) and the difference between the two (c).

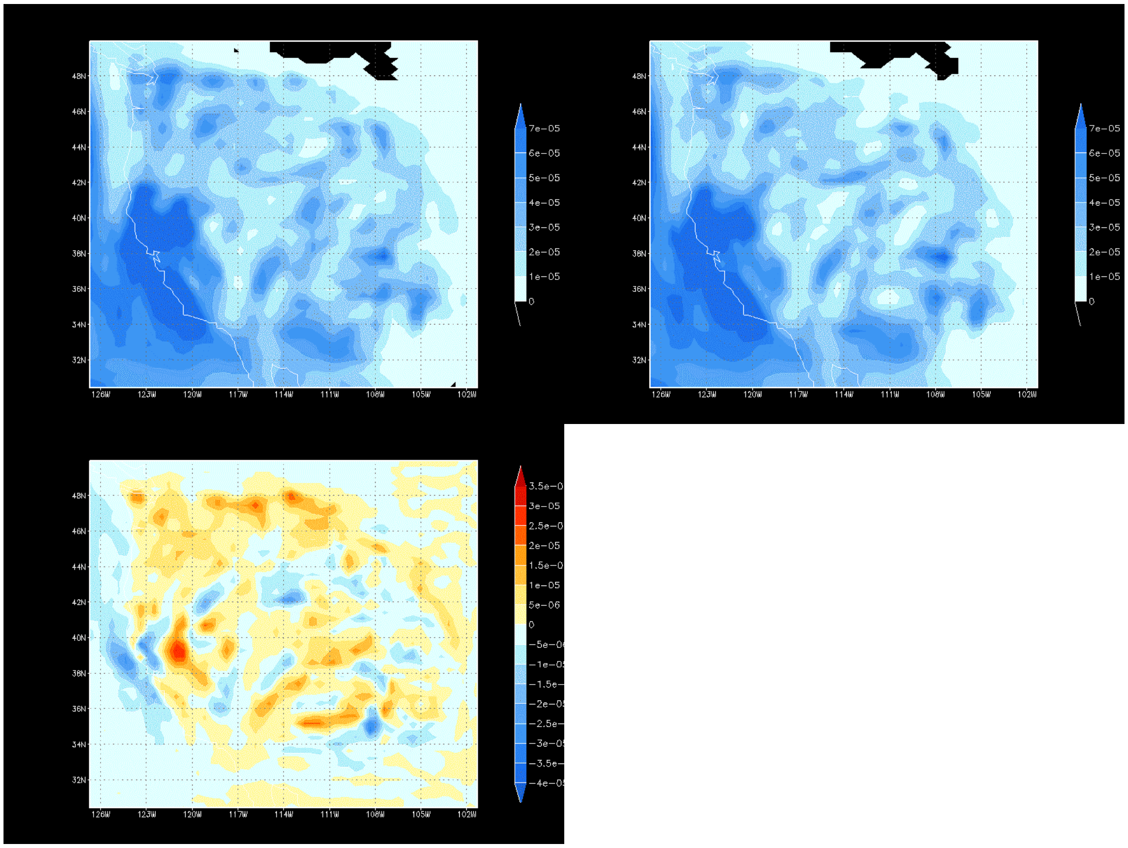


Figure HK3. Precipitation rate filed from the control run (a) and the spectral nudging run (b) and the difference between the two (c).

EXPERIMENTAL FIREDANGER PREDICTIONS

Predicting the influence of weather on fire ignition and spread is an operational requirement for US and global fire planning by the US National Interagency Coordination Center (NICC), which is the US's support center for wildland firefighting. NICC is home to seven federal agencies including the Bureau of Land Management, National Park Service, Fish and Wildlife Service, and Bureau of Indian Affairs, all in the Department of the Interior; and the Forest Service, in the Department of Agriculture. NICC's Predictive Services produces national wildland fire outlook and assessment products at weekly to seasonal time scales. This is currently done by considering standard National Weather Service seasonal forecast products of temperature and precipitation (see Brown et al. 2002, 2003) along with other indicators, and carefully exercised human judgment.

By contrast, nowcasts of fire danger potential at individual locations have been carried out for decades at individual US station locations using the US Forest Service (USFS) National Fire Danger Rating System (NFDRS; Deeming and others, 1977). This process has been automated and implemented nationwide, resulting in web-based displays of the NFDRS indices. The NFDRS explicitly describes the effects of local topography, fuels and weather on fire potential. Fuel moisture models relate moisture content to cumulative precipitation, precipitation extent and variation, temperature, and relative humidity. These fire danger nowcasts are updated almost daily, but they only allow fire managers to react to the current weather and climate conditions, rather than plan for the upcoming fire season. Can NFDRS indices also be forecast with a state of the art dynamical seasonal prediction model? Again, official NWS forecasts are only issued for temperature and precipitation. Forecasts for a number of more fire relevant variables, such as relative humidity, and windspeed, are still experimental and in many cases the fire community has had to empirically adapt to the official NWS forecasts of temperature and precipitation.

The ECPC has therefore been attempting (Roads et al. 2003e) to develop experimental forecasts of the NFDRS indices in order to augment current nowcasts from station observations and current seasonal forecast output of only temperature and precipitation. Basically, since dynamical models have demonstrated some skill for forecasting various meteorological variables like temperature, relative humidity, and mean windspeed at seasonal time scales, a goal of the ECPC has been determine whether the perceived meteorological forecast skill can carry over to forecasts of fire danger and whether the federal fire agencies should develop a more comprehensive seasonal firedanger forecasting capability. Encouragingly, Roads et al. (2001a) did show that a simplified measure of fire danger, namely the Fosberg (1972) Fire Weather Index (FWI) was capable of being predicted at seasonal time scales, mainly because of the inherent predictability of relative humidity, which is a significant component of the FWI, and as shown in **Figures JR4 and JR5**, other NFDRS indices. In addition, the FWI is forecast globally, as well as just over the US and given its US skill, may eventually prove to be useful in other global regions.

A COMPARISON OF NOAH AND VIC LAND SURFACE MODELS IN COUPLED AND FORCED SIMULATIONS

The variable infiltration capacity (VIC) macro-scale hydrologic land surface model is being coupled with the Regional Spectral Model (RSM), which currently uses a version of the NCEP land surface model (Noah). Water and energy budgets from off-line and coupled versions of the models are being compared over the southwestern United States semi-arid region. When both models use RSM precipitation, they produced relatively dry land surface conditions, because the RSM forecast/analysis (1-day forecast) produced less precipitation than observed. Wetter conditions were produced when observed (from CPC) precipitation was used although the Noah model was still relatively dry over the US Southwest presumally due to excessive evaporation occurring in the Noah model. Similar results occur in the coupled versions. Both evaporation and precipitation parameterizations need to be further improved in the atmospheric and land surface models. We have also developed a web site showing near real time daily to monthly forecasts for the US Southwest, with a focus on hydrology components (See http://ecpc.ucsd.edu/projects/uastc/) as well as links to sites describing the atmospheric and land surface models.

EXPERIMENTAL SINGLE COLUMN MODEL PREDICTIONS

This research uses our single-column diagnostic model, in conjunction with observations, to develop, validate and improve regional-scale parameterizations of physical processes important to ENSO time- and space-scale forecasting. The single-column model (SCM) is a diagnostic one-dimensional (vertical) model containing a full set of modern GCM parameterizations. The SCM is computationally efficient and serves as an ideal platform to test and evaluate model parameterizations (Iacobellis and Somerville, 2000; and Somerville, 2000). To force and constrain the SCM in this study, the advective terms in the budget equations are specified observationally from the NCEP GSM forecast model (Iacobellis et al. 2003; McFarquhar et al. 2003). Additionally, the surface sensible and latent heat fluxes from the GSM are used as forcing for the SCM.

Currently, we are operating the SCM at the three operational sites of the Atmospheric Radiation Measurement (ARM) Program. The three sites are located in the U.S. Southern Great Plains (SGP), the Tropical Western Pacific (TWP), and the North Slope of Alaska (NSA). Results from the SCM simulations, as well as from the NCEP GSM forecasts, are compared to ARM observations to evaluate model parameterizations and to develop improvements. The suite of parameterizations in our standard version of the SCM is also being evaluated against the ARM observations, to determine whether any of these algorithms are performing better than current schemes within the NCEP model. In the future, the SCM forecasts will be rerun as necessary to evaluate any changes made to model parameterizations.

The SCM forced with NCEP data has been operating since May, 2000. The archived SCM results along with data from the NCEP GSM model runs are continually compared with ARM measurements as they become available. **Figure SI1** shows the evolution of the monthly mean downwelling surface shortwave radiation at the three ARM sites from both models and from ARM measurements for the period May 2000 to December 2002. At the Southern Great Plains (SGP) site the downwelling surface shortwave from the GSM consistently overestimates the downwelling surface shortwave radiation compared to ARM measurements. The SCM results compare more favorably during the entire period and suggest that the cloud and/or radiation parameterizations in the SCM are producing more realistic results than those in the GSM. At the Tropical West Pacific (TWP) site, the GSM generally underestimates the downwelling surface shortwave flux compared to the ARM measurements. The SCM results compare much better to the ARM measurements up to about Jan 2002, at which time the GSM results are much closer to the observational data. The location of the TWP site is at about 167°E, 2°S corresponding to the ARM site on Nauru Island. The improved accuracy of the GSM during the first few months of 2002 may be due to longitudinal shifts in convective activity associated with the increasing El Nino (warm phase) conditions during this period.

The errors in the downwelling surface shortwave radiation from the GSM are largest during the spring months. The probability distribution frequencies of daily mean cloud fraction, downwelling surface shortwave radiation and OLR from the SCM, GSM, and observations were examined to try and understand the nature of these errors. **Figure SI2** shows these probability distribution frequencies for the months of March through May of 2001-2002 (6 months total) during times of no precipitation. During this time period, the GSM is clearly underestimating the cloud fraction which results in an overestimation in both the downwelling surface shortwave radiation and the OLR. The mean values and the width of the distributions from the SCM are much closer to the observations. **Figure SI3** shows the same plots during episodes of moderate to high precipitation rates (> 3 mm day^{-1}). Here the distribution from the GSM is much broader, but still the mean value of cloud fraction is significantly underestimated, which again results in overestimations of the downwelling surface shortwave radiation and the OLR. From these plots, it appears that the problems within the GSM are not limited to cases of no precipitation or cases of high precipitation rates.

Measurements at the ARM SGP site indicate that the GSM is underestimating the surface sensible heat flux and overestimating the surface latent heat flux (a positive flux represents an upward heat flux leaving the surface). The bias errors, which are on the order of about 50 W m^{-2}, offset each other to some extent resulting in a net heat flux that compares fairly well with the observations indicating that there may be errors in the Bowen ratio of the GSM.

While the net heat flux compares well with observations, the biases in the GSM sensible and latent heat fluxes used to force the SCM, may be causing errors in the SCM boundary layer temperature and humidity fields. Additional runs of the SCM were performed during the period June to August 2000 using observed surface sensible and latent heat fluxes from ARM observations at the SGP. One of the main differences in the SCM results between these two sets of runs was in the mean vertical profile of cloud fraction as shown in **Figure SI4**. In the original runs using the GSM surface heat fluxes, the SCM overestimated the amount of high cirrus clouds compared to ARM observations using cloud radar measurements. The amount of high cirrus clouds in the new SCM runs compares much better to these observations. Using the observed surface heat fluxes in these new runs results in changes to the SCM boundary layer temperature and humidity that affect the convective intensity and the amount and location of detrained cloud water/ice. These changes in the SCM cloud cover are significant; they result in an average increase in the monthly mean surface downwelling shortwave radiation of 11 W m^{-2}. It is likely that convection (as well as other model physics) in the GSM are affected by these errors in the surface fluxes.

Future work is planed to help better understand and correct deficiencies in the SCM, as well as those in the cloud-radiation parameterizations of the GSM. Some of these planned experiments will force the SCM with data from the RSM. The results from these SCM runs will be compared to the earlier runs using the GSM forcing data and the differences will be analyzed.

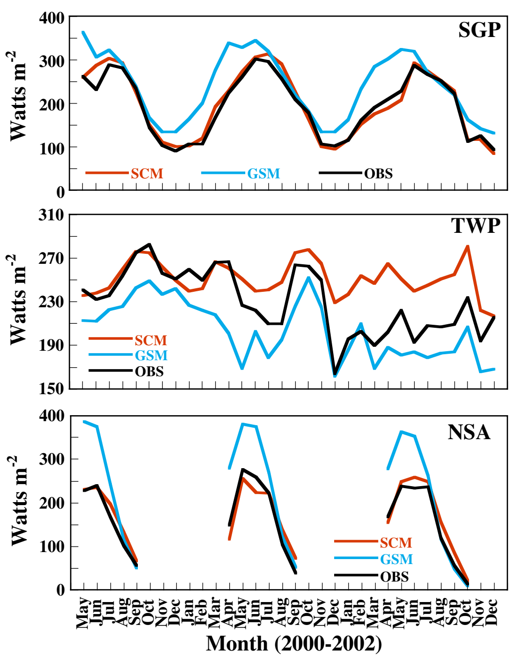


Figure SI1. Monthly mean downwelling surface shortwave radiation produced from the SCM (red), GSM 0-24 hour forecasts (blue) and surface observations (black) at the three ARM sites for the period May 2000 to December 2002.

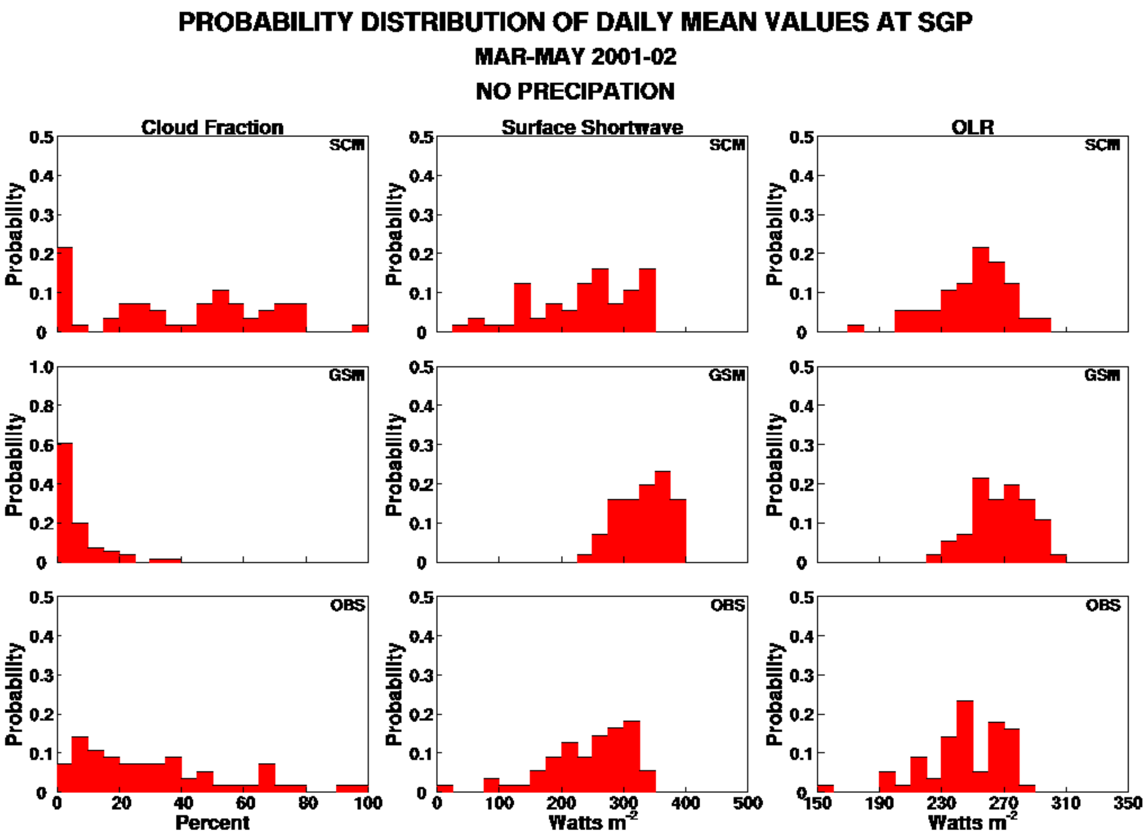


Figure SI2. Probability distribution frequencies of daily mean cloud fraction, downwelling surface shortwave radiation and OLR from the SCM, GSM, and ARM observations during periods of no precipitation for the months of March-May 2001-2002.

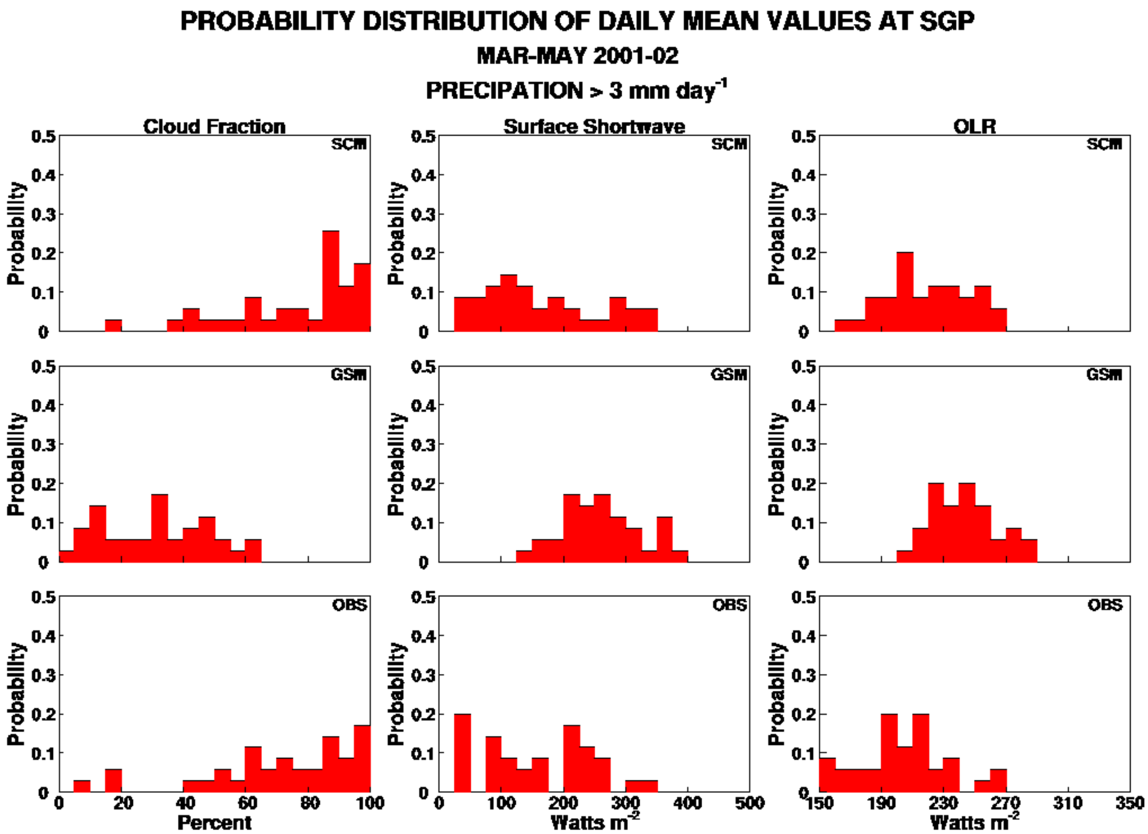


Figure SI3. Probability distribution frequencies of daily mean cloud fraction, downwelling surface shortwave radiation and OLR from the SCM, GSM, and ARM observations during periods of moderate-high (> 3 mm day^{-1}) precipitation for the months of March-May 2001-2002.

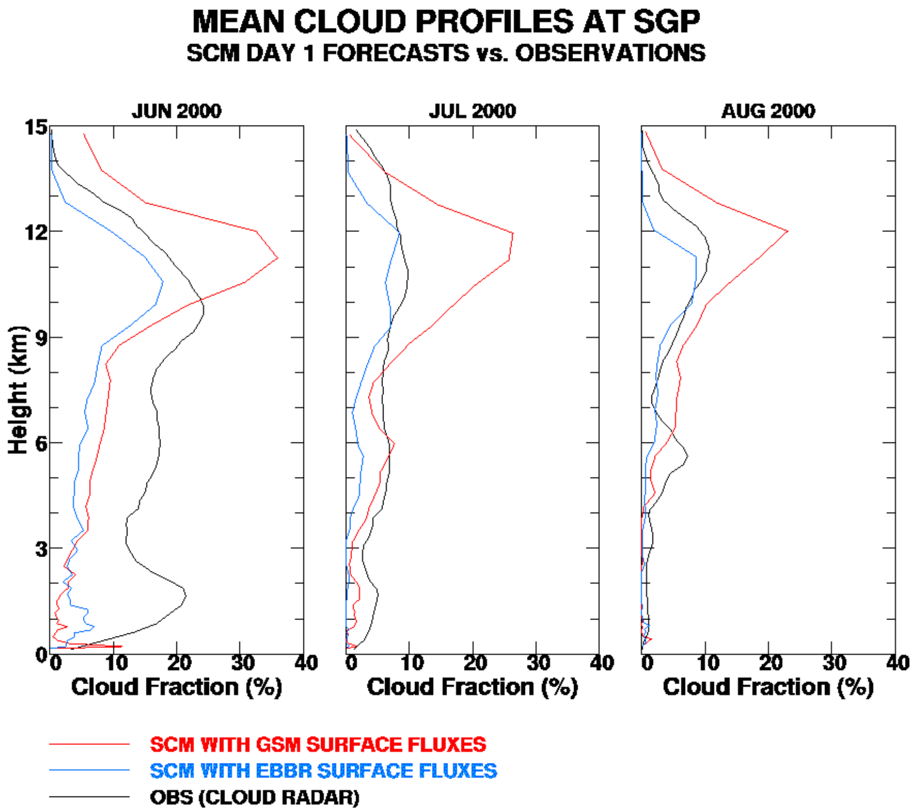


Figure SI4. Mean vertical profile of cloud fraction from the SCM control run (red curves), the SCM run using observed surface heat fluxes (blue curves), and from ARM cloud radar observations (black curves) for the months June to August, 2000.

EXPERIMENTAL OCEAN PREDICTIONS

Di Lorenzo (2003) investigated the seasonal cycle circulation dynamics of the Southern California Bight to determine the processes controlling a long-term warming of the California Current. Although upwelling favorable winds increased in recent decades, warming by surface heat fluxes suppressed this upwelling and resulted instead in a decrease in upward nutrient fluxes. This suggests the observed decline in zooplankton was due to a fundamental change in the physical environment. An article on the effect of climate changes on the sardine abundance off California is about to be submitted. It proposes a new theory that closely links biology and climate. In addition, using hydrographic data from key CalCOFI (California Cooperative Oceanic Fisheries Investigations) cruise, along with satellite observations of sea level, a primitive equation ocean model (Regional Ocean Modeling System; ROMS) has been initialized by fitting the model to the 3-week cruise periods using a Green's function inverse method. Development of the adjoint for ROMS is nearly complete and will be tested as an alternative fitting method in a 4DVAR framework. The forecasts are validated against subsequent hydrographic surveys and sea level from the satellites. The ecosystem response to these changes has also been studied using the CalCOFI nitrate, chlorophyll, and zooplankton data along with satellite measurements of chlorophyll. These physical and ecosystem forecasts are intended to become the prototype for real-time nowcasting and forecasting systems for an observational network in the Southern California Bight. We are currently working to come up with a practical application that will enable us to offer a "*Fisheries Outlook*", i.e., a forecast of some variable/s that could be directly used by the fish industry in order to approximately anticipate their catch values. This on-going effort is complicated as it combines conceptual models, observed biological (recent) data and physical forecast variables (e.g., ocean temperature).

Auad et al. (2003) evaluated the model skill of our OPYC oceanic forecasts using two more years of available forecasts (now a total of 5). **Figures GA1, GA2, GA3** show recent warming of the anomalous heat storage forecast for June, July and August of 2003 (a measure of the average oceanic temperature in the upper 400m) The patterns shown there resemble the interdecadal warming pattern of the Pacific Decadal Oscillation (PDO; see Auad 2003).

This pattern agrees with current estimations of the PDO index (http://tao.atmos.washington.edu/data_sets/pdo/) that also show a warming trend for the present days. Auad (2003) showed clear differences (dynamical and descriptive) between decadal and interdecadal variability in midlatitudes. Auad et al. (2003) further showed the novel idea that Intermediate Waters, as opposed to Bottom Waters, are the ones that mostly react to atmospheric climate changes (and perhaps interact with them). Auad (2003) also showed that the climate changes that took place both, at the end of the last glacial age and in 1976-1977 bear many similarities. This similarity between both warming episodes is relevant to understand global warming.

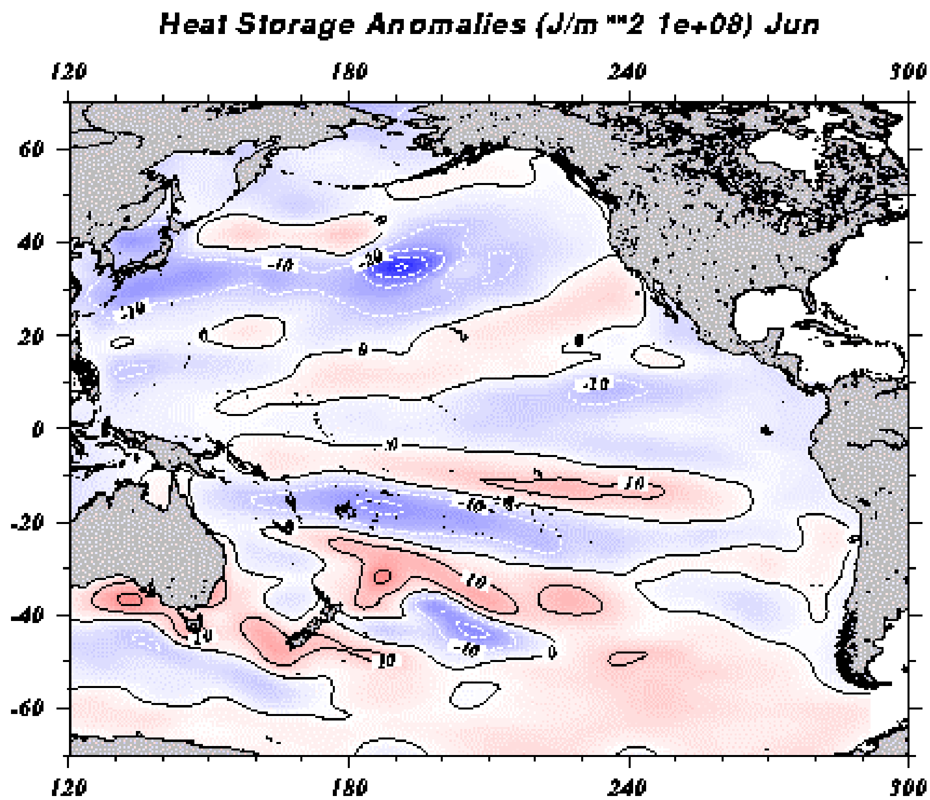


Figure GA1. Anomalous heat storage forecast for June of 2003 (reds are positive anomalies while blues are negative anomalies).

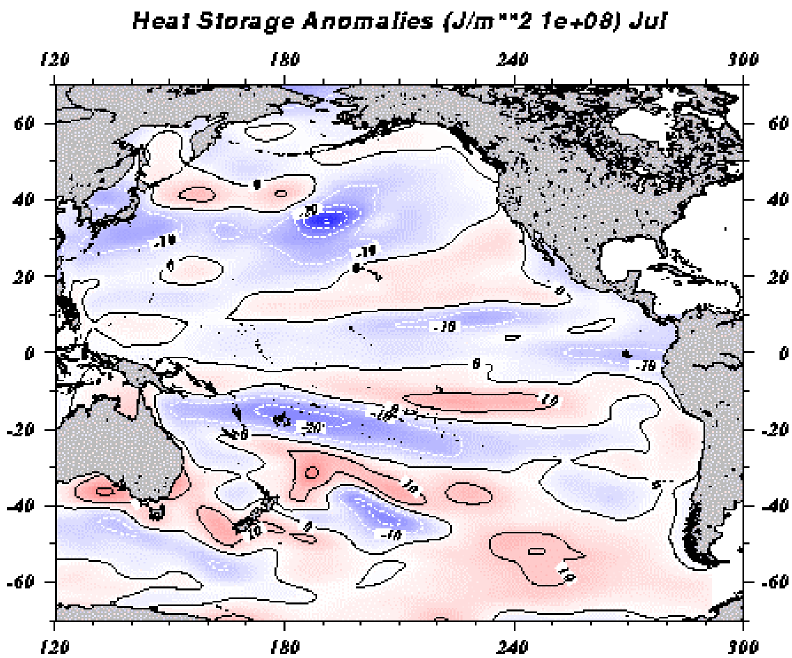


Figure GA2. As in Figure 1 but for July of 2003.

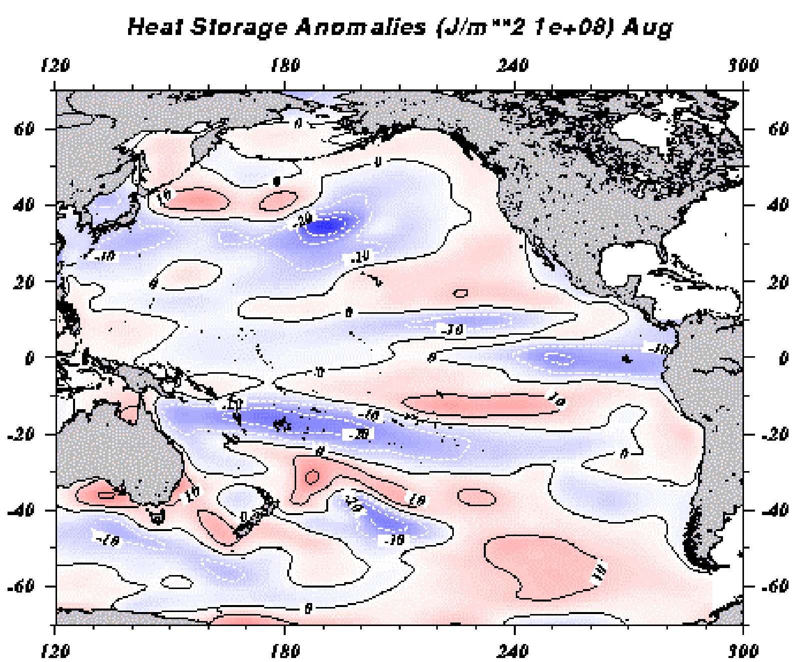


Figure GA3. As in **Figure. 1** but for August 2003.

COUPLED MODELING STUDIES

Efforts aimed at coupling the MIT ocean with the NCEP seasonal forecast model were continued. Firstly, the appropriate oceanic initial state conditions for the period from January 1992 to December 2001 were calculated. These simulations were performed by integrating for ten years of the 1°x1° MIT ocean model forced with corrected NCEP/NCAR reanalysis data. The hydrostatic version of the MIT model included the ECCO package, the GM eddy parameterization and ocean vertical mixing KPP scheme. The fluxes corrections were obtained from the state estimation of the global ocean circulation experiment (Stammer et al., 2002) in which the appropriately defined 'cost function', measuring the departure of the model from observations was minimized by adjusting control parameters such as air-sea fluxes, the wind field, the initial conditions etc. The comparison with NCEP/NCAR reanalysis revealed that the MIT model had a good skill in hindcasting of the sea surface temperature over most of the ocean. However, the MIT model is not appropriate for SST forecasting/hindcasting with the NCEP/NCAR Reanalysis I air-sea fluxes without flux correction. The numerous experiments with a stand-alone version indicated that the model has a climatology that differs from the observations.

The initial state for the atmosphere was obtained by averaging the 10 ensemble members of the AMIP experiment in which the NCEP seasonal forecast model was forced with observed SST anomalies (Kanamitsu et.al, 2002). The coupled run was performed on the Scripps Linux cluster machine utilizing 50 processors. The flux exchange between the atmospheric and oceanic components was implemented every 24 hours. In the control experiment no flux correction was made.

Figure EY1 shows heat content defined as the temperature integral over the mixed layer depth averaged over the NINO3.4 region (5°S-5°N and 170°W-120°W). The coupled run started January 1-st, 1993 and was performed for 5 years. As was mentioned above, the initial conditions for the ocean and for the atmosphere were taken from the corresponding hindcast runs of stand-alone models. The coupled model does not experience any initial shock. The simulated by the coupled model oceanic mixed layer heat content (red line) does not exhibit any significant trend. The heat content simulated by the coupled model is very similar to the one simulated by the MIT model forced with corrected NCEP/NCAR reanalysis fluxes (blue line).

Figure EY2 shows the corresponding NINO3.4 SSTs simulated by the coupled model (blue line) and by the stand-alone MIT model forced with corrected NCEP/NCAR Reanalysis fluxes (red line). The coupled model NINO3.4 SST has a cooling trend of around 0.5° K/year. It should be noted, however, that the de-trended NINO3.4 SST (lower panel) simulated by the coupled model is similar to the de-trended NINO3.4 SST hindcasted by the MIT model forced with corrected fluxes. The comparison of the air-sea fluxes (not displayed here) has shown that over the NINO3.4 region the biggest difference is observed in the meridianal wind stress field and in the short wave radiation.

The findings described above suggest that the coupled model skill can be improved by heat flux tuning. **Figure EY3** shows the proposed "zero order" heat flux correction. The simulated coupled model SST shown in **Figure EY4** (green line) is still colder than the observed (red line). Therefore, the analogous integration was performed in which the heat flux correction was increased by a factor of 2 (magenta line). The corresponding NINO3.4 sea surface temperature is warmer than the observed. Therefore, additional tuning is necessary. We are currently conducting additional experiments aimed on the coupled model tuning.

Another approach to the air-sea flux adjustment will be to estimate the flux correction from the run in which the surface temperature and salinity relax to the climatology. In this case, the simulated NINO 3.4 SST (dashed green line) is closer to the observations than in the coupled run without flux correction and does not exhibit cooling trend. A longer integration (underway) will be used for flux correction estimations.

Overall, the experiments with the coupled model have shown that the simulated SSTs are closer to observations than the ones simulated with the stand alone MIT forced with NCEP/NCAR reanalysis without flux correction (blue stars on **Figure EY4**). The coupled model has a good skill in hindcasting the oceanic mixed layer heat content. Additional tuning should be performed in order to increase the coupled model skill.

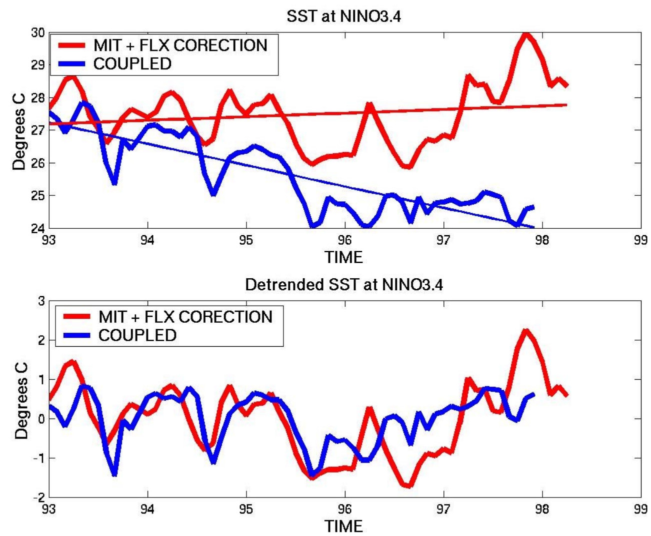


Figure EY1. Top panel: Simulated sea surface temperature averaged over NINO3.4 region (5°S-5°N and 170°W-120°W) by coupled model without flux correction (blue line) by MIT forced with NCEP/NCAR reanalysis air-sea fluxes with corrections. Lower panel: same as the top panel but the SSTs are detrended.

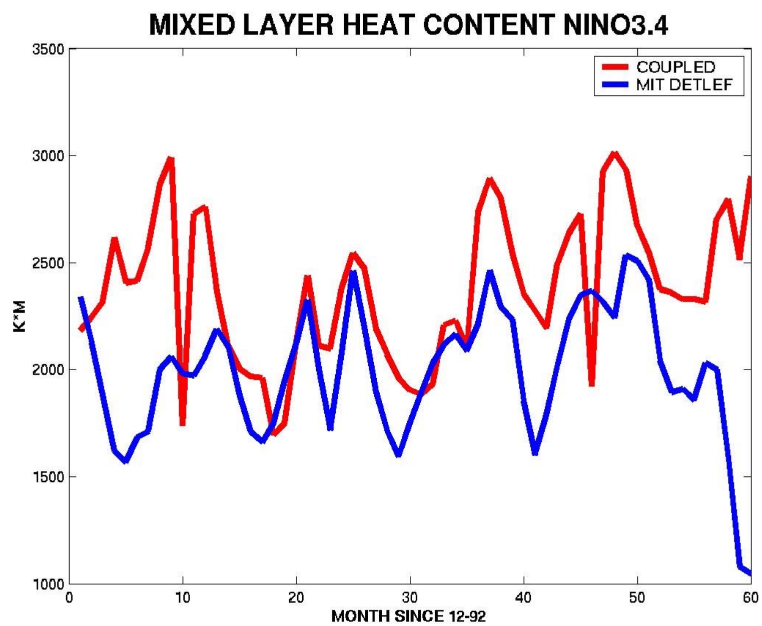


Figure EY2. Same as Figure 1 (top panel) but for the temperature integrated over the oceanic mixed layer: red line - coupled model, blue line – stand-alone MIT

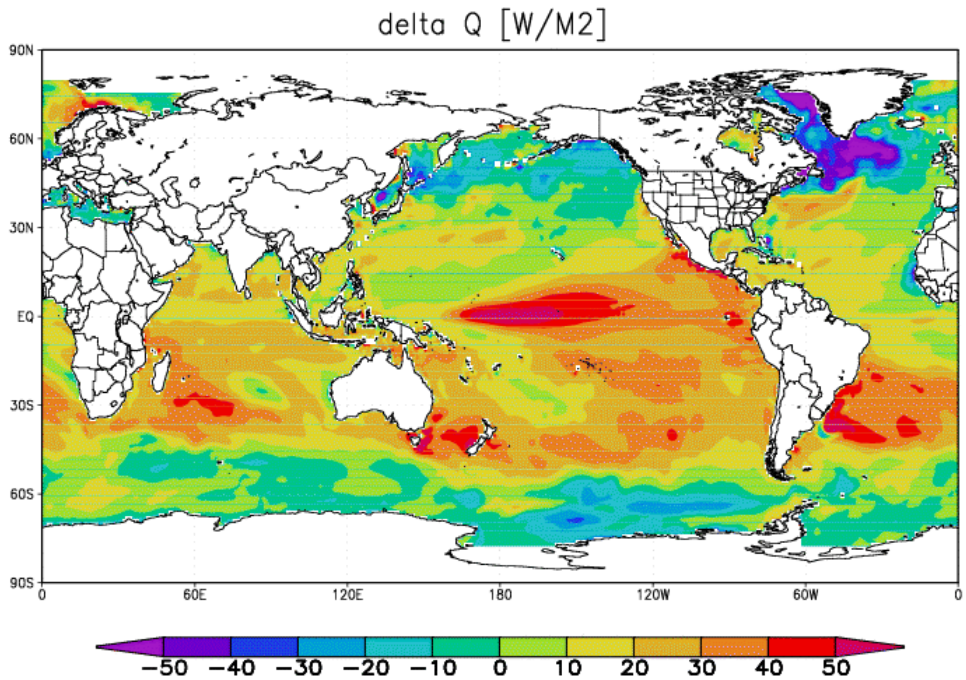


Figure EY3. Zero-order heat flux correction calculated from the difference between the observed and simulated SSTs.

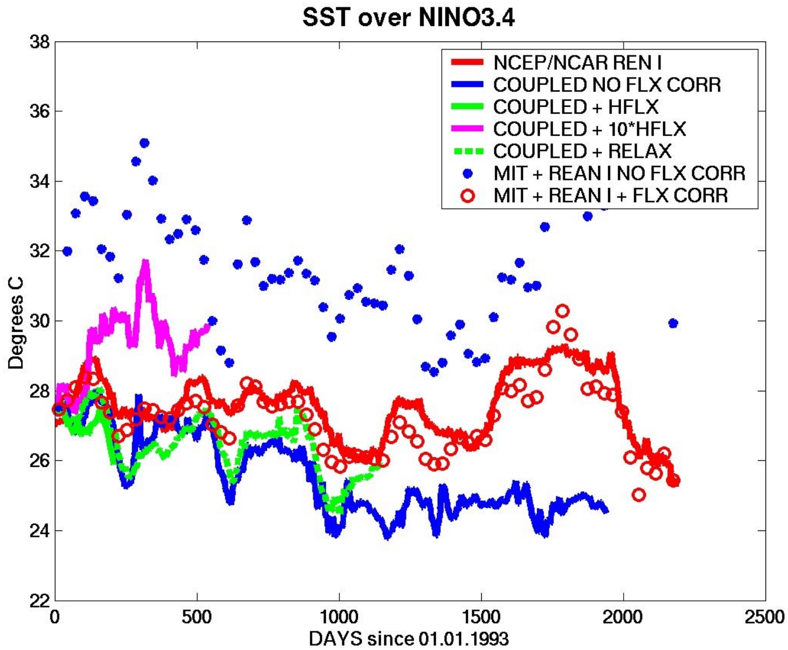


Figure EY4. Comparison between the observed and simulated NINO3.4 SSTs.
Red line – NCEP/NCAR reanalysis
Blue line – Coupled MIT/NCEP model, no flux correction
Green line – Coupled MIT/NCEP model, with heat flux correction as shown in Figure. 3
Magenta line - Same as green, but for twice larger flux correction
Dashed green line - Coupled MIT/NCEP model, SST and SSS relax to climatology at a time scale of one month.
Red circles – MIT forced with NCEP/NCAR reanalysis fluxes with flux correction
Blue stars - MIT forced with NCEP/NCAR reanalysis fluxes, no flux correction

INTERANNUAL VARIABILITY STUDIES

White and Tourre (2003a) conducted an MTM-SVD analysis of covarying sea surface temperature (SST) and SLP from 40°S to 60°N during the 20th Century (Kaplan et al., 1998). They found the local fractional variance spectrum yielding a discrete set of signals that dominate global climate variability in covarying SST and SLP anomalies (top, **Figure WW1**). They are the QBO (~2.2-year period), the ENSO (3- to 7-year period band), QDO (~11-year period), and BDO (~20-year period) signals. This global analysis produced the same signals observed for the Pacific and Atlantic oceans by Tourre et al., (1999, 2001). The complex empirical modes for each of these signals are composed of mixed global standing modes and traveling waves that are similar in pattern and evolution (see **Figure WW1** for representative global SST modes/waves). For each signal, the global traveling wave is composed of global zonal wavenumbers-1 and –2, directed eastward with a phase speed that takes 1 to 2 cycles to traverse the global ocean between 40°S and 40°N. Earlier White and Cayan (2000) and White and Allan (2001) had observed the slow eastward phase propagation of global waves in the QBO and ENSO signals. In the present study, White and Tourre (2003a) observed eastward phase propagation of similar global waves in the QDO and BDO signals. White and Tourre (2003a) opined that the existence of these global traveling waves in covarying SST and SLP anomalies over the ocean may improve the predictability of seasonal and annual temperature and precipitation indices over the global land surface. This hypothesis was tested in the subsequent two studies.

White and Tourre (2003b) conducted the MTM-SVD analysis of covarying surface temperature (ST), sea level pressure (SLP), and precipitation (PCP) anomalies over the globe from 60°S to 70°N from 1979 to 2002, when the latter dataset became available (Xie and Arkin, 1997). Again, they found the local fractional variance spectrum of these three variables yielding a discrete set of signals; i.e., the QBO near 2.4-year period, the ENSO signals near 3.0-, 3.8-, and 7.1-year period, and a secular signal for periods > 9 years, the latter composed of a combination of the QDO near 11-year period and the BDO near 20-year period from White and Tourre (2003a). Again, each of these global signals are composed of global standing modes and traveling waves that are similar in pattern and evolution,

similar to those in **Figure WW1**. Here, White and Tourre (2003b) found the patterns of PCP and SST on each period scale nearly identical to one another over the tropical and subtropical oceans, with high (low) PCP anomalies occurring over warm (cool) ST anomalies. Moreover, the evolution of these global modes/waves over the ocean were found to be contiguous with representative PCP indices over land (e.g., southeast Australia, southwest United States, equatorial Africa). In fact, the superposition of QBO, ENSO, QDO, and BDO signals explained 37% to 83% of year-to-year variability in representative regional indices over the globe (top, **Figure WW2**). Thus, regional drought/flood indices over the globe are related to one another by the superposition of these 4 global signals, with regional PCP indices differing from one another not only because of the different temporal and spatial phases in the 4 signals but because of their different local magnitudes (bottom, **Figure WW2**). Thus, the QDO and BDO signals dominate in some regions during some seasons (i.e., yielding multi-year drought and flood), while the QBO and ENSO dominate in other regions (i.e., yielding mostly year-to-year changes in precipitation). These four signals were also found to dominate most seasonal (i.e., unfiltered) PCP indices over the global land surface, the evolution of the global waves leading the latter by 3-to-6 months. This further supported the hypothesis that the evolution of these global SST/SLP/PCP modes/waves over the ocean may be useful in forecasting seasonal PCP indices over land.

White et al. (2003) found the global patterns and evolution of surface temperature (ST) anomalies associated with the QBO, ENSO, QDO, and BDO signals able to forecast global patterns of winter/summer (unfiltered) PCP anomalies from 1979 to 2001, yielding significant global-average cross-validated forecast skill that increased over the 6 months leading up to each forecast season. During winter in both hemispheres, significant cross-validated forecast skill (i.e., > 0.20) occurs over most of the North America, Asia, Australia, South America, and Africa driven by global ST patterns and evolution characteristic of the 4 signals, including influence from the Arctic oscillation and Antarctic oscillation at high latitude and the Antarctic circumpolar wave in the Southern Ocean. Here we display statistics for the cross-validated forecast skill of DJF precipitation over the Northern Hemisphere land surface from the evolution of ST patterns during the previous SON (**Figure WW3**). In the tropics and subtropics during summer, significant forecast skill occurs over most of India, the southern United States, and equatorial Africa, where global SST patterns and evolution characteristic of the 4 signals modulate the monsoon circulation. Representative DJF and JJA season PCP indices, together with their cross-validated forecasts, are displayed in **Figure WW4**. Thus, the forecast skill of winter and summer PCP anomalies over the different continents from the evolution of component QBO, ENSO, QDO, and BDO signals rises significantly above the noise. Over most of the extra-tropics, the QDO and BDO signals dominate QBO and ENSO signals, leading to multi-year drought/flood cycles (e.g., White, McKeon, and Syktus, 2003). Moreover, the trends in most locations are successfully forecast (see **Figure WW4**), indicating that they are driven by the evolution of global SST warming over the 23-year record, which has precipitation trending upward in some locations and downward in others.

To summarize, these studies have identified the patterns and evolution of global signals in surface temperature (ST), sea level pressure (SLP), and precipitation (PCP) operating during the 20th Century; i.e., the quasi-biennial oscillation (QBO) near 2.2-year period, the ENSO signals near 3.0-, 3.8-, and 7.1-year period, the quasi-decadal oscillation (QDO) near 11 year period, and the bi-decadal oscillation (BDO) from 15- to 25-year period. These global signals are able to statistically forecast seasonal precipitation indices over North America, South America, Australia, and South Africa. The seasonal evolution of regional precipitation indices, and their predictability, connected via the evolution of these global signals.

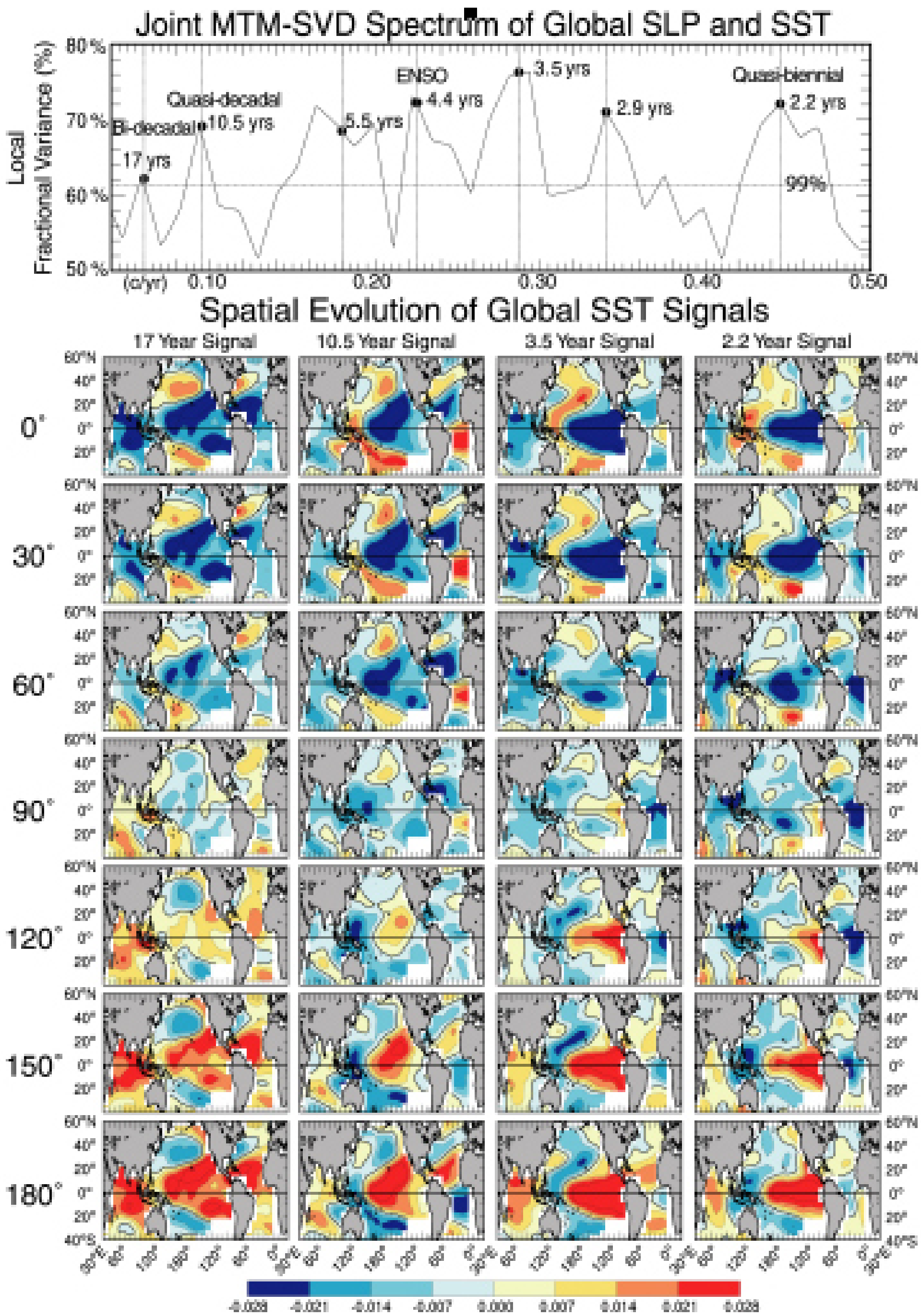
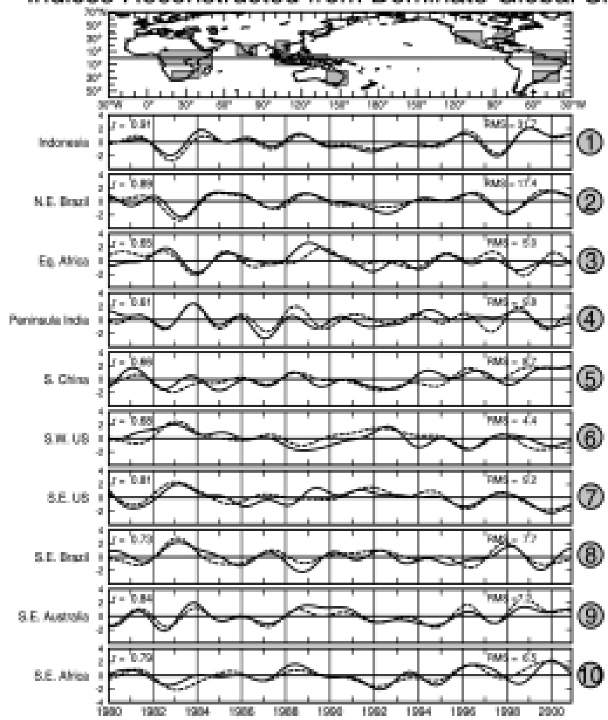


Figure WW1. (top) Spectraum of the joint SST-SLP local fractional variance as a function of frequency explained by the first joint MTM/SVD mode. The horizontal dashed line represents the 99% confidence limit in the spectrum. Dashed vertical lines represent the peak frequencies for BDO, QDO, ENSO, and QBD signals. Frequencies are given in cycles per year. (1 through 7). (bottom) Spatial evolution for SST variability in the BDO signal near 17-year period, the QDO signal near 11—year period, the dominant ENSO signal near 3.5-year period, and the QBO signal near 2.2-year period. Seven maps are chosen to represent 1/2 cycle of each signal extending over 180 degrees of phase. The SST weights are color contoured, with blue (yellow-to-red) indicating negative (positive) weights, with the contours of the relative weights given in the color bar at bottom.

Representitive PCP Indices, Compared with
Indices Reconstructed from Dominate Global Signals



Percentage of Precipitation Indices
Explained by Projection of Global Modes/Waves

	Index Location	5 signals summed	2.4-year signal	3.0-year signal	3.8-year signal	7.1-year signal	secular signal
1	Indonesia	81	37	24	42	15	34
2	N.E. Brazil	78	24	18	55	25	17
3	Eq. Africa	40	22	11	26	20	5
4	Peninsula India	38	36	6	17	3	4
5	S. China	61	21	11	20	15	47
6	S.W. US	59	14	10	28	25	39
7	S.E. US	77	10	26	44	22	42
8	S.E. Brazil	63	17	17	44	26	7
9	S.E. Australia	71	41	20	23	23	34
10	S.E. Africa	69	13	21	34	20	45

Figure WW2. (top) The location of 10 PCP indices located at representative locations over land around the globe. (1 through 10) These indices are located over (1) Indonesia, (2) northeast Brazil, (3) equatorial West Africa, (4) peninsula India, (5) southern China, (6) southwest United States, (7) southeast United States, (8) southeast Brazil, (9) southeast Australia, and (10) southeast Africa. (middle) Time sequence of low-pass filtered PCP indices (for periods > 2 years), computed over the land at the 10 indices around the globe (top), together with identical indices reconstructed from the 5 signals determined by the MTM-SVD analysis. The root-mean-square of the observed index and its cross-correlation with the reconstructed index are given at each location. (bottom). A table giving the percentage of the RMS of low-pass filtered anomalies (for period > 2 years) in the 10 regional PCP indices over land deriving from that associated with each of the QBO, ENSO, and secular signals and from their sum.

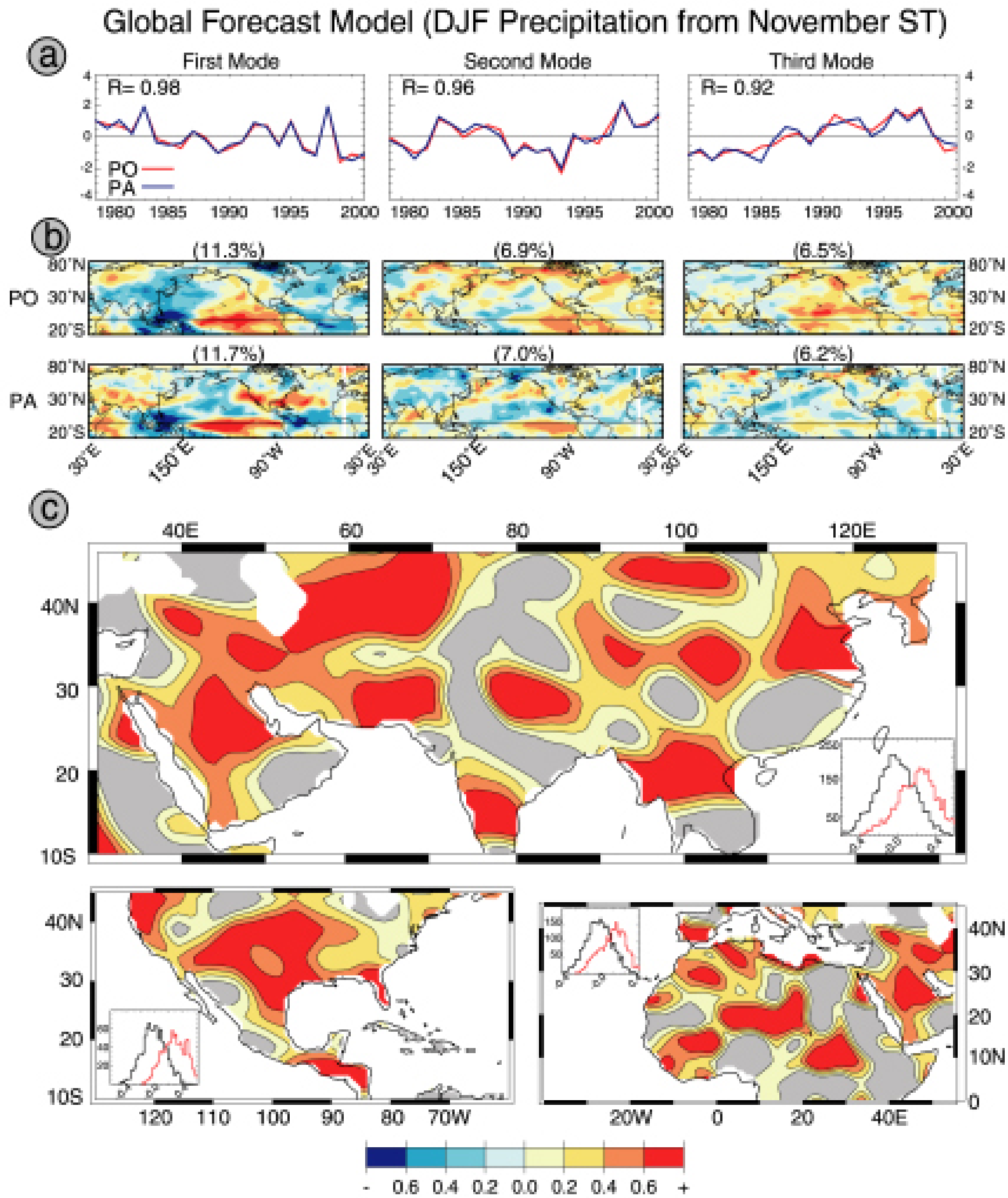


Figure WW3. The statistical forecast of anomalous DJF PCP patterns from anomalous September-October-November extended monthly ST patterns over the Northern Hemisphere from 20˚S to 80˚N. (a) Amplitude time sequence of the global patterns of the extended ST predictor and the DJF PCP predictand for the first three modes that explain most of the observed PCP variance. (b) The spatial pattern of cross-correlation between the amplitude time sequences of predictor and predictand in (a) and the November ST and DJF PCP anomalies over the globe, respectively. (c) The cross-validated forecast skill of Asia, North America, and Africa. The contour interval is 0.2, with gray color indicating forecast skill < 0.2.

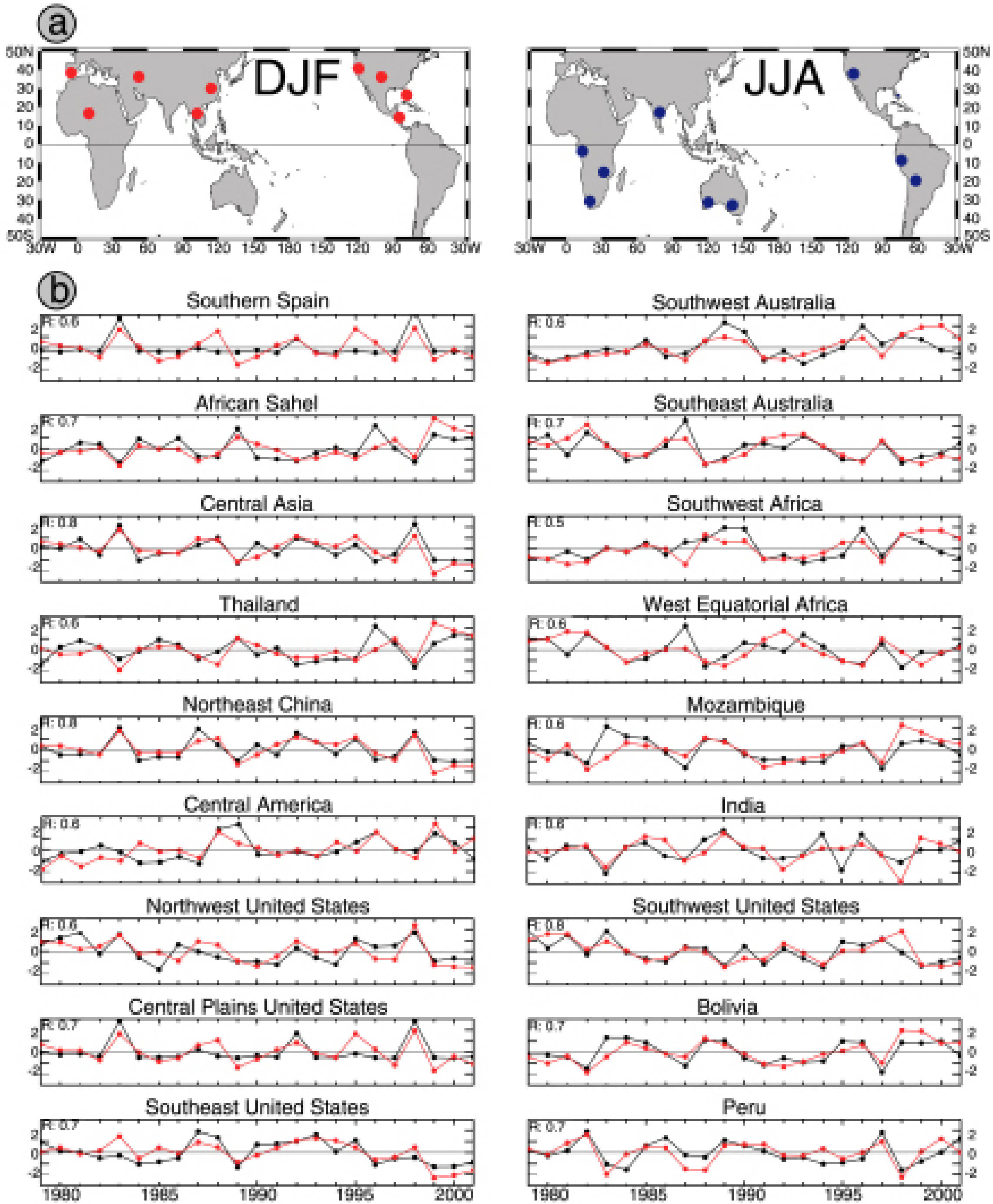


Figure WW4. (a) A map of the globe displaying the distribution of DJF and JJA PCP indices. (b)Time sequences for anomalous DJF PCP indices over land, together with forecasted estimates from 1979 to 2001 at 9 locations over the globe; southern Spain, African Sahel, central Asia, Thailand, eastern China, Central America, northwest United States, central plains of United States, southeast United States. Time sequences for anomalous JJA PCP indices over land, together with forecasted estimates from 1979 to 2001 at 9 locations over the globe; southwest Australia, southeast Australia, southwest Africa, west equatorial Africa, Mozambique, India, southwestern United States, Bolivia, and Peru.

REGIONAL APPLICATION CENTERS

USFS

The ECPC maintains several active collaborations with USFS researchers. We have been evaluating forecasts of firedanger indices that are now obtained only from observed data (Burgan et al., 2000a,b). These fire danger indices are more widely accepted by the fire community and are part of the standard US Fire Danger Rating System. The goal of this project has been to demonstrate the added utility of skillful long-range predictions of these standard indices. For Brazil we previously investigated experimental fireweather and agriculture forecasts for Brazil as part of an international USFS AID project. These experimental forecasts were also used to support field campaigns by the USFS in Brazil.

CEFA

ECPC maintains an active collaboration with CEFA to investigate experimental fireweather forecasts, as well as experimental fire climatology assessments. CEFA is also actively engaged in evaluating ECPC forecasts with remote automated weather station data (RAWS). Hall et al. (2000) describe such an evaluation and show a standard decrease in skill with increasing forecast lead-time. CEFA is also attempting to extract the maximum information possible from ECPC's experimental forecasts. In fact, CEFA is now providing partial funding to ECPC for this effort, as part of its work with the Bureau of Reclamation.

Asia

There are currently three efforts being investigated in collaboration with researchers in Asia. ECPC helped to set up the long-range regional forecasting effort for Taiwan at NTU, which is being examined by various university researchers as well as the Taiwan Weather service. Like the Hawaii regional modeling effort, the ECPC experimental long-range forecasts drive the regional model for Taiwan. A similar effort was begun this year in collaboration with the Hong Kong Observatory, which is responsible for high-resolution climate forecasts for the Hong Kong region. The Meteorological Bureau of Heilongjiang Province, Harbin, China, recently invited us to investigate the feasibility of developing long-range regional fire weather forecasts over Northeastern China. In addition, we are developing a collaboration with a Korean scientist (Dr. S. Hong), who was formerly working at NCEP on our experimental GSM/RSM prediction system.

Other Collaborations

There are a number of other global collaborations that the ECPC fosters. ECPC has worked with the Global Fire Monitoring Center in Freiburg, Germany, to provide and evaluate global forecasts of fireweather. We work with the California NASA RESAC to investigate regional climate forecasts for the US West. As part of this effort we have helped to convert the NCEP/DOE driving reanalysis to grid point space. Like many of our other regional collaborations, we also provide experimental global forecasts to drive experimental regional forecasts.

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MIXED LAYER HEAT TRANSPORT IN THE TROPICAL ATLANTIC

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TASK/THEME: 2A

SUMMARY

An array of 80 drifters was designed to contribute to the observations of the tropical Atlantic “dipole vascillation”, especially to the advection of thermal anomalies by ocean circulation. Additional research considerations were to obtain enhanced observations of wind and sea level pressure in the path of the North Atlantic hurricanes during the June-November period. The JIMO part of the project was to acquire drifters in the most cost effective manner that retains the integrity of the developing technology and send these for deployment by the Global Drifter Center at AOML. In 2003 and 2004 hurricane seasons, drifters will be deployed from C-130 aircraft, for which JIMO designed and tested a new deployment package (Figure 1).

APPROACH

This project is the observational component of research conducted in the Atlantic Ocean for the study of ocean and atmospheric climate change on annual and interannual time scales. The approach is to observe ocean currents and SST, to which data from satellites can be added. Observations from drifters are used to validate the accuracy of satellite retrievals that are plentiful and to use satellite observations to fill in gaps in space and time from drifters that are accurate but sparse.

RESEARCH ACCOMPLISHMENTS AND RESULTS

Drifter Acquisitions

In FY’2002 JIMO purchased 86 SVP drifters on an equal basis from Clearwater Instrumentation (Watertown, MA) and Technocean, Inc. (Clearwater, FL). This acquisition represents an increase of 10% over the number purchased in FY’2001 due to the changes in the design of the SVP drifter components and manufacturing techniques instituted by JIMO. These drifters have all been delivered to AOML for deployment. On April 14, 2003 the Global Drifter Data Center reported that 71 drifters were operational within 20 degrees of the Atlantic equator (16 appeared to be on the beach). Because the tropical Atlantic is divergent drifters leave this region and they populate the mid-latitude Atlantic as well. An additional 29 drifters were operational within the regions of 20-30N degrees. The desired tropical Atlantic array was fully implemented in FY’2000 and has been gathering observations with full-time on drifter broadcasts for the past two full years.

Data Files and Distribution

The data is placed on GTS by Service Argos under the careful eye of Etienne Charpentier, the Executive Secretary of the DBCP, for operational use. AOML quality controls and processes this data to regular time intervals and on six-month intervals sends it to MEDS/Canada for international distribution. JIMO produces gridded fields of velocity from this data that has been corrected for wind slip and also makes this product available to the scientific community. JIMO has been funded under a separate grant by OGP/NOAA for the analysis of this tropical data, as well as all of the other drifter data acquired from the Atlantic Ocean since 1991 under OGP sponsorship as well as other programs. Papers that have been published or submitted for publication from the global drifter data sets made available jointly from AOML, MEDS and JIMO can be viewed on: http://www.aoml.noaa.gov/phod/dac/drifter_bibliography.html.

Hurricane Drifters

In 2002-2003, JIMO acquired, jointly with ONR sponsorship, 16 Minimet drifters for deployment in front of Atlantic hurricanes. This 2003 hurricane season deployment target a specific hurricane with will be a significant departure from previous four years of hurricane drifter deployments. In the 1999-2002 seasons, drifters with wind sensors had been placed in the general area of the tropical Atlantic where hurricanes have been in the past by early June. Analyses of these data revealed that no hurricane had passed over drifters because winds in excess of 27m/sec had not been recorded by any of the 40 wind sensors deployed in this mode.

To target specific hurricanes required the training of “Air Force Reserve-53rd Hurricane Hunter Squadron” at Keesler AFB, MS to deploy drifter packages from C-130J aircraft. Eight simulated packages were built, shipped to Keesler and deployed successfully from air in the period July 16-19, 2003. Figure 1 displays one of these deployments on a land-based Drop Zone near Keesler. The 53rd crews are trained and ready to deploy the 16 Minimets, which have been shipped to Keesler AFB, in front of a targeted hurricane in 2003.

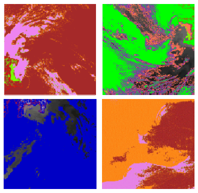
CONCLUSIONS AND RECOMMENDATIONS

Recommendations

1. The NOAA Climate Observations plan recommends that full implementation of the global drifter array of 1250 drifters, all equipped with barometers, be accomplished by 2005. Wind sensors would be added by 2007. This would require a significant increase of funding of this JIMO task. Some of this increase occurred in the 2003 funding cycle to JIMO and AOML that allowed the purchase of a total of 695 SVP drifters, 116 of which have barometers. The future NOAA requirements will depend upon international contributions that will be discussed at the October 2003 DBCP meeting in Brazil.

2. To return meaningful data with drifters from Atlantic hurricanes, targeted deployments should be implemented. JIMO research has shown that the AF Hurricane Hunter Squadron can be trained to safely deploy drifter containers on an operational basis. Research in 2003 and 2004 will demonstrate how well data can be recovered from drifters in hurricane strength winds under open ocean conditions.

Figure 1.



SEASONAL TO ANNUAL CLIMATE PREDICTION

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TASK/THEME: 3A

GLOBAL PREDICTABILITY

Reichler and Roads (2003a) examined the importance of initial state and boundary forcing for atmospheric predictability on global to regional spatial scales and on daily to seasonal time scales. A general circulation model was used to conduct predictability experiments with different combinations of initial and boundary conditions. The experiments were verified under perfect model assumptions as well as against observational data. From initial conditions alone, there was significant instantaneous forecast skill out to 2 months. Different initial conditions showed different predictability using the same kind of boundary forcing. Even on seasonal time scales, using observed atmospheric initial conditions led to a substantial increase in overall skill, especially during periods with weak tropical forcing. The impact of boundary forcing on predictability was detectable after 10 days and led to measurable instantaneous forecast skill at very long lead times. Over the Northern Hemisphere, it took roughly four weeks for boundary conditions to reach the same effect on predictability as initial conditions. During events with strong tropical forcing, these time scales were somewhat shorter. Over the Southern Hemisphere, there was a strongly enhanced influence of initial conditions during summer. We concluded that the long-term memory of initial conditions was important for seasonal forecasting.

Reichler and Roads (2003b) examined the sensitivity of monthly mean tropical atmospheric forecasts to initial and boundary conditions during boreal winter. Five ensemble experiments were performed with an atmospheric general circulation model, forced with different combinations of initial and boundary conditions. The experiments were verified under the perfect model assumption. Boundary forcing was the main contributor to tropical predictability. Using persisted instead of observed boundary conditions led to loss in skill after 3 weeks. At lead times out to one season, the model appeared to perform considerably better when good initial conditions were provided. Regions of largest predictability were Indonesia and the central Pacific Ocean. The good predictability over the Pacific was related to ENSO, whereas that over Indonesia was strongly related to the large persistence of tropical divergent flow. It is suggested that the long persistence time scale could be related to a positive feedback of large-scale convective anomalies. The results show that good observations in the tropics are needed, and that good initial conditions should be used for numerical predictions.

Reichler and Roads (2003c) investigated the predictability of the tropical Madden-Julian oscillation (MJO) during 22 northern winter seasons (1979-2000) with six different ensemble experiments using the NCEP seasonal forecasting model. Each experiment was forced with a certain combination of initial and boundary conditions to examine the sensitivity of the simulated MJO to uncertainties in those conditions. The model simulated magnitude and spatial distribution of the intraseasonal variability quite well. About 10% of the model's intraseasonal variability was caused by forcing with observed weekly sea surface temperatures (SSTs). When the model was forced with observed SSTs, it simulated a very reasonable MJO. The only shortcoming was that the spectral peak of the MJO was too broad. When climatological SSTs were used, the model produced an MJO at too high frequencies, indicating that the simulated MJO was sensitive to boundary forcing. When model, initial and boundary conditions were all perfect, the useful range of MJO predictability was about four weeks. This suggested that the MJO has the potential to improve long-range predictability. When using persisted instead of observed SSTs, the useful range reduced to about three weeks, and with climatological SSTs it was less than two weeks. The predictability of the MJO was insensitive to ENSO, but MJO predictability was higher when the MJO was more active. By decomposing the MJO into magnitude and phase of its wavenumber-one component, it was shown that the propagation of the MJO could be better predicted than its strength, but that imperfect boundary conditions affected mostly the propagation of the MJO, indicating that air-sea interaction was important for good simulation of the MJO propagation. Initial conditions affected the MJO out to 40 days. After this time, forcing with observed boundary conditions produced some small non-zero forecast skill. This boundary forced skill was particularly high during years with large intraseasonal SST energy. In a case study, the synchronizing effect of SST forcing on the phase of the MJO was demonstrated. By analyzing many MJO events it was shown that MJO and SST in nature were about 60° or 6-7 days out of phase, whereas in the model they were in phase. The consequences from this high sensitivity to boundary conditions are discussed.

Reichler and Roads (2003d) investigated the global 3-dimensional structure of long-range (2 weeks to 1 season) atmospheric predictability with a general circulation model. Main focus was to find out the role of initial conditions for such predictability as a function of lead-time and space. Four types of predictability experiments with different types of initial and boundary conditions were conducted to this end. The experiments were verified against model data and reanalysis to determine perfect as well as real world forecast skill. Spatial maps and vertical cross sections of predictability at different lead times and for the two contrasting seasons were analyzed to document the varying influence of initial and boundary conditions on predictability. It was found that the atmosphere was remarkably sensitive to initial conditions on the week 3-6 forecast range. Particularly, the troposphere over Antarctica, the region over the tropical Indian Ocean, and the lower stratosphere were affected. It was shown that most of the initial condition memory was related to the persistent nature of the atmosphere in these regions, which in turn was linked to the major modes of atmospheric variability. Possible influences from stratosphere-troposphere coupling were also discussed.

THE IRI/ARCS REGIONAL MODEL COMPARISON PROJECT

Roads et al. (2002) described a regional modeling intercomparison project for Brazil among the: (1) Scripps Experimental Climate Prediction Center regional spectral model (RSM), (2) Florida State Univ. nested regional spectral model (FSUNRSM), (3) Goddard Institute for Space Studies regional climate model (RCM), and (4) IRI regional climate model (RegCM2) is described herein. All regional models were driven by the NCEP/NCAR I global reanalysis over a S. America domain focused on Brazil. In comparison to new Xie and Arkin .5° land observations, the regional models had a seasonal systematic precipitation error that was somewhat similar to the driving NCEP/NCAR reanalysis systematic error, although the regional model ensemble mean was somewhat smaller, indicating a potential value for using multiple model ensembles. However, correlations, threat scores and biases were not noticeably improved over individual models. In short, regional models do not appear capable of overly improving upon large-scale analyses, which already have considerable skill.

Chen and Roads (2003) further examined the regional model dynamical downscaling methodology using the regional spectral model (RSM) with 50-km grid space increment over South America has been developed. The RSM was originally developed at NCEP (the National Centers for Environmental Prediction). NCEP 28 vertical levels T62 spectral resolution (~200 km grid space at the center of the simulation domain) reanalysis are used to initialize and force the regional model for the periods covering March 1, 1997 through May 31, 1999. It was found that there is a drying trend in the model soil moisture and hence the precipitation after the initial 3 months of continuous integration. The drying trend is a response to the positive feedback between the imperfect cumulus parameterization scheme and the soil moisture module in the model. The drying trend can be prevented by tempering the soil moisture in the model during the integration. Two experiments were designed. The first experiment is to prescribe the reanalysis daily soil moisture at second layer; the second experiment is to utilize the available observed precipitation to interactively correct the second layer soil moisture during the integration. By comparing the simulation results of these two runs against the available observed half-degree grid precipitation, it is shown that both runs hardly outperform the forcing reanalysis in terms of correlation, covariance, and threat scores and biases. However, a proposed anomaly threat scores and biases show an added skill (better than reanalysis) at extreme precipitation threats. The interactive soil moisture corrected run also outperformed the specified run at all threats indicating the value of the more correct soil moisture in simulating regional climate over this region.

GLOBAL FORECASTS

The latest version of the NCEP operational Seasonal Forecast Model (Kanamitsu et al. 2002) has been transferred to Scripps Institution of Oceanography Linux PC and Linux clusters. The performance of the model was carefully monitored and tuned. **Table MK1** shows how efficiently the model runs on those computers. The performance on Linux PC is quite reasonable, and is applicable for performing a number of long integration experiments. Considering the Linux PC's relatively low cost, this will definitely save our limited resources and increase our capability. More importantly, the performance of the model on Linux cluster is excellent. The T62L28 model using 64 processors takes roughly 20 seconds wall clock time to complete 1-day integration. This efficiency is nearly equivalent to that on the NCEP IBM-SP2. The SIO Linux cluster is made of 384-processor IBM PC running Linux operating system and is becoming available to the Scripps researchers without cost. We are planning to use this facility for production of operational real time ensemble forecast as a part of the joint IRI/CPC consortium effort, being developed as a continuation of this global modeling effort started on this grant.

Table MK1. **Computer performance of T62 L28 seasonal forecast model on various computers.**
(Note that the single processor performance of the Scripps Linux Cluster is much worse than Intel Xeon processor, but the 60 processor performance is nearly equivalent to that of the IBM-SP2.)

Computer and Number of Processors	Wall clock time in second to run 1 day of forecast
Linux Intel Xeon Dual processor	380 secs
Scripps Linux Cluster 2 processors	1500 secs
Scripps Linux Cluster 4 processors	840 secs
Scripps Linux Cluster 8 processors	240 secs
Scripps Linux Cluster 16 processors	140 secs
Scripps Linux Cluster 32 processors	56 secs
Scripps Linux Cluster 60 processors	22 secs
DEC Alpha Dual processor	~ 300 secs
NCEP IBM-SP2 60 processors	~ 20 secs

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MEASUREMENTS OF VARIATIONS IN ATMOSPHERIC OXYGEN/NITROGEN AND ARGON/NITROGEN RATIOS, AND CARBON DIOXIDE CONCENTRATION IN RELATION TO THE CARBON CYCLE AND CLIMATE

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TASK/THEME: 3A

SUMMARY

Since 1989, the principal investigator has maintained a program measuring changes in atmospheric O_2/N_2 ratios and CO_2 concentrations from flasks collected from a global network of stations. This program has been supported by the present NOAA grant, as well as prior awards from NSF and EPA. The principle scientific goals of this program are the following: (1) to place constraints on the land and oceans sinks of CO_2, both globally and on smaller spatial scales; (2) to improve estimates of the rates and dynamics of the ocean biological carbon pump; (3) and to provide insights into the sensitivity of land and ocean biogeochemistry to climate changes on interannual time scales. The program has recently included measurements of changes in Ar/N_2 ratios for the purpose of placing constraints on air-sea heat exchanges. The program has the goal of advancing the technology for measuring O_2/N_2 ratios while at the same time ensuring, to the extent possible, the maintenance of homogenous time series to provide the greatest sensitivity in the detection of global change. A final goal is the training of students and postdocs in areas of carbon cycle and climate research.

APPROACH/EVALUTATION/METHODOLOGY

Flasks are routinely collected in triplicate from nine stations worldwide at roughly two-week intervals and returned to La Jolla, where they are analyzed using an interferometric oxygen analyzer and a nondispersive infrared (NDIR) carbon dioxide analyzer. The flask collections are made in collaboration with numerous agencies, as summarized in the Project Data Sheet.

Times series for O_2/N_2 ratio from our program are shown in Figure 1. The data resolve seasonal cycles, long-term trends, gradients in O_2/N_2 and CO_2 concentrations, as well as interannual variability associated with El Niño events and possibly also North Pacific decadal variability. A database of O_2/N_2 variations has been made available to users on request. Our CO_2 results have been incorporated into the GlobalView data product (Globalview_CO2, 2002).

In August 2001 we brought into service a mass spectrometer system for flask analyses, which allows Ar/N_2 ratios to be measured, as well as providing a redundant measurement of O_2/N_2 ratios. While the internal precision on the mass spectrometer rivals that of the interferometer, the replicates have more large outliers. When the interferometric and mass spectrometric data from each station are merged, the resulting time series is probably at least as precise as our earlier series using interferometeric data alone. Nevertheless, we are continuing to work to improve the mass spectrometer measurement precision.

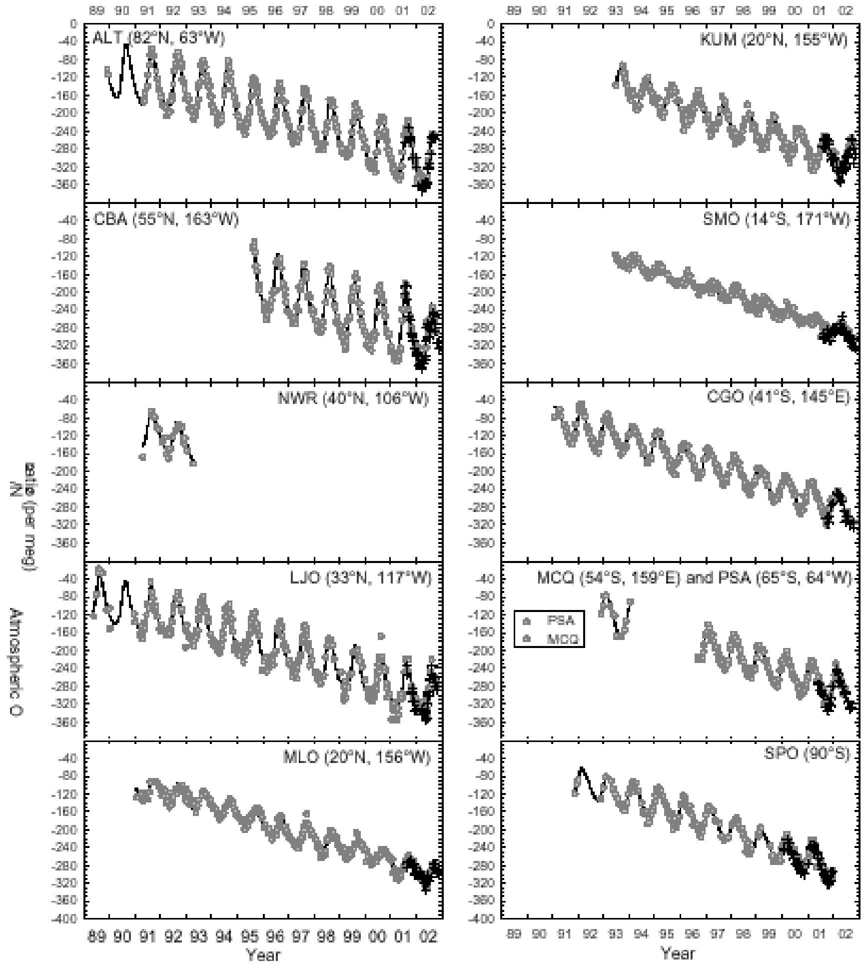

Figure 1. Trends in atmospheric O_2/N_2 ratio from the Scripps program. Each point represents the mean of flask replicates collected on a given day. Circles: interferometer results. Plus signs: mass spectrometer results. Curves: least-squares fit (stiff spline plus four harmonics).

RESEARCH ACCOMPLISHMENTS AND RESULTS

Our data continue to support the existence of a substantial land sink for carbon dioxide, in addition to an oceanic sink. The results from our program (Manning, 2001) formed the basis for estimates of global land and carbon sinks through the 1990s in the IPCC Third Assessment Report (IPCC, 2001). Subsequent to this report, we revised our estimates of the mean value of these sinks (Keeling and Garcia, 2002), to more fully allow for oceanic O_2 outgassing due to increasing greenhouse gases and associated ocean stratification. The revisions are small, reducing the land sink and increase the ocean sink by ~0.2 Pg yr, relative to Manning (2001). After revision, the decadal average annual sinks are 1.26 ± 0.8 Pg C /yr (land) and 1.86 ± 0.7 Pg C/yr. The revised estimates have been used in support of a model/data comparison by Le Quéré et al., (2003), which summarizes our current understanding of the variability in land and global ocean CO_2 sinks. Our data provide evidence that the land carbon sink is highly variable from year to year, and dominates the interannual variability of the atmospheric CO_2 growth rate (see Figure 2). Our data also provide clear evidence of interannual variations in the biogeochemical cycling of carbon and oxygen in the ocean, although the data alone is not sufficient enough to resolve separately the carbon and oxygen components of this variability.

Our Ar/N_2 data are marginally able to resolve seasonal cycles in this ratio related to air-sea heat exchange (Keeling et al., 2003). With continued measurements, and the ability to average over more years, the precision in these cycles

will be improved. These cycles place constraints on air-sea heat exchange and atmospheric transport, as described by Battle et al. (2003).

We have initiated a modeling study as part of the TRANSCOM collaboration, to investigate the controls on the seasonal cycles in atmospheric O_2/N_2 ratio. This project is aimed at exploring the usage of atmospheric O_2/N_2 ratio as a constraint on atmospheric transport, particularly between continents and oceans within the Northern Hemisphere, which is of relevance for inversion studies to derive land carbon sinks.

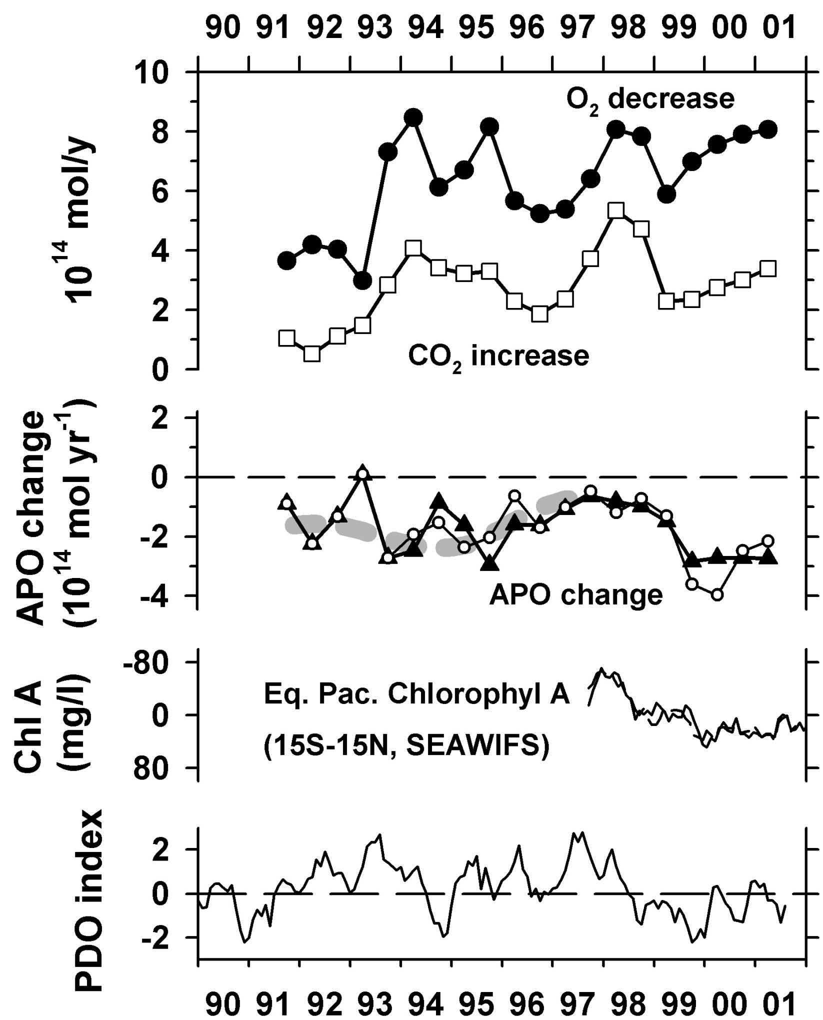

Figure 2. Time derivatives of the total burden of atmospheric CO_2, O_2, and APO = O_2 + 1.1CO_2. Chlorophyll A from the SeaWIFS data, integrated from 15°S to 15° N (C. LeQuere, personal communication). That the interannual variability in CO2 is dominated by exchanges with land biota is implicated by the strong correlation with O_2. APO variations are insensitive to land exchanges which produce compensating influences on O_2 and CO_2. The interannual variability in APO thus results from interannual oceanic exchanges of O2 and CO2. PDO Index from Mantua et al. (1997). For APO the triangles are computed from 3-station composite global record, while the circles employ a variable number of stations, according to data availability. Thick dash line is from Battle et al. (2000). Derivatives are computed assuming N_2 burden is constant.

CONCLUSIONS AND RECOMMENDATIONS

The tightest constraints on land and ocean uptake of CO_2 on decadal time scales arguably are those provided by combined measurements of atmospheric O_2 and CO_2 concentrations. These data thus provide crucial insight into changing carbon stocks, and are thus likely to grow in importance in the future in the context of strategies to curtail CO_2 emissions.

While the interpretation of global trends in O_2 and CO_2 in terms of global O_2 and CO_2 sinks is relatively straightforward, the interpretation of spatially-resolved O_2 and CO_2 data for resolving sinks on smaller scales, requires inverse modeling approaches. This is an area that would benefit from further developments. There is also the need for developing inverse approaches involving coupled ocean/atmosphere models, in order to deal with the complexities in the interactions of CO_2 and O_2 in air-sea exchange.

In order to achieve the goals of resolving air-sea heat exchanges using Ar/N_2 data, particularly on time scales other than seasonal, it may be necessary to implement more stringent protocols for air sampling and laboratory gas handling. Such efforts are underway in our laboratory. These steps will likely also lead to improvements in the O_2/N_2 data that allow for more sensitive tests of ocean models.

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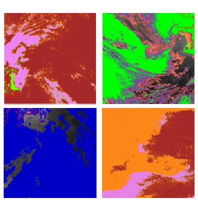
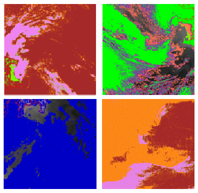


EVOLUTION OF ENSO AND TROPICAL PACIFIC CLIMATE OVER THE LAST MILLENNIUM: A CONTINUOUS CROSS DATED RECORD FROM FOSSIL CORALS

Christopher Charles
Scripps Institution of Oceanography

TASK/THEME: 3A

This project involves using fossil coral specimens to extend the record of tropical Pacific climate change, building from a successful case study at Palmyra Island in the central Pacific. In this initial 3 month period, we have made tentative plans for the first field campaign (Christmas Island in early 2004) that will provide the bulk of the raw material for this project. In the meantime, we have made steady progress in analyzing the remainder of the Palmyra Island coral samples, focussing initially on extending the record from the 12th century. We will continue this work with the existing collection of Palmyra corals throughout the first year of the project, until the new samples are collected.



DYNAMICAL FORECASTING OF ENSO: A CONTRIBUTION TO THE IRI NETWORK

Mark A. Cane, Dake Chen and Alexey Kaplan
Lamont-Doherty Earth Observatory of Columbia University

TASK/THEME: 2A

ACCOMPLISHMENTS

During the first year of this three-year project, considerable progress has been made in the following four research areas.

Operational ENSO Forecasting

We have been producing seasonal forecasts of ENSO on a monthly basis. Our forecast webpage

(http://rainbow.ldeo.columbia.edu/~dchen/forecast.html)

is updated in the first week of each month and is used by the IRI in several different ways. In particular, our predictions have recently been incorporated into the ensemble forecasting procedures of the IRI, thus becoming an integral part of the official IRI forecasts. Our predictions are also published in the monthly Climate Diagnostic Bulletin, and in the quarterly Experimental Long-Lead Forecast Bulletin. The maintenance of this forecast system requires retuning of the system every time when the nature of our input data streams change. A suite of forecast experiments have been run to ensure a smooth transition. In the last year we had to accommodate two of such transitions: the FSU group switched from their subjective analysis procedure to the objective ones; the altimetry-based sea level height products by CNES changed when the Jason data became available.

Initialization of a Coupled Model via Data Assimilation

Alicia Karspeck (a Ph.D. student) worked on a low-dimensional “adjoint” technique for initializing an ENSO forecasting model and estimating model error covariance. The method developed in her work is a pragmatic alternative to the computationally costly use of a full dimensional adjoint to the ENSO forecasting model. Low-dimensional Markov model approximations to the full non-linear model were used in an “inverse” fashion to arrive at initial states that start a model trajectory best fitting the observed data. These inverse solutions can then be refined through the iterative application of low-order, empirically derived tangent-linear models. The method presented here is generally applicable to forecasting models that can be adequately represented as low-order systems, such as many general circulation models. The new initialization procedure leads to improved forecast skill in general, and improves the timing and rapidity of the 1997/1998 El Nino forecast in specific. Estimates of model error covariances are also presented as a by-product of our low-dimensional “adjoint” method.

Evaluation of Wind Products in ENSO Forecasting

Four different wind products, including the NCEP reanalysis, a blended scatterometer product and two FSU analyses, were evaluated in terms of their application to ENSO prediction. These wind products were used to initialize the LDEO model for monthly retrospective forecasts from 1980 to 2002. The wind product that includes satellite scatterometer data has the highest scores, with the NCEP reanalysis and the new FSU objective analysis closely behind. The latter is a major improvement over the old FSU subjective analysis which has some serious problems in recent years. It seems that the wind products from remote sensing, in-situ observation and model reanalysis are all useful for ENSO prediction. At present, an ensemble of forecasts initialized with various wind data sets is probably our best bet.

ODASI Consortium: Variability Bias in Ocean Models

Our group was actively involved in the ODASI consortium work. Among other activities, we finished a large study comparing monthly interannual anomalies of tropical Pacific sea level height from Topex/Poseidon with simulation and assimilation products from a variety of models, ranging from our own assimilations into a simple linear long wave approximation model to various OGCMs, including those involved into ODASI studies. Surprisingly, the spatial structure (albeit not magnitude) of error variance are very similar for all models. This pattern is traced to the pattern of small-scale variability in sea level height ("noise"). We investigated the nature of this variability. Monte Carlo experiments identified the areas where high small-scale sea level height variability is wind-driven, caused by a similar pattern of variability in the wind stress. Model products systematically underestimate signal variance in such areas. Variability in other areas is due to the instability of ocean currents, require non-linear high resolution models and have their own host of simulation problems. These error properties have to be taken into account by data assimilation schemes, and we work on some possible ways to do it.

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NORTH PACIFIC CLIMATE VARIABILITY AND STELLER SEA LION ECOLOGY: A RETROSPECTIVE AND MODELING ANALYSIS

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NOAA/NMFS, Pacific Fisheries Environmental Laboratory

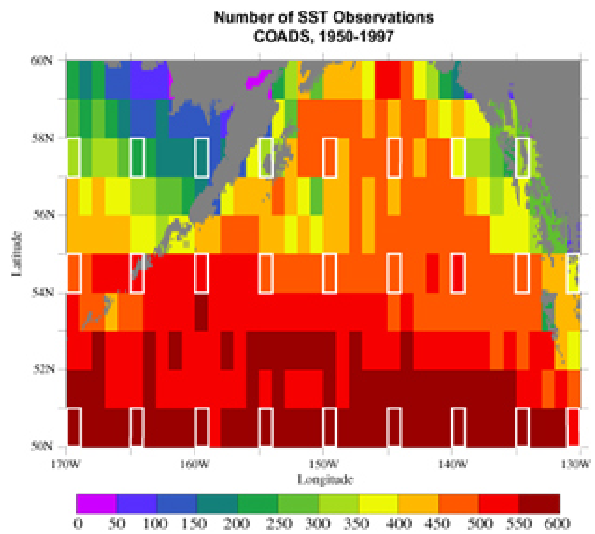
Michael J. Alexander and Antonietta Capotondi
NOAA-CIRES, Climate Diagnostics Center

TASK/THEME: 2A

OBJECTIVES AND METHODS

Our effort towards understanding Steller Sea Lion (SSL) declines involved three separate groups working towards an understanding of how climate changes may have contributed. Underlying our approaches is the assumption that large-scale changes in the physical environment of the North Pacific Ocean, such as the basin-wide interdecadal change in both the physical state and ecology of the North Pacific, which occurred near the end of 1976 (e.g. Mantua et al. 1997), could influence SSLs through several processes, including altering the food web. We are examining this assumption through both a retrospective study of observations and through modeling efforts using both a large, course resolution model of the North Pacific, as well as a relatively high-resolution model of the Gulf of Alaska (GOA)

The Group at the Pacific Fisheries Environmental Laboratory (PFEL) is performing a retrospective study using *in situ* oceanic and atmospheric observations (COADS) from 1950-97. Historical oceanic data from the northern Gulf of Alaska and Bering Sea are rather sparse. Their initial focus is therefore on the more commonly observed surface properties using COADS sea surface temperature (SST) and surface winds fro the period 1950-1997. Their study domain covers the region 50°-60°N and 130°-170°W. Figure 1 shows the number of monthly COADS SST observations in 1° boxes for this period from which they focused their analysis on a subset of spatially representative boxes. State-space models were used to separate non-linear trends from seasonal trends in the monthly mean time series. Subspace identification techniques were used to estimate common climate trends of all series. Finally cluster analysis was used to interpret the spatial patterns of observed climate variability.



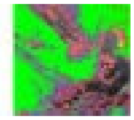
PFEL's principal objectives are to: (a) identify long-term trends in surface oceanic and atmospheric variables; (b) identify periods of abrupt climate change; (c) describe the spatial patterns and forcing mechanisms of the observed variability; and (d) speculate on the impact of this variability on local ecosystem structure, particularly the impact on SSLs through bottom-up forcing.

Using a physical-ecosystem ocean model, the group at NOAA-CIRES is examining whether changes in the physical environment, particularly those associated with the 1976-1977 North Pacific climate regime shift, influenced the lower trophic levels of the food web. This effort uses the National Center for Atmospheric Research (NCAR) Ocean General Circulation Model (NCOM, Gent et al. 1998; Li et al. 2001) coupled with a 10 compartment biological model. The biological model contains 2 phytoplankton, 2 zooplankton, 3 forms of nitrogen, 2 forms of silicate and CO_2 (Chai et al. 2002). The model domain extends from 45°S to 65°N in the Pacific, with a horizontal resolution of 2° longitude by 2° latitude (north of 20°N) and 40 vertical levels. The model is forced with observed atmospheric winds over the period 1960-1999.

The group at the Scripps Institution of Oceanography (SIO), are also using a biological/physical coupled model to examine the effects of the 1976-1977 climate shift on circulation in the Gulf of Alaska and the effect of that on biological production. SIO is using the Regional Ocean Modeling System (ROMS) from Rutgers on a domain extending from 50°N to 60°N and 170°W to 128°W with 20 vertical levels. The overall resolution of the model is approximately 10km in both longitude and latitude. The size of the domain allows SIO to consider the relative changes of both the east side (Alaska Current) and west side (Alaska Stream) of the GOA. So far SIO has considered only the effects of changes in the strength and pattern of the monthly-mean wind stress forcing, taken from the NCEP reanalysis fields

SIO explored changes in circulation for two scenarios: (1) a 49-yr hindcast from 1951-1999 forced by the total NCEP wind stress; (2) a pair of statistical equilibrium runs forced by only the seasonal cycle of wind stress defined for the 6 years before and the 6 years after the climate shift (1976/1977). Case 1 includes the effects of changes in mean winds, fluctuating winds and mesoscale eddy variance, while Case 2 includes only changes in mean winds and mesoscale eddy variance.





RESULTS

PFEL's analysis of SST and winds in the GOA and eastern Bering Sea reveal prominent climate trends and events that have well-defined characteristic spatial patterns. The SST variability clusters into five distinct geographical regions, with the western and eastern GOA experiencing different climate dynamics over the past 50 years. A clear warming trend began in the early 1970s in most areas, followed by an acceleration after 1976. This suggests that regime "shifts" may have different regional impacts and responses, and that the transition from one regime to the next may be a longer process than has been recognized. The impact of the 1957-1958 El Nino was strongest in the eastern GOA, while other El Nino events had their largest impacts in coastal British Columbia and the West Wind Drift. A similar analysis of the surface wind field suggests that changes in SST correspond to shifts in large-scale atmospheric forcing. An important result from this analysis is the identification of strong regional differences in climate variability, which may result in different climate-induced changes in the eastern and western SSL populations.

NOAA-CIRES also documented the potential for climate change impacting the physical and biological state of the Pacific Ocean. While not distinguishing differences between the eastern and western GOA, they did find that the model produced an approximate 20 percent reduction in the spring plankton bloom in the GOA in 1977-1998 relative to 1960-1976. They determined that reduced Ekman pumping in the later period caused the halocline to deepen, leading to deeper mixed layers along the south coast of Alaska. This, coupled with less light (more clouds), could lead to a decrease in plankton during the spring eventually leading to negative impacts on the higher trophic levels including SSL's. These model results have to be reconciled, however with some observational studies that have suggested an increase in plankton and fish populations in the northeast Pacific after 1976. Additionally, the model inadequately treats iron as a limiting nutrient which likely results in an overestimate of the mean phytoplankton concentration as well as possibly affecting long-term plankton variability.

Examining a 49-year hindcast from 1951-1999 (Case 1, above) and comparing the results to that of separate runs based on forcings from the six years before and after the 1976/1977 regime shift (Case 2), SIO found that in both the mean circulation intensified after the climate shift in the northwestern GOA, north of Kodiak. The stream weakened southwestward of Kodiak. Accompanying this, the mesoscale eddy variance (kinetic energy) also increased in the boundary current region north of Kodiak Island and somewhat reduced southwestward of Kodiak. These results concur with the PFEL results that climate changes can lead to different changes in the eastern and western SSL populations. If mesoscale eddies are indeed important in fluxing nutrients from the upwelling interior ocean of the GOA into the downwelling shelf-slope regions, then these results also suggest, as found by NOAA-CIRES, that there would be a reduction in the phytoplankton biomass. However, the reduction would be based on lowered nutrient fluxes into the surface waters as opposed to light level attenuation, which may also be present. We are running an NPZD-type ecosystem model currently and will soon examine the relative contributions of light and nutrient limitations to phytoplankton growth. In any case, the SIO models, based on nutrient reduction, recorded larger decreases in the region southwestward of Kodiak Island where large populations of SSL reside.

Interestingly, the Alaska Current in the eastern GOA did not noticeably change after the shift in the model Case 1. Additionally, the Alaska Current only appears in Case 1 in which fluctuating winds are included in the experiment. We are exploring whether the driving mechanism for the Alaskan Stream can be attributed to the rectification of topographic Rossby waves along the shelf-slope system.

FUTURE WORK

In addition to the ongoing work mentioned above, SIO is continuing to the effects of changes in surface heat fluxes, fresh-water fluxes (including streamflow), and southern boundary condition, as well as the inclusion of tides and synoptic-scale atmospheric forcing. NOAA-CIRES continues to analyze the long-term model runs relative to observed trends (as mentioned in the results section). Since many trophic interactions within marine ecosystems are closely tied to the seasonal cycle so variations in seasonality could have important consequences even at higher trophic levels. With this in mind, PFEL will also continue its analysis of SST and winds and will be examining temporal changes in the seasonal components of these environmental variables. Where available they will also examine temporal changes in subsurface oceanic data. PFEL will also use the observed climate trends to force regional coupled physical-biological models and explore bottom-up forcing of fish stocks and marine mammals in Alaskan waters.

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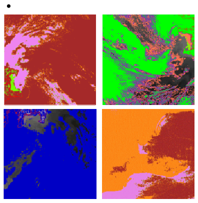

PROJECT ASIAN BROWN CLOUD-AIR POLLUTION IN THE ASIA PACIFIC REGION: IMPACT ON CLIMATE AND THE ENVIRONMENT-INTEGRATION OF SCIENCE, IMPACT ASSESSMENT, POLICYMAKING AND REGIONAL CAPACITY BUILDING

V. V. Ramanathan

Scripps Institution of Oceanography

TASK/THEME: 2A

For the Project Atmospheric Brown Cloud (ABC) – Asia, the first priority is to establish the first two climate observatories, in the Maldives and Nepal, as reflected by preliminary work carried out during the six-month report period.

NEPAL CLIMATE OBSERVATIONS FOR PROJECT ABC (V. RAMANATHAN & M.V. RAMANA)

The first direct observations of aerosol radiative forcing have been carried out in winter 2003 in Nepal, as a part of ABC. Aerosol and radiometric data have been collected at Kathmandu (27.67° N 85.31° E, elevation – 1347m), the capital of Nepal, and Nagarkot (27.71° N 85.52° E, elevation -1950m), a remote hilly site above the Kathmandu valley 32 km east of Kathmandu. The directly measured aerosol and radiometric quantities included aerosol optical depth (AOD), aerosol single scattering albedo (SSA), aerosol vertical profile and global broadband short-wave fluxes at the surface.

Microtops sunphotometers have been used at both locations to measure AOD at 340, 440, 500, 675, 870 and 1020 nm, total column water and ozone. The Radiance Research portable M903 Nephelometer and Particle Soot Absorption Photometer (PSAP) have been used at the Kathmandu site to measure the near-real-time aerosol scattering and absorption coefficients at 550 nm, respectively. The measurements have been made at Godavari, a remote place about 10 km south of Kathmandu in the Kathmandu valley. SSA (the ratio of the aerosol scattering coefficient to the total aerosol extinction coefficient) has been computed from the simultaneous measurements of aerosol scattering and absorption coefficients.

For the first time, Lidar observations of tropospheric aerosols have been carried out in the Himalayan region using a high-resolution (0.030 km) Micro-Pulse Lidar (MPL) system. MPL has been installed inside a climate-controlled housing at Kathmandu site and operated continuously during February 9-17, 2003 at 523nm. The MPL signals have been averaged and stored at 1-min time intervals up to the altitude of 30 km and have been processed. The Microtops AODs at 523 nm have been used to calibrate the MPL. The aerosol extinction profile has been determined.

CM21 Kipp and Zonen ventilated pyranometers have been used at both sites to obtain broadband (280-2800 nm) global radiative fluxes at the surface. The pyranometer absolute accuracy is ±9Wm^{-2} and the error due to directional response is about ±10Wm^{-2}. Pyranometers and Microtops have been purchased just before the start of this study and calibrated at Kipp & Zonen and Solar Light Co respectively.

Direct aerosol radiative forcing at the surface has been derived for the first time from aerosol and radiometric observations in the Himalayan region. In winter 2003, monthly mean aerosol optical depth (AOD) at 500 nm was 0.34 at Kathmandu and 0.19 at Nagarkot. Aerosol single scattering albedo (SSA) at Kathmandu was in the range from 0.7 to 0.9 indicates the presence of highly absorbing aerosols. Elevated aerosol layers were observed in the Lidar profiles at 1.5 km above the ground level over Kathmandu.

The radiative forcing estimates have been obtained by integrating AOD and SSA measurements with lidar observations and a Monte Carlo radiative transfer model. The diurnal mean aerosol radiative forcing has been estimated following *Satheesh and Ramanathan* [2000]. The presence of strongly absorbing aerosols resulted in a relatively large diurnal mean aerosol surface radiative forcing efficiency –73 Wm^{-2} at Kathmandu and –44 Wm^{-2} at Nagarkot.

Results are being summarized in the paper entitled: The Direct Observations of Large Aerosol Radiative Forcing in the Himalayan Region by M.V. Ramana, V. Ramanathan, Bidya Banmali Pradhan and I.A. Podgorny. Submitted to the Geophysical Research Letters. Another paper is being under preparation for Nature in collaboration with NASA colleagues.

NEGOTIATION ON THE MALDIVES CLIMATE OBSERVATORY (MCO) (H.V. NGUYEN & V. RAMANATHAN)

During January-June 2003, negotiation was carried out between SIO Center for Clouds, Chemistry and Climate (C4) and the Maldives' Ministry of Home Affairs, Housing and Environment, and the United Nations Environment Programme (UNEP) Asia-Pacific, with the aim toward a Memorandum of Understanding to construct the observatory on the Hanimaadhoo Island in northern Maldives.

PUBLICATIONS

M.V. Ramana, V. Ramanathan, Bidya Banmali Pradhan and I.A. Podgorny. The Direct Observations of Large Aerosol Radiative Forcing in the Himalayan Region. Submitted to Geophysical Research Letters, 2003.

THE SUMMERTIME ATMOSPHERIC HYDROLOGIC CYCLE OVER THE SOUTHWESTERN US AND NORTHWESTERN MEXICO

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Bruce T. Anderson
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TASK/THEME: 2A

SUMMARY

We proposed an investigation of the large-scale summertime hydrologic cycle associated with the southwestern branch of the North American monsoon. Preliminary findings indicate that over most of the southwestern United States and northwestern Mexico there is positive vertically-integrated columnar moisture divergence above approximately 700 mbar, implying that local convective activity provides much of the moisture for the monsoon precipitation. In addition, these findings suggest that the desert southwest is one of the largest upper-air (<700 mbar) sources of moisture for the continental US. We will use a suite of surface and satellite-based observations, reanalysis products, and regional model simulations to evaluate the findings presented here. Further, we will investigate the variability of this hydrologic balance on synoptic to inter-annual time-scales.

METHODOLOGY

We are using a global to regional modeling system developed at the National Centers for Environmental Prediction (NCEP) to produce regional simulations of the summertime atmospheric hydrologic cycle in this region. At present, continuous simulations of seasonal (July, August, September) hindcasts for the U.S. Southwest have been performed. The modeling system nests the 25km resolution RSM within daily forecasts from NCEP's global spectral model (GSM); these GSM forecasts are initialized using NCEP's operational analysis data. Importantly, the regional model produces explicitly calculated sigma-level time-integrated diagnostic budget terms for the water vapor tendency equation. These budget terms will be used to analyze the important hydrodynamics of the system. To help with this analysis, we have also archived diagnostic terms related to the atmospheric hydrologic cycle derived from both reanalysis and observational data products. From the reanalysis, monthly values of the large-scale horizontal and vertical moisture flux divergence have been calculated from 1958-2002. In addition, we are presently obtaining sigma-layer moisture flux divergence estimates related to convective processes, including evaporative and precipitation values. Observationally, we have archived both the 1x1-degree monthly precipitation dataset available through GPCC and the 0.25x0.25 degree daily Unified precipitation dataset available through CPC. In addition we have estimates for large-scale 4xdaily moisture flux divergence values, calculated from radiosonde profiles throughout the domain. Finally, we will be archiving the LDAS evaporation estimates to compare with the vertically integrated convective terms taken from the Reanalysis and the RSM.

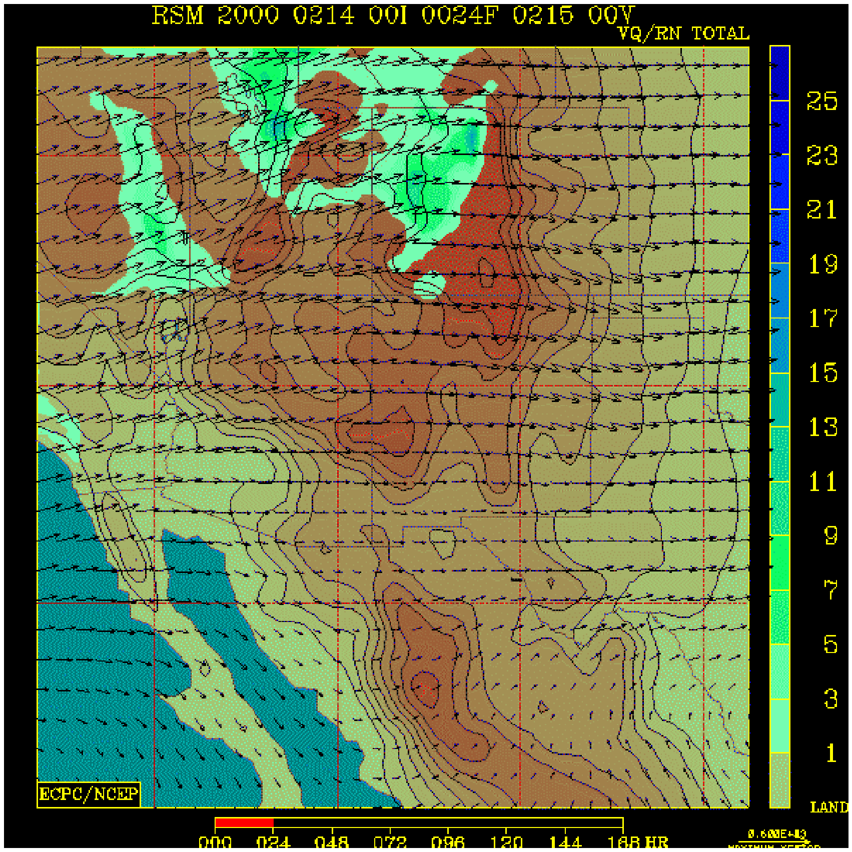

Figure 1. SW model domain for experimental predictions. A 24-hour precipitation forecast valid 0215 00UTC

RESULTS AND ACCOMPLISHMENTS

Regional Simulation of Summertime Precipitation

Using results taken from the fine-scale (25km), regional modeling simulation for the summer of 1999, along with contemporaneous daily surface observations, synoptic variations in climatological summertime precipitation over the southwestern United States have been described and analyzed by Anderson and Roads (2002). Two separate techniques for characterizing and evaluating large-scale summertime precipitation patterns within the observed and simulated systems are presented; in addition, these evaluation/characterization techniques are used to analyze the hydrologic forcings associated with observed and simulated modes of rainfall variability. Overall, two robust spatio-temporal precipitation patterns are identified (**Figures 2, 3**), involving: 1) precipitation over the western portion of the Rocky Mountain plateau centered on eastern Arizona and southern Utah and; 2) precipitation located over the eastern portion of the plateau and the elevated orography of eastern New Mexico and southern Colorado. Time-series associated with these two precipitation regimes are correlated with low-level and mid-level circulation patterns in order to investigate the related large-scale environmental conditions. It is found that for both regimes intraseasonal precipitation is related to the intrusion of mid-troposphere, mid-latitude low-pressure anomalies over the southwestern US, resulting in synoptic-scale shifts in the position of the climatological mid-troposphere monsoon ridge. The interaction between the resultant mid-troposphere pressure fields and the quasi-stationary monsoon surface pressures found over the Rocky Mountain plateau during the summertime produce large-scale vertical velocities consistent with the observed and simulated rainfall patterns associated with each regime.

Regional Simulation of Intraseasonal Variations

In addition, using results taken from these simulations, the summertime hydrologic cycle over the southwestern United States is characterized by Anderson (2002). Climatologically, the precipitation fields are balanced principally by the vertical diffusion of moisture into the column via evaporation, with only small contributions from large-scale moisture convergence via dynamic transport (**Figure 4**). However, intraseasonal variations in the hydrologic cycle associated with the two spatio-temporal precipitation patterns points to a more complicated set of hydrodynamic balances. Over the western portion of the Rocky Mountain plateau, columnar moisture divergence associated with precipitation is balanced by a combination of seasonal-mean convective moisture convergence and anomalous upper-air (> 4km) large-scale moisture convergence. The actual precipitating events themselves are predicated upon the anomalous upper-level advection of water vapor into the precipitating region; absent this large-scale advection at upper levels, vertical diffusion of moisture into the atmosphere balances large-scale divergence at midlevels with little precipitation occurring. The anomalous large-scale advection during precipitating events is due primarily to anomalous large-scale vertical fluxes of moisture, with only a slight contribution from large-scale horizontal moisture fluxes. For precipitation located over the eastern portion of the plateau and the elevated orography of eastern New Mexico and southern Colorado, correlated moisture budget terms indicate that precipitation is again related to mean convective moisture convergence and anomalous mid-troposphere large-scale moisture convergence. As with the western-plateau precipitation regime, this anomalous convergence is strongly correlated with an anomalous vertical advection of moisture; however for the eastern plateau regime, this vertical term is the sole source of large-scale moisture convergence contributing to rainfall in the region. In both cases, the vertical moisture convergence appears to be associated with the previously mentioned intraseasonal modifications of the upper-level monsoon ridge centered over the Sierra Madres, which results in significant large-scale vertical velocities over the precipitating regions.

RSM Simulations

1-day forecast simulations of the Southwest climatology are being developed with full budget implementation, for the period Sept. 27, 1997-present. In addition, continuous simulations are being developed to contrast how the regional model may improve certain aspects of the various simulations. Corresponding GSM 1-day and continuous simulations are being developed. Finally, we are developing continuous simulations with an upgraded version of the NCEP RSM that will be used for participation in the NAME Intercomparison project.

The Summertime Climatological Atmospheric Hydrologic Cycle

In order to fully analyze the hydrologic cycle in this region, we have also collected appropriate observational datasets to compare with the large-scale reanalysis product (as well as fine-scale regional model output). At present, we have archived and analyzed the monthly and daily precipitation data taken from the Climate Prediction Center's (CPC) unified data archive, which is a daily, 0.25-degree resolution precipitation dataset spanning 55 years (1948-2002) for the continental United States. We have also archived and analyzed the 1x1 degree monthly GPCC dataset, which spans from 1996-2002. To help evaluate the atmospheric hydrologic cycle estimates from the two simulation products, we have produced estimates of the large-scale moisture flux divergence from the region using 4xdaily radiosonde profiles. In addition, we will acquire the LDAS evaporation estimates.

We have begun evaluating the climatological characteristics of the analyzed and simulated precipitation fields. In addition, we have also begun evaluating large-scale diagnostic budget terms from the Re-analysis and observational products, using those calculated explicitly from the coarse-scale RSM modeling system. A manuscript describing the large-scale climatological hydrologic cycle for the southwestern US is in preparation (Anderson et al. 2003).

PUBLICATIONS

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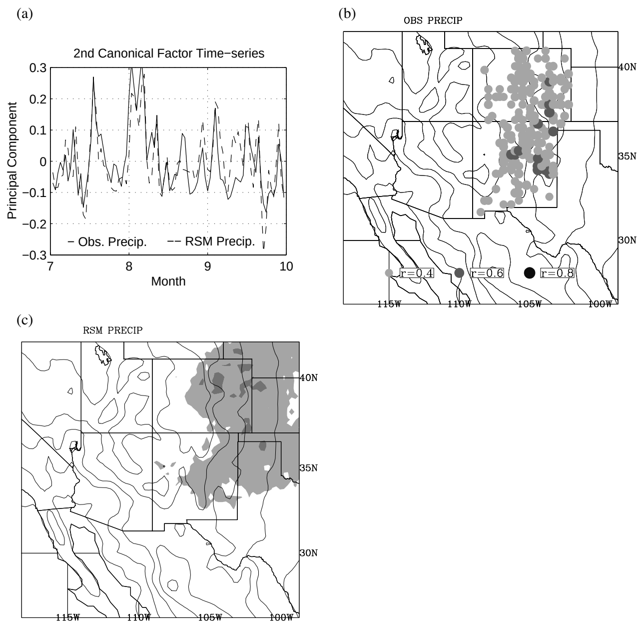


Figure. 2 a) normalized time-series of the first canonical factor of observed (solid line) and simulated (dashed line) precipitation. b) Grid-point correlations for the first canonical factor of observed precipitation. Shading interval is 0.2; minimum shading is 0.4. Positive values are shaded; negative values are black. c) Grid-point correlations for the first canonical factor of RSM precipitation. Shading interval is 0.2; minimum shading is 0.4. Negative values are not shown.

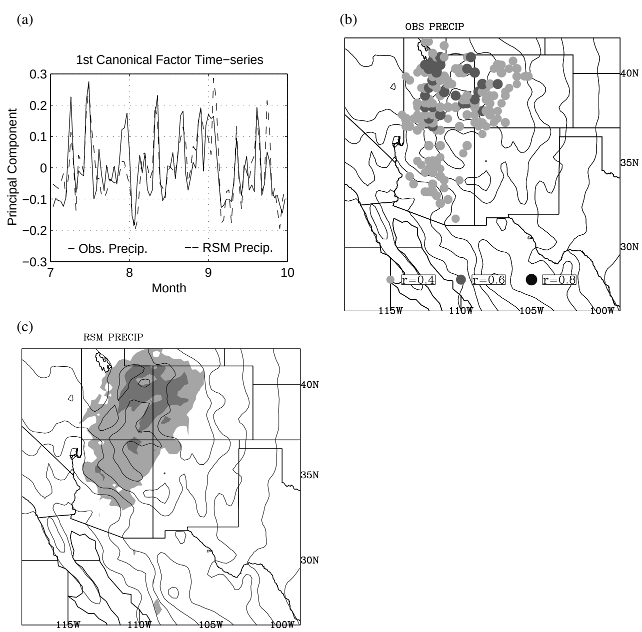


Figure. 3 Same as **Figure 2** except for second canonical factor of observed and simulated precipitation

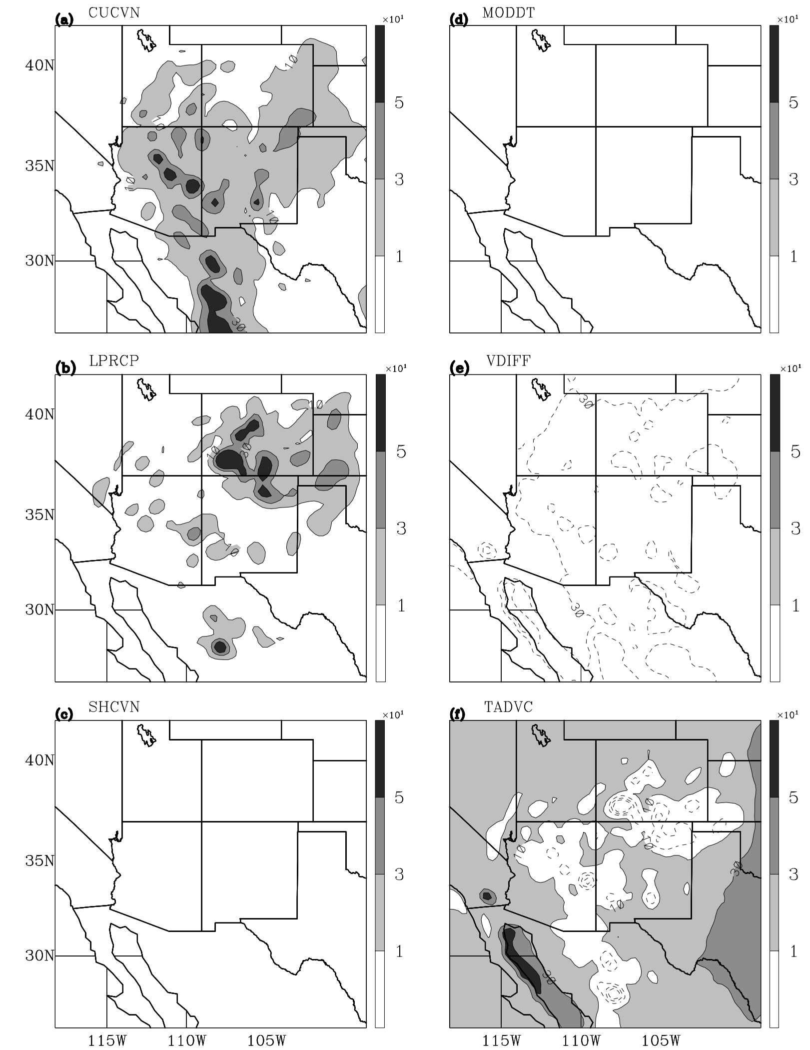
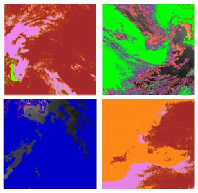


Figure. 4. Mean daily summertime (JAS) vertically-integrated RSM diagnostic moisture tendency terms. Shading interval is 20x10^{-6} kg m^{-2} s^{-1}; minimum shading is 10x10^{-6} kg m^{-2} s^{-1}. (a) convective precipitation; (b) large-scale precipitation; (c) shallow convective precipitation; (d) moisture tendency; (e) vertical diffusion moisture divergence; (f) large-scale total moisture divergence.



NCEP ENSEMBLE SEASONAL FORECAST VERIFICATION AND APPLICATION PROJECT: A CONTRIBUTION TO THE ARCS/IRI NETWORK

J. Roads and M. Kanamitsu
Scripps Institution of Oceanography

TASK/THEME: 2A

BACKGROUND

The original goal of the project was to diagnose the skill of the current operational NCEP seasonal forecast model (SFM). However, we soon discovered at the outset that it was prohibitive to implement the massive transfer of needed diagnostic data to Scripps and that it would be better to simply run the seasonal forecasts in-house. This turned out to be even better since a number of improvements have since been made to the ECPC version of the NCEP SFM. These improvements may eventually lead to a better seasonal forecast model at NCEP. We were also asked to contribute these seasonal forecasts to the Seasonal Climate Diagnostics Consortium at CPC, as well as to the IRI multi-model ensemble, and we have now started to do so on a routine basis.

ECPC/NCEP SFM

The ECPC/NCEP seasonal forecast model (SFM) is the global spectral model with a resolution of T62L28 (about 200km) used operationally at NCEP for routine seasonal prediction and as the basis for the NCEP/DOE reanalysis II (Kanamitsu et al. 2002a). This resolution is good enough for representation of transient disturbances in extra-tropics and is also capable of simulating strong tropical cyclones. The model uses a reduced grid strategy to save running time by 20-30 %. The model physics includes long and short wave radiation, cloud interaction, convection, large-scale heating, shallow convection, boundary layer physics, gravity wave drag and hydrology. The model has been extensively tested for seasonal prediction (Kanamitsu et al., 2002b), and is now running operationally at NCEP. Due to the lack of personnel, the model has been frozen since 2001. At ECPC, the model has been further updated to improve predictions over semi-arid regions. This was done by using better land surface characteristics and different formulation of evaporation from soil. The model's hydrology has recently been examined intensively for budget studies, and was revised to strictly conserve water (and snow) in the model integration. This will have a significant impact on soil moisture simulation in the long integrations. The model also has the capability to test various new physical packages (already coded), and we plan to examine them systematically from the seasonal forecast output. A number of small improvements were made to the original global SFM based on the work by Kanamitsu and Mo (2003). These improvements include change to the basic land surface data sets (vegetation type, vegetation cover, soil type) from USGS, and associated change in surface roughness parameter and albedo, and formulation of the direct evaporation from soil. One 20-year AMIP run was ran with these improvements and compared with the original SFM. The improvements in the simulation were found to be small compared to shorter RSM simulations, probably due to the non-linear effect of the land surface on general circulation.

ECPC/NCEP Ensemble Seasonal Forecasts

10-member AMIP runs for the period 1979-2000 were made by Thomas Reichler for his dissertation work (Reichler and Roads, 2003a,b,c,d). We used these AMIP runs as a basis for participating in the NCEP/IRI consortium activity.

The completed forecast system is made of the two components: 1) a system to perform 1-month continuation of the 10-member ensemble AMIP runs at the beginning of each month using observed SST of the previous month; near real time SST is obtained from NCEP, courtesy of Dr. Wesley Ebisuzaki; 2) 10-member seven-month integrations are then made using predicted SST provided by IRI. The forecast results are sent to IRI and CPC on time for their official issuing of the seasonal outlook forecasts. We occasionally attend a monthly seasonal forecast teleconference sponsored by CPC to get feed back of our model forecast. In addition, in order to satisfy the requirement of the consortium protocol, work is in progress to extend 20-year AMIP runs to 50 years (currently 6 members have been completed).

Examination of a limited number of forecasts and hindcasts indicate that the quality of our prediction is equivalent to that of the current operational NCEP seasonal forecast. Since the model used in the prediction is a slightly upgraded version of the NCEP SFM, the prediction provides important additional information on the NCEP SFM predictions. The major difference between the two predictions are 1) the use of AMIP simulation as initial conditions in ECPC forecast while operational analysis is used at NCEP; 2) the hindcast of 50 years for ECPC forecast but only 20+ years for NCEP forecast. The impact of initial conditions and sample size are being examined. Depending upon available resources, we will continue to provide the seasonal forecast to IRI and CPC routinely on a monthly basis.

WORK PLAN

During the coming year, we intend to:

1. Produce routinely (monthly) 7-month ensemble seasonal forecasts.
2. Provide the forecasts to IRI/CPC.
3. Develop a large ensemble of 50+ year simulations, which will be used as initial conditions for the routine 7-month ensemble seasonal forecasts.
4. Assess systematic error of the forecast for different seasons as well as for different lead times.
5. Assess seasonal forecast skill using CPC's standard verification scores to the near surface temperature and precipitation.
6. Compare these forecasts to the official CPC forecasts.
7. Make an automatic system of verification.
8. Calculate forecast skill score of other variables by comparing against CDAS and Reanalysis-2 extension.
9. Examine the forecast skill of the temporal variance prediction.

FUTURE WORK

A natural extension of this work would be to couple the atmospheric model with ocean model to perform more physically consistent predictions and this is being actively pursued within the ECPC. This coupling will initially make use of these seasonal forecasts to drive the ocean model off-line. Our eventual goal is to develop coupled seasonal forecasts analogously to the way we are currently making and analyzing the current uncoupled seasonal forecasts. However, before we can do this we need to first assess the impact that erroneous atmospheric forecasts will have on ocean forecasts.

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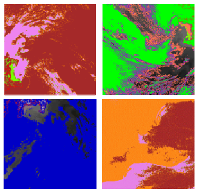
Reichler, T. and J. O. Roads (2003c): Long-range predictability in the tropics. Part II: 30-60 days variability, J. Climate, (submitted).

Reichler, T. and J. O. Roads (2003d): Time-space distribution of long-range atmospheric predictability, J. Atmos. Sci., (submitted).



OFF-CAMPUS SATELLITE DATA PROCESSING

Brian Gregory Mitchell
Scripps Institution of Oceanography

TASK/THEME: 2A

SUMMARY

Our research objectives were to manage and operate an off-campus satellite data processing unit at the NOAA Southwest Fisheries Science Center (SWFSC) including to enhance scientific applications at Scripps Institution of Oceanography, University of California San Diego (SIO/UCSD). Detailed objectives include:

- Accomplish collaborative scientific research between SIO/UCSD and NOAA/SWFSC using time-series of satellite ocean color and sea surface temperature data.
- Collect, analyze and evaluate real-time NOAA/AVHRR satellite data of radiometric Sea-Surface Temperature (SST).
- Conduct satellite imagery research in close cooperation with scientists conducting marine optical observation studies.
- Work cooperatively with NOAA researchers in their plans for the expansion of satellite processing needs to include additional remote-sensing platforms (color, SAR, scatterometer) for the advancement of research applications.
- Maintain records on the uses of the satellite data radiometric SST and provide a written annual report.
- Oversee the transmission of satellite image files to research vessels conducting field observations as required.
- Collaborate with CoastWatch Central Operations to evaluate and maintain the most current technical systems
- Collaborate with CoastWatch Central Operations to refine the programming algorithms of the satellite data.

RESEARCH ACCOMPLISHMENTS

Research objectives were fully met. This period saw the application of SST and color imagery in an analysis of small coastal eddies in the Southern California Bight (SCB), as well as two applications to the analysis of the 1997-99 El Niño-La Niña cycle. Small eddies in the SCB, most less than 10 km, are predominantly cyclonic and are more abundant than previously reported. Time series of phytoplankton net primary production (NPP) in the California Current were derived using satellite data and the VGPM primary productivity model for a 5-year period (1997-2001) including the 1997-98 El Niño. NPP showed a strong annual periodicity that was modulated by the El Niño-La Niña cycle. In the other application of satellite data to the EN-LN cycle record setting changes in the strength of the California Countercurrent / Undercurrent were reported. The collaboration between UCSD/SIO and NOAA SWFSC benefited the scientific pursuits of both institutions, through shared technical expertise on satellite data processing and analysis, and through the availability of processed data products.

Two new projects were initiated; in one programming and scripts have been created to download satellite altimeter files from a Navy source to produce sea height maps in the same configuration as the SST imagery. The results are being evaluated against a second data source. The primary objective is to confirm apparent mesoscale eddies in the SST with sea height measurements. The second is to produce a consensus of mesoscale eddies and the

seasonality of large offshore jets in the California Current, based upon the 10 years of CoastWatch SST imagery (Figure 1). The methodology to attempt this project is being developed.

SST May 2001

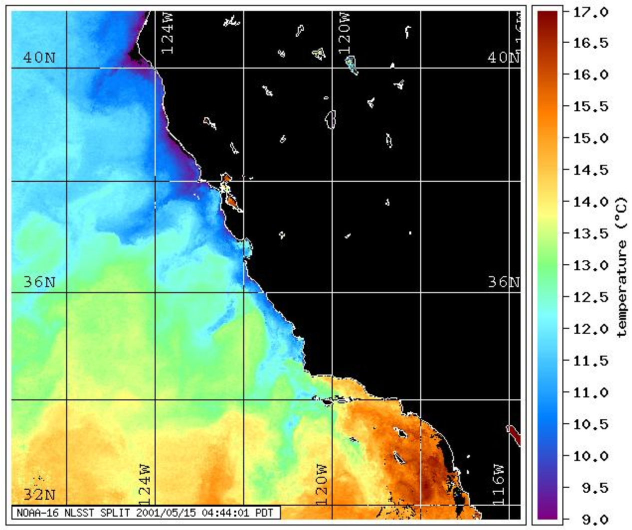


Figure 1.

There was a continuation and enhancement of the West Coast CoastWatch Node activities centered about the processing of AVHRR satellite data and creation of SST imagery for application to research projects. SST images derived from NOAA/AVHRR data are processed, archived, and made available to the research community on the CoastWatch website. This node supplies imagery for coastal waters from Vancouver Island to southern Baja California at various resolutions in user-friendly formats. The data is ready for downloading and utilities are provided for conversion to common formats and to produce composites.

Presently, data streams from two polar orbiting satellites, NOAA 15 and NOAA 16, are being downloaded and processed on a daily basis. Security remains an issue, but a new firewall continues to be successful in preventing attacks. The improved interface of the reconstructed monthly and mid-monthly composite page proves to be highly useful to many users. In excess of 900 satellite passes were received and processed into 16 images twice each day and made available to researchers, educators, and other end users in near-real-time.

CoastWatch to supports research vessels that operate for the Southwest Fisheries Science Center, by supplying real-time SST imagery to research vessels. The survey tracks of SWFSC fish egg and larval surveys are modified in response to real-time updates in satellite imagery. While the number of users signed on as receiving real-time CoastWatch data products has increased to over 3900, it is the support of the west coast marine research community that is the focus of this program.

The El Niño Watch Advisory continued to be issued on a monthly basis and posted on the web page. This Advisory is capturing increased interest due to the development of El Niño conditions in the tropics. A graphical time series of U. S. west coast regional SST anomalies provides an index to monitor the local development of potential effects.

A report of CoastWatch activities was presented at the annual CoastWatch Node Managers Meeting in Turtle Bay, HI. This meeting also serves as an opportunity to exchange information on the rapidly developing changes in satellite technology and science.

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FORECASTING CLIMATE CHANGES OVER NORTH AMERICA FROM PREDICTIONS OF OCEAN MIXED LAYER ANOMALIES IN THE TROPICAL AND MID-LATITUDE PACIFIC

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TASK/THEME: 3A

SUMMARY

North American climate undergoes fluctuations on interannual-to-decadal time scales, with significant changes in precipitation, surface temperature and geopotential height changes, as well as in river run-off, agricultural output and Pacific fishery. Predictions of climate over North America are therefore desirable and potentially beneficial for society. In this project we explore the skill and physics of a forecast system that predicts anomalies of heat flux convergence in the tropical and North Pacific surface mixed layer and converts these to northern hemisphere climate anomalies using a coupled ocean mixed layer - atmosphere general circulation model.

The hypothesis to be explored states that North American climate anomalies on time scales of years to decades result from anomalous conditions in the Pacific equatorial upwelling regions, and the North Pacific Kuroshio-Oyashio extension (KOE), where anomalies in the ocean's thermocline are efficiently coupled to the surface (Xie et al. 2000). In these areas, changes of upwelling, thermocline depth, water mass properties, stratification, and advection impart a heat flux convergence at the ocean's surface mixed layer. In response to this forcing, the coupled atmosphere - ocean mixed layer system adjusts, and generates anomalies of sea surface temperature (SST) over the entire Pacific, including the central and eastern North Pacific where the ocean's mixed layer is effectively insulated from the thermocline, and anomalies of North America climate.

This philosophy, put forward recently for the Atlantic (Sutton et al. 2002) and Pacific (Yulaeva et al. 2001), is in contrast to the use of SST anomalies as a boundary condition of the atmosphere. The latter approach suffers from an inconsistency by prescribing SST anomalies where the atmosphere determines the SSTs. In fact, prescribing SST decouples them from air-sea heat fluxes, represents an infinite and unrealistic heat sink for the atmosphere, and artificially selects those atmospheric circulation patterns that are least affected by this damping (Barsugli and Battisti 1998).

Using the new method, forecast of North American climate require predictions of heat flux convergences over the tropics and the KOE region. In the tropical Pacific, interannual SST anomalies associated with ENSO are routinely and skillfully predicted with a lead-time of a few seasons. In the KOE, low-frequency anomalies of SST can be predicted from Rossby wave dynamics and observations of the surface wind stress during the preceding years (Schneider and Miller 2001). The forecast system to be investigated here formulates these predictions in terms of the forecasting of the ocean heat flux convergences and applying them (as anomalous boundary forcing) to the atmospheric coupled to an ocean-mixed layer (slab-ocean) model (coupled AGCM/SOM). The anomalies over North America simulated by this model represent the climate forecast.

While the role of the tropical forcing for climate anomalies over the North Pacific and North America is well established, the effect of anomalies in the KOE have only recently received attention, with encouraging results. Yulaeva et al. (2001) forced an AGCM/SOM with idealized anomalies of the ocean mixed-layer heat budget in the tropics and in the KOE region and found statistically significant changes over the winter-time northern hemisphere to both forcings. The response to heat budget perturbations in the tropics consisted of a PNA pattern and associated SST anomalies in the mid latitudes. Forcing over the KOE region caused significant changes over the North Pacific and North America in sea level pressure (SLP), precipitation, SST and 500 mb heights (Z500). The major goal of this project is to establish if these results remain with realistic forcing, and to determine if the combined forcing in the tropics and KOE yield additional climate forecast skill.

The approach pursued here relies on the coupled adjustment of the ocean mixed layer and atmosphere. This raises the question of the sensitivity of this adjustment to processes in the ocean mixed layer. The ocean mixed layer can

consists of a bucket of constant or seasonally prescribed depth, or employ a sophisticated 1-dimensional mixed layer dynamics (Alexander and Deser, 1995). For low frequency climate variations over the North Pacific, of interest here, temperature advection by anomalous Ekman currents in the mixed layer are important (Miller et al. 1994, Seager et al., 2001, Schneider et al,. 2002). Thus a second goal of this work is the determination of the sensitivity of the internal, low frequency variability of the coupled mixed-layer atmosphere system to the inclusion of Ekman advection.

PROJECT GOALS

1. Is the prescription of surface heat budget anomalies as successful as a prescription of tropical SST anomalies in reproducing teleconnected climate anomalies over the northern hemisphere?
2. How sensitive is the atmosphere to additional processes affecting the surface heat budget? In particular, does the consideration of Ekman advection in an AGCM/SOM affect the intrinsic and forced atmospheric variability?
3. Do realistic heat flux convergences in the KOE region significantly affect the climate over the Northern Hemisphere? If so, does the inclusion of KOE surface heat budget anomalies increase the skill of an AGCM/SOM hindcast of northern hemisphere climate anomalies?
4. Can the hindcast and forecast skill of predicting surface anomalies in the KOE region be improved over the simple equivalent barotropic Rossby wave model by using a full ocean general circulation model (OGCM) driven by observed winds?
5. Can climate anomalies over North America be predicted from a forecast of tropical and of KOE heat budget anomalies?

METHODOLOGY

The above questions are addressed using hindcasts of climate for the last 40 years, and extended integrations of unforced climate models. Ocean heat flux convergences in the tropics and KOE were diagnosed from ocean models, forced by the history of observed wind stress, while surface temperature and salinity are relaxed to their seasonal cycles. In this way, any perturbation of the ocean surface heat budget is dominated by the influence of anomalies in the thermocline. For multi-year to decadal time scales, the air-sea heat flux balances and will be used to determine the ocean heat flux convergences. The time series of the ocean heat flux convergences in the KOE and tropics is applied to the ocean mixed-layer in an AGCM/SOM, and any significant atmospheric and mixed-layer responses will be determined by ensemble integrations.

The importance of Ekman advection for internal variability of the atmosphere was determined by inclusion of temperature advection by anomalous Ekman transports in the mixed-layer of an AGCM/SOM. Long control runs with this forcing was contrasted with similar runs that lack this process to determine the effect of changes of the mixed layer heat budget on the atmosphere. The forecast procedure based on the prediction of the oceanic mixed layer heat flux convergence anomalies will be developed and tested by first evaluating the forecast skill of ocean heat-budget convergences in the tropics and KOE. In the tropics, an El Nino forecast model will be used, while for the KOE ocean GCM spin-down experiments will be used and contrasted with simple Rossby wave dynamics models (Schneider and Miller 2001). Skillful forecasts will then be used to force SOM/AGMC to determine what, if any, additional forecast skill can be garnered from this procedure.

The simulations will be conducted with the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM3) coupled with the Slab Ocean Model (SOM). CCM3 is a global model with T42 spectral resolution (approximately 2.8x2.8) and with 18 vertical levels in a generalized terrain-following hybrid vertical coordinate. A detailed description of physical parameterization can be found in Kiehl et al. (1998). The ocean models include MIT and POP models, and for ENSO prediction the Scripps hybrid coupled model will be employed.

RESULTS AND ACCOMPLISHMENTS

Evaluation of the Role of Anomalous Ekman Advection

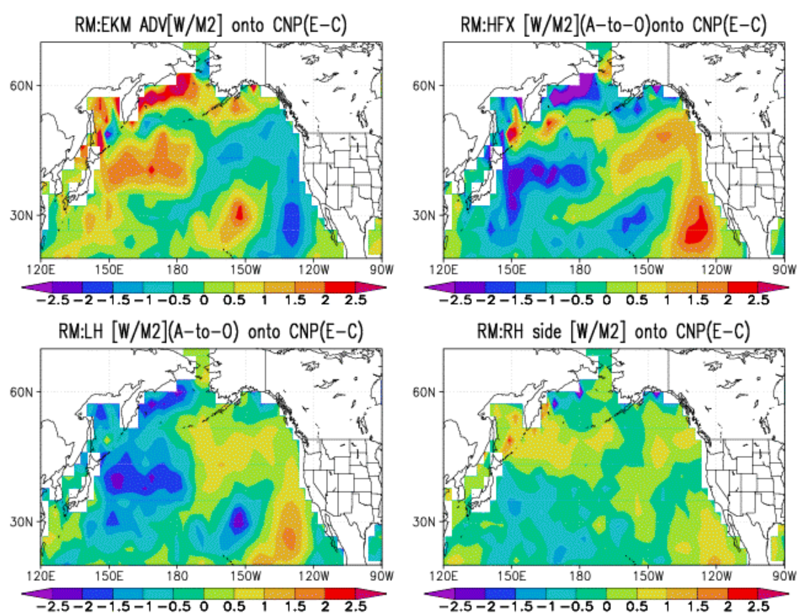
The effect of Ekman advection was determined as follows.

The mixed layer temperature equation was augmented by adding the advection of the climatological monthly mean temperature by the horizontal Ekman current due to wind stress anomalies. The term describing Ekman advection of the anomalous temperature by the climatological Ekman currents was omitted, since on the decadal time-scale, this term is much smaller. In order to isolate the effect of the North Pacific, the Ekman advection was included only in the

Pacific Ocean north of 20 degrees latitude. After initial spin-up, the model with Ekman Advection in the North Pacific was integrated for 60 years.

The model output was then compared to the control run. The analysis of the SST variability revealed that in the control run the SST variance was the largest over the Central North Pacific. Over the KOE region the variance in the control run was somewhat smaller, but the difference between the control and Ekman advection runs was the largest. In order to identify the spatial structure of the atmospheric response corresponding to the those features of the SST variability, we regressed all the variables onto the low-pass filtered (longer than 2 years period) time-series of the SST anomalies over (1) Central North Pacific (CNP) region (35°N-45°N, 160°E-150°W) and (2) the KOE region (35°N-45°N, 120°E-160°E).

The regression pattern of the Ekman advection onto the timeseries of the SST anomalies in the CNP region is shown in Figure 1a. The Ekman advection heats the ocean in the central and western North Pacific with a maximum amplitude of 2.5 W/M2 at around 160°E and 45°N. The sign of the Ekman advection is determined by the easterlies over the region that are associated with the SST anomalies in the central North Pacific. These easterlies transport warmer temperature.

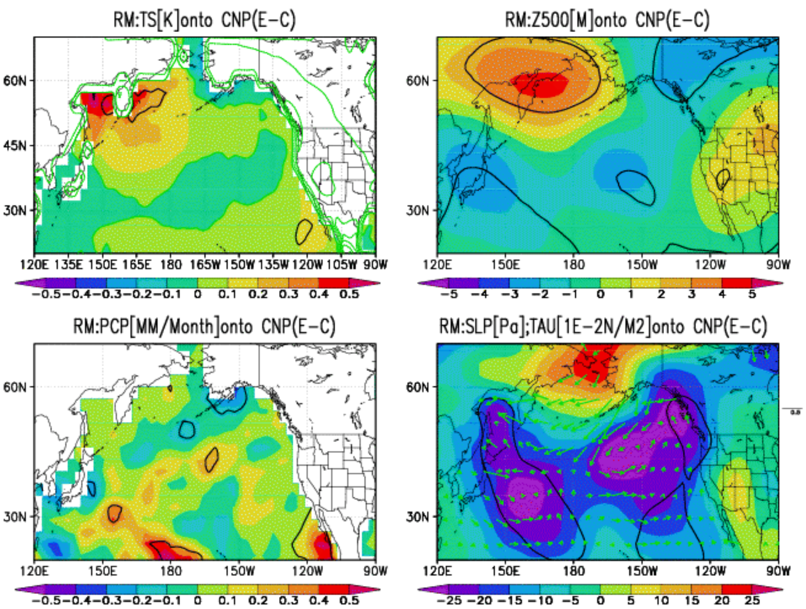


Coupled System Response to the SST Variability in the CNP Region

Figure 1. Regression onto the Central North Pacific SST index: Maps show the difference between the run that includes Ekman advection and the control run.
a) (upper left panel) the Ekman advection forcing (W/M2).
b) (upper right panel) the total air-to-sea heat flux (W/M2).
c) (lower left panel) the latent heat flux (W/M2)
d) (lower right panel) the sum of (a) and (b)

The difference in the atmosphere-to-ocean heat fluxes between the control and Ekman advection runs is shown in Figure 1b. The pattern is basically identical to the pattern of the Ekman advection taken with the opposite sign. The sum of these two terms shown in Figure 1d is much weaker than each part. Thus the heat added to the ocean by anomalous Ekman advection is balanced by the change of the atmosphere-to-ocean heat fluxes. The heat is transferred to the atmosphere primarily by the latent heat flux, as shown in Figure 1c.

The response of SST and the atmosphere to this forcing is determined by the difference of the regression of control and Ekman advection runs with the SST anomalies in the central North Pacific. Figure 2 exhibits the difference for the surface variables and the free atmosphere. The response in the SST anomalies field is significant only off the shore of Kamchatka. Warm SST anomalies in the northwestern part is accompanied by the downstream surface low that reduces the downstream high surface pressure of the control run (Figure 2d), and reduce surface easterlies. The downstream cyclonic circulation (panel d) lead to a slight increase in the precipitation (panel c) over this region.



Coupled System Response to the SST Variability in the KOE Region

Figure 2. Regression onto the Central North Pacific SST index: Maps show the difference between the run that includes Ekman advection and the control run.
a) (upper left panel) sea surface temperature (K).
b) (upper right panel) 500 mb height (M).
c) (lower left panel) precipitation (mm/month)
d) (lower right panel) sea level pressure (Pa) and surface wind stress (N/m2)

The corresponding Z500 pattern exhibits trough downstream the region of the increased heat fluxes into the atmosphere and ridge over the region of the increased SSTs. Thus, we find that the atmosphere removes the extra heat due to latent heat flux by advection and the formation of the downstream low. The linear atmospheric response to the anomalous heat fluxes at the surface themselves cannot explain the baroclinic response of the large-scale anomalies in the free atmosphere; therefore we analyzed the non-linear dynamics that induced these changes in the atmospheric circulation.

The wintertime mean atmospheric circulation is characterized by high tropospheric baroclinicity over Far East and North Western Pacific and synoptic-scale storm-tracks downstream of the KOE region. The low-frequency variability of the mean circulation causes changes in the synoptic scale eddy activity. On the other hand the transient eddies anomalies in the storm track entrance region induce changes in the downstream mean atmospheric circulation through the anomalous eddy vorticity flux convergence. The inclusion of the Ekman advection changes the transient-eddy activities and therefore increases the geopotential height over the CNP. This tendency is balanced by the mean flow divergence over the region.

A similar analysis was conducted on the coupled responses to changes in the KOE region. Here the regression of the Ekman advection onto the time-series of the SST anomalies in the KOE region (Figure 3) consists of the east-west dipole. The Ekman advection heats the ocean over the western half of the region north of 35°N North Pacific with maximum amplitude of 2W/M2 at around 160°E and 45°N. East of the dateline, the Ekman advection cools the ocean with the maximum amplitude of 2.5 W/M2 at around 160°W, 45°N. The change in sign of the Ekman advection forcing is explained by the changes in the wind direction from easterlies to westerlies associated with SST anomalies over the KOE region.

The heat due to the Ekman advection is balanced by the changes in the atmosphere-to-ocean heat fluxes. The heat flux difference between the control and Ekman advection runs is shown in Figure 3b and resembles the pattern of the Ekman advection taken with the opposite sign. It is much larger then the residual of the Ekman advection and heat fluxes (Figure 3d.) and dominated by changes of the latent heat fluxes shown in Figure 3c with a smaller contribution from the sensible and long wave heat flux. These changes in the ocean-to-atmosphere heat fluxes induce an atmospheric response that feeds back into the ocean.

Figure 4 exhibits the difference between the response of surface variables and of the free atmosphere to the heat flux anomalies over the North Pacific. The response in the SST anomalies field is significant only over a small area off the shore of Alaska. Atmospheric heating over the KOE region is accompanied by a downstream surface low that reduces the downstream high surface pressure of the control run, and reduces the surface easterlies. The precipitation pattern over the North Pacific (panel c) is determined by SST anomalies. Increased precipitation at 30°N and the date line corresponds to warmer SSTs over this region.

The Z500 pattern exhibits a low over the region of the increased heat fluxes into the atmosphere and is associated with the increase of the eddy activity over the region. These lead to positive geopotential height tendencies over the Gulf of Alaska that are balance by changes in the divergence of the mean circulation.

In summary, the inclusion of anomalous Ekman advection in the oceanic mixed layer induces significant, non-local responses in the ocean that alter the relationship between anomalies of SST and the atmospheric state. As expected, the changes in the atmosphere remove the heat added to the ocean by Ekman advection. The adjustment involves changes of the atmospheric storm track. This suggests, that changes of the upper ocean heat budget in the extra-tropical Pacific can, and in fact have to induce a significant atmospheric response. Prescription of SST will not capture this response.

Figure 3. Same as in Figure 1 but for the regressions onto the KOE SST index.

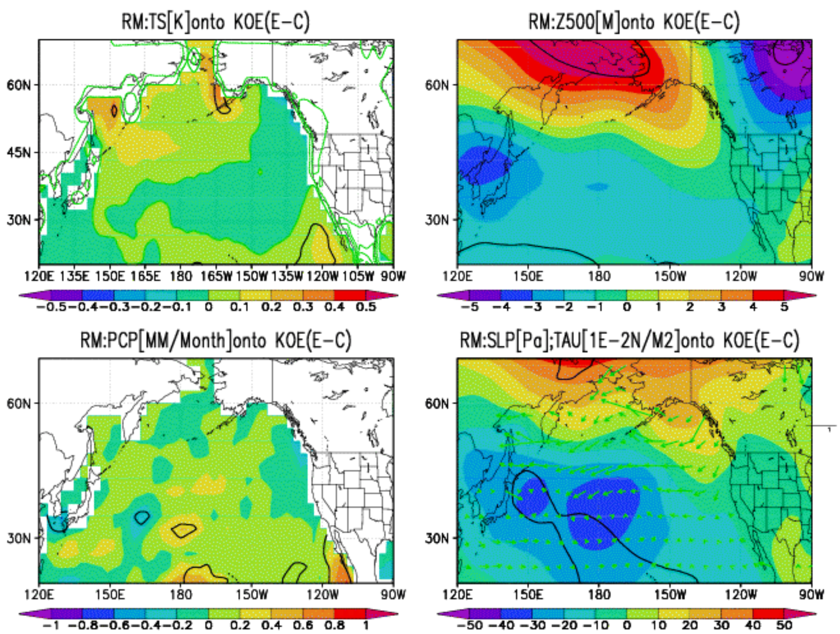
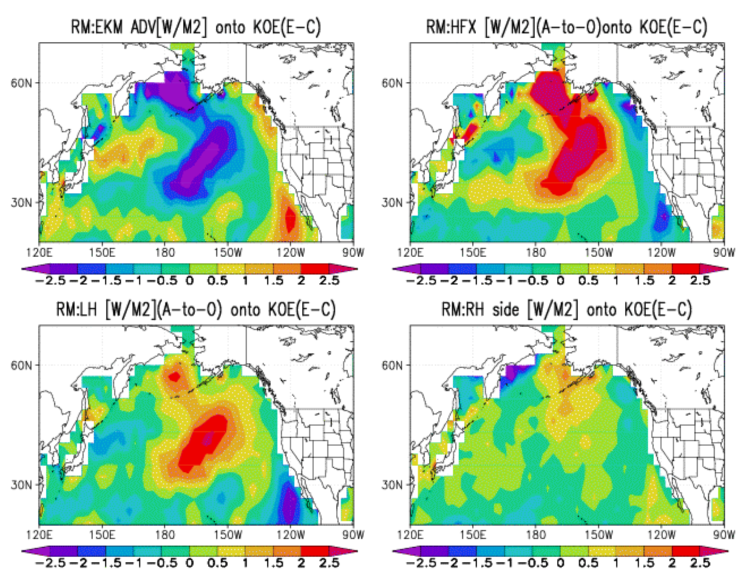


Figure 4. Same as Figure 2, but for the regressions onto the KOE SST index.



The Skill of the Two-Tier System's Hindcast of the Low-Frequency Climate Variability over North Pacific/North America

As was reported in the YR2002 report, the ocean GCMs have a good skill in hindcasting the thermocline depth and mixed layer temperature low-frequency anomalies over the KOE and equatorial Pacific regions when forced with the NCAR/NCEP reanalysis wind stress, while relaxing SST and sea surface salinity (SSS) to their climatological values.

In order to determine the possible atmospheric response to these perturbations, the hindcasted monthly oceanic heat flux convergence anomalies for the period of January 1960 to December 1999 in the KOE region and in the tropical Pacific were applied as anomalous forcing in the coupled CCM3/SOM model. We performed one 40-year integration of the CCM3/SOM forced with the hindcasted monthly oceanic heat flux convergence anomalies for the period of January 1960 to December 1999 in the KOE region and in the tropical Pacific. We performed one 40-year integration of the CCM3/SOM forced with the time dependent oceanic heat convergences (DQ forcing) in the tropical Pacific and KOE region, while elsewhere the climatological forcing was retained. Additional realizations of these runs are being performed to check the robustness of our results. We are currently performing additional 4-member ensemble integration. The members of the ensemble were obtained by shifting the initial conditions by one day each.

To identify the atmospheric response to the KOE forcing alone and to validate the statistical analysis, we repeated the CCM3/SOM integration, but applied the DQ forcing in the tropical Pacific only. The differences between this integration and the corresponding CCM3/SOM integration with both tropical and KOE forcing, indicates the effect of the KOE DQ forcing on the mean atmospheric state and on the pdf of the intrinsic atmospheric modes.

Our preliminary findings (based on one realization only) can be summarized as follows:

- As expected, the anomalous ΔQ forcing over the tropical Pacific sets the global anomalous climate patterns over North Pacific/North America. These patterns include the SST and air-sea heat flux anomalies over North Pacific. Over the KOE region the SST and heat flux anomalies are strongly correlated with the heat flux forcing of the tropical Pacific.
- When the KOE forcing is added, the relationship between the SST and air-sea heat flux anomalies changes. The air-to-sea heat flux anomalies over the KOE region are correlated with the tropical heat flux anomalies. However, there is a 0.4 correlation (as compared to 0.6 for the case with the tropical forcing only) between the SST anomalies over the KOE region and over the NINO3.4 region.
- The additional forcing over the KOE region augments the teleconnection from the tropics. The changes are exhibited in the surface variables as well as in the free atmosphere.
- Comparison with the observations reveals that the anomalous forcing over the KOE region sets the changes in the precipitation patterns over the west coast of the North US and Canada. The corresponding 2m temperature anomalies are most pronounced over Alaska and west coast of Canada.

CONCLUSIONS

The most significant outcomes of our research can be summarized as follows:

1. The inclusion of the Ekman advection in the extra-tropical ocean affects the atmosphere in a systematic way. To some extend this is not a surprising result, since the atmosphere has to balance the heat added to the system by the Ekman advection to compensate for the increasing SST tendency. The most interesting outcome of our experiments is that the changes of the ocean heat budget in the extra-tropical surface ocean induce global changes in the dynamics of the free atmosphere including the variability of the transient eddies.
2. The SST patterns induced by the Ekman advection have little spatial relation with the heat flux perturbations. This implies that prescribing SST anomalies to determine the atmospheric responses can lead to misleading results.
3. Prescribing oceanic heat flux convergences in the tropical and extra-tropical 'windows' of surface ocean to the oceanic memory in the thermocline is a viable alternative to estimating the low-frequency teleconnected atmospheric responses.

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IRI/ARCS REGIONAL MODELING APPLICATIONS PROJECT

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TASK/THEME: 2A

SUMMARY

The ARCS/IRI regional consortium is attempting to develop regional applications of seasonal forecasts. Regional issues that this consortium is addressing include: (1) seasonal forecast and global change hydrologic predictions over the US West as well as the US Southwest; (2) crop forecasting over the southeast; (3) fire danger forecasts over the US; (4) regional applications over Brazil, and Asia. It should be noted that not all applications intend to use regional models and some will utilize instead only the global forecasts along with empirical or statistical downscaling appropriate for a particular application model. In that regard, it should be noted that statistical downscaling is likely to be successful so long as the application input is restricted to standard variables like temperature and precipitation. However, some of the applications require additional variables, such as surface wind and humidity, whose long-term observations are unavailable. Therefore it may ultimately prove advantageous to use the comprehensive output from

the regional models, although one might also simply use a mixture of global model output and judiciously downscale only precipitation or temperature.

ARCS/IRI Regional Consortium Project Leaders were identified for various aspects of this project and include:

- NCEP Global and Regional model forecasts, H. Juang, J. Han
- IRI Global and regional model forecasts for Brazil, J. Qian, S. Zebiak, A. Robertson
- US West Hydrology, D. Lettenmaier
- US Southwest Hydrology, J. Roads
- US Northwest Hydrology, E. Salathe, E. Miles
- S.E. US Crop Forecasting, S. Cocke, T. Larow
- US Fire Danger Forecasts, J. Roads, S. Chen
- Asia Hydrology and Fire Danger, S. Chen, J. Roads

The Scripps ECPC has now set up an ARCS/IRI Regional Consortium WWW home page for this project that describes the various regional and application models, regions, and regional applications (http://ecpc.ucsd.edu/projects/iri_regional.html). This home page will eventually link to all relevant regional application activities. However, in the following, we describe only explicit ECPC activities pertinent to this Regional Consortium. Activities of the other involved groups will be provided under separate cover. It should also be noted the Scripps ECPC is once more holding the 5th International RSM workshop (see Roads 2002 for an overall description of this workshop) in Seoul Korea. The purpose of this workshop is to gather the RSM users together to present progress as well as to describe the latest versions of the model available to the general RSM user community.

APPROACH/METHODOLOGY

Models

Global Models

NCEP's operational global seasonal forecast model will be one of the models examined. Operational 7-month forecasts from a 20 member ensemble along with a rolling climatology from 21 (the corresponding month but for each of the previous 21 years) 10 member ensembles. The challenge with this model will be to provide appropriate data for various regional applications as well as to drive various regional models. Another global model previous used for some of the regional downscaling experiments is the NASA Seasonal to Interannual Prediction Project (NSIPP, See Roads et al. 2002) model. Limited simulations were made with this global model to drive various regional models but this global model will not be pursued further for the time being.

ECPC's global 16 week forecasts, made every weekend beginning 00 UTC, Sept. 27, 1997, also provides a large ensemble for driving similar regional forecasts. In fact, regional forecasts are being made for several regions in order to develop useful regional applications as well as to assess regional forecast skill. The ECPC global model is currently an earlier version of the NCEP global model (the NCEP/NCAR reanalysis model), but there are plans to upgrade the model to a version corresponding to the current operational seasonal forecast model. Given bandwidth and storage limitations, we believe it is important to run the global model locally to drive regional models as well as to access the current operational archives at NCEP and other locations.

Regional Models

ECPC's regional spectral model (RSM) was originally developed at NCEP (Juang et al. 1997) and has been used for many our regional modeling efforts (e.g. Chen et al., 1999; Roads and Chen, 2000; Roads et al. 2002). The RSM has the same vertical structure (sigma coordinates) and physical parameterizations as NCEP's global spectral model (GSM) used for the NCEP/NCAR and NCEP-DOE reanalysis (Kalnay et al. 1996; Kanamitsu et al. 2002). Base fields may be either global or regional model output or analysis fields. Perturbation fields are represented by double Fourier trigonometric functions, which are relaxed to zero at lateral boundaries. A new CVS version of the RSM has been developed to closely emulate the new Seasonal Forecast Model at NCEP and was used for global change experiments (Han and Roads 2003) this past year. The new CVS version will provide a possible methodology for the community to share and test new GSM parameterizations being developed at NCEP in various regions. New physics are also being developed for the global and regional models and will include a prognostic cloud scheme (which will replace the large scale precipitation) with cloud interation in radiation package (the cloud tuning for radiation in the previous versions is gone). Angular momentun and moisture mixings are being implemented to avoid the false production of hurricanes. The surface vegitation is being changed to a heteorogeneous type with 13 kinds. The gravity wave drag will have multi-direction effects depending on wind direction. Finally, the parallelization of the Regional Spectral Model is now almost complete with the help of San Diego Super Computing Center. The code will go through further optimization for IBM machines. The model will also optimized for Earth Simulator Center Computer for large scale downscaling experiments.

Regional Application Models

VIC. A number of groups are using the variable infiltration capacity (VIC) hydrologic model for making streamflow and surface hydrology forecasts. VIC is described in detail by Liang et al. (1994) and at http://hydro.washington.edu. As shown in various land surface comparisons (E.g. Pitman et al. 1999), VIC not only provides a useful macroscale hydrologic budget it also compares well with other models and observations in small scale regions. VIC balances both energy and water over a grid mesh, in this application at a 1/8-degree resolution, using a 3-hourly time step. At the 1/8-degree resolution, the model represents about 23,000 computational grid cells within the Mississippi River Basin. The VIC model computes the vertical energy and moisture fluxes in a grid cell based on a specification at each grid cell of soil properties and vegetation coverage. VIC includes the representation of subgrid variability in soil infiltration capacity, and a mosaic of vegetation classes in any grid cell. Drainage between the soil layers (three were used in this application) is entirely gravity-driven, and the unsaturated hydraulic conductivity is a function of the degree of saturation of the soil, with base flow produced from the lowest soil layer using the nonlinear ARNO formulation (Todini, 1996). To account for subgrid variability in infiltration, the VIC model uses a variable infiltration capacity scheme based on Zhao et al. (1980). This scheme uses a spatial probability distribution to characterize available infiltration capacity as a function of the relative saturated area of the grid cell. Precipitation in excess of the available infiltration capacity forms surface runoff.

Fire Danger

The National Fire Danger Rating System (NFDRS, Deeming et al. 1977), which has served the US fire management community for over 20 years, and is used to monitor daily fluctuations of fire danger across broad geographic areas, prior to fire occurrence will be used to forecast potential fire danger. Fire managers currently only determine daily readiness levels based on this information but have expressed an interest in looking at long-range forecasts of such information. Development of high-resolution information may also be useful to the FARSITE system, which predicts rate of spread based upon local winds. Both systems integrate the effects of fuels, topography, and weather information to fire spread and intensity. At their core is the Rothermel fire spread model, which simulate the quasi-steady state forward rate of spread of the flaming front at the head of the fire. The NFDRS, as well as the Hawaii Division of Foresty and Wildlife, also uses the Keetch-Byram Drought Index (KBDI) to evaluate drought effects on fire potential. The KBDI simulates the counterbalancing effects of precipitation and evapotranspiration on moisture content in the first 20 cm of the soil. The KBDI requires high-resolution precipitation data. In addition, soil moisture from the regional models can be utilized for comparison to the KBDI.

EXPERIMENTAL APPLICATIONS

Southwest Hydrologic Modeling

ECPC is developing an experimental US Southwest hydrologic prediction system, using the Regional Spectral Model (RSM) and the Variable Infiltration Capacity (VIC) macro-scale hydrologic land surface model, along with a routing model to simulate streamflow for specific basins (Rio Grande and Colorado River). In particular, daily US observations of precipitation (25 kms) from the Univ. of Arizona Precipitation Estimation precipitation products and RSM daily forecasts of temperature (max and min), wind speed, and solar radiation are used to continuously force water and energy balance versions of the VIC at daily time scales. VIC daily, weekly, and monthly forecasts are also made from the routine ECPC RSM forecasts for the US (50 kms) and Southwest forecasts (25 kms). As will be shown, there are noticeable differences between the streamflow (and other variables) forecasts and continuous simulations due to various biases in the forecast variables (especially precipitation). As long as these forecast biases are empirically corrected, useful predictions can be made. Streamflow predictions can also be empirically corrected a posteriori. Daily Land Data Assimilation System (LDAS) products from NCEP are also being used to initialize and force the VIC model but present additional assimilation problems, such as how to incorporate the LDAS soil moisture, snow water equivalent and other state variables. Eventually we would like to expand our region of interest beyond U.S. Southwest to the entire US.

Fire Danger Forecasts

ECPC is developing an experimental US fire danger prediction system using the Regional Spectral Model (RSM) and the National Fire Danger Rating System described above. Our goal is to assess the meteorological forecast skill of the basic input variables, utilize the operational analyses to update these variables for the initial state, and to eventually assess the skill of these fire potential forecasts by comparison to fire occurrence and size data. Eventually we intend to move beyond the US boundaries to other regions by using satellite information as well as weather information to drive fire danger models (Burgan et al. 1998, Deeming et al. 1978). For example, we have started to build ECPC long-range global/regional forecasting system into the fire-danger rating system of Heilongjiang Meteorological Bureau, China. We are also working with the USFS to provide necessary input data for their seasonal forecasts for specific regions. Current USFS long range prediction methodology relies on statistical relationships between forecast 500 mb heights.

Brazil

Roads et al. (2002) described a regional modeling intercomparison project for Brazil among the: (1) Scripps Experimental Climate Prediction Center regional spectral model (RSM), (2) Florida State Univ. nested regional spectral model (FSUNRSM), (3) Goddard Institute for Space Studies regional climate model (RCM), and (4) IRI regional climate model (RegCM2) is described herein. All regional models were driven by the NCEP/NCAR I global reanalysis over a S. America domain focused on Brazil. In comparison to new Xie and Arkin .5° land observations, the regional models had a seasonal systematic precipitation error that was somewhat similar to the driving NCEP/NCAR reanalysis systematic error, although the regional model ensemble mean was somewhat smaller, indicating a potential value for using multiple model ensembles. However, correlations, threat scores and biases were not noticeably improved over individual models. In short, regional models do not appear capable of overly improving upon large-scale analyses, which already have considerable skill.

Chen and Roads (2003) further examined the regional model dynamical downscaling methodology using the regional spectral model (RSM) with 50-km grid space increment over South America has been developed. The RSM was originally developed at NCEP (the National Centers for Environmental Prediction). NCEP 28 vertical levels T62 spectral resolution (~200km grid space at the center of the simulation domain) reanalysis are used to initialize and force the regional model for the periods covering March 1, 1997 through May 31, 1999. It was found that there is a drying trend in the model soil moisture and hence the precipitation after the initial 3 months of continuous integration. The drying trend is a response to the positive feedback between the imperfect cumulus parameterization scheme and the soil moisture module in the model. The drying trend can be prevented by tempering the soil moisture in the model during the integration. Two experiments were designed. The first experiment is to prescribe the reanalysis daily soil moisture at second layer; the second experiment is to utilize the available observed precipitation to interactively correct the second layer soil moisture during the integration. By comparing the simulation results of these two runs against the available observed half-degree grid precipitation, it is shown that both runs hardly outperform the forcing reanalysis in terms of correlation, covariance, and threat scores and biases. However a proposed anomaly threat scores and biases show an added skill (better than reanalysis) at extreme precipitation threats. The interactive soil moisture corrected run also outperformed the specified run at all threats indicating the value of the more correct soil moisture in simulating regional climate over this region.

East-Asia Regional Applications

ECPC has been working with scientists in National Taiwan University (NTU), Hong Kong Observatory (HKO), and recently with Heilongjiang Weather Bureau (HWB), China on various regional problems. In preparing for the surface hydrology global change impact assessment in Taiwan, a pilot study in evaluating regional downscaling over south East-Asia was done by Chen at al. (2003). The ECPC version of regional spectral model (RSM) was initialized and forced by simulations from the community climate model version 3 (CCM3) with CO_2 concentration at present date as well as two times of present date levels. Three RSM setups, RSM0, RSM1, and RSM2, with resolution of 280, 50 and 15 km, respectively, have been used. The RSM0 setup has effective resolution similar to the T42 CCM3 simulations. While the spatial distributions of RSM1 and RSM2 simulation over Taiwan are greatly improved over the CCM3 simulation, intensity of the unique wintertime drizzle is overestimated, especially in RSM2. Despite this systematic bias in wintertime simulation, the regional response under the doubling CO_2 scenarios consists of a more summer-like wintertime precipitation characteristics over the northeastern and eastern sides of Taiwan with increased intensity mostly in the extreme events. The summertime simulation, however, found only insignificant changes.

However there was a distinct bias in CCM3 resolution comparable RSM0 simulation over this region, when compared to CCM3. Chen (2002) suggested that this bias is caused by the mismatch of the regional and the driving global models' physical parameterizations. A method to identify and to correct the large-scale biases in regional climate simulations is proposed. It is suggested that simulations at spatial resolution similar to the driving global model should be used to estimate the possible bias in the higher resolution simulations. This correction is shown for a climate downscaling experiment over Southeast Asia. The global model is the NCAR community climate model (CCM3), and the regional model is the regional spectral model (RSM) of NCEP. The bias is estimated by taking the difference between a RSM0 and the CCM3 solution. Once this bias is removed, the resulting seasonal-mean at higher resolution simulation shows a large-scale pattern more similar to that of the driving CCM3, but still retains additional realistic regional details.

There are also other intrinsic problems in regional climate model. For example, in the past it was often found that RSM overestimated precipitation over the top of mountain. This problem has been investigated in collaboration with scientist and student from National Taiwan University (Lee et al. 2003). The wintertime precipitation in Taiwan is characterized by light drizzle over the northeastern part of island produced by a shallow marine northeasterly impinging the north-south oriented steep (over 3 km height) orography. It is suspected that the regional high mountain might have produced spurious horizontal diffusion on the sigma surface under the current code. In such cases the warm-moist air at the foothills spread over to the high elevations through the numerical diffusion process. Although this computational process is only operated on small-scale wave of model perturbations, these perturbations from the coarser resolution base state could reflect a significant portion of the true atmosphere stratification when the mountain is steep in the model. The simple Laplacian diffusion on sigma surfaces is therefore replaced by a somewhat more complicated diffusion on pressure surfaces. The new formula becomes nonlinear and cannot be adapted in the semi-implicit scheme. Nevertheless the results are quite encouraging.

New diffusion improved RSM code is now running at National Taiwan University at 25 km resolution over Taiwan area and Hong Kong Observatory at 15 km over South East China using the sectional data from ECPC weekly global seasonal forecasts. The hydrology seasonal forecast applications will be evaluated at NTU using a streamflow model developed at Rutger University. Precipitation and min/max temperature forecasts are the primary interested application for HKO. Recently, a joint proposal in applying GSM/RSM fire danger forecasts has been submitted to Heilongjiang Provincial Forestry Bureau. Initial scientist exchange visits will take place early this spring to facilitate this collaboration.

SUMMARY

The previous highly focused ARCS/IRI regional modeling intercomparison project centered over Brazil has now evolved toward a larger project with less of a regional focus than the previous project but with the promise of eventually developing a greater number of regional applications in several additional regions. There are certainly a number of overlapping efforts. Most of the projects intend to examine and incorporate the NCEP and IRI global forecast products as part of their regional applications. Several of the US based projects also intend to examine and incorporate the NCEP regional forecast products. In addition to statistical downscaling, several efforts will also use physical downscaling to drive the regional applications (NCEP, IRI, ECPC, and FSU RSM). Some of the hydrologic efforts also use the VIC model.

To summarize, the Scripps ECPC has been involved in 5 main efforts this past year:

1 Brazil downscaling intercomparison and downscaling activities, which are winding down now that the papers have been submitted.

2 Hydrologic models have been set up for the US Southwest and Taiwan.

3 Fire Danger models have been set up for the US

4 Regional models have been set up over Taiwan, Hong Kong, North China (Helinjong province) and model output will eventually be used to develop high resolution seasonal forecasts of precipitation (Hong Kong), hydrology (Taiwan) and fire danger (Helinjong, China) forecasts

5 ARCS/IRI Regional Consortium Home page has now been set up (http://ecpc.ucsd.edu/projects/iri_regional.html).

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Chen, S.-C., 2002, Model mismatch between global and regional simulation. Geophs. Res. Letter, 29, 4.1-4.4.
Chen, S. -C. and J.O. Roads, 2003: Sensitivity of Soil Moisture in the Regional Spectral Model Simulations for South America (submitted)
Chen, S.-C. M.-C. Wu, S. Marshall, H.-M. H. Juang and J.O. Roads, 2003: 2xCO2 Eastern Asia Regional Responses in the RSM/CCM3 Modeling System. Global and Planetary Change (in press).
Han, J. and J. Roads, 2003: US Climate Sensitivity Simulated with the NCEP Regional Spectral Model. Climate Change (in press)
Lee, C.-T., M.-C. Wu, H.-M. H. Juang, and S.-C. Chen, 2003: Improvement of mountain precipitation in Regional Spectral Model over Taiwan Island. (in preparation).
Roads, J.O. 2002: The Fourth International RSM Workshop: Meeting Summary. *Bull. Amer. Meteor. Soc*. (submitted)
Roads, J., S.-C. Chen, M. Kanamitsu, 2002. US Regional Climate Simulations and Seasonal Forecasts. *Journal of Geophysical Research-Atmospheres* (in press).
Roads, J., S. Chen, L. Druyan, M. Fulakeza, S. Cocke, T. Larrow, J. Qian, 2003: The IRI/ARCS

THE ATLANTIC OCEAN: EMERGING TROPICAL CIRCULATION WITH AN EMPHASIS ON CONNECTIONS TO MID-LATITUDES

Peter Niiler
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TASK/THEME: 3A

OBJECTIVES

In numerical models, the tropical Atlantic interannual time variations of the SST gradient north of the equator are linked to the interannual rainfall in regions Brazil and sub-Saharan Africa. The cause of the SST gradient is vertical mixing of upwelled water and horizontal advection of thermal energy across the equator. The negative feedback is latent flux release to the atmosphere. The objective of this research is to quantify the relative roles of advection and diffusion from observations of circulation, SST and fluxes in the tropical Atlantic.

SUMMARY

This JIMO task is a three-year research program to use data gathered from drifting buoys in the Atlantic to evaluate the role of advection in the thermal energy balances of the surface layers of the ocean. The first year was devoted to data acquisitions and processing. To accomplish this required the collection of the complete drifter data sets and processing of these data into uniform formats. Corrections to the velocities due to wind biases are to be made. The SST data sets are acquired and are at hand.

RESEARCH ACCOMPLISHMENTS

Completed the calculation of the time-mean circulation and absolute sea level of the North Atlantic for 1992-2003.

RESEARCH RESULTS AND RECOMMENDATIONS

The research results of this project are summarized in the publications that are listed in the Project Data index. This project will continue supporting analysis for 2003-04 as drifter data from the tropical Atlantic Ocean becomes available. Figure 1 shows the latest result of the analyses, which is the surface geostrophic velocity of the North Atlantic.

PUBLICATIONS

Niiler, P. P.: The world ocean surface circulation. In *Ocean Circulation and Climate*, edited by G. Siedler, J. Church and J. Gould, Academic Press, pp. 193-204. (2001)

Niiler, P.: Global ocean circulation observations. In *Observing the Oceans in the 21st Century*, edited by C.J. Koblinsky and N.R. Smith. Australian Bureau of Meteorology, Melbourne, pp. 306-323. (2001)

Cuny, J., P.B. Rhines, P.P. Niiler and S. Bacon: Labrador sea boundary currents and the fate of the Irminger Sea water. *J. American Meteorological Society* 32: 627-647 (2002)

Orvik, K.A. and P.P. Niiler: Circulation of Atlantic water in the northern North Atlantic and Nordic Seas. *Geophys. Res. Lett.* 2-1 to 2-4. (2003)

Reverdin, G., P.P. Niiler and H. Valdimarsson: North Atlantic Ocean surface currents. *J. Geophys. Res.*, 108, 2-1 to 2-19. (2003)

Milliff, R.F., P.P. Niiler, J. Morzel, A.E. Sybrandy, D. Nychka and W.G. Large: Comparing observations of surface winds from NSCAT and MINIMET drifters in the Labrador Sea. *J. Atmos. Ocean. Tech.*, 30, 513-5333. (2003)

Flatau, M.K., L.D. Talley and P.P. Niiler: The North Atlantic oscillation, surface current velocities and SST changes in the subpolar North Atlantic. *Journal of Climate*. 16, 2355-2369. (2003)

Centurioni. L. R. and P. P. Niiler: On the surface currents of the Caribbean Sea. *Geophys. Res. Lett.,* 30, 12-1 to 12-4. (2003)

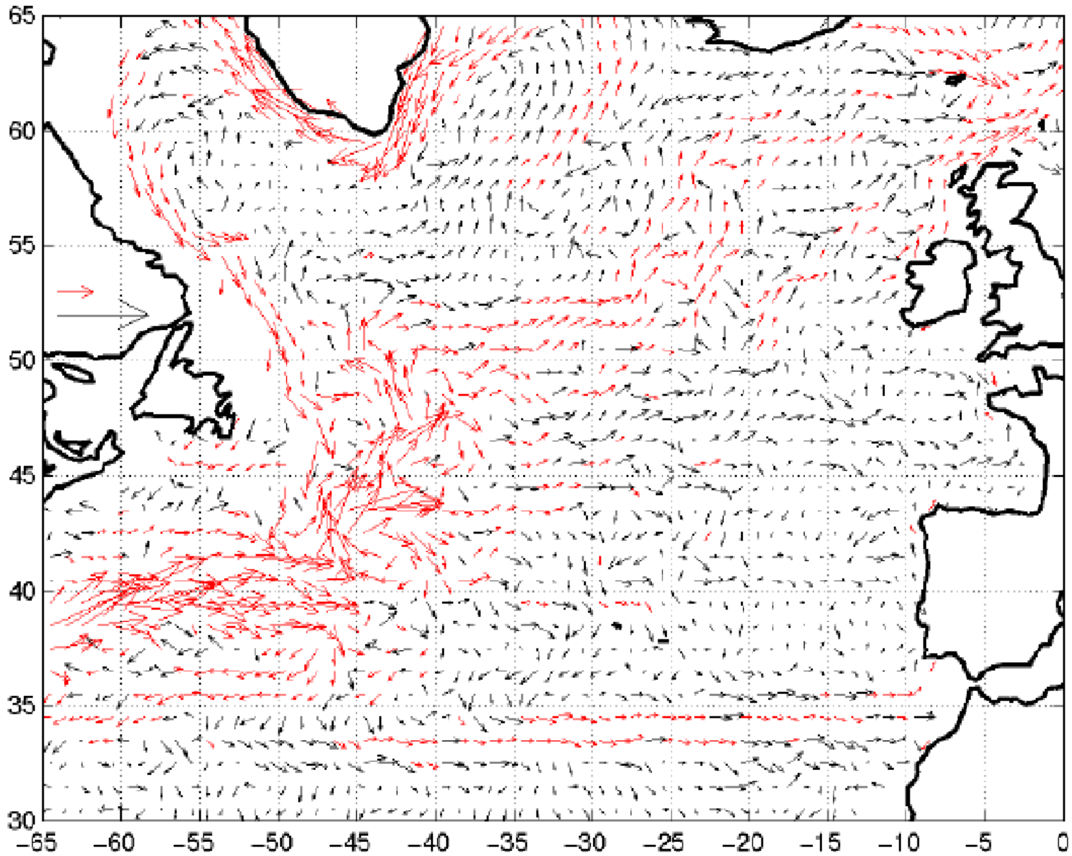
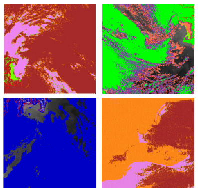


Figure 1. Mean geostrophic velocity (1-degree grid), cm.



ENSEMBLE SIMULATIONS OF OBSERVED CLIMATE VARIABILITY: VERIFICATION METHODS AND FORECAST APPLICATIONS

Simon J. Mason
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TASK/THEME: 3A

OBJECTIVES

The primary concerns of the research have been to advance our ability to make reliable seasonal climate forecasts, primarily through the development of methods for analyzing the ensemble predictions from general circulation models, and to assist in the improvement of operational forecasts by implementing the technologies developed and by communicating effective ways of interpreting verification measures.

The stated objectives of the research were to develop methods for:

- the interpretation and verification of ensemble output,
- the statistical inflation of ensemble sizes,
- the recalibration and combination of seasonal climate forecasts;
- To transfer developed technologies to other centers.

SUMMARY

- Methods for calculating the significance of the areas beneath the relative operating characteristic (ROC) and levels (ROL) curves that were explained and developed during the first year of the project, have been extended to allow for the comparison of areas. The comparison of ROC and ROL areas can be informative when considering the dependence of forecast skill on the season or lead-time, for example, or when comparing the areas from competing forecast strategies.
- Comparisons between the statistical interpretations of ROC and ROL areas, and permutation and bootstrap procedures have been defined.
- Elements of the research on methods for calculating the statistical significance of the area beneath the ROC curve and for calculating the significance of differences between ROC areas has been incorporated into the World Meteorological Organization (WMO) Standardized Verification System.
- Much of the research on verification has been presented at numerous training and capacity building workshops.
- Guidelines for performing a cluster analysis of ensemble predictions to identify forecast climate regimes have been clarified.
- A method of forecast combination has been tested and implemented at the IRI.

RESEARCH ACCOMPLISHMENTS

Research accomplishments are detailed under each objective.

Interpretation and Verification of Ensemble Output

In the first year of the project, a relationship between the areas beneath the relative operating characteristics (ROC) and levels (ROL) curves, and the Mann-Whitney *U*-test was demonstrated. This relationship provides a basis for performing a simple test for the statistical significance of the areas beneath the curves, and for interpreting the areas in the form of the relatively easy to understand two alternative forced choices (2AFC) test. In the second year of the project, conditions under which the statistical properties of the Mann–Whitney *U*-distribution, can validly be used to determine the statistical significance of the areas beneath the curves were defined: the test is equivalent to (but much less computationally intensive than) a permutation test, and can therefore be applied whenever the assumptions of the permutation test are valid. In a seasonal climate forecasting context, the Mann-Whitney *U*-test can be applied in the context of a set of forecasts that are temporally independent, such as a series of forecasts for a single point or area. Where forecasts are not independent, which is likely to be the case if forecasts are aggregated over space, bootstrap procedures may be more appropriate.

The relationships between the ROC or ROL areas and the *U*-statistic, and their relationships to the 2AFC test can be exploited for comparing the ROC or ROL areas of two or more sets of forecasts, as well as for testing the statistical significance of an individual area (e.g., Hanley and McNei,l 1983; Metz *et al.,* 1984; McClish,1987; DeLong *et al., 1*988; Campbell, 1994; Swaving *et al.,* 1996). The comparison of ROC areas can be informative when considering the dependence of forecast skill on the season or lead-time, for example (e.g., Mullen and Buizza 2001), or when comparing the areas from competing forecast strategies (e.g., Winston, 1988; Buizza *et al., 1*998). The recommended approach for testing the statistical significance of differences in the ROC areas is different in these two cases, and so they were considered separately. Similarly, the comparison of ROL areas is informative when comparing the predictive skill of alternative models or for different periods.

The primary consideration when comparing the ROC or ROL areas for weather or climate forecasting systems is whether or not the areas were calculated using independent sets of forecasts. The procedure is simplest in the case of independent sets of forecasts, which would be applicable when comparing forecast performance for two different seasons or (sets of) years using the same model, for example. The comparison of ROC or ROL areas for forecasts at different lead-times will involve independent sets of forecasts only if the difference in lead-times is sufficiently large. If the sets of forecasts can be considered independent, a two-sample Kolmogorov–Smirnov test can be used to compare two ROCs (Gail and Green, 1976; Campbell 1994), and makes no parametric assumptions about the distributions of the forecast probabilities (Sheskin, 2000). Parametric alternatives have been suggested, based primarily on the *t*- and χ^2 tests (Swets *et al., 1*961; Dorfman, and Alf, 1969; Metz, 1978; Metz and Kronman, 1980; Hanley and McNeil, 1982), and have been applied in a weather forecasting context (Winston 1988). These techniques could be similarly applied for the comparison of ROL areas.

When the one set of forecasts is not independent of the other, which is the case when comparing the performances of competing forecasting systems over identical time periods, an allowance has to be made for the correlations between the ROC or ROL areas. The tests proposed for comparing dependent ROC areas differ primarily in the methods of estimating the variances and covariances of the areas (Hanley and McNeil 1983; Metz *et al., 1*984; Nelson 1984; McClish 1987; DeLong *et al., 1*988; Swaving *et al., 1*996). The nonparametric method of DeLong *et al., (1*988) is probably the most widely used and, in the case of a comparison of two ROC areas, *A* and *B*, can be expressed as:

$$z = \frac{A - B}{\sqrt{\left(S_A^2 + S_B^2 - 2 r_{AB} S_A S_B \right)}},, \quad (1)$$

where S_A is the standard error of area *A*, r_{AB} is the correlation between the two areas, and z is a test statistic whose properties are described below. In practice, the denominator can be more easily calculated by pre- and post-multiplying the variance-covariance matrix of the areas, by a contrast matrix [see DeLong *et al., (1*988), who provide additional details on the comparison of multiple ROC areas], but in the form of Eq. (1), an equivalence to the *t*-test for paired samples (Conover, 1999; Sheskin, 2000) becomes evident (Hanley and McNeil, 1983). Therefore, one interpretation of *z* in Eq. (1) is that it is a Student's *t*-statistic. If the samples used to calculate the ROC areas *A* and *B* are assumed to be large, then because Student's *t*-distribution becomes normal with large samples, *z* can be interpreted as a standard normal variate, i.e., $z \approx N(0,1)$, (DeLong *et al., 1*988). The additional implicit assumption that sampling errors in calculating the ROC areas are asymptotically normally distributed is justified by Hoeffding, (1948), and is related to the validity of the normal approximation of the Mann–Whitney *U*-distribution, as discussed in section 3.

Full details of the research on the statistical significance, interpretation, and comparison of ROC and ROL areas are to be published in *Quarterly Journal of the Royal Meteorological Society* (Mason and Graham, 2002).

In addition to providing detailed guidelines for interpreting and comparing ROC and ROL curves, thus building on the earlier research of Mason and Graham (1999), research has been conducted on a commonly used method for analyzing ensemble output: namely, cluster analysis. In the context of forecasting, cluster analysis has been used frequently to identify sets of distinct forecasts in an ensemble (Ferranti *et al., 1*994; Brankovi *et al., 1*996; Molteni *et al., 1*996; Toth *et al., 1*997; Atger, 1999; Stephenson and Doblas-Reyes, 2000), and thus constitutes a form of synoptic typing. While the relative merits of alternative approaches to cluster analysis have been reviewed extensively (Fovell and Fovell, 1993; Gong and Richman, 1995; Jackson and Weinand, 1995), little attention has been given to the calculation of the distance matrix, which forms the basis for any clustering. The most commonly used distance metric in the climatological literature is Euclidean distance (e.g., Fovell, 1997; Yao, 1997; Gerstengarbe *et al., 1*999) because of its intuitive appeal. However, the assumption implicit with Euclidean distances that the variables are uncorrelated is frequently ignored. Mahalanobis distances account for differences in variance and for correlations between variables, and so recommendations have been made for its use over Euclidean distances (Stephenson, 1997). Accordingly, the metric is being used increasingly in the climatological literature (e.g. Stephenson, 1997; Remund and Long, 1999; Stephenson and Doblas-Reyes, 2000). In a companion paper based on research funded by Scripps Institution of Oceanography (Mimmack *et al,.* 2001), the importance of the method of calculating the distance matrix was considered. It was suggested that when cluster analysis is used for defining regions (using a single meteorological parameter), Mahalanobis distances are inappropriate because of the exaggeration of the noise components in the data, and because there is reason to incorporate the correlations between the variables when defining the regions. It was therefore recommended that Euclidean distances should be calculated using unstandardized principal component scores based on only the major principal components. Under the current research, the conclusions of Mimmack *et al.,* (2001) have been extended to application of Euclidean and Mahalanobis distance metrics in the context of identifying synoptic types or climate regimes is considered (Mason *et al.,* 2002). In support of Stephenson's (1997) conclusions, it is suggested that truncated Mahalonobis distances are the most appropriate metric for defining synoptic types and climate regimes, including identifying regimes within ensemble of forecasts, but that care should be taken to select appropriate numbers of principal components and clusters.

Methods of Forecast Combination

Statistical models have been used to recalibrate seasonal climate predictions from single general circulation models, and to combine predictions from different models. The procedure is illustrated in Figure 1, and involves the following steps:

1. Sort ensemble members for each season and from each model so that each member represents a percentile of the forecast distribution.
2. Filter the 50 years of model data by a principal components analysis of the correlation matrix of the sorted ensemble members. Each model is filtered separately because of different numbers of ensemble members.
3. Retain a subset of the principal components of each model to isolate the model signal(s). A different number of components may be retained for each model.
4. Re-filter, if necessary, to:
    a. reduce the number of variables;
    b. ensure that variables are orthogonal.
5. Use a canonical variate analysis (or alternative statistical model) to relate the GCM signals to the observed data.

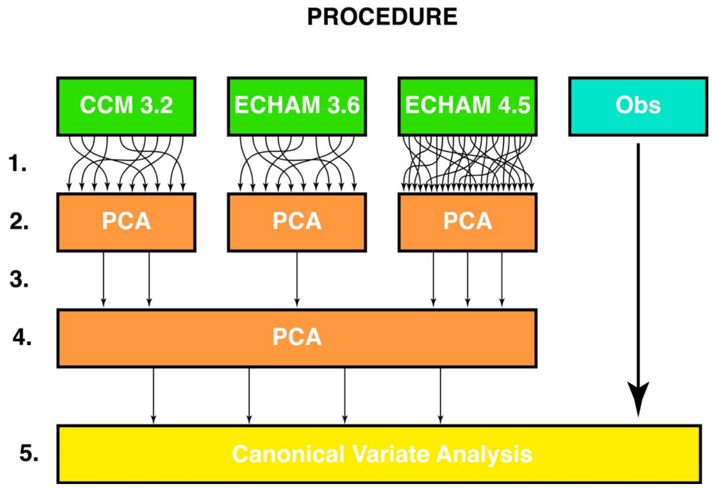

FIGURE 1. Statistical procedure for recalibrating and / or combining ensemble seasonal climate predictions.

Examples of recalibration results are shown in Figure 2, where cross-validated ranked probability skill scores (RPSS) for the recalibrated scheme are compared to those for the uncalibrated model predictions. Results are similar for different general circulation models. The performance of the scheme was found to be sensitive to the numbers of principal components and canonical variates retained in steps 2, 4, and 5, and was found to be most effective when a strict criterion was defined for determining how many canonical variates to retain. Improvements in skill are evident in areas of moderate to high predictability, but in the extratropics the recalibration performs poorly.

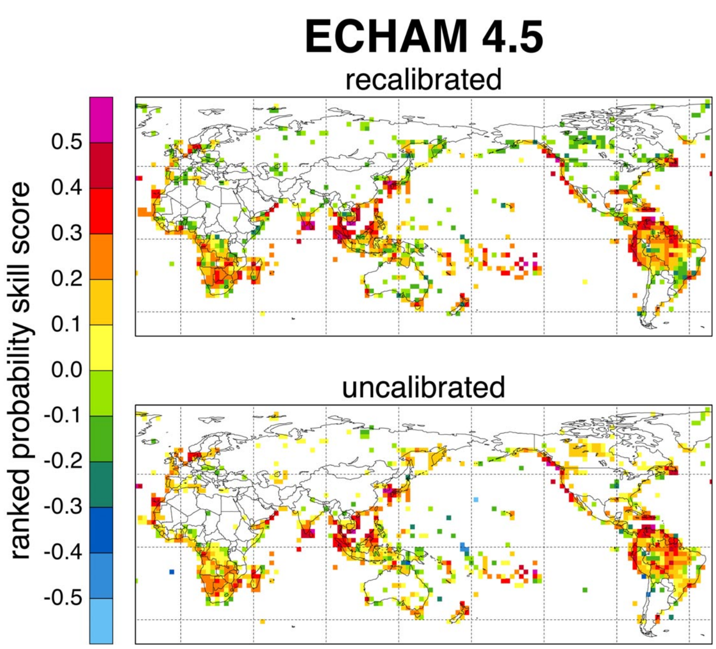

FIGURE 2. Cross-validated ranked probability skill scores for simulations of January – March 2 m air temperatures over the period 1950-1998 using 24 ensemble members of the ECHAM 4.5 model. Scores are compared for the calibrated and uncalibrated probabilities.

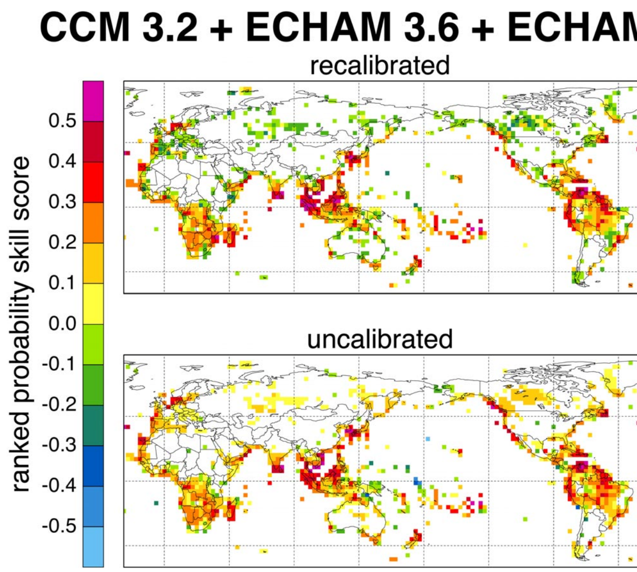

FIGURE 3. Cross-validated ranked probability skill scores for simulations of January – March 2 m air temperatures over the period 1950-1998 using 24 ensemble members of the ECHAM 4.5 model. Scores are compared for the calibrated and uncalibrated probabilities.

Similar results were obtained for the forecast combination: the procedure is ineffective in areas of weak predictability such as the extratropics, but does show some promise in areas of moderate to high predictability (Figure 4). Improved results were obtained by recalibrating the models individually, and then computing a simple average of the recalibrated probabilities. This latter procedure has been implemented in operational mode at the IRI, and its performance has been tested relative to the subjective "net assessment" procedure over the four-year period 1998-2001. Detailed results are provided by Barnston *et al.,* (2002). A detailed description of the procedure and an analysis of its performance is being prepared for publication (Mason 2002).

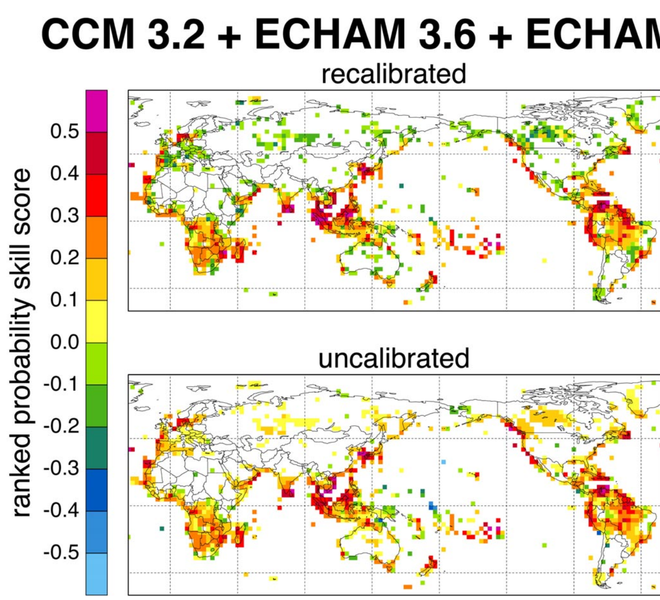

FIGURE 4. Cross-validated ranked probability skill scores for simulations of January – March 2 m air temperatures over the period 1950-1998 using 24 ensemble members of the ECHAM 4.5 model, and 10 members each of the CCM 3.2 and ECHAM 3.6 models. Scores are compared for the calibrated (combined) and uncalibrated (average of the uncalibrated) probabilities.

TECHNOLOGY TRANSFER AND CAPACITY BUILDING

Considerable progress was made in transferring technology to other centers, and in training other scientists in the interpretation of forecast verification measures.

1. Methods of forecast recalibration and combination have been implemented at IRI, and are now used in the routine production of the monthly net assessment forecasts, and in the post-processing of the general circulation model predictions. The recalibration scheme has been used in the IRI's experimental malaria forecasts.

2. The test for the statistical significance of the area beneath the ROC curve has been installed at the IRI for use in the diagnosis of the skill of the general circulation models used in the monthly forecasts.

3. The research on methods for calculating the statistical significance of the area beneath the ROC curve and for calculating the significance of differences between ROC areas has been introduced to the World Meteorological Organization (WMO) Commission for Basic Systems (CBS) and Commission for Climatology (CCl) Expert Teams on Verification. The Meeting of the Expert Team to Develop a Verification System for Long-Range Forecasts, Montreal, Canada, 22–26 April 2002, decided to propose inclusion of the methods as recommended significance tests in the WMO Standardized Verification System.

4. Arrangements are being finalized to install various verification procedures, including those developed in this project, for operational use at the South African Weather Services.

5. Methods for interpreting measures of forecast verification, and for assessing forecast quality have been presented at the following workshops:
    a. *CLIPS Training Workshop for Eastern and Southern Africa*, Nairobi, Kenya, 29 July – 9 August 2002.
    b. *Roving Seminar on Latest Developments with the El Niño Episode and Seasonal Forecasting Capabilities and Products*, Yangon, Myanmar, 22–23 July 2002.
    c. *Advanced Training Institute on Climatic Variability and Food Security*, Palisades, NY, U. S. A., 8–26 July 2002.
    d. *Asian Climate Training, Module 3: Applying Climate Information for Decision Making*, Bangkok, Thailand, 10–16 May 2002.
    e. *Workshop on the Development of Seasonal Forecasting for the Indochina Region*, Hanoi, Vietnam, 21 – 25 January 2002.
    f. *Workshop on Regional Climate Forecast Methodology*, Singapore, Singapore, 26 November – 7 December 2001.

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Barnston, A. G., S. J. Mason, L. Goddard, D. G. DeWitt, and S. E. Zebiak, 2002: Multimodel ensembling in seasonal climate forecasting at IRI. *Bull. Amer. Meteorol. Soc.*, submitted.

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Mason, S. J., and N. E. Graham, 2002: Areas beneath the relative operating characteristics (ROC) and levels (ROL) curves: statistical significance and interpretation. *Quart. J. Royal Meteorol. Soc.*, in press.

Mason, S. J., J. S. Galpin, N. E. Graham, and L. Goddard, 2002: Forecast reliability given moderately sized samples. *J. Appl. Meteorol.*, under revision.

Mason, S. J., G. M. Mimmack, L. Goldstein, I. Abramson, and J. S. Galpin, 2002: Choice of distance matrices in cluster analysis: identifying climate regimes and synoptic types. *J. Climate*, under revision.

The following presentations on work conducted under this project have been made at conferences, workshops, and seminar series (additional presentations at training workshops are referred to under the section on Technology Transfer and Capacity Building):

Presentations

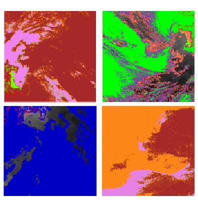
Mason, S. J., and N. E. Graham: The areas beneath the relative operating characteristics (ROC) and levels (ROL) curves: Do they mean anything useful? *IRI Seminar Series*, Palisades, NY, U. S. A., 12 December 2001.

Mason, S. J.: Combining multiple seasonal forecasts. *Workshop on Regional Climate Forecast Methodology*, Singapore, Singapore, 26 November – 7 December 2001.

Mason, S. J., and G. M. Mimmack: Comparison of some statistical methods of probabilistic forecasting of ENSO. *26th Annual Climate Diagnostics and Prediction Workshop*, La Jolla, CA, U. S. A., 22 – 26 October 2001.

The following posters on work conducted under this project have been presented:

Mason, S. J., A method for recalibrating and combining ensemble forecasts. 16th Conference on Probability and Statistics in the Atmospheric Sciences / 13th Symposium on Global Change and Climate Variations, Orlando, FL, U. S. A., 13–17 January 2002.



CLIMATE, WATER AND WATER CHEMISTRY-- A SIERRA NEVADA OBSERVATION PROGRAM TO UNDERSTAND IMPORTANT CHANGES IN CALIFORNIA WATER RESOURCES

D. Cayan, M. Dettinger, K. Redmond

Scripps Institution of Oceanography

TASK/THEME: 3A

SUMMARY

Observations are fundamental to understanding regional climate variability and change and making decisions there from. We have begun an effort to provide a set of hydrological and meteorological stations in Yosemite National Park and the close by environs. California's water resources depend vitally upon runoff from its high elevations, including rainfall-dominated coastal ranges or the snowmelt-dominated Sierra Nevada. These watersheds are also conduits that carry sediment, nutrients and pollutants and also act as vital arteries in the regional airshed. Climate variability is high however, and annual precipitation and runoff fluctuate from under 50% to over 200% of climatological averages.

In Yosemite National Park, we are working on our second field season of installing small portable sensors along three transects: the Highway 120 (Tioga Road) trans-Sierra road corridor and the Tuolumne River and Merced River watersheds (Figure 1). Collaborators include the California Department of Water Resources, the U.S. Geological Survey, and the National Park Service. A new source of funding for our wilderness monitoring efforts has been identified from the California Energy Commission.

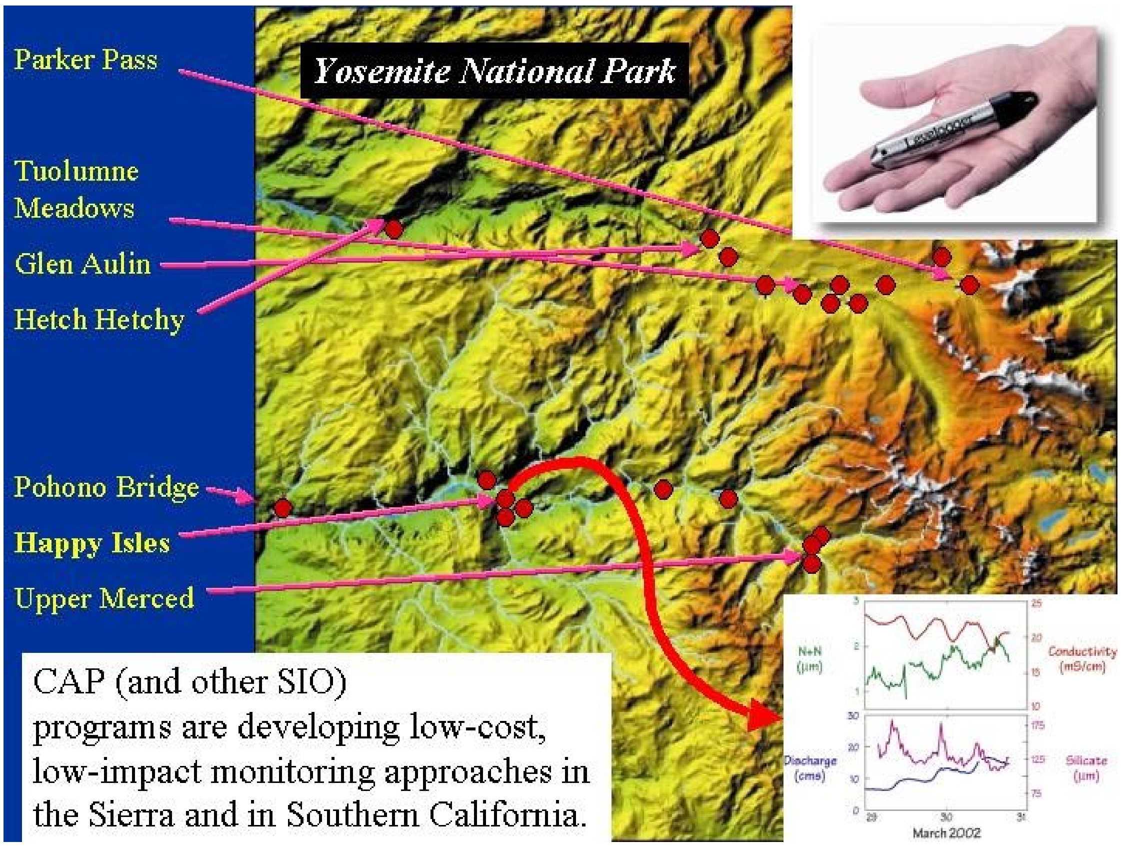


Figure 1. Monitoring locations in Yosemite National Park.

Along Highway 120, during Summer 2002, we began to instrument a set of meteorological stations that augment the snow/meteorological stations that are operated by the California Cooperative Snow Surveys

Figure 2. Installing towers along Highway 120.

(Figure 2). Presently, our stations consist of approximately 25 internally-recording temperature/relative humidity sensors, stationed along Highway 120 from just above the San Joaquin Valley floor, along the west slope of the Sierra up to the crest of Tioga Pass, and down to the Owens Valley at Lee Vining. This array will monitor weather systems and air masses as they sweep across the Sierra from the Pacific, or occasionally, from the interior via the White Mountains and the Owens Valley. We have plans to expand the sensor suite at several of these stations to include other elements such as wind and solar radiation. We also hope to implement, before the winter season settles in, a webcam at Tioga Pass to view snow in surrounding alpine areas (Figure 3).

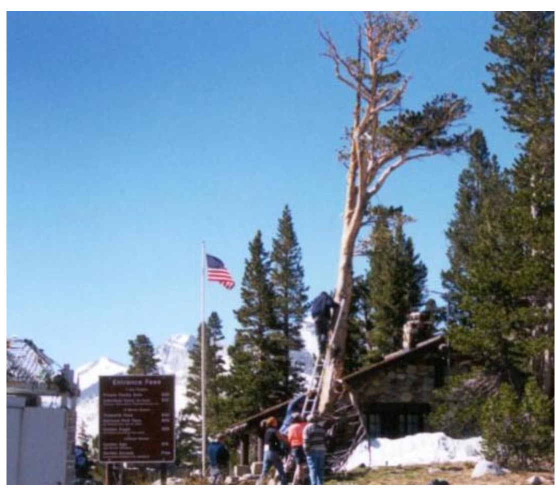


Figure 3. Tioga Pass webcam preparation.

Along the Tuolumne and Merced Rivers, we began in summer 2001 to install an array of stream pressure and temperature and atmospheric temperature and humidity sensors. Figure 4 shows a group of us installing a stream gage below the Rafferty Creek Bridge.

Figure 4. Installing stream gage below Rafferty Creek Bridge.

This set of gages is providing much finer detail than has been previously available on hydrologic variability, including snowmelt, summer desiccation, stream temperatures, and in some cases stream chemistry. For example the last year of samples from the Merced River near Echo Creek (Figure 5 inset shows USGS colleagues making stream chemistry and flow measurements underneath bridge carrying pack horses used to ferry equipment into the Upper Merced backcountry) illustrates the features of the last water year.

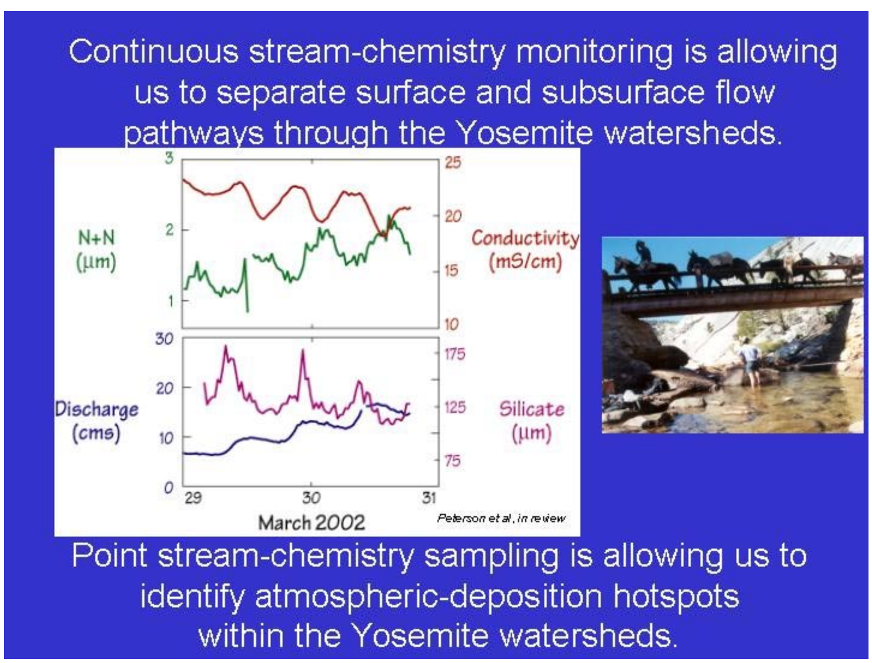


Figure 5. Stream chemistry monitoring example.

The 2001-2002 water year shows how the river becomes quiescent during winter (water temperatures settle down to near freezing), spring snowmelt pulse, and then several day alternations of higher and lower flow surges. Diurnal fluctuations of approximately 10% of mean daily flow are typical. 2001-2002 was an exceptionally early snowmelt year. The first snowmelt pulse occurred in mid-March, which is among the earliest melt commencement dates since the flow record at the Merced River Happy Isles gage began in water year 1916. The data provided from the array of new gages that we have installed will elucidate where/when and maybe how the snowmelt occurs in the important upper reaches of these Sierra Watersheds. In addition to our stream and atmospheric temperature/humidity gages, we are collaborating with Frank Gehrke of California DWR to install a full snow/meteorological station at Merced Lake this fall (GOES telemetry).

Communications in the Park are difficult because of the high and severe relief. Conditions are especially challenging in river channel bottoms, which are crucial in providing stream gage data but are often isolated by surrounding topography. We are exploring potential wireless communications options that include digital cellular, satellite, and land line (phone line). At several sites we have obtained or have requested Park approval to install communications infrastructure. There is tension between Park resource management interests, who are seeking more environmental information and Park wilderness preservation interests, who are concerned that instrumentation will degrade the wilderness values that they are paid to preserve. This tension sometimes presents obstacles to our research effort. We hope to get a few stations online yet this fall, with help from Greg McCurdy a weather observation specialist from DRI.

In the Santa Margarita Ecological Reserve (SMER), operated by SDSU and featuring communications link to HPWREN, we are building an array of meteorological and hydrological observation stations. Our vision is to develop a set of microclimate and hydrologic time series observations to characterize the variability of water and weather in this coastal Southern California watershed. This summer, relying largely upon the work of undergraduate student Alex Revchuk, UCSD Environmental Systems Program, SIO staffer Larry Riddle, and SMER staff members Pablo Bryant and Mark Van Scoy, we have installed fifteen 10-meter meteorological towers. This tower array is aligned along and across the Santa Margarita river channel. The towers (Figure 6) will serve as platforms for meteorological sensors, data loggers to access the meteorological and (in some cases) hydrological sensors, and antennas. The towers are also available for housing sensors such as cameras, sound monitors, and air quality monitors deployed by other investigators.

Figure 6. Tower installation in SMER.

In the meantime, SIO Development Engineer, Douglas Alden, is building a low cost, low power data logger (Figure 7) that will log, record and transmit data from several meteorological and hydrological sensors.

Figure 7. Installation of data logger and communications module designed by Douglas Alden.

The logger is designed for wilderness applications and will accommodate several standard meteorogical and hydrological sensors. The current version will be powered by a small battery pack and its 32MB of memory is adequate to store several months of data (at a few minute sample intervals). In SMER, the data will be transmitted via "free wave" spread spectrum, unlicensed band radios to selected SMER telecommunications nodes. The present strategy will employ a Cerf Cube Linux server at the SMER telecommunication nodes to convert the freewave radio signal into TCP/IP protocol. This signal will be transmitted to the SMER 2.4 GHz grid antenna that links the intra-reserve network to the 45 Mbps HPWREN backbone.

There is much to do to make this array function. With approximately 20 towers installed since July 2002, we are striving to get them instrumented before the winter rain (optimistically speaking) season begins. On the SMER reserve, there are issues that prevent us from immediately installing infrastructure on the wild eastern highland area of SMER that is under federal (BLM) jurisdiction. We must work through the necessary permitting and access process in order to instrument this area, which could be vital in characterizing some of the highest precipitation within the SMER watershed. Also, recently, with the help of John Helly of SDSC, we have begun discussions with the Resources staff of Camp Pendleton to consider extending the SMER hydro/met array to the coast along the Santa Margarita through the marine base. If wireless communications via HPWREN can be provided, the architecture that is being developed in SMER will be extended into this coastal segment.

PUBLICATIONS

Lundquist, J.D., D.R. Cayan and M.D. Dettinger. Meteorology and hydrology in Yosemite National Park: A Sensor network application. In Information Processing in Sensor Netwroks, F. Zhao and L. Guibas 9eds.0: IPSN 2003, LNCS 2634, 518-528 (2003)

Lundquist, J.D. and D.R. Cayan. Seasonal and spatial patterns in diurnal cycles in streamflow in the western United States. J. Hydromet., 3, 591-603 (2002).

Lundquist, J.D., D.R. Cayan and M.D. Dettinger. Synchronous springs in the Sierra Nevada: Is snowmelt independent of elevation? *Submitted to J. Hydromet.* (2003)

CLIMAS – CAP PARTNERSHIP ACTIVITIES

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TASK/THEME: 3A

SUMMARY

Climate information, though used in some strategic planning for wildfire management, is still not fully utilized in wildland fire management practices; especially time scales of decadal and longer. When climate forecasts are utilized in some management applications, the probabilistic nature of climate forecasting and related variability in forecast skill prompts many managers to be skeptical of prediction usefulness. We are convinced, though, that a range of forecast products exists, beyond the short-range time scales of fire meteorology, that can be of benefit to fire management. For example, statistical seasonal fire forecasts can be made with modest skill using prior years' moisture indices. The fire community has been somewhat skeptical of the value of this tool, but is beginning to pay more attention. Identifying current and potential entry points for climate information and demonstrating the economic benefits of utilizing this information has been difficult because of the complex structure of wildfire management. We propose to spend the 2002-2003 RISA funding year building an essential foundation for carrying out an economic assessment of climate information in wildland fire management through characterizing the network, including key information flows and decision nodes, through which strategic planning for management occurs. An important element of this will be characterizing the decision calendars associated with each node. Understanding the structure of strategic planning, key individuals, and major potential entry points for climate and other information will provide us with the information we need to proceed, during 2003-2004, with a structured economic analysis of climate impacts on fire and, by extension, the value of climate information.

This research collaboration between CAP and CLIMAS researchers is led by Anthony Westerling and Daniel Cayan at CAP and Barbara Morehouse at CLIMAS. The California Applications Program (CAP) is a collective of university, federal and private agency scientists studying the impacts of climate variability and attempting to improve climate and extended weather forecasts in the California region. CAP, operating under funding by the National Oceanographic and Atmospheric Administration, is working to improve climate information and forecasts for fire prevention and management, water resources and hazards, and human health. To evaluate the utility of this information, the program has identified and is collaborating with a selected set of partners at the federal, state, and local level to address the needs of these specific applications. The Climate Assessment Project for the Southwest (CLIMAS) was established to assess climate variability and longer-term climate change in terms of impacts on human and natural systems in the Southwest. The CLIMAS goal is to improve the ability of the region to respond sufficiently and appropriately to climatic events and climate changes. CLIMAS aims to foster participatory, iterative research involving researchers, decision makers, resource users, educators, and others who need more and better information about the nature, causes, and consequences of climate change and variability in the Southwestern United States. In support of these efforts, CLIMAS serves as a focal point for identifying and providing the climate variability and change information needs of stakeholders at the local, state, national, and international levels.

We are assisted by partners in DOI and USDA land management agencies. Tom Wordell of the Predictive Services branch of the National Interagency Fire Center (NIFC) has facilitated meetings, interviews, and the conduct of our survey at NIFC, the Joint Fire Sciences Program (JFSP) and various Geographic Area Coordinating Centers. This project also entails assistance from personnel in the fire management offices of Yosemite National Park and Sequoia-Kings Canyon National Park, the Cleveland, Sequoia, San Bernadino, Coconino, and Gila National Forests, and the

Northern and Southern California, Northwest, and Southwest Geographic Area Coordinating Centers of the National Interagency Coordinating Center at NIFC.

METHODOLOGY

CAP and CLIMAS will conduct a network analysis of communications and data flows with regard to strategic planning for fire management, and ascertain the decision calendar for key nodes and intersections in the management structure. This research involves the use of phone and personal interview techniques and semi-structured questionnaires; it also requires considerable background research.

1. Questionnaire and interview design will be undertaken jointly by CAP and CLIMAS.
2. This survey will focus on the National Interagency Fire Center (NIFC), Geographic Area Coordinating Centers (GACCs) and their advisory boards, and U.S. Forest Service (USFS) and National Park Service (NPS) structures at local FMO to national levels. Interviews will begin at the national level at NIFC and will be coordinated jointly by CLIMAS and CAP. Contacts with the GACCs and national USFS and NPS structures will be initiated through Predictive Services at NIFC. For surveys of management at regional and local levels, CAP will focus on the Southern California GACC and key USFS/NPS offices in that area. Likewise, CLIMAS will focus on the Southwest GACC and key USFS/NPS offices in that area.

The limited institutional and regional focus assumes that information from these groups will be representative of the system West-wide. Eventual expansion of this survey to other western GACCs in subsequent studies may be warranted if this assumption proves false. The current study will serve as a demonstration project.

RESEARCH QUESTIONS

a. What is the structure through which interactions occur (communications, flow of data) with regard to strategic planning and related decision making processes?

b. Who are the key people who participate in these communications and flows?

c. What kinds of strategic-planning related communications occur, about what, with whom, and at what time(s)? What communications venues are used (e.g. meetings, phone, email, formal written reporting processes, etc)?

d. Where are the key decision making nodes in the structure and who participates in making decisions at these points? What information is used to make the decisions at these points?

e. What is the decision calendar at each of these nodes (timing, nature of information needed, what lead times required, etc)?

f. Where are the key entry points for introducing climate information, and how can the information gathered in (e) best be introduced at these points? What research is needed to fill in gaps? What changes might need to be made to content, visualization, timing, etc. of existing products?

g. How can the findings of (f) be successfully carried out?

ACCOMPLISHMENTS

Thomas Corringham, a graduate student hired for this project, has conducted a wide-ranging review of the relevant literature for this study and assembled a literature review to support our analysis.

We have designed a short survey on the timing and information used in fire management decision making patterned after a similar survey conducted by the Western Water Association for water management.

We have thus far distributed surveys, conducted interviews, and/or led focus groups of personnel at

- Predictive Services and Intel Services at NIFC
- National Fire Director for the Park Service at NIFC
- Northwest Coordinating Center in Portland, Oregon
- Cleveland National Forest

- Yosemite National Park
- Sequoia National Park

We have interviewed personnel from the Northern and Southern California GACCs and from Park and Forest administrative units in California while at a California Firescope (16 April 2003, Sacramento, CA) and the National Seasonal Assessment Workshop, sponsored by the National Interagency Coordinating Center – Predictive Services Group and the Climate Assessment for the Southwest (Mesa, AZ, February 25-28, 2003).

Currently, we are transcribing and tabulating the results of these contacts. We have additional interviews to conduct, and then we will need to follow up on all of these contacts with phone and in-person interviews to clarify our findings.

CONCLUSIONS

We are making steady progress on this project. Our interview schedule is currently on hold, because our interviewees are busy with the peak of the 2003 fire season. We will be able to proceed to our final phases of interviews once the fire season begins to abate next month.

It is too early to draw extensive conclusions about our findings. However, we do note that, while we anticipated that the most important potential use of long range climate forecasts and information would be at the seasonal to annual scope for use in prescribed fire scheduling and budget planning, our interaction with our partners in the fire management agencies has led us to believe that there is significant scope for incorporating longer range information about climate variability and climate change into fire management planning.

This project will produce a decision calendar that can be used to understand cycles of decision making in wildfire management, and what climate information is or might be relevant for these decisions. This will help to identify existing climate information products that are currently used that might be improved for fire management purposes, as well as existing products that are not used but might be, and to identify avenues of research and development that might be of benefit to the fire management agencies.

EVALUATION OF THE USE OF 20-30 YEAR CLIMATE FORECASTS TO IMPROVE REGIONAL LONG-RANGE ENERGY MASTER PLANS IN SOUTHERN CALIFORNIA: A PRIVATE SECTOR/UNIVERSITY EFFORT

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Scripps Institution of Oceanography

TASK/THEME: 3A

SUMMARY

This report addresses the climate science portion of the project in collaboration with SAIC to factor long term climate forecasts into projections of energy supply and demand for southern California in the next 30 years. Hybrid dynamical-statistical forecasting methodology was developed and applied to estimate the effect of global climate change on regional temperature and precipitation statistics. Because energy consumed in southern California is produced by a network of power generation stations across the western United States, and because it is climatologically viable, the forecasts address climatic changes in the entire west. In this first report, anthropogenic changes in summer and winter seasons' temperatures and winter precipitation are projected for the first three decades of the 21st century.

Specifically, average daily minimum temperatures, as well as frequencies of daily cold extremes are projected for January-March while average daily maximum temperatures as well as frequencies of daily warm extremes are projected for July-September. A dynamical model (coupled ocean-land-atmosphere global circulation model, GCM) was used to estimate patterns of anthropogenic climate change as manifested in Pacific Ocean temperature for a historical period (1950-1999) and a statistical model was used to project these patterns onto temperature statistics observed at 84 stations across the western US. The statistical downscaling model trained on this fifty-year period was then used to project the patterns of model-estimated climate change on station temperature statistics. Below, we present the rationale, the methodology and the results of this investigation.

Total precipitation and frequencies of heavy daily precipitation events were also projected for January-March. This was done using a similar statistical model trained on the atmospheric circulation simulated for the historical period with the atmospheric component of the GCM forced with observed global Ocean temperatures. Because the western half of the northern hemisphere circulation was considered, the projection was made for the entire contiguous United States. The precipitation results and the rationale for the somewhat different forecasting approach are presented after the temperature results.

GENERATING A REALISTIC REGIONAL CLIMATE FORECAST

Statistical vs. Dynamical Downscaling

All anthropogenic climate change forecasts start with a dynamical global climate model (GCM) forecast. These models typically resolve 300X300 km squares (grid cells). A few such grid cells cover all of California. Regionally, even if these grid cells were accurate, such coarsely resolved climate information is useless for practical applications. An additional problem is that not all model variables are realistic. Precipitation and sub-seasonal temperature extremes, for example, are notoriously poorly modeled by GCMs. Furthermore, even for well-modeled variables, only large-scale patterns determined by many grid cells approach the truth, while individual grid cells are known to have strong biases and inconsistencies. In any case, a GCM forecast needs to be related or downscaled to useful regional information in such a way as to correct and/or minimize the effect of systematic bias, especially on the grid-cell level.

A typical downscaling approach involves nesting a finer-resolution regional dynamical model within the coarse GCM grid cells over a region of interest. A fundamental problem with dynamical downscaling is the well-known regional systematic inaccuracy of global models (see Gershunov and Barnett, 1998a, for example). In other words, nested regional dynamical models are driven by inaccurate grid cells of global models. Dynamical downscaling does nothing to correct GCM systematic biases, it merely downscales them. Statistical downscaling techniques, on the other hand, have been developed to correct GCM biases and shown to perform better than dynamical techniques in seasonal forecasting (Gershunov et al., 2000).

Statistical downscaling uses a statistical relationship between *large-scale* quality global model predictor variables (e.g. sea surface temperatures (SST) or atmospheric circulation) and observations of the regional predictand (e.g. temperatures or precipitation). Large-scale patterns drive the statistical downscaling model. GCMs are far from perfect, but they are good at simulating large-scale patterns in the ocean and atmosphere circulation. Since observed predictand data is used in training the statistical model, the large-scale forcing patterns from a GCM do not even need to be accurate, they need merely be consistent. The statistical downscaling model, therefore, is designed to correct GCM systematic biases. For these reasons, statistical downscaling models are much more skillful than dynamical ones in seasonal to interannual forecasting (Gershunov et al., 2000 and Gershunov and Cayan, 2002). For the same reasons, we expect statistical methods to perform better in downscaling regional effects of global anthropogenic climate change.

The combination of the GCM with statistical downscaling is termed the "hybrid" (i.e. dynamical/statistica) approach (see Appendix A). For studying regional effects of global anthropogenic climate change, two variants of the hybrid approach are possible:

1. The predictor field (e.g. SST) is derived from a "historical" coupled ocean-land-atmosphere model integration where the dynamical climate model is forced only by the observed anthropogenic signal, (i.e. increasing CO_2 and aerosols). Both the predictor and predictand (e.g. observed temperature) fields are filtered for long-term trends. A statistical model relating these two *filtered* fields is developed and used to project the future anthropogenic trend onto future regional predictand trends. The future anthropogenic trend in the predictor field is simulated in the same GCM, which is forced with the projected anthropogenic trends in CO_2 and aerosols. This is the approach we used to project the anthropogenic signal onto temperature statistics in the western US.

2. The predictor field (e.g. atmospheric circulation) is derived from an atmospheric model (the atmospheric component of the coupled GCM) forced with observed SST for the historical period. A statistical relation

between the *unfiltered* predictor and predictand fields is developed and used to project the future anthropogenic signal (simulated as in variant one) onto the predictand field. In this variant of the approach, the high-frequency variability is retained, but since in the future anthropogenic projection, only the long-term trends are expected to match reality, the final result is filtered. This is the approach we take to project anthropogenic changes in precipitation, which is intimately and directly related to atmospheric circulation.

Detailed information on the methodology and the GCM is found in Appendices A and B, respectively. The predictand variables considered here are derived from daily station data compiled by Eischeid et al., (2000). The results are presented and described below.

TEMPERATURE RESULTS

Western US temperature is a well-behaved homogeneous variable that shows clear relationships with Pacific SST. It also shows steady linear warming trends. The GCM used here is known to have successfully simulated the observed trend patterns of Pacific SST and subsurface heat content in the last fifty years (Barnett et al., 2001). The Pacific Ocean is well recognized to determine seasonal temperature statistics in western North America and is expected to be the primary agent of regional anthropogenic temperature changes. We, therefore, take SST trends in the tropical and north Pacific generated by the PCM historical run to be the predictor variable for western US temperature trends. Data from the last 50 years of the historical integration (1950-1999) are smoothed to extract the long-term trend and related to the long-term trend extracted from station temperature. SST anthropogenic trend patterns are then projected onto the future Pacific SST data from the climate change integration of the PCM and the station temperature changes out to 2030 are obtained by the statistical model trained on the historical period.

January – March Minimum Temperature

Western US temperature shows steady linear warming trends. As a matter of fact, one of the strongest trends that are most clearly attributed to anthropogenic forcing is a decreasing trend in diurnal temperature range (Tmax – Tmin) and this is occurring because daily temperature minima are warming faster than daily maxima (result not shown). Average January-March minimum temperature (Tmin) is a variable related to wintertime heating costs. The top panels of Figure 1 show the monotonic warming trend in both Pacific SST and Tmin in the Western US. The Pacific SST modeled anthropogenic signal (recall that it was obtained with a dynamical model forced only with observed CO_2 and aerosols) reaches 0.6 ºC/decade in the Gulf of Alaska (3ºC warming during the last half of the 20^{th} century) and less then 0.2ºC/decade elsewhere with cooling in the Bering Sea and the central north Pacific. This modeled anthropogenic signal bears similarity to the observed trend (not shown).

Wintertime Tmin has meanwhile been warming over most of the western US, notably in the mountainous west where warming reaches 0.5-0.7ºC/decade. In California, the observed warming has been on the order of 0.1-0.25ºC/decade, amounting to roughly one degree warming in the last 50 years in southern and coastal California. In southern and coastal California and in the northwest, about half of this warming trend can be attributed to anthropogenic causes by the statistical model relating these changes in modeled SST and observed Tmin trends (Figure 1d).

JANUARY-MARCH AVERAGE MINIMUM TEMPERATURE

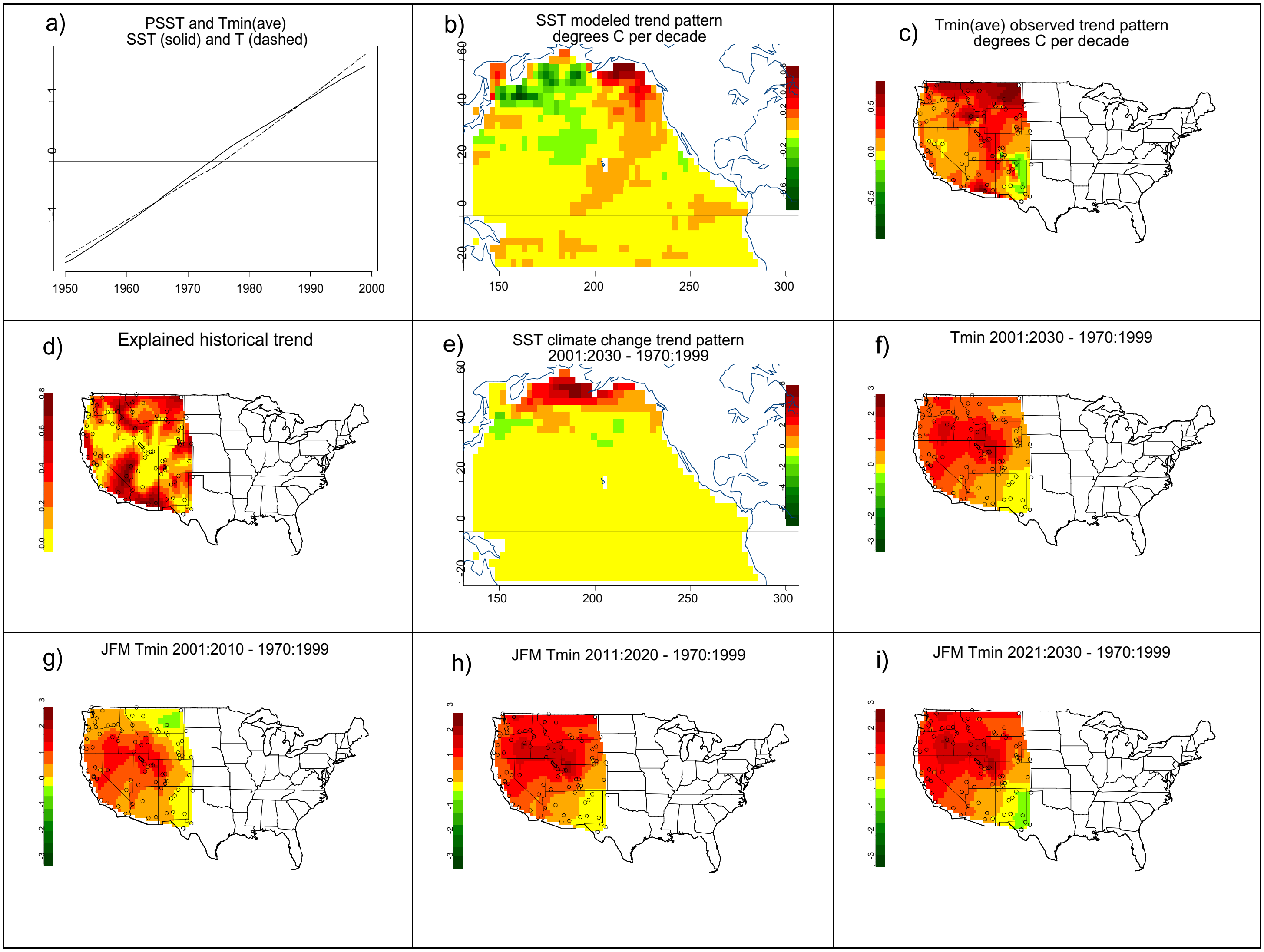

Figure 1. JFM average minimum temperature (Tmin). Coupled sea surface temperature (SST from the historical PCM run) and Tmin trend (a). The modeled anthropogenic SST trend pattern (b) and the observed Tmin pattern (c) expressed in degrees per decade. The skill of the statistical model in explaining the observed Tmin trend from the modeled anthropogenic Pacific SST signal expressed as correlation at each location (d). The projected climate change SST pattern (e) and the Tmin change pattern predicted from it (f), both expressed in ºC difference between the projected 30-yr 2001-2030 and 1970-1999 periods. Plates (g, h and i) show the progression of Tmin change by decade.

Projected average change in the first 30 years of the 21^{st} century amounts to strong warming in the far northern Pacific (up to 6ºC warming in the Bering sea, probably mainly due to melting sea ice), and continuing moderate warming of up to 1ºC mostly everywhere else as compared with the modeled Pacific SST of the last 30 years of the 20^{th} century (Figure 1e). Using the statistical model developed for the historical period, this pattern of SST warming projects onto a pattern of general warming of the western US shown in Figure 1f. This warming is a result of a projected monotonic trend (not shown) and can be broken down by decade (Figure1g,h,i) showing average minimum wintertime daily temperatures warming continuously spreading across the west. This warming amounts to less than 1ºC in southern California during the current decade, and grows to about 1.5ºC in the 2020's. Northern California is projected to be warmer (up to 1.5ºC in the 2000's and up to 2ºC in the 2020's). Generally, the warming is projected to spread and intensify from the central western US to the north amounting to up to 3ºC in the northwest but remaining moderate in the southwest.

January-March Daily Cold Extremes Frequency

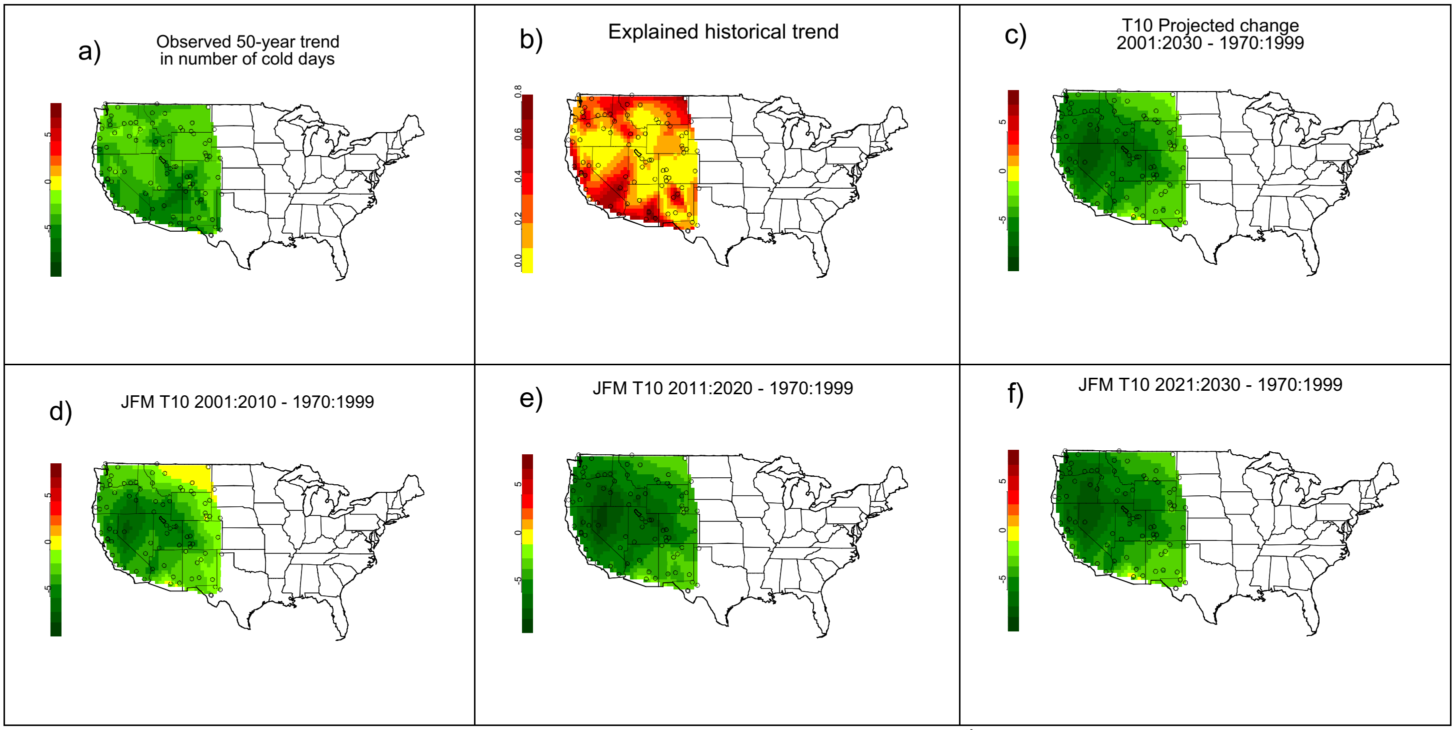

Figure 2. JFM frequency of cold minimum temperatures (below the local 10th percentile events, T10). The observed T10 trend in numbers of cold events (days/nights) (a). Skill of the statistical model explaining the observed T10 trend from the modeled anthropogenic Pacific SST signal (Figure 1b) expressed as correlation at each location (b). The projected T10 change pattern (c) predicted from the projected SST trend. T10 change is expressed in total number of cold events difference between the projected 30-yr 2001-2030 and 1970-1999 periods. Plates (d, e and f) show the progression of T10 change by decade.

Frequency of January – March Cold Extremes

For the January – March (JFM), we define a cold extreme event as a winter day with minimum temperature below the 10th percentile of the local daily observed JFM Tmin distribution. For the three-month season, the frequency of extremely cold days (or nights) is then defined as the number of such locally cold events in a season of (T10). Tmin is directly related to the impetus for turning on the heat in the winter. Figure 2 shows the observed and projected changes in T10, it does not show the wintertime modeled historical and projected Pacific SST trend patterns as they are the same as those shown in Figure 1.

The observed warming pattern is manifested in a general decrease of wintertime cold extremes amounting in southern California to about 5 events fewer per winter in the last 50 years of the 20th century, a decrease of about 50%) in the 1990's as compared to the 1950's (Figure 2a). More than half of this trend in southern California is attributed to the anthropogenic signal (Figure 2b).

The projected change is a continuing decrease in cold extremes. In southern California, it amounts to a loss of roughly 3-5 more cold extremes in the winters over the next three decades (Figure 2c-f). The warming trend accounts for a progressively greater decrease in the number of cold extremes further to the north (Figure 2d,e,f), where Pacific SST is projected to undergo a more drastic warming. In any case, the trend projected for the southwest is slower than that which has already been observed. This may be related to an anthropogenic increase in the variability of wintertime daily minimum temperatures.

July – September Maximum Temperature

As in winter, a significant anthropogenic warming of the Pacific has been modeled for the last 50 years (Figure 2a,b) and this warming has been reflected in JAS maximum average temperature, mostly in the northwest. In the summertime, modeled anthropogenic signal differs somewhat from the observed (not shown) and it is not as strong as the winter signal. A decrease in maximum temperatures has been observed mostly in the interior west (Figure 3c).

The observed signal in summertime Tmax is not as clear or homogeneous as the observed signal in wintertime Tmin (Figure 1c). However, the statistical model is able to explain much of the weaker observed trends by the anthropogenic signal (Figure 3d). Summer temperatures in the western US are more directly related to the Pacific SST than temperatures in winter. In the winter, large-scale, often remote sea-surface temperature patterns influence Pacific storm activity and the movement of air masses; while in the summer, Pacific SST more directly controls coastal temperatures by proximity.

In any case, the projected anthropogenic summertime Pacific SST warming translates to strong and rapid warming in the northwest (Figure 3f-i) by proximity to warmest projected SST in the north Pacific (Figure 3e). Most of the western US (Great Plains excluded) are projected to experience a summertime anthropogenic warming in maximum temperatures amounting to about 1°C in southern California, up to 4°C in the northwest by the 2030's (Figure 3i).

July-September Average Maximum Temperature

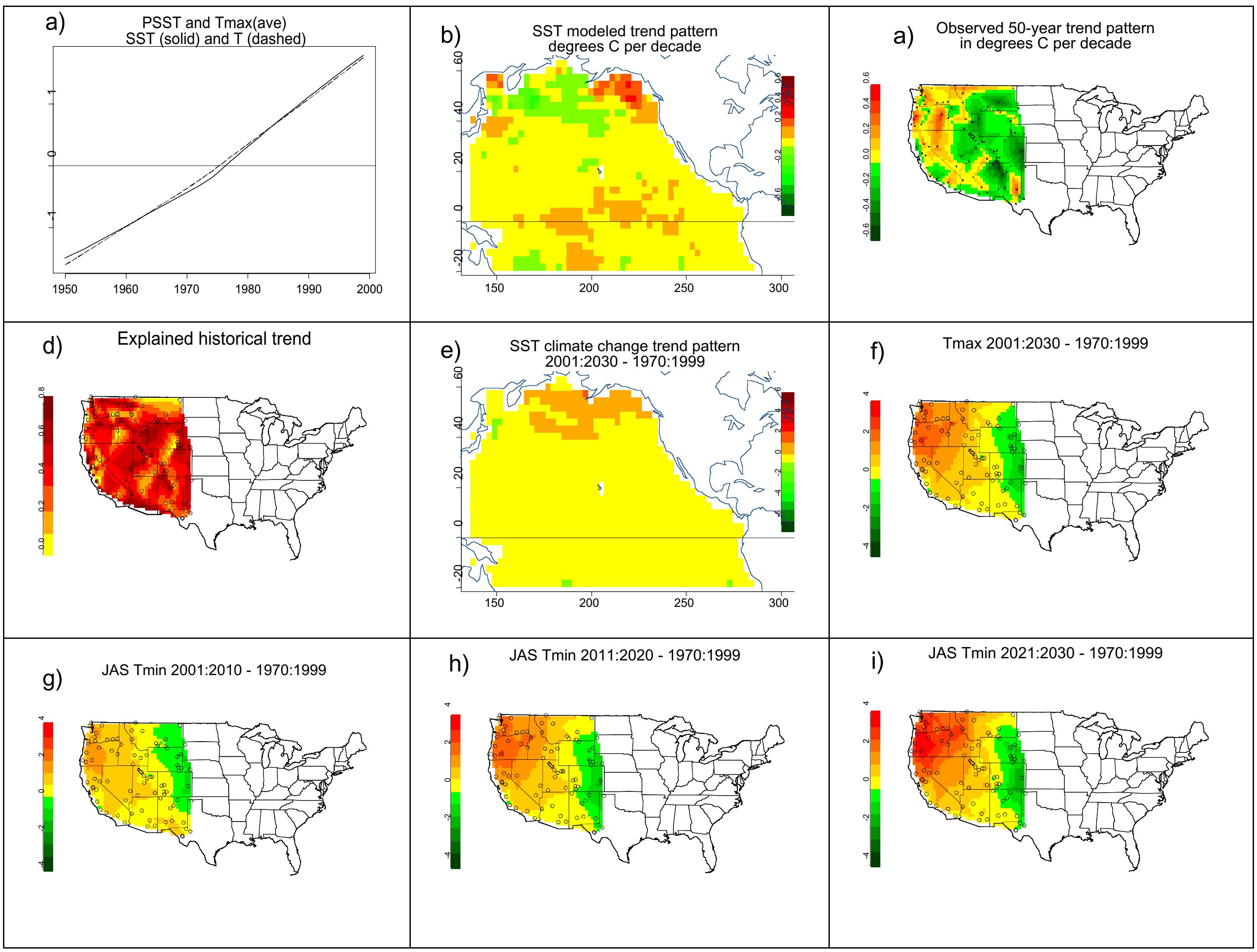

Figure 3. JAS average maximum temperature (Tmax). Same as Figure 1, but for JAS Tmax.

Frequency of July-September Warm Extremes

A warm extreme is defined as maximum daily temperature exceeding the 90th percentile of the JAS daily observed normal. The seasonal frequency of such extremes is termed "T90". T90 is directly related to energy demand for cooling in the summertime. Observed changes in T90 (Figure 4a) closely mirror observed Tmax changes (Figure 3c). Although some increases and decreases in summertime warm extremes have been observed (decreases notably

along the coast and in the interior west (Figure 4a) during the last 50 years) the projected Pacific warming (Figure 3e) translates into a strong and steady trend of significant increases in T90 along the California coast and especially in the interior of the state (Figure 4f) amounting to a doubling of warm extremes into the 2030's as compared to the last 30 years of the 20th century. Summertime warm extremes are, therefore, expected to respond strongly and consistently to anthropogenic climate change with obvious consequences for summertime energy demand.

July-September Daily Warm Extreme Frequency

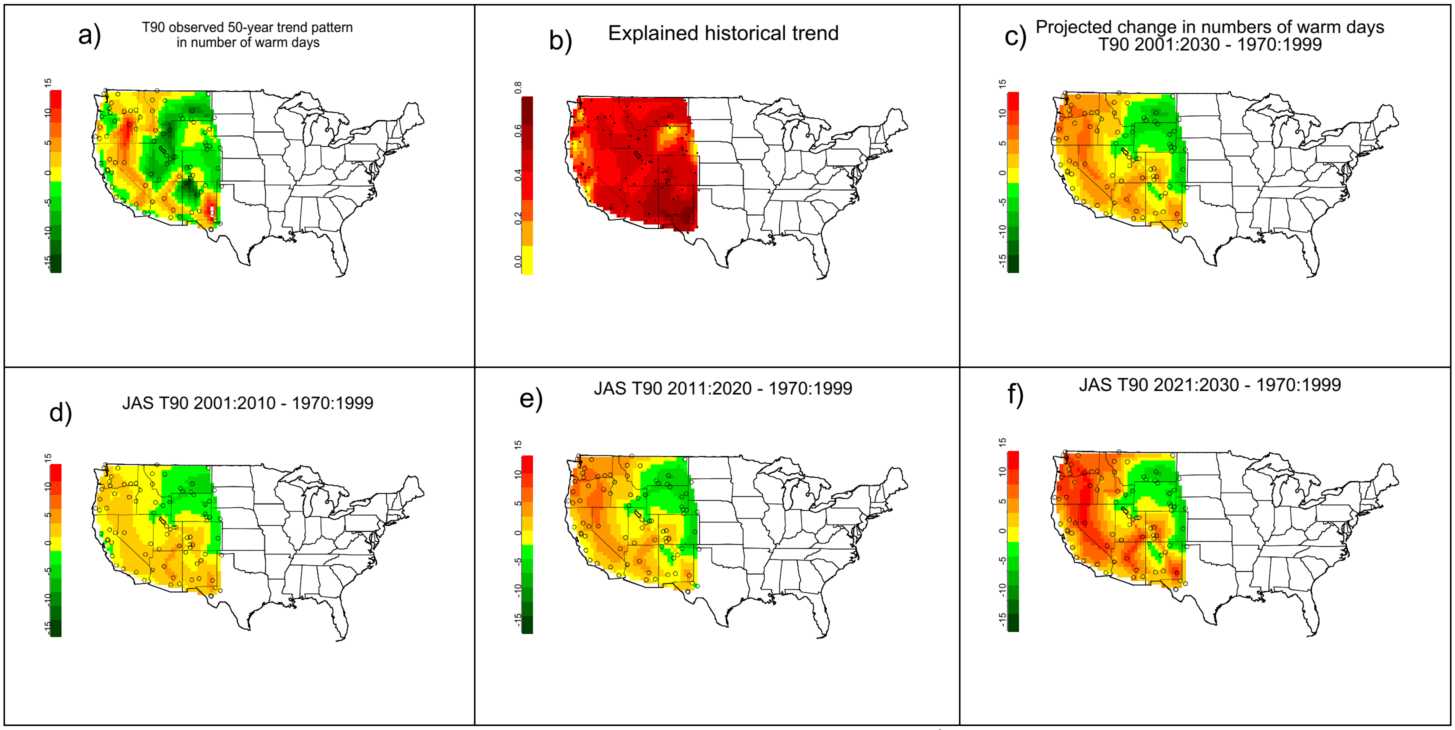

Figure 4. JAS frequency of warm maximum temperatures (above the local 90th percentile events, T90). Same as Figure 2 but for JAS T90. The relevant SST changes are shown in Figure 3 b and e.

PRECIPITATION RESULTS

Winter precipitation is related to winter, spring and summer streamflow and therefore to energy production. Winter precipitation patterns are produced directly by atmospheric circulation patterns. We therefore took an alternate approach to projecting anthropogenic changes in winter precipitation. The predictor was taken to be geopotential height field (500 millibar heights, or Z500) simulated by the atmospheric component of the coupled ocean-atmosphere dynamical model forced simply with observed global SST for the historical period (1950-1999). For consistency, this simulated Z500 field was scaled to the climatology of the coupled historical model run forced with the observed anthropogenic signal (CO_2 and aerosols). Because the forcing was observed global SST, we have confidence in the global historical Z500 patterns and the entire western half of the northern hemisphere (relevant for US precipitation) was considered. The statistical model was then developed between thus obtained unfiltered Z500 field and the entire contiguous US precipitation as observed at 262 stations for the historical period. This statistical model was then used to project the Z500 unfiltered field from the future climate change run unto station precipitation. The anthropogenic trend was then obtained by filtering this projection for low frequencies.

Wintertime Total Precipitation

The common trend in Z500 and total JFM precipitation (Ptot) is clearly seen in the leading coupled canonical correlation mode between the two fields (Figure 5a). This trend is superimposed on shorter timescales of El Nino-Southern Oscillation (ENSO). The Z500 and Ptot patterns associated with this interannual variability and trend are shown in Figure 5b as the correlation coefficient between the data and the time series of the leading coupled mode. Z500 has been increasing everywhere except above the far northern Pacific (notably right off the west coast) and the southern portion of the contiguous US. This ENSO-like pattern is clearly seen in the precipitation response (Figure 5b, colors). The Ptot trend (Figure 5c) closely resembles this ENSO-like pattern and this is why it is captured in the leading coupled mode. Ptot has been on the increase in the southern tier United States, notably in southern California and decreasing in the northwest and the Ohio River valley. Southern California has experienced winters up to 50% wetter in the past decade as compared to the 1950's. A significant portion of this trend and the shorter timescale variability is captured by the statistical model (Figure 5d).

The Z500 anthropogenic trend pattern projected for the next 30 years by the PCM (Figure 5e, contours) bears resemblance to the changes observed to have occurred. Not surprisingly, the hybrid forecast of the Ptot trend (Figure 5f) bears close resemblance to the observed Ptot changes during the historical period. The projected increase in southwestern precipitation is monotonic ranging from 10-30% of the 1970-1999 normal in the 2000's and 50-70% in the 2030's.

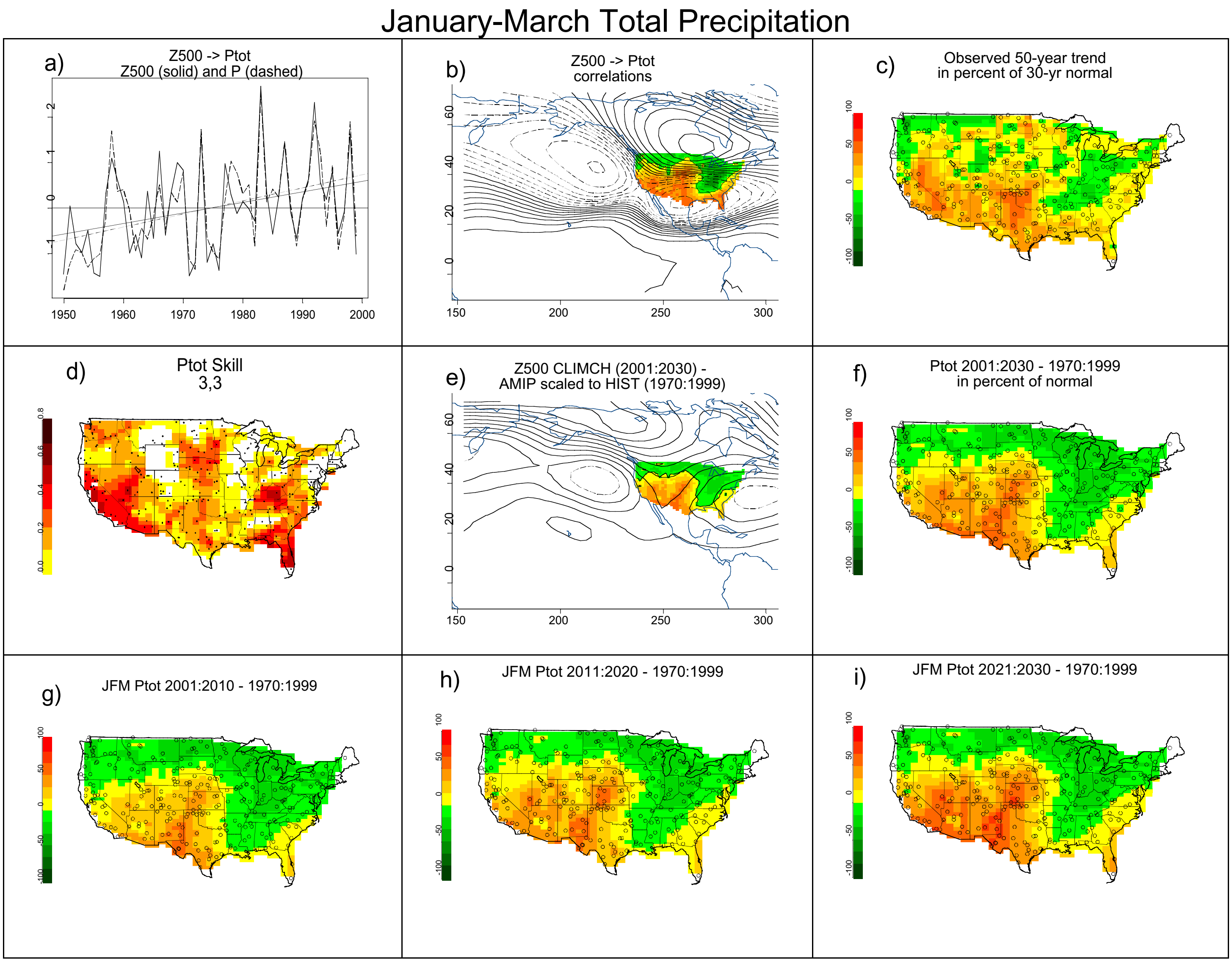

Figure 5. JFM total precipitation (Ptot). Leading mode of co-variability and trend of atmospheric circulation (500mb heights, Z500) from an AMIP run of the CCM3 (the atmospheric component of the PCM forced with observed global SST) and Ptot (a). The leading coupled pattern of Z500 and the observed P90 (b) expressed as correlations between the data and the time series in (a). Contours are drawn at 0.1 intervals, negative contours are dashed. The observed Ptot trend expressed in percent of normal local precipitation for the 1971-1999 period (c). The skill of the statistical model in explaining the observed Ptot trend from the modeled-simulated Z500 signal expressed as correlation at each location (d). The projected climate change pattern in Z500 (e) and the Ptot change pattern predicted from it (e and f), both expressed in difference between the projected 30-yr 2001-2030 and 1970-1999 periods (contours on plate e are drawn every 5 meters, negative contours are dashed). Plates (g, h and i) show the progression of Ptot change by decade.

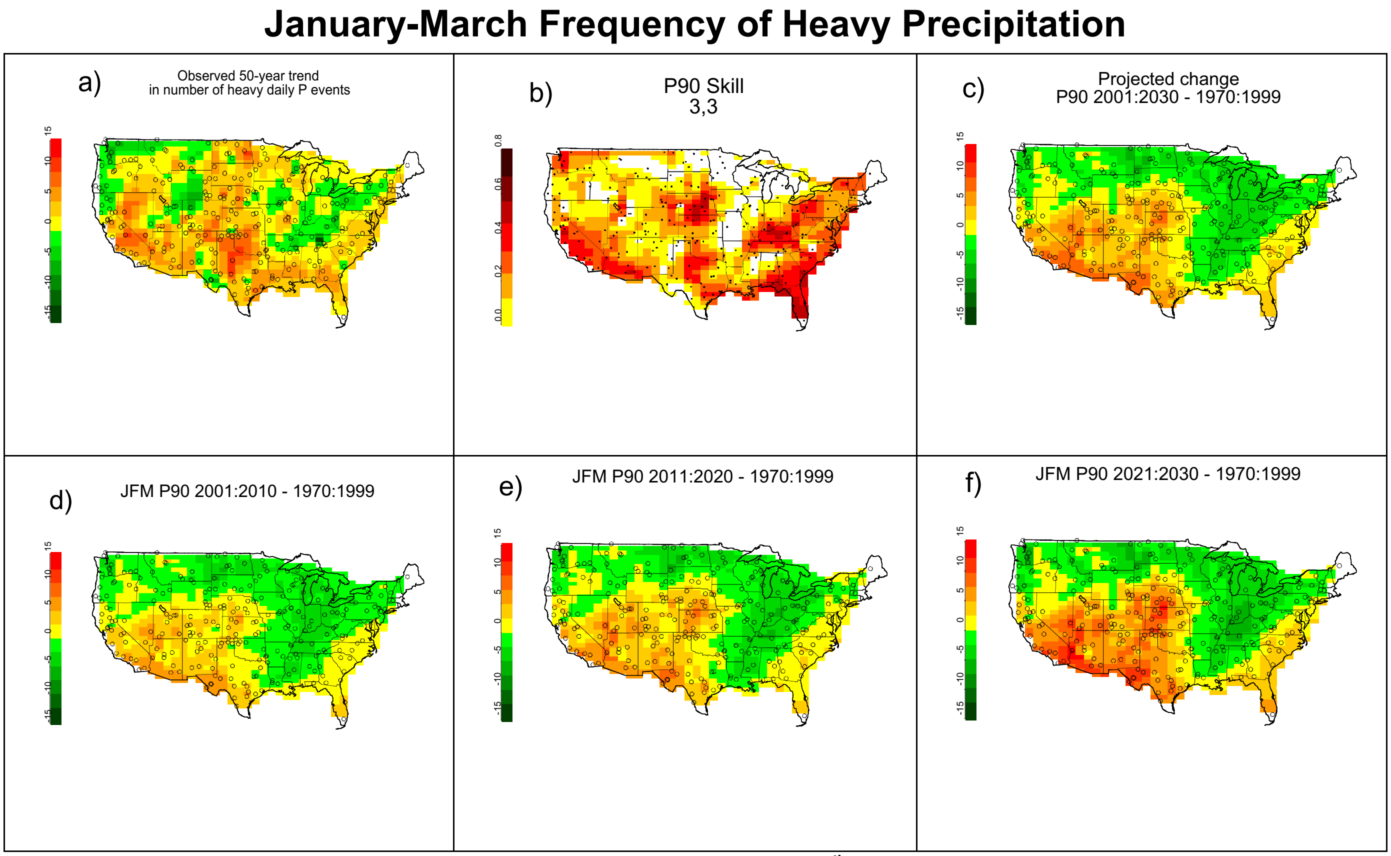

Figure 6. JFM frequency of heavy precipitation (above the local 90th percentile events, P90). Same as Figure 2 but for P90. The relevant Z500 changes are shown in Figure 5 b and e. Co-variability and trend are similar to Figure 5a.

Wintertime Heavy Precipitation Frequency

Wintertime heavy precipitation is defined as the daily JFM precipitation amount exceeding the 90th percentile of the daily JFM historical normal. Observed changes in the frequency of heavy precipitation (P90, Figure 6a) closely resemble those for Ptot, as Ptot is largely made up of heavy events and the same Z500 patterns are responsible for P90 variability and trend. It is projected that heavy precipitation will increase in the southwest by up to 10 events per winter during the first 30 years of our century as compared to the last 30 years of the last (Figure 6c). This increase is expected to be monotonic as seen in Figure 6d-f.

SUMMARY

Although, these results represent a reasonable approach to the problem of regional anthropogenic climate estimation compared to other approaches currently in use (see Appendix A), they must be taken with caution, as no long-term projection of expected anthropogenic change is a perfect forecast. Although skill estimated for the historical period is a benchmark, future climate change skill is difficult to estimate and it most certainly depends on the dynamical model chosen. Our statistical methodology was developed to correct as much as possible the systematic biases in the dynamical model, but, although, these results may represent the best projection currently available, it is difficult to say exactly how good this projection is. Moreover, the predicted trends cannot take into account interannual and decadal non-anthropogenic variability. This natural variability can in some decades greatly enhance or reduce, even reverse the anthropogenic trend. Although possible, such misbehavior was not seen to be an obvious problem in our experience with the PCM projection for the first 30 years of the 21st century. However, it must also be kept in mind that not all of the observed historical trend can be attributed to anthropogenic causes.

The proximity of the Pacific Ocean exerts a moderating, as well as controlling effect on western US temperature. In the Pacific sector, SST influence is more related to the passage of storms over the western US and to the exchange of warm/humid and cold/dry air masses between the tropics and the polar belt. In the summer, when midlatitude storms are less frequent, Pacific SST affects western US temperatures (especially along the coast) more directly.

The temperature results can be summarized as follows:

- Projected warming of wintertime minimum temperatures is moderate (~1ºC) in southern California, but larger (~2ºC) in the northwest. This warming trend can be expected to continue throughout our current century.
- Wintertime cold extremes have undergone a substantial decrease in the last 50 years, a trend that is expected to continue at a slower pace during the next 30 years. This trend is not so much of a factor in the southwest, where much of the decrease in cold extreme frequencies, beyond what can be attributed to anthropogenic influences, appears to already have taken place.
- Summertime maximum temperatures are expected to increase moderately in southern California (up to 1ºC), but strongly in the northwest (up to 4ºC) where warmer projected SST in the far north Pacific should exert a strong direct influence.
- Summertime warm extremes are expected to respond strongly to anthropogenic climate change resulting in more frequent air conditioning use in southern California along the coast, but especially inland where warm extreme frequency is projected to increase two-fold by the 2030's.

Precipitation is a much less homogeneous variable than temperature. It is more directly related to atmospheric circulation than to SST. Projected January-March precipitation changes can be summarized as follows:

- Total precipitation is projected to continue increasing in the southern tier United States, and decrease in the northwest and in the Ohio River valley. The changes in the southwest are expected to be steady monotonic ranging from 10-30% of the 1970-1999 normal in the 2000's and 50-70% in the 2030's.
- Changes in the frequency of heavy precipitation events are projected to mirror those in total precipitation as these heavy events largely make up total precipitation. The anthropogenic trend in the southwest is projected to result in a roughly two-fold increase in the frequency of heavy precipitation events by the 2030's as compared with the 1970-1999 normal.

APPENDIX A: DESCRIPTION OF HYBRID DYNAMICAL-STATISTICAL METHODOLOGY

The hybrid method involves a global dynamical model forecast statistically downscaled to a region of interest. Hybrid methodology (e.g. Gershunov et al., 2000) was applied to estimate and downscale the parameters describing seasonal rainfall and temperature statistics under in an anthropogenically-changed climate. This was done through the application of a canonical correlation analysis (CCA: Barnett and Preisendorfer, 1987) model that matches patterns in the predictor with patterns in the predictand fields.

Essentially, the approach consists of two steps. First, a GCM historical run (either historical CO_2 and aerosol trend-based coupled GCM or the atmospheric GCM component [AGCM] forced with observed SST) is used to define a statistical relationship between the model large-scale circulation (e.g. 500 mb heights) and observations of a variable of interest at the station level. Then, an anthropogenic change estimation of the variable of interest is obtained by running the same AGCM coupled to an ocean and land surface models forced with anthropogenically increased CO_2. The statistical relationship obtained in step one is used to downscale the dynamically forecast large-scale circulation to the variable of interest at the station level. Eighty-four stations with five decades of daily records were used to describe temperatures in the western US.

The hybrid approach works for several reasons: (1) the predictor variables from the AGCM (e.g. geopotential heights) are the best behaved variables in the model and only the large-scale patterns of these variables (not individual grid cells) are important, while seasonal statistics of daily temperature and precipitation (the predictand variables) are poorly modeled by dynamical models even on the large scales and especially regionally (Gershunov and Barnett, 1998a); (2) while the AGCM is free to respond to nuances as well as to previously unobserved structures of the SST forcing field, the statistical downscaling component trained on observed data keeps the estimation stable and realistic. Moreover, the implicit inclusion of observed and modeled trends that are known to exist in the global predictors and regional predictands, especially in Southern California (Gershunov and Cayan, 2002) guarantee that the hybrid scheme has the correct sensitivity to global climate change. For these reasons, we expect the performance of the hybrid forecasting methodology to be superior to other methods currently in use, which are driven by grid-cell-level GCM estimations of variables known to be poorly simulated by GCMs at face value.

The downscaling system is seasonally based, but seasonally aggregated daily temperature statistics (e.g. seasonal means, standard deviation of daily values, frequencies of daily extremes, heating and cooling degree days, etc.) are all legitimate predictands provided that daily observations exist to train the statistical model. Our experience suggests that for cold season precipitation, the large-scale atmospheric circulation is be an adequate predictor, while for temperature, especially during the warm season, sea surface temperature is important. These predictands were obtained from an AMIP-type and historical anthropogenic change atmospheric GCM experiment (AGCM driven with observed SST and a coupled GCM driven with observed radiative anthropogenic signal, respectively) covering the same time period as the observations, i.e. the last half of the 21^{st} century.

The statistical relationship (CCA: Barnett and Preisendorfer, 1987) estimated on this historical/observational period was then used to downscale from a climate change simulation, provided the GCM in the simulation is the same as the one used in the statistical model training (historical simulation). Gershunov et al., (2000) compared the hybrid forecasting approach with the nested regional dynamical model downscaling approach in the context of ENSO-based forecasts and found that the hybrid approach is far superior in many respects including skill and computational efficiency. This result translates directly to the anthropogenic climate change context.

APPENDIX B: THE COUPLED DYNAMICAL OCEAN-LAND-ATMOSPHERE CLIMATE MODEL

The PCM (Washington et al., 2000) is a numerical model of the global climate system that couples atmospheric, ocean, sea-ice, and land-surface components. The PCM realistically represents historical climate variability and accurately simulates observed long-term rises in the temperature of the world's oceans (Washington et al., 2000; Barnett et al., 2001). The atmospheric component is a parallelized version of the National Center for Atmospheric Research's Community Climate Model version 3 run at horizontal resolution of T42 (about 2.9° in latitude and longitude) with 18 hybrid levels in the vertical (Kiehl et al., 1998; Hack et al., 1998). Initial conditions and radiative forcings for the PCM simulations were developed to provide for realistic historical and future climates with minimal spin-up problems from slowly evolving ocean conditions.

Atmospheric circulation fields used as precipitation predictors are 500mb heights from CCM3 AGCM (the atmospheric component of PCM), run in AMIP mode (forced with observed global SST) for the period 1950-1999. AGCM data are 10-member ensemble averages resolved on the T42 grid (roughly 2.8° x 2.8°). These are “base” runs that form the climatology for making anomalies for the International Research Institute for Climate Prediction (IRI) forecasts.

The PCM HIST (historical) simulation was initiated from realistic, modern (1996) ocean conditions and then spun up for at least 5 years, prior to commencement of the "actual" simulations with radiative forcings characteristic of the year 1870. For purposes here, we begin analysis in 1950, allowing yet another 80 years for various model components to come into dynamic agreement with each other. This historical simulation represents another realization of the climate during the 20^{th} Century with only the time-dependent historical concentrations of greenhouse gasses and sulfate aerosols specified.

The future-climate simulation studied was initiated from a data-assimilated estimate of ocean salinity and temperature conditions for the year 1996 (from D. Stammer, Scripps Institution of Oceanography), spun up for 5 years, and then allowed to simulate variations of the global climate system during the 21^{st} Century with FC greenhouse gasses and sulfate aerosols held constant to increase a "business-as-usual" scenario. This BAU scenario is the same as described by Dai et al., 2001, is similar to the Intergovernmental Panel on Climate Change's (IPCC's) "IS92a" scenario (Leggett et al., 1992), and is roughly in the center of the spectrum of published possible scenarios of future greenhouse-gas and sulfate-aerosol concentrations during 21^{st} Century.

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TRAVEL SUPPORT FOR INTERNATIONAL RSM WORKSHOP

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TASK/THEME: 3A

Figure 1. Front Row (l to r): D. Chen, C. Shiao, H. Kanamaru, L. Sun, J. Roads, M. Kanamitsu, S. Brenner, S. Hong, A. Bamzai, T. Reichler. 2nd Row (l to r): H. Juang, H. Seo, A. Ruane, G. Geernaert, O. Ndiaye, J. Kao, J. Vergara, J. Kim, J. Chen, D. Moncunill, A. Kao. 3rd Row (l to r): H. Yuan, J. Han, Y. Cui, S. Chen, V. Misra. Not shown: (V. Rasic, J. Reisner, K. Costigaan).

SUMMARY

The 4th International Regional Spectral Model (RSM) Workshop, which was hosted by Los Alamos Institute for Geophysics and Planetary Physics, the Scripps Experimental Climate Prediction Center, the International Research Institute, and NOAA's Office of Global Programs, was held at Los Alamos, NM, 7/31-8/02, 2002. This workshop was attended (**Figure 1**) by over 25 participants from over 11 countries (Brazil, Canada, Chile, China, Croatia, Germany, India, Japan, Korea, Senegal, Taiwan).

The major purpose of this international workshop was to discuss the RSM, which was originally developed (Juang and Kanamitsu, 1994; see also Juang et al., 1997) at the National Centers for Environmental Prediction (NCEP) to provide regional details for the NCEP global spectral model (GSM). Since the RSM uses the same physics and code structure as the NCEP GSM, the workshop not only discussed the RSM but also the parent GSM. A growing number of users are now using the RSM to simulate and forecast regional climate in a variety of regions. These regional simulations and forecasts are thus helping the atmospheric modeling community to better connect to various application communities, which need the highest resolution possible. Our goal at this workshop was to attempt to better organize and communicate some of the features of our individual GSM and RSM model setups, biases, and numerical techniques for various regional climate (and weather) simulations.

As is traditional at these workshops, the first day was devoted to tutorials and updates on the basic model by J. Han, H. Juang, and M. Kanamitsu. S. Chen and L. Sun also described the Scripps Experimental Climate Prediction Center and International Research Institute's global to regional modeling system.

The second and third day were then devoted to presentations by individual users describing their particular regional applications over Africa, South America (Brazil and Chile), the Mediterranean, Taiwan, India, Hawaii, and the mainland US. Aspects of the parent global spectral model were also briefly discussed in a few presentations. Besides traditional meteorological investigations, applications of the RSM to land surface, oceans, and hurricane models were also discussed. Along with the program and abstracts, some of the RSM presentations can be found at

http://ecpc.ucsd.edu/projects/RSM/RSM2002/.

On the last day of the international workshop, the participants discussed a number of general issues.

At previous workshops many presentations had noted precipitation excess on mountaintops. It was suggested at this workshop that this excess precipitation might be related to the way horizontal diffusion was currently handled in the RSM and that an explicit diffusion on pressure surfaces should be implemented. Although this change did reduce the bias, the RSM community did not uniformly accept it since to accurately include this horizontal pressure diffusion term requires triple products, which are aliased by the RSM transform grid. An alternative suggestion to simply remove the horizontal diffusion of moisture was also not uniformly accepted since some simulations had previously shown this allowed too much spectral noise. Suffice it to say that more work is still needed to solve this general problem.

Another bothersome issue is that there are now two versions of the RSM, RSM97 and RSM/CVS. RSM/CVS is the one most being actively developed and changed. Similar changes and development for RSM97 only occur much later as voluntary time and resources permit. In addition, RSM97 still has some additional capabilities, like the nonhydrostatic version developed by Juang (2000) that is needed by some users. However, RSM97 will eventually stop being supported and it is important that users be prepared to switch to the new RSM/CVS in the near future.

To help coordinate RSM community activities, the Scripps ECPC is in the process of hiring a new postdoc to become the new RSM model master to replace Dr. Han (current RSM model master), who has since taken another full time job at NCEP. The RSM model master will further develop the RSM home page (http://ecpc.ucsd.edu/projects/RSM/), including the basic user manuals, instructions on downloading the publicly available RSM models, maintaining a mailing list of active users, posting announcements of upcoming conferences and employment opportunities, and posting a periodic summary of updates and bug fixes. Two user lists have been established (rsmusers@ecpc.ucsd.edu for information relevant to the general RSM user community and rsmcvsusers@ecpc.ucsd.edu for users interested in immediate notifications of immediate fixes within the CVS system). Another list for users of the parent GSM has also been established (gsmcvsusers@ecpc.ucsd.edu).

Finally, the 5th International RSM workshop is now being planned to take place in Seoul, Korea, Jul. 14-17 (following the 2003 IUGG meeting in Sapporo, Japan). Local arrangements will be finalized in the next few months by the local host (Dr. Song-You Hong) and then the 1st announcement will be sent to the RSM users and posted on the RSM home page (http://ecpc.ucsd.edu/projects/RSM/). Selected papers presented at the upcoming Korea workshop, will be submitted to a special issue of the Korean J. Meteor. Future international workshops in Chile and China are also being planned.

Additional researchers are welcome to the next workshop. We note that the RSM users workshop has continued to increase in size as the international community has come to appreciate the advantages of this particular regional modeling system. We also note that the workshop is beginning to attract users and developers of the parent GSM, which has similar structure and parameterizations as the RSM.

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NORTH PACIFIC RIGHT WHALE ACOUSTIC RECORDING
AND
ACOUSTIC STUDIES OF RIGHT WHALES IN THE BERING SEA
AND
MARINE MAMMAL ACOUSTIC RECORDING PACKAGES

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TASK/THEME: 2B

OBJECTIVES

The objective of these projects were to make acoustic recordings of north Pacific right whales (*Balaena glacialis*) in the Bering Sea region. These whales are on the endangered species list, and less than 50 of them are thought to remain. Acoustic recording provides an efficient means to monitor for their presence. The ultimate goal of this research is an acoustic census of North Pacific right whales.

SUMMARY

In 2000 four acoustic recording packages (ARPs) were deployed in the Bering Sea to record right whales. In 2001 two of these ARPs were recovered by ship and two were returned by discovery, providing data over 7 months on four instruments. Also in 2001 two acoustic recording packages were re-deployed in the Bering Sea. In 2002 we attempted recovery of both ARPs by ship (without success), however one ARP was later recovered by discovery, providing a record of acoustic data from fall 2001 – Summer 2002. We have analyzed these data for right whale calls and find that they are present in the Bering Sea as early as May and as late as November. The ARP data provide the only monitoring that has been conducted during the winter season, when shipboard visual surveying is difficult due to poor weather conditions.

RESEARCH ACCOMPLISHMENTS

Field Work/Data Collection

In July and August 2002, SIO Graduate Student Lisa Munger and Specialist Allan Sauter participated on a NMFS/NMML cetacean research cruise in the Gulf of Alaska and Bering Sea. The first priority of the cruise was to locate North Pacific right whales (*Eubalaena japonica*) and obtain photographs, skin biopsy samples, and acoustic recordings. Directional (DIFAR) sonobuoys were deployed to listen for calling right whales and direct the ship to them when possible.

The total ship time in the Bering Sea was about four weeks, during which approximately 250 hours of data were recorded using DIFAR sonobuoys. We recorded calls from right whales, fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera noveangliae*), and killer whales (*Orcinus orca*). During the July portion of the cruise, right whales were detected on four occasions acoustically but not visually. During the August portion of the cruise, the visual observation team sighted right whales on four occasions, two of which were directed by initial acoustic detections.

At the end of July, Lisa Munger disembarked in Dutch Harbor, AK, to retrieve data disks from the fourth long-term acoustic recording package (ARP) deployed in 2000 in the southeast Bering Sea. This instrument had drifted from its deployment site and was found by a fishing vessel in waters near the Russian border. Already in our possession were two ARPs recovered by ship in 2001, and one ARP that was found on a beach near Nelson Lagoon and recovered in Spring 2002. Having data from all four ARPs from 2000-2001 increases the precision with which we can localize and track calling animals recorded on multiple instruments. The recording period of the first ARP array was from October 2000 through April 2001 (one instrument ceased recording in December 2000).

Data Processing

Sonobuoy Recordings

Recordings made by sonobuoys during the summer 2002 cruise are currently being analyzed. We will use these recordings to describe/quantify right whale call types and temporal calling patterns. We will also use visual and genetic data from the cruise to corroborate locations and numbers of animals, and to examine variation in calling behavior with group size, composition, and behavior. Information on calling behavior will be vital to developing abundance estimates based on ARP array recordings, as discussed later.

Additionally, we are beginning to model the propagation of baleen whale calls in the Bering Sea, based on cruise data where recordings were made from whales with known locations. These models can then be applied to ARP array data to locate and track calling whales throughout the long-term, continuous recording period of Fall 2000-Spring 2001. Whale localization techniques will also ultimately aid in abundance estimates based on ARP recordings.

ARP Recordings

In Fall 2002, we developed an automated right whale call detector and used it to screen data from the four ARPs for potential right whale calls. The call detector is based on spectrogram correlation, provided in the software Ishmael (written by David Mellinger at NOAA/PMEL and OSU). The detector is modeled after the predominant "up-call" described for Bering Sea right whales (McDonald and Moore, 2002). Humpback whale calls that overlap in frequency and duration were also detected by the right whale spectrogram correlator.

Detections made by Ishmael are then reviewed by a researcher to verify calls and identify species. Criteria that we use to distinguish right whale calls from humpback whale calls include frequency and duration characteristics of calls, as well as temporal calling patterns known for the two species. Right whales are not known to 'sing', and calls tend to occur in irregular bouts, whereas humpback whales call in repetitive phrases.

We are also developing several methods to locate and track whales recorded by multiple instruments in the ARP array. Travel time inversion is one such method, where call arrival times and the speed of sound in the Bering Sea are used to find ranges to the sound source and triangulate the animal's position from three or more instruments. Another example is using modal dispersion of calls to estimate range to calling animals. This second technique relies on cruise data to calibrate the extent of modal dispersion with known distances to a calling animal. Other techniques to locate whales recorded by ARPs include match-field processing, hyberbolic localization, and beam forming.

These localization techniques, combined with information on calling behavior gained from cruises, will enable us to estimate abundance of right whales based on fixed acoustic array recordings. The long-term acoustic data set also allows us to describe temporal changes in right whale abundance and distribution in the southeast Bering Sea. These changes will then be examined in the context of other available oceanographic data sets, such as data on productivity and circulation, to more fully understand right whale ecology. We are currently downloading SeaWIFS data (satellite data on surface chlorophyll concentration) and also plan to examine satellite altimetry data, for the southeast Bering during our ARP recording period.

Findings

Preliminary findings have yielded new information about seasonal distribution and temporal calling patterns of right whales in the Bering Sea. Right whale call recordings on ARPs were detected and verified by eye through October and into early November, suggesting that right whales are present in the Bering Sea later in the year than previously thought. In addition, we have found that right whales call more frequently at night than during the day. This was true during the NMFS summer 2002 cruise as well as on ARP recordings. The ARP recordings showed peak calling times corresponding to dawn and dusk hours, which were not apparent on sonobuoy recordings from summer 2002.

COLLECTION AND ANALYSIS OF CETACEAN SOUNDS COLLECTED IN THE ANTARCTIC

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TASK/THEME: 2B

OBJECTIVES

This project made acoustic recordings of whales and dolphins in the Antarctic, in collaboration with the Australian Antarctic Division. The goal of this project is to gain knowledge of sounds made by various species of marine mammal, so that acoustic data can be used for marine mammal population assessment. Data are especially lacking for remote areas such as the Antarctic. An opportunity to collect data in the Antarctic was provided by working with the Australian Antarctic Division during a cruise to Mawson Station on the Research Vessel *Aurora.*

SUMMARY

In January-February 2003 a graduate student (Julie Oswald) was sent aboard the Australian icebreaker *Aurora* in Antarctic waters. She collected hundreds of hours of acoustic recordings using Navy surplus sonobuoys. Various species of marine mammals were encountered including humpback, sperm, leopard seal, pilot whales and various dolphins.

RESEARCH ACCOMPLISHMENTS

We are studying these data to detail sound characteristic for various Antarctic marine mammals. The frequency content and duration characteristics of these calls are being studied to allow them to be separated by marine mammal species.

ACOUSTIC SURVEY OF MARINE MAMMALS OFF EASTERN SEABOARD USING TWO TOWED ARRAYS

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TASK/THEME: 2B

OBJECTIVES

The fundamental objective of the project is the development of a passive two-dimensional acoustic tracking algorithm for free-ranging dolphins, using two towed arrays deployed behind a survey ship, and exploiting certain properties of a particular dolphin sound called a “whistle.” The algorithm would be of interest in future acoustic censuses of dolphins, by providing an acoustic estimate of group size. The algorithm would also be useful for future studies of potential social interactions between individuals.

SUMMARY

During February 2002 Dr. Thode participated in a cetacean survey cruise off the Atlantic Seaboard, in order to collect acoustic data from free-ranging dolphins. The survey was conducted off the R/V Gordon Gunter, operated by the National Marine Fisheries Service, Southeast Branch. The data were recorded at night on two towed arrays spatially separated by 350 m. A cumulative total of 20 hours of sounds from dolphin schools were recorded, along with multiple additional recordings of sperm whales and various species of odontocetes. Anthony Martinez led the overall acoustic effort, assisted by Jack Stamates.

Dr. Thode, with assistance from Eric Howarth of San Diego State University, then wrote a program in MATLAB that scans the acoustic data for dolphin whistles, while ignoring ship noise and echolocation clicks. As the whistles are recorded on two hydrophones, it is possible to estimate the bearing from which the whistle arrives. By combining bearings from two arrays, a cross fix is obtained, yielding a 2-D position for each whistle. The procedure differs from other work on dolphin acoustic localization in that it operates in the frequency domain, as opposed to the time domain. As a result the algorithm is completely automated, and is not stymied by overlapping (simultaneous) whistle contour.

RESEARCH ACCOMPLISHMENTS

As of July 2003, the tracking algorithm had been completed. Figure 1 shows a spectrogram of acoustic data collected around midnight on February 17, which illustrates representative acoustic data recorded during an encounter with a dolphin school. Ship noise, echolocation clicks, and overlapping whistles are visible in the raw spectrogram in the top subplot. The bottom subplot shows the results of the whistle detection algorithm. A bearing from each contour is computed automatically.

When the analysis is repeated on the second array, a set of 2-D locations of dolphin whistles can be derived, as shown in Figure 1. Each color group represents a 15 s interval. It can be seen that a group of animals can be tracked moving past the ship. The MATLAB algorithms have been tested on other data sets, and have been donated to other dolphin researchers for free. The algorithms will also be posted on a website in the near future.

PUBLICATIONS

Automated two dimensional passive tracking of free-ranging dolphins using two towed arrays and frequency-domain beamforming," by Aaron Thode, Eric Howarth, and Anthony Martinez. Abstract. Presented to 144th meeting of the Acoustical Society of America, Dec. 2002, Cancun, Mexico.

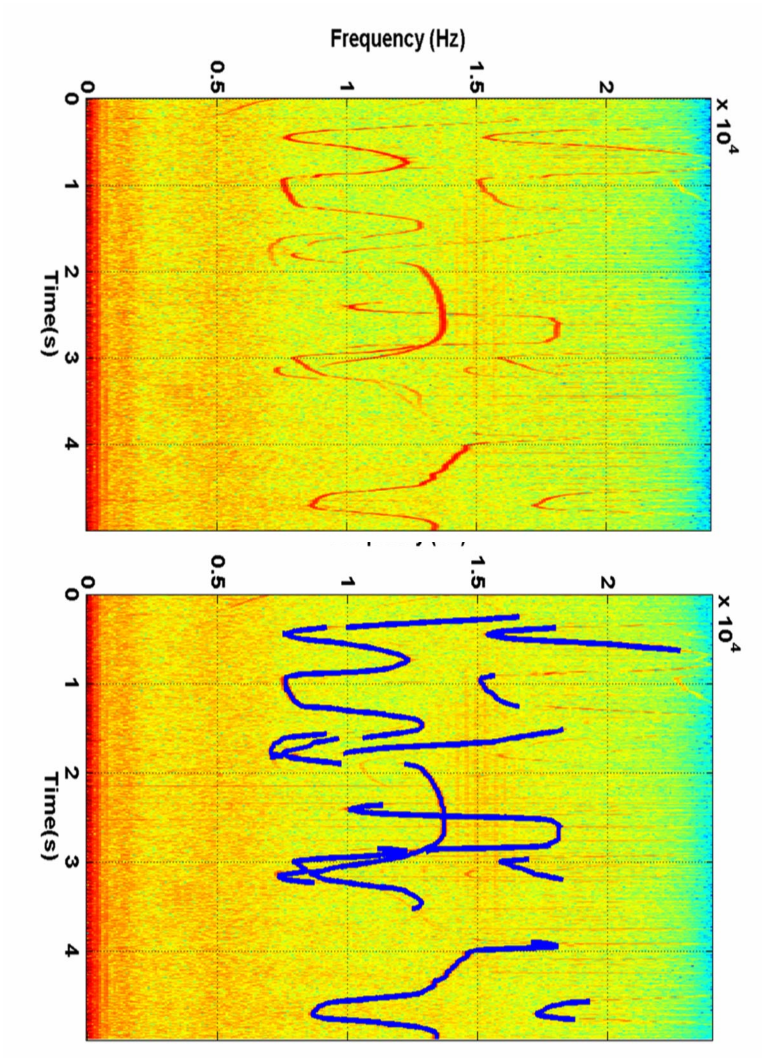

Figure 1. (top) Spectrogram of sample dolphin sounds collected on Feb. 17, 2002, (bottom) Output of whistle contour detection procedure.

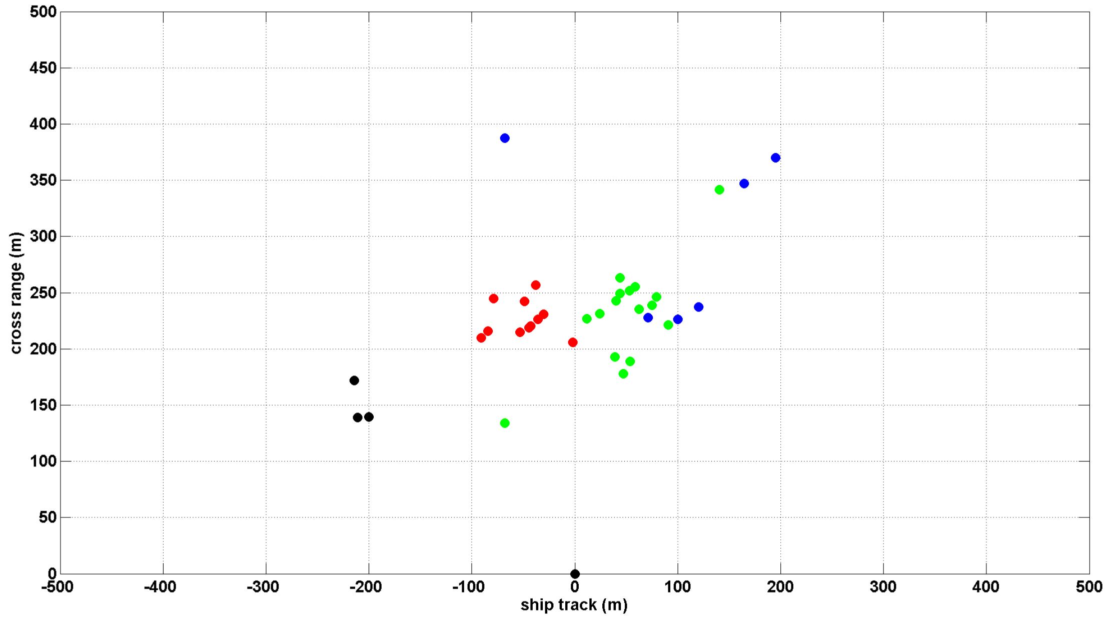

Figure 2. 2-D fixes of dolphin group relative to ship over one minute. Each color group represents a set of whistles occuring within a 15 s interval. The forward array is located at the origin

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CLIMATE-DRIVEN BOTTOM-UP PROCESSES AND KILLER WHALE ABUNDANCE AS FACTORS IN STELLAR SEA LION POPULATION TRENDS IN THE ALEUTIAN ISLANDS

George L. Hunt, Jr.
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TASK/THEME: 3B

SUMMARY

Due to a continuing population decline, the western stock of the Steller sea lion (*Eumetopias jubatus*) is listed as endangered. Hypotheses to explain declines in populations from Kodiak Island, the Alaskan Peninsula and the Aleutian Island Arc include: 1) commercial fisheries are competitors for prey; 2) there is significant predation by killer whales (*Orcinus orca)*; and 3) changes in climate have affected the productivity of sea-lion habitat, thus diminishing the abundance or availability of prey, particularly in the western portion of their range. Management actions necessary to mitigate the possible effects of fisheries have severely restricted the inshore portion of the commercial groundfish fishery. To improve the basis for future management decisions, more information is required about how killer whales and climate variations impact the ecosystem on which Steller sea lions depend. Our project, the Aleutians Passes Study, focused on two fundamental goals: (1) examination of productivity near sea lion rookeries and haul outs and (2) documentation of the number and ecotype of killer whales in waters between Unimak and Tanaga passes in the Aleutian chain.

To this end, in May and June 2002 we conducted investigations in seven passes through the Aleutian Islands: Unimak Pass, Akutan Pass, Umnak Pass, Samalga Pass, Amukta Pass, Seguam Pass, and Tanaga Pass (Fig. 1). The passes border Steller sea lion rookeries and haul outs where populations are either in decline or holding steady; none are increasing. These passes provided the opportunity for a suite of comparisons of hydrography and productivity at dynamic centers of seawater exchange between the North Pacific and the Bering Sea. In each pass, we characterized and quantified: 1) the physical regime (P. Stabeno, NOAA/PMEL), 2) nutrient availability (C. Mordy, NOAA/PMEL), 3) primary production (S. Zeeman, U. New England), 4) the distribution and abundance of zooplankton and micro-nekton (K. Coyle, U. Alaska, Fairbanks), 5) the foraging ecology of marine birds as indicators of prey availability (G. Hunt, U. California, Irvine), and 6) the distribution and relative abundance of killer whales, and where possible, obtained identification-quality photographs and biopsy samples from them (S. Moore, NOAA Nat'l Marine Mammal Laboratory). This study is the first multi-disciplinary, integrated examination of the marine ecosystem in the critical habitat of the western population of the Steller sea lion. It provides initial examinations of two of three hypotheses most likely to explain the decline of the sea lions, and has the potential to provide information of significant value for the future management of sea lion recovery and the fisheries of the region.

In 2002, we were in the eastern portion of our Aleutian Islands study area nearly a month earlier than we were in 2001. Therefore, in 2002, we began our sampling in Unimak and Akutan Passes on 20 May, before proceeding to Tanaga Pass, from which we worked our way eastward back to Unimak and Akutan Passes, where we finished up on 19 June. By visiting Unimak and Akutan Passes at both the beginning and the end of the cruise, we minimized aliasing our comparisons of eastern and western passes with a seasonal signal. This approach also allowed us to compare late spring and early summer conditions in the two eastern passes. In 2002, we experienced considerable stormy weather, with low pressure systems moving through the Aleutians with intervals of one or two days of calm weather between two- to three-day periods of stormy weather. This high frequency of storms and the loss of several days of sampling, because of poor weather necessitated a conservative approach to our cruise plan. Thus, we went no farther west than Tanaga Pass. As we managed to keep or exceed our planned work rate in the western passes, we added investigation of Umnak Pass and a more thorough study of Unimak Pass than was originally anticipated.

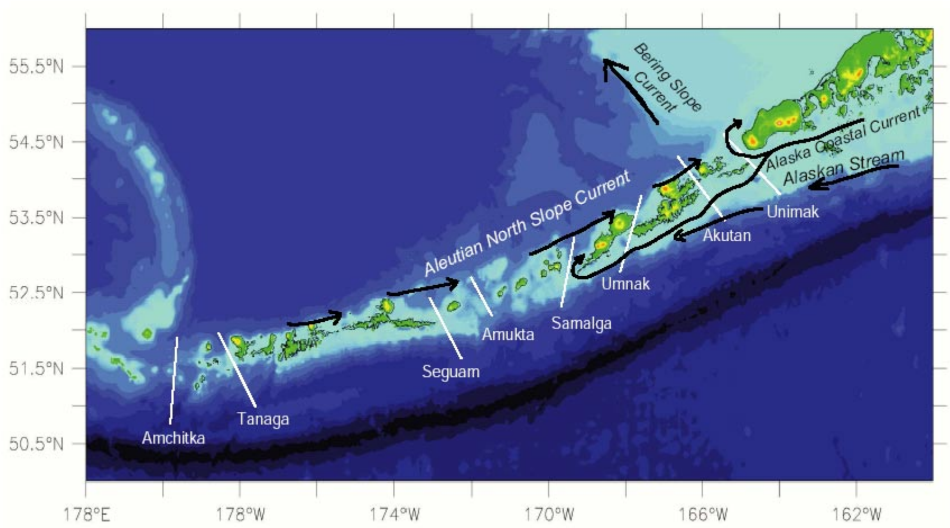

Figure 1. Map of the Aleutian Islands. Passes noted in the text are marked with white lines; currents are marked with black lines. From Ladd et al., ms.

To accomplish our goals, we conducted transects through and across the passes to assess physical processes using CTD casts. Zooplankton distribution and abundance were assessed with acoustic surveys, and tows of CalVET and MOCNESS nets. Chlorophyll abundance was measured at each CTD station, and rates of primary production were measured at a subset of stations within the passes. The distributions and abundances of birds and marine mammals were assessed during each of the surveys along the fixed transects, and additional inshore surveys were conducted to search for killer whales. In 2002, we conducted 164 CTD casts for determination of hydrographic structure, nutrients (750 samples), and chlorophyll abundance (765 determinations), 35 ^{14}C-based studies of primary production, and collected 690 samples of phytoplankton for cell counts. Zooplankton sampling included 83 tows of a CalVET net for zooplankton community composition, 51 deployments of a MOCNESS multiple-opening-closing net for zooplankton abundance, and approximately 920 km of acoustic surveys. In addition, we conducted 1520 km of marine bird surveys, and collected 10 short-tailed shearwaters, 18 northern fulmars and 5 least auklets for determination of food habits. We completed 350 hours of marine mammal surveys, conducted photo-ID encounters with 23 pods of killer whales and obtained 26 biopsy samples from killer whales in the study area.

This year's cruise yielded a number of exciting findings including: documentation of the westernmost pass with a significant northward flow of Alaska Coastal Current Water; a repeat of the 2001 finding of a strong east-west gradient in primary production and zooplankton abundance and species composition; a strong east-west shift in species composition of marine birds and their diets; and strong seasonal and east-west variations in the species composition and abundance of cetaceans. As was the case in 2001, we saw very few pinnipeds in the water anywhere in our study area. We had remarkable opportunities to observe foraging seabirds in a number of passes, but the most impressive were extraordinarily large aggregations of shearwaters foraging on euphausiids at frontal structures at the northwest corner of Unimak Pass. There were more than 100 humpback whales amongst the shearwaters. A remarkable concentration of killer whales was found foraging on fish (that appeared to be salmon) in Samalga Pass. Several groups of what were apparently transient-ecotype killer whales were encountered feeding on a gray whale calf in Unimak Pass.

We have begun to accrue the data necessary to show that there are striking step-functions in the physics, primary production, zooplankton types and biomass, and in the species composition and foraging ecology of marine birds as one goes from the eastern to central Aleutian Islands. These shifts in the marine ecosystem are at similar locations to those where sea lion diets change, and where regional population trajectories of sea lions may change. Our data also show that killer whales are numerous in the region, and that there are transient-ecotypes present that could be predators of sea lions. Given the numbers of resident-ecotype killer whales in the region and their foraging habits, it would be interesting to know whether they could be significant competitors with sea lions for Atka mackerel, salmon, herring and other forage fishes in the passes.

APPROACH, EVALUATION AND METHODOLOGY

Physical Oceanography

To quantify the differences in the physical habitats of Steller sea lions in the eastern and central Aleutian Islands, in May and June 2002, we conducted conductivity, temperature, depth (CTD) casts through seven passes: (Unimak, Akutan, Umnak, Samalga, Amukta, Seguam, and Tanaga). To measure flow through the passes, we conducted CTD casts across four passes (Samalga, Amukta, Seguam, and Tanaga). When possible, local tidal currents were taken into consideration in timing surveys through the passes. In addition, we made a CTD cast every hour for a full ebb and flood tidal cycle at a site in northern Akutan Pass.

Productivity and Nutrient Studies

During the cruise, we determined primary production in the on-deck incubators at 32 stations. Some stations were visited twice to assess variability. Chlorophyll concentrations were determined at 137 stations, usually at standard depths of 0,10,20,30, and 50 meters, as well as several at deeper depths. These samples were for calibrating the *in situ* fluorometer, although they will also be used in the production calculations. Samples for phytoplankton cell counts were taken at the same stations and depths as the chlorophyll samples. In addition to the transect stations, we also sampled at the surface and bottom for chlorophyll and cell counts at the 16-hour station in Akutan pass. During the cruise, we employed a Pulse Amplitude Modulated (PAM) Fluorometer (Water-PAM, Heinz Walz GmbH) to investigate the physiological efficiency of the photosynthetic mechanism. We measured the maximal photochemical yield (Fv/Fm) and the apparent Electron Transport Rate (ETR) at 8 light intensities to generate a light curve, similar to the ^{14}C incubation experiments.

Zooplankton

The goal of the zooplankton and acoustics component of the Aleutian Passes Project was to characterize the abundance, biomass, species composition and distribution of major zooplankton and micronekton taxa in the region around the Aleutian passes. Since zooplankton are the primary food of forage fishes, characterization of the zooplankton resources is central to understanding processes influencing the concentration, distribution and composition of Steller sea lion forage species in critical sea lion habitat. Samples were taken both north and south of the passes as well as in the passes.

Zooplankton samples were collected with a CalVET (CalCOFI vertical egg tow) net and a MOCNESS (Multiple Opening Closing Net and Environmental Sampling System) system. The CalVETs were equipped with 0.15 mm mesh nets and General Oceanics digital flow meters to monitor volume filtered. The nets were fished vertically from 100 m depth to the surface or from 5 m above the bottom to the surface in shallower regions. The MOCNESS sensors measured volume filtered, net angle, depth, salinity, temperature and fluorescence. The MOCNESS was equipped with nine 0.500 mm mesh nets, which were fished at discrete depths to obtain depth distributions of the major taxa.

The acoustic equipment consisted of an HTI (Hydroacoustics Technology Inc.) model 244 digital echosounder with transducer frequencies of 38, 120, 200 and 420 kHz. All of the transducers are split beam and therefore collected target strength data in addition to volume scattering. The transducer array was towed beside the vessel at 5-6 knots during surveys. In addition, acoustic data were taken during each MOCNESS tow to aid in scaling the acoustic data. Early in the cruise, the preamp in the 38 kHz transducer failed. Failure of the 38 kHz transducer will complicate interpretation of the data, since the 38 kHz data are important for distinguishing fish and plankton targets. In addition to the narrow-band HTI system, an experimental broad-band system was used. The broad-band system was multiplexed with the narrow-band HTI system to provide broad band target information for each depth interval and integration interval in the upper 200 m. Since the broad-band system characterizes the frequency response of targets between 110 and 190 kHz, it may provide a means of recovering some of the information lost by the failure of the HTI 38 kHz transducer.

CalVET samples were taken at CTD (Conductivity Temperature Depth) stations taken on transect lines through Unimak, Akutan, Samalga, Amukta, Seguam, and Tanaga passes. MOCNESS samples were taken at stations along the transect lines through Unimak, Akutan, Samalga, Seguam, and Tanaga passes. Acoustic transects were run through Unimak, Akutan, Umnak, Samalga, Amukta, Seguam, and Tanaga passes. The above sampling plan has generated sufficient material to allow us to characterize of the zooplankton resources in the passes and on either side of the passes.

Marine Birds

The goal of the marine ornithology component was to use seabirds as indicators of the potential of different regions to support upper trophic level organisms, including Steller sea lions. The rationale was that birds, depending upon species, forage on the prey of sea lion prey, or share the use of small fishes consumed by sea lions. Thus regions or processes that support high densities of seabirds might be expected to also be favorable foraging areas for sea lions. Thus, the objective of the seabird component of this study was to assess whether there were greater numbers of foraging seabirds in Pacific versus Bering Sea waters, and whether passes with certain characteristics, such as those with shallow sills, might support more birds. We also tried to determine whether there were certain physical oceanographic processes that might enhance the foraging opportunities of top predators within or near the passes.

Seabird observations were made during daylight when the ship was underway at speeds of 5 knots or greater within the study area. All birds within an arc of 90° from the bow to the side with the best visibility were counted from the bridge, and were recorded on a laptop computer for analysis. Behaviors of all birds were recorded.

In Unimak, Samalga, Seguam and Tanaga passes, we sampled the abundant seabird species at foraging aggregations. Stomach contents were removed from birds within 1 hour of collection, and stored in 80% ETOH. Northern fulmars were collected in Unimak (1 bird) Seguam (9 birds) and Samalga Pass (8 birds). Five short-tailed shearwaters were collected in Seguam Pass and 5 in Unimak Pass. Four least auklets (*Aethia pusilla*) were collected in Tanaga Pass.

Marine Mammal Studies

Marine mammal surveys were conducted throughout the study area and were focused on the occurrence of killer whales at seven Aleutian passes: Tanaga, Seguam, Amukta, Samalga, Umnak, Akutan, and Unimak. The passes border Steller's sea lion rookeries and haul outs where populations are either in decline or holding steady, none are increasing.

Marine mammal observers maintained a watch from the port and starboard sides of the bridge (height 9.67 m) of the R/V ALPHA HELIX daily from early morning (0700-0800) to late evening (2100 to 2200; hours shifted depending on light conditions) when conditions were suitable (i.e., Beaufort <6; visibility >.5 km). Observers at port and starboard stations searched with naked eye and 7X (or higher) binoculars with reticules (some had no reticules). Observers scanned for one hour at each station, followed by a one-hour break. The two primary observers were assisted in finding marine mammals by seabird researchers conducting surveys from either the port or starboard side (depending on glare), and by the ship's crew. Data was recorded by the starboard observer using WinCruz software on a laptop interfaced directly to the ship's Global Positioning System (GPS). Positions along the cruise track were updated at 2-minute intervals. When marine mammals were seen, estimated bearing and reticule or distance to the sighting, species, and number (best/high/low) of animals were recorded. Sightings of cetaceans other than killer whales were recorded in passing mode, except in two instances when sperm whales (*Physter macrocephalus*) and humpback whales (*Megaptera novaeangliae*) were approached to obtain biopsies.

When killer whales were seen within the study area and time permitted, the marine mammal team moved to the bow of the ALPHA HELIX to photograph and biopsy whales, as the ship maneuvered into the desired position. On six occasions, sea conditions permitted us to launch a rigid-hull inflatable boat (RHIB) for additional and sometimes closer access to the whales. The RHIB was deployed with a driver and at least two team members (1 biopsy person and 1 photographer), and sometimes a combination of team members with a ride-a-long from another project). Whales were approached from behind on their left sides for both photographs and biopsies. Standard identification photographs of their dorsal fins and saddle patches were taken using two Nikon cameras with fixed 300mm lenses and black and white 1600ASA Fuji film. Biopsy tissue samples were taken using either a Larsen gun or crossbow to deliver a hollow-tipped dart. Attempts to biopsy focused on distinctive individuals that were photographed during the encounter. Tissue samples were divided in two samples: a skin sample, stored in DMSO for DNA and isotopic analysis; and a blubber sample, frozen for analysis of contaminants.

RESEARCH ACCOMPLISHMENTS AND RESULTS

Physical Oceanography

The cross-pass density differences necessary to create geostrophic currents were greatest at Samalga Pass and Seguam Pass. In Amukta Pass, the transect appeared to contain two eddies affecting the upper 100m, and the reversal of flow associated with the eddies was apparent in the flow at the surface,

The eastern passes (Unimak, Akutan, and Umnak Pass) are shallower and generally narrower than the western passes (Samalga, Amukta, Seguam, and Tanaga Pass) (Fig. 1). The shelf south of the eastern passes is broader

than it is farther west. This isolates the eastern passes somewhat from "true" Pacific water, but exposes them to Alaska Coastal water flowing westward near the shore. We saw the low-salinity signature of Alaska Coastal water as far west as Samalga Pass, where it was diverted to flow northward through the eastern half of the pass. The minimum salinity at Unimak Pass was near 32 PSU, but west of Samalga Pass, it was near 33 PSU. The shelf to the north of all the passes is narrow and Bering Sea water is pulled up into all the passes during strong southward tides.

Temperature is affected by local heating or cooling, advection of colder or warmer water from elsewhere, upwelling of colder water from deeper in the ocean, mixing by wind, and mixing by tides in the passes. Water temperatures were cooler in 2002 than in 2001. For example, the maximum temperature in Unimak Pass was greater than 7° C in 2001, and near 6° C in June of 2002. The pass warmed by about a degree during the three weeks between late May and mid-June of 2002. Temperature was warmer in the eastern passes than the western passes, probably because of the larger reservoir of cold subsurface water available to be mixed up to near the surface in the west. Surface temperatures were warmest south of the passes, decreased in the passes because of mixing there, and increased to intermediate values north of the passes.

*Pr*oductivity and Nutrient Studies

Figure 2 illustrates a pattern of higher chlorophyll levels in the east near the larger islands than near the smaller islands and large passes west of Samalga Pass, but for a later time in the year than we were in the field. Results from the 2002 cruise showed a similar pattern. Akutan and Unimak passes had the highest rates of production, as well as chlorophyll concentrations measured during our cruise. At the western passes, production and chlorophyll were much lower. The exception was Seguam Pass, where the potential for high production rates was found in a patch of high chlorophyll concentration at the start of the east-west transect. Unlike 2001, there was no distinct trend for higher production on the north or south side of the passes. The trends in P_{max} in both Unimak and Akutan were almost identical to the trends of Fv/Fm determined by PAM fluorometry. Tanaga Pass was also very similar in both measures.

During a 16-hour station in Akutan, we were able to collect Fv/Fm measurements for both surface and bottom samples. These show that phytoplankton in the bottom layer were not very efficient photosynthesizers. The Fv/Fm values ranged, on average, between 0.2 and 0.4. It is generally accepted that a maximum value for Fv/Fm is 0.8 - 0.835 in higher plants, and in phytoplankton it is probably close to 0.7. The surface values showed a changing trend during the 16 hours, which reflected the tidal change in the pass. The high values of Fv/Fm in the surface marked times when chlorophyll was also more abundant. At the surface these values ranged to 0.6 and higher, indicating that phytoplankton from surface waters were healthier than those in the bottom waters.

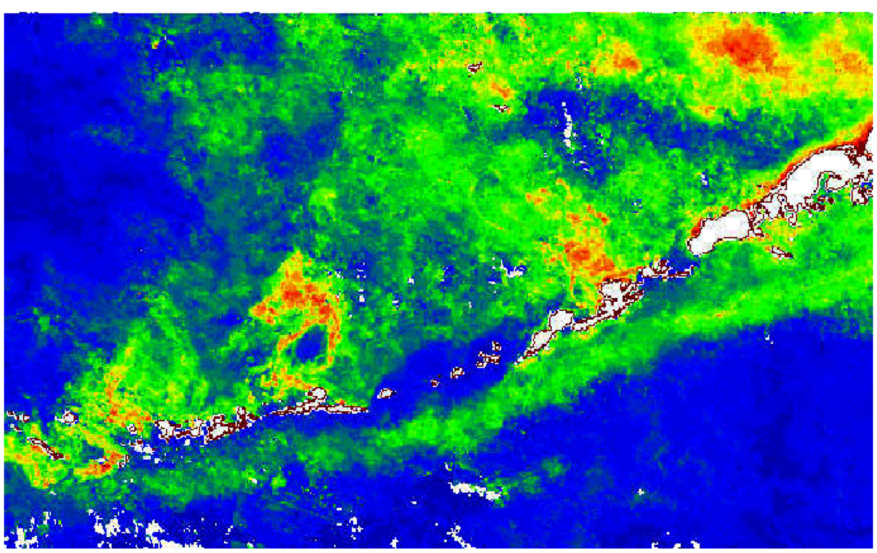

Figure 2. Composite near-surface chlorophyll for August-September from SeaWIFS imagery. Blue lowest to red highest. Notice the lack of chlorophyll in the passes and south of the islands west of Samalga Pass. From Ladd et al. ms. Composite created by Sigrid Salo, NOAA/PMEL.

Zooplankton

Preliminary observation of volume scattering suggests that considerably higher densities of sound scattering organisms may occur in the eastern region (Unimak – Akutan) relative to the western area (Samalga, Amukta, Seguam and Tanaga passes). Much of the scattering in the Unimak - Akutan area appeared to be from euphausiids, which were often the dominant organisms by weight in the MOCNESS samples. Additional scattering may have resulted from gadid fish larvae, which can dominate the acoustic return when they are present at high densities. Zooplankton in the western region seemed to be dominated by copepods. Zooplankton samples in the eastern region contained large amounts of phytoplankton in May, but phytoplankton was not observed in the June samples.

The zooplankton samples collected in the MOCNESS and CalVET nets are still being worked up. Information from the samples will include the species composition, life history stages of the copepod taxa, the abundance and wet weight biomass of all the taxa and stages. The acoustic data will be analyzed using analytical and empirical sound scattering models and correlation techniques. Neural net software may aid in relating the acoustic signatures of both the narrow and broad-band data to sound scattering organisms collected by the MOCNESS. In addition, broad-band signatures from previous trawl studies may aid in identifying fish targets not sampled by the MOCNESS. Statistical comparisons of the distribution, composition, abundance and biomass of the zooplankton in each of the passes should help document any consistent differences in zooplankton resources between the eastern and western regions of the Aleutian archipelago.

Marine Birds

During the 2002 cruise, we surveyed a total of 1,520 kilometers: 190.1 km on the northern side of the Aleutian Islands, 310 km on the southern side and 1011 km within the passes. We counted a total of 95,683 seabirds between Unimak Pass (eastern survey limit) and Tanaga Pass (western survey limit); 71,925 of them were feeding or sitting on the water. The most abundant seabirds were small alcids (least, crested [*A. cristatella*], parakeet [*Cyclorrhynchus psittacula*], and ancient murrelets [*Synthliboramphus antiquus*], with 28,539 individuals and 40% of birds observed feeding or on the water), short-tailed shearwaters (24,733 individuals, 34% feeding or on the water), northern fulmars (15,575 individuals, 22% feeding or on the water), and Tufted Puffins (2,661 individuals, 4% feeding or on the water).

Seabird abundance was greater (48.0 birds/km_) on the Pacific Ocean side of the Aleutians than on the Bering Sea side (32.7 birds/km_). On both sides of the Aleutian Archipelago, small alcids and northern fulmars were the most common birds. The biggest concentrations occurred as we crossed tiderips associated with nearby passes. Thus, these averages do not reflect the densities of seabirds in the shelf waters away from the influence of passes.

Within the passes surveyed, seabird densities were higher in the relatively narrow, shallow passes (Unimak, Umnak, Samalga, Seguam and Tanaga). In these passes, large flocks of least auklets, shearwaters, or northern fulmars aggregated to forage at the frontal areas at the ends of the passes. Mean seabird abundance was 406 birds/km_ in Unimak Pass, 203 birds/km_ in Tanaga Pass, 76 birds/km_ in Seguam Pass, 51 birds/km_ in Samalga Pass,) and 32 birds/km_ in Umnak Pass. In comparison, Amukta Pass, which is wide and deep, supported only 1 bird/km_.

There was a marked difference in the species composition of the seabirds encountered in the passes. In the eastern passes (Unimak, Akutan and Umnak), short-tailed shearwaters and tufted puffins were the dominant species, in the central passes (Samalga, Amukta and Seguam) fulmars were dominant, whereas in the west (Tanaga Pass), small alcids were dominant (Figure 3). In Unimak Pass, short-tailed shearwaters comprised 98% of the birds feeding or sitting on the water. In Akutan and Umnak passes, tufted puffins comprised 63%, and 57%, respectively, of the birds feeding or sitting on the water. In Samalga, Amukta and Seguam passes, northern fulmars comprised respectively 98%, 44% and 90% of the birds feeding or sitting on the water. In Tanaga Pass, least auklets comprised 98% of the birds feeding or sitting on the water.

Within Unimak, Samalga, Seguam and Tanaga passes, small alcids, northern fulmars and short-tailed shearwaters were observed foraging at frontal regions that crossed the ends of the passes. These were tidal fronts where either stratified Pacific Ocean or Bering Sea waters were interacting with the well-mixed water of the passes. At the northern end of Unimak Pass, short-tailed shearwaters were foraging on euphausiids. Similarly, northern fulmars and short-tailed shearwaters at Seguam Pass were foraging on adult euphausiids (mostly or all *Thysanoessa longipes*). Shearwaters and fulmars were also found foraging in patches along the sides of the passes, with lines of foraging flocks parallel to the long axis of the pass. We were not able to determine if there was a physical mechanism that was organizing these foraging aggregations, although it seems possible that they may be the result of processes in a shear zone that could be separating the fast moving water in the center of the pass from the slower flowing water at the sides. Small alcids and northern fulmars collected at tidal fronts in Samalga, Seaguam and Tanaga passes were foraging mostly on copepods (probably *Neocalanus plumcrus/flemingerii).*

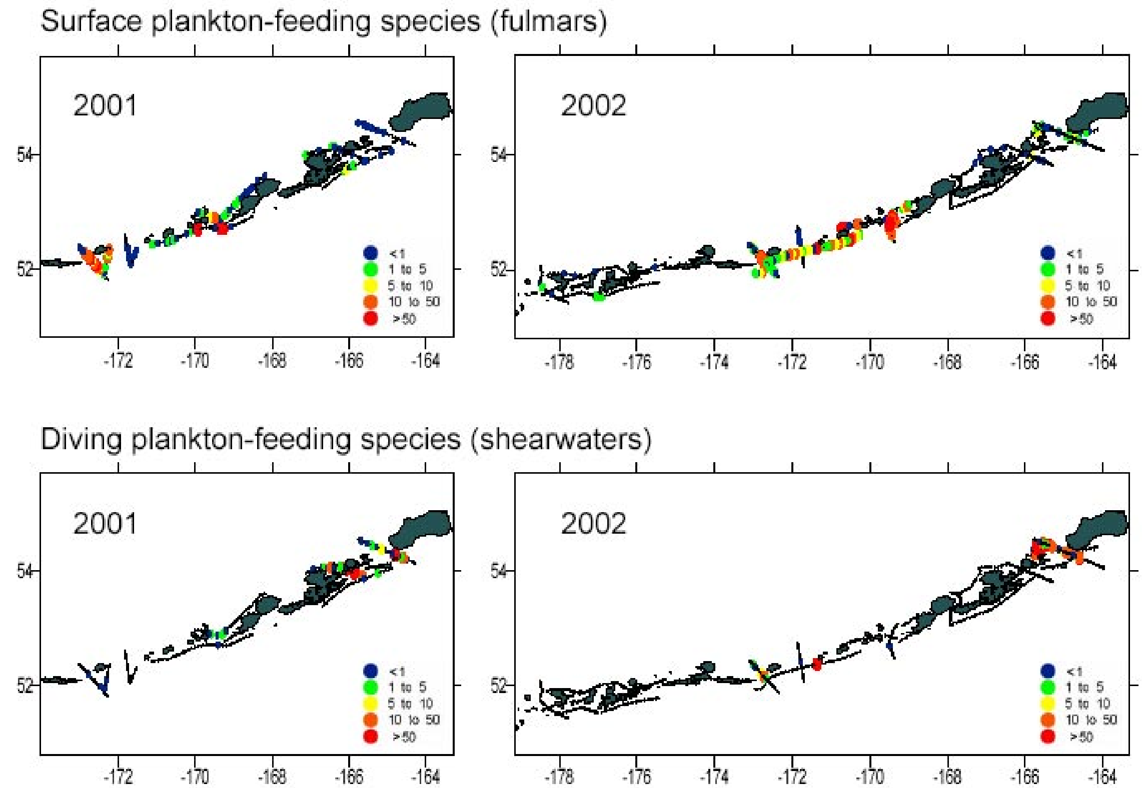

Figure 3. Distributions of Northern Fulmars (*Fulmarus glacialis*) and short-tailed shearwaters (*Puffinus tenuirostris*) in 2001 and 2002. Most fulmars were seen in the western portion of the study area and most shearwaters in the east.

Marine Mammals

Approximately 350 hours of survey for marine mammals was completed in the study area. Roughly 135 of 350 (39%) survey hours were dedicated to search for killer whales and 58 of 135 (43%) hours were direct effort on sightings, or encounter groups. Overall, weather and viewing conditions were poor compared to the 2001 survey with visibility often reduced to <1-3 nm due to fog, rain, wind, and increased Beaufort sea state to 4-5, and sometimes 6.

Ten marine mammal species were positively identified, three pinniped and seven cetacean. Steller's sea lions (Eumatopeas jubatus) were the most common pinniped seen (when animals hauled out on land were included). None were sighted in the water. Elephant seals (*Mirounga angustirostris*) and fur seals (*Callorhinus ursinus*) were also sighted several times each. Dall's porpoise (*Phocoenoides dalli*) were the cetacean seen most often and were abundant throughout the study area. Although ubiquitous, they were particularly common west of Unalaska Island and an order of magnitude higher in Tanaga, Seguam, Amukta, Samalga, and Umnak passes. However, they did not have similar densities in the Unimak/Akutan passes region where sightings were scarce by comparison. Sightings of Dall's porpoise were absent on the south side from Umnak pass to the easternmost region of the study area near the south end of Unimak pass. Minke whales (*Balaenoptera acutorostrata*) were sighted 18 times throughout the study area with higher concentrations occurring in the western-most passes of the study area, Tanaga and Seguam. All other minke whales sightings occurred on the south side of the island chain. Sperm whales (*Physeter macrocephalus*) were most prolific in the Tanaga pass region near the Delarof Islands where 35 sightings were recorded. (It is important to note that most of these sightings were recorded over a 1.5-2.0 hrs duration while the ALPHA HELIX was either milling or transiting <4 knots while awaiting the return of the RHIB deployed for biopsy work.) The remaining five sightings of sperm whales occurred in Amukta pass and north of Seguam Island in Seguam pass. Humpback whales (*Megaptera novaeangliae*) were sighted east of Amukta pass and occurred most often in the Unimak/Akutan passes region, either in the north end of Unimak pass (one event >100 spread over several miles) or the south end of Akutan pass. Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), harbor porpoise (*Phocoena phocoena*), and Baird's beaked whales (*Berardius bairdii*) were sighted one time each in the study area. Consistent with the 2001 survey, fin whales (*Balaenoptera physalus*) were not seen in the study area.

Killer Whale Encounters and Sightings

There were 26 sightings of approximately 500 killer whales (summation of the best estimates of group size) seen in the study area from Tanaga Pass to Unimak Pass. These provisional counts likely under-represent the total number of animals present because (1) animals were often spread over a large area, (2) time allotted to work each group was limited, and (3) the counts made while in passing-mode are probably low. There were 23 sightings of killer whales where the cruise schedule permitted approach and focused efforts to obtain identification photographs, and 3 sightings where only counts were obtained while the ship was in passing-mode. Seventy-four rolls of film were shot during 22 encounters (3 groups passed; 1 group never resighted). Each encounter usually started with the sighting of a comparatively small group of animals (1- 5 whales, always including at least 1 adult male), but after approach of the first identified animals, additional whales were seen.

We were able to approach 23 of 26 sightings of killer whales however, attempts to successfully photo-identify and obtain representative biopsy samples of each group were hindered by (1) time constraints expected on a non-dedicated marine mammal survey, (2) inclement weather, and (3) elusive and difficult to work animals. While the film has not yet been processed, we presume that half of the 26 encounter groups are either not photographed (15%) or only photo-identify <10% of the group. Nearly one-fourth (23%) are photographs of poor quality (low-light) and photo-identify <25% of the group. Less than one-fourth (19%) photo-identify >50% of the group, and few (08%) photo-identify 100% of the individuals in a group. Biopsy tissue samples were obtained from 15 of 26 encounter groups (58%). It is important to note that these samples do not necessarily represent separate sub-groups seen within each encounter or sighting group. Twenty-six tissue samples were obtained from 45 attempts (58%) and averaged 2.2 hours of effort per biopsy.

Killer whales were seen in regions where they previously had been photographed during the 1992, 1993 and 2001 surveys, including Makushin Bay along the north coast of Unalaska Island, Seguam Pass, Samalga Pass, and the Unimak/Akutan passes area. The largest group (75-100 animals) was seen in an area not previously surveyed, south of Amlia Island while transiting to the western edge of the study area. Killer whales were seen in the westernmost region of the study area on two occasions near Tanaga pass. No killer whales were seen between Seguam and Tanaga pass, however a large segment—on both sides, north and south—of the island chain was transited at night.

While the photographs have not yet been analyzed for cross-matching killer whales seen during 1992, 1993 or 2001 surveys, we observed at least 4 whales that appeared to be individuals photographed during the earlier surveys. In addition, numerous animals had distinctive dorsal fins and saddle patches that will aide in identifying individuals and groups on future surveys.

Killer Whale Predation

We did not witness an attack by killer whales on any marine mammal, but we did encounter a large group of transients (30 minimum) feeding on a gray whale (*Eschrichtius robustus*) carcass, presumably a calf taken the previous day. We saw a small group of killer whales shadowing a minke whale on one occasion, but inclement weather moved in, the killer whales were evasive, and we lost the minke whale after several surfacings. We did not see killer whales near Steller's sea lion haul-outs. Although biopsy tissue samples have not yet been analyzed to determine eco-type, we presume that at 15 of 26 (58%) groups of killer whales encountered are fish eaters (because open or fingers in saddle patches were seen in the group or they exhibited fish-foraging behaviors). With certainty, we conclude that at least one group (observed feeding on gray whale carcass) are mammal-eaters. With less certainty, we assume 2-4 additional groups may be mammal-eaters (group numbers were small, individuals had ragged dorsal fins, and other physical and behavioral characteristics of transients were noted). The remaining groups are unknown eco-types because they were either seen in passing mode only, were never resighted, or they had no indicative physical or behavioral characteristics.

CONCLUSIONS AND RECOMMENDATIONS

During the May-June 2002 cruise to the eastern and central Aleutian Islands and in the work up of samples and data analyses that have been on-going since the cruise, we have come to appreciate that there is striking heterogeneity in the marine ecosystems of the Aleutian Islands. All components, from physics to marine birds and mammals showed a pattern of change from east to west, with decreased primary production and decreased standing stocks of zooplankton, seabirds and marine mammals to the west. For a number of groups, there was an abrupt shift in species composition at Samalga Pass, the break point for a major shift in the diets of Steller sea lions from pollock in the east to atka mackerel to west of this pass. This pass also marked the westward extent of Alaska Coastal Current

Water. East of the pass, there was considerable chlorophyll, nutrient values were low, and the water was relatively warm and fresh. West of the pass, water temperatures were lower, nutrient concentrations were elevated and chlorophyll levels low.

Our results suggest that there may well be a bottom-up explanation for the stronger declines in the Steller sea lion population as one goes westward out the Aleutian Chain. Our results also show that there are killer whales of the mammal-eating ecotype in the Aleutian Islands. Thus, our results support the conclusion that it is premature to dismiss these explanations as contributory to the patterns in Steller sea lion declines in the Aleutian Islands.

Our results are based on two cruises, one of about three weeks and one of about a month in duration. We have investigated the eastern Aleutians and to a lesser extent the central Aleutians. Funding limits precluded conducting research in the western Aleutians, where the declines in the Steller sea lion populations have been most severe. It would be useful to follow up on our findings with a strong effort in the western Aleutian Islands. Just as there is a marked shift in the ecosystem at Samalga Pass, there may be other breaks in the system that reflect strong changes in physical processes. There needs to be additional research on the possible mechanisms that would link changes in currents along the Aleutians and through the passes to interdecadal and inter-annual variations in climate patterns. The development of a time series for the Aleutian passes

SUMMARY OF RESULTS

Overview

In 2002, we were in the eastern portion of our Aleutian Islands study area nearly a month earlier than we were in 2001. Therefore, in 2002, we began our sampling in Unimak and Akutan Passes on 20 May, before proceeding to Tanaga Pass, from which we worked our way eastward back to Unimak and Akutan Passs, where we finished up on 19 June. By visiting Unimak and Akutan Passes at both the beginning and the end of the cruise, we minimized aliasing our comparisons of eastern and western passes with a seasonal signal. This approach also allowed us to compare late spring and early summer conditions in the two eastern passes.

In 2002, we experienced considerable stormy weather, with low pressure systems moving through the Aleutians with intervals of one or two days of calm weather between two- to three-day periods of stormy weather. This high frequency of storms and the loss of several days of sampling because of poor weather necessitated a conservative approach to our cruise plan. Thus, to conserve potential weather days, we went no farther west than Tanaga Pass. As we managed to keep or exceed our planned work rate in the western passes, we added investigation of Ummak Pass and a more thorough stud of Unimak Pass than was originally anticipated.

To accomplish our goals, we conducted transects through and across the passes to assess physical processes using CTD casts. Zooplankton distribution and abundance were assessed with acoustic surveys, and tows of CalVET and MOCNESS nets. Chlorophll abundance was measured at each CTD station, and rates of primary production were measured at a subset of stations within the passes. The distribution and abundances of birds and marine mammals were assessed during each of the surveys along the fixed transects, and additional inshore surveys were conducted to search for killer whales. In 2002, we conducted 164 CTD casts for determinaton of hydrographic structure, nutrients (750 samples), and chlorophyll abundance (765 determinations), 35 ^{14}C-based studies of primary production, and collected 690 samples of phytoplankton for cell counts. Zooplankton sampling included 83 tows of a CalVET net for zooplankton community composition. 51 deployments of a MOCNESS multiple-opening-closing net for zooplankton abundance, and approximately 920 km of acoustic surveys. In addition, we conducted 1520 km of marine bird-surveys, collected 10 short-tailed shearwaters, 18 northern fulmars and 5 least auklets for determination of food habits. We completed 350 hours of marine mammal surveys, conducted photo-ID encounters with 23 pods of killer whales and obtained 26 biopsy samples from killer whales in the study area.

This year's cruise yielded a number of exciting findings including: documentation of the westernmost pass with a significant northward flow of Alaska Coastal Current Water, a repeat of last year's findings of a strong east-west gradient in primary production and zooplankton abundance and species composition: a strong east-west shift in species composition of marine birds and their diets; and strong seasonal and east-west variations in the species composition and abundance of cetaceans. As was the case last year, we saw very few pinnipeds in the water anywhere in our study area. We had remarkable opportunities to observe foraging seabirds in a number of passes, but the most impressive were extraordinarily large aggregations of shearwaters foraging on euphausiids at frontal structures at the northwest corner of Unimak Pass.

We have begun to accrue the data necessary to show that there are striking step-functions in the physics, primary production, zooplankton types and biomass, and in the species composition and foraging ecology of marine birds as one goes from the eastern to central Aleutian Islands. These shifts in the marine ecosystem are at similar locations to those where sea lion diets change, and where regional population trajectories of sea lions may change. Our data also show that killer whales are numerous in the region, and that there are transient-ecotypes present that could be predators of sea lions. Given the numbers of resident-ecotype killer whales in the region and their foraging habits, it would be interesting to know whether they could be significant competitors with sea lions for Atka mackerel, salmon,herring and other forage fishes in the passes.

UNIMAK AND AKUTAN PASSES

In 2002, we visited the Unimak/Akutan study area between 19 and 26 May, and again between 12 June and 19 June. In 2001, we were there between 14 and 20 June. As in 2001, in Unimak and Akutan passes in 2002, we found that cold, salty water was being pushed up into the passes from the north during the ebb tides. We expect that this water is a source of nutrient replenishment of the surface waters in the north of, and in the pass. Strong salinity and temperature fronts separated the fresher, warmer waters in the south from the colder, saltier water from the Bering Sea.

In May 2002, chlorophyll was abundant in the surface waters of both Unimak and Akutan passes, as well as to the north and south of the passes, suggesting that the spring phytoplankton bloom was still in progress. This was in marked contrast to the situation in June 2002 (and June 2001), when we found little chlorophyll present in the passes. In June 2001, but not in June 2002, we found elevated levels of chlorophyll in the stratified water just north of these passes, whereas in June 2002, the little chlorphyll that was present occurred south of the passes. A set of 16 CTD casts taken at hourly intervals on the shelf at the north end of Akutan Pass illustrated the intrusion of cold, salty water at depth, and the presence of a small patch of chlorophyll that was advected into the pass near the end of the ebb tide.

Acoustic surveys in May 2002 showed that copepods were abundant in Unimak and Akutan passes, as well as to the north and south of the passes. There was also a considerable biomass of euphausiids at the north end of Akutan Pass, with lesser amounts present at the north end of Unimak Pass. In May 2002, large biomasses of fish were detected in the north-central portion of Unimak Pass, and at the north end of Akutan Pass. By June 2002, there was comparatively little biomass present in Akutan Pass or in Unimak Pass with the exception of a large biomass of what were probably euphausiids at the north end of the Unimak Pass.

In May 2002, seabirds were scarce in Unimak and Akutan passes when compared to what we encountered in June 2001. On 12 June 2002, numbers of migrant shearwaters (Puffinus spp.) had increased compared to what we had found in May 2002. However, visibility during these surveys was very poor, and we may have missed important concentrations. In May 2002, marine mammals in these passes were scarce compared to what we found in other passes, but humpback whales (Megaptera novaengliae) were more prevalent here than elsewhere. Few marine mammals were seen in the 12 June CTD and acoustic surveys, because viewing conditions were extremely poor (fog).

However, when we returned to Unimak Pass on 16 June, we encountered 100+ humpbacked whales and several million short-tailed shearwaters (Puffinus tenuirostris) foraging at the north end of the pass over dense concentrations of biomass. The shearwaters and smaller numbers of northern fulmars (Fulmarus glacialis) were foraging on euphausiids that were concentrated in patches and long streaks that gave the sea surface a reddish color. In several instances, fish about 25 cm long were boiling at the surface, or could be seen swimming below the surface layers of euphausiids. They appeared similar to the herring (Clupea Pallasil) caught in 2001 at the north end of Akutan Pass. The humpback whales were in pairs of adults, and were making short dives. There was no indication as to what prey they were eating. On 27 June, we did a pair of transects along the frontal area and a pair of transects across the frontal area to take CTD measurements and to obtain acoustic profiles of the biomass in the water. We also obtained MOCNESS tows to characterize the species composition of the biomass concentrations in the vicinity of the frontal system. The CTD profiles along the front revealed areas of strong convergence, possibly associated with a mesoscale meander, at which chlorophyll was concentrated. The cross-shelf CTD transect showed evidence of on-shelf movement of water where tidal currents impinged on the bathymetry of the pass. Acoustic data showed large amounts of biomass being forced up into the pass, much of which was likely euphausiids, given the preliminary examination of the MOCNESS tows. This biomass was the top of the shelf edge, where the euphausiids were being concentrated. A transect along the Unimak Pass Y-line on 18 June showed that shearwaters on this line were concentrated on the north end of the line. This transect did not capture the highest concentration of shearwaters, as they were north of the point where the line had to be started. Neither the shearwaters nor the humpback whales were in evidence in May or at the beginning of our visit 11 or 12 June. Likewise, they were reported absent by R. Pitman (Pers. Com.) who transited Unimak Pass about 13 July. In this set of visits to Unimak Pass (16-18 June), several pods of killer whales were encountered, including three or four that were likely to have been residents and three that were eating a gray whale (Eschrichtius robustus) calf on the eastern side of Unimak Pass.

In summary, our three visits (May 2002 and June 2001 and 2002) to the Unimak/Akutan passes region suggest a strong seasonal shift in productivity and fauna between mid-May and mid-June. There is accumulating evidence that ebbing tides consistently result in the movement of cold, salty water from depth into the northern ends of the passes. However, it seems that flood tides do not bring similar, cold, salty water into the southern ends of the passes, perhaps because of the wide expanse of shelf south of the passes. There also appears to be considerable interannual variation in the amount of chlorphyll and zooplankton present in these passes. In May 2002, these passes did not appear to support high numbers of foraging marine birds or mammals. However, moderately high numbers of small auklets were present in the tide rips of Akutan Pass. In June 2002, there were modest numbers of alcids present in Akutan Pass and immense numbers of shearwaters concentrated in the Bering Sea side of Unimak Pass. In contrast, in June 2001, high numbers of seabirds foraged in Akutan Pass, with lower numbers found in Unimak Pass. Cetaceans were moderately abundant in these passes in June 2001, and in 2002, they were scarce in Akutan Pass and abundant in Unimak Pass.

A JOINT PROGRAM FOR TRAINING AND RESEARCH IN MARINE RESOURCE MANAGEMENT MODELING

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TASK/THEME: 4B

SUMMARY

The primary purpose of our project was to develop a Ph.D. degree study program that will produce quantitative marine ecologists and resource economists with a background in fishery management. Students were enrolled in the Marine Ecology Area of Emphasis of the Graduate Group in Ecology or in the graduate program of the Department of Agricultural and Resource Economics at UC Davis. The secondary goal of the project was to pursue research in collaboration with the students in the program, post-docs, and NMFS scientists from the Southwest Fisheries Center. The funding is primarily for graduate student support. This report is for the second year of the program, so it is still ramping up as far as identified students are concerned. In brief, with regard to training, we have developed a program and taught these courses on related fishery topics. We have one identified, funded student in the program doing research on estimation of the effects of fishing on the sustainability of populations, and we have between 5 and 10 students taking our seminars who are funded from other sources.

APPROACH, EVALUATION AND METHODOLOGY

Our approach to the training program has been to develop a program of courses, develop new courses where needed, to attract and identify students funded under this program, to teach the various courses to these students and other marine ecologists interested in fishery issues,

In this past year, we taught a graduate course on Advanced Population Dynamics, WFC 222. This course covers population dynamics, accounting for age, size and spatial structure, with a focus on population stability and persistence, particularly in response to harvest. We also taught a seminar course on biological reference points in the west coast groundfish fishery based on readings from the North American Journal of Fisheries Management. Seminar courses such as these keep students abreast of evolving approaches in fisheries.

Thus far we have selected one student to be funded under this program, Mike O'Farrell. Mike has completed most of his course work, which has included all of the courses on population dynamics offered at UC Davis and a background in mathematical statistics. His thesis topic is the development of methods for the estimation of the impact of fishing on populations for which only samples of the size distribution early and late in the fishery development are available. He is interested in the Cow Cod Closure, and may compare his methods with the one used in that stock assessment to estimate SSB/R. We have discussed participation in the surveys with John Butler, and Mike is planning to go on some of the ROV cruises.

RESEARCH ACCOMPLISHMENTS AND RESULTS

Our research results are mainly an extension of projects funded from other sources, with our focus in this program being primarily on the fishery aspects. This research has been primarily on marine reserves. There is a great public concern for collapsed fisheries and an accompanying interest in the implementation of marine reserves as a quick fix for this problem. That has created a need by decision makers for a rational assessment of how marine reserves could contribute to increased fishery yields, better protection of ecosystems, improved sustainability of fish stocks, and reduced dependence of management on uncertainty. We have shown that marine reserves produce approximately the same yield as conventional fisheries. They will increase yield in a fishery only if the fishery is heavily fished. We have developed conditions for sustainability in systems of marine reserves, and have shown that sustainability and yield both depend on mean larval dispersal distance of the species. Larval dispersal distances are poorly known, hence are a significant source of uncertainty in marine reserves. Through development of an economic model of fisherman behavior, we have shown that the shift in effort when reserves are implemented makes them much less attractive, as compared to conventional management.

We have also been pursuing research on methods to characterize the reproductive consequences of the current distribution of white abalone, but do not yet have results.

CONCLUSIONS AND RECOMMENDATIONS

Our conclusions with regard to training are that the problem that NMFS has regarding the availability of stock assessment scientists starts at the undergraduate level. To address that, we have developed a program in quantitative ecology at the undergraduate level. We are also making greater efforts to advertise our program and build up to 3 or 4 funded students.

Our research conclusions are the results presented above, and we have made every effort to provide them to policy-makers. We are participating in several programs to establish an objective view of the efficacy of marine reserve.

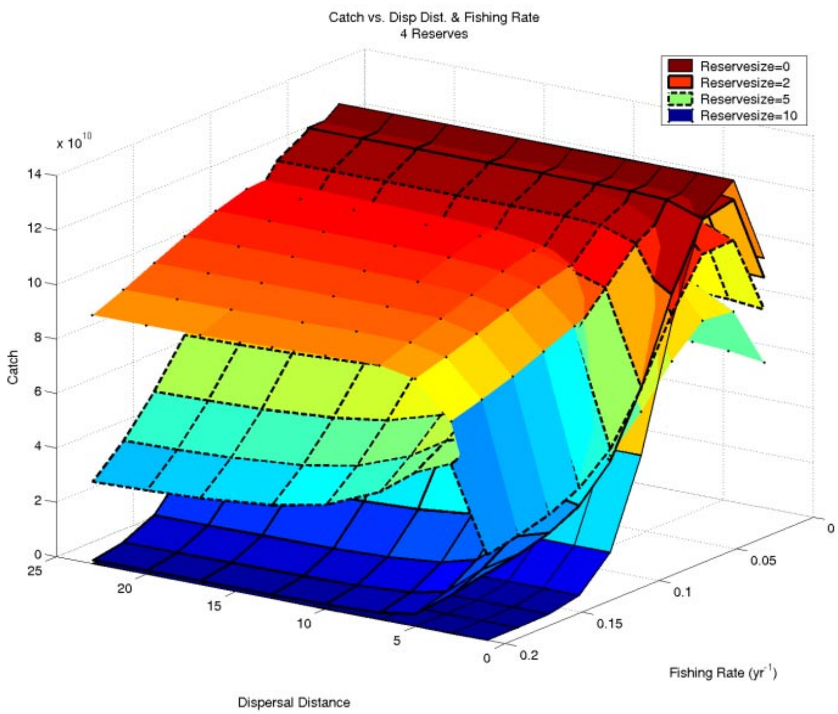


Figure 1. (Legend). An example of how catch in a fishery with marine reserves depends on fishing mortality rate, the size of reserves, and the mean dispersal distance of the species. Note (1) that marine reserves provide greater yield only at high fishing mortality rates, and (2) that yield depends on dispersal distance, a major source of uncertainty.

Copper Rockfish (*Sebastes caurinus*)

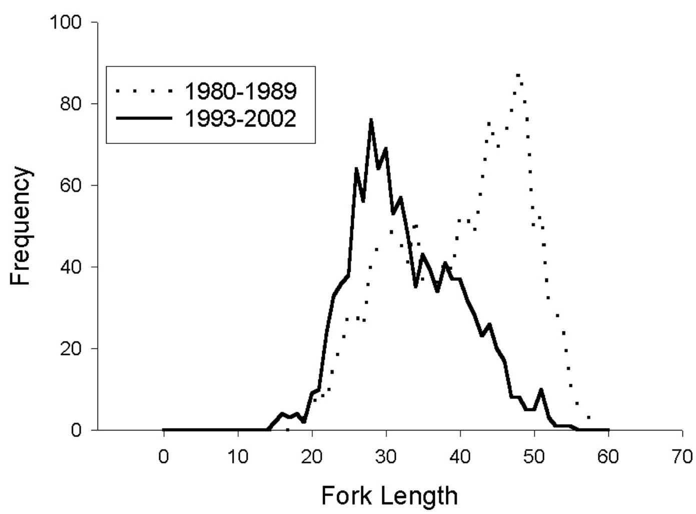
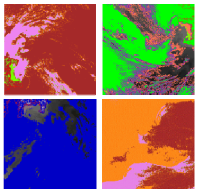


Figure 2. Thesis research of Mike O'Farrell involves development of a method for estimating the effect of changes in size distributions due to fishing on the persistence of populations such as this rockfish.



PHYTOPLANKTON STUDIES IN SUPPORT OF THE U.S. ANTARCTIC MARINE LIVING RESOURCES (AMLR) PROGRAM, JANUARY - MARCH 2002

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TASK/THEME: 3B

SUMMARY

The overall objective of our research project was to assess the distribution and concentration of food reservoirs available to the herbivorous zooplankton populations throughout the AMLR study area during the austral summer. The specific objective of our work was to determine the distribution and biomass of phytoplankton in the upper water column (surface to 200m), with emphasis on the upper 100m, and in conjunction with the NASA SIMBIOS program, (1) to determine the concentrations of all the major cellular photosynthetic pigments by High Pressure Liquid Chromatography (HPLC), from which one can estimate the relative proportions of various phylogenetic groups of phytoplankton and (2) to calibrate satellite imagery of spectral reflectance to surface chlorophyll concentrations. However, the distribution of phytoplankton is dependent upon local currents as well as availability of growth promoting factors (light or nutrients), both of which are conditioned by physical and chemical properties of the upper water column. In order to better understand mixing processes in our study area, this year we deployed drifter buoys to examine direction and speed of surface currents.

METHODS AND ACCOMPLISHMENTS

The major types of data acquired during these studies, together with an explanation of the methodology employed, are listed below.

Sampling Strategy

The CTD carousel and independent profiling units were used to obtain samples of the water column for analyses as well as to obtain data from various profiling sensors as listed below:

- For both Legs, water samples were obtained from 10-liter Niskin bottles (with Teflon covered springs) which were closed at 10 standard depths (5, 10, 15, 20, 30, 40, 50, 75, 100, and 200m) from every station upcast of the CTD/rosette unit.
- For both Legs, a Sea Tech transmissometer was used to determine the attenuation of collimated light (by both scattering and absorption) during CTD casts.
- For both Legs, a Sea Tech profiling fluorometer was used to measure in situ chlorophyll fluorescence.
- For both Legs, a Biospherical QCP200L profiling PAR (photosynthetically available radiation) sensor was used to measure the in situ light regime.

Measurements and Data Acquired

Chlorophyll-a Concentrations: Chl-a concentrations in the water samples were determined by measurement of chl-a fluorescence after extraction in methanol. Sample volumes of 100 mL were filtered through glass fiber filters (Whatman GF/F, 25mm) at reduced pressure (maximal differential pressure of 1/3rd atmosphere). The filters with the particulate material were placed in 10 mL of absolute methanol in 15 mL tubes and the photosynthetic pigments allowed to extract at 4EC for at least 12 hours. The samples were then shaken, centrifuged, and the clear supernatant poured into cuvettes (13 x 100 mm) for measurement of chl-a fluorescence before and after the addition of two drops of 1.0 N HCl (Holm-Hansen et al., 1965; Holm-Hansen and Riemann, 1978). Fluorescence was

measured using a Turner Designs Fluorometer model #700 that had been calibrated using spectrophotometrically determined chl-a concentrations of a prepared standard (Sigma). Stability of the fluorometer was verified daily by use of a fluorescence standard (Turner Designs #7000-994).

Measurement of Photosynthetic Pigment Concentrations: HPLC samples will be used for the analysis of various chlorophylls and associated pigments. Samples from 5 meter bottle samples at 184 CTD stations were obtained by filtering 1 L water through 25mm GF/F filters. Samples were frozen and stored in liquid nitrogen until their analyses can be made at SIO. The ratio of chlorophyll and associated pigments will be used to determine the proportions of algal classes contained in the phytoplankton community.

Measurement of Beam Attenuation: A Sea Tech transmissometer (660 nm, 25 cm path) was fixed onto the Seabird CTD carousel for deployment at all stations. Previous studies have shown that beam attenuation (660nm) coefficients can be used to estimate total particulate organic carbon in Antarctic waters (Villafañe *et al.*, 1993). This calculation assumes that there is a negligible load of inorganic sediment in the water, a condition that is apparently satisfied throughout much of the study area.

Measurement of Chlorophyll fFuorescence: A Sea Tech profiling fluorometer was used to obtain measures of chlorophyll fluorescence intensity in the water column. These data will be used (in conjunction with the measurement of *in situ* PAR) to estimate chlorophyll concentrations in the water column, using the algorithm of Holm-Hansen *et al.* (2000) as applied specifically for the AMLR survey region.

Measurement of *in situ* light: A Biospherical Instruments cosine PAR (photosynthetically available radiation, 400-700 nm) sensor (Model #QCP-200L) was used to measure light attenuation profile in the water column. This sensor is also used in conjunction with the SeaTech fluorometer to estimate chlorophyll concentrations *in situ*, and to provide a parameter to measure the variability of photophysiological responses of phytoplankton.

Satellite Oceanography: SeaWiFS chlorophyll images were obtained for 8-day and monthly average composites from NASA archives (http://eosdata.gsfc.nasa.gov/). These data were sufficient to evaluate the time-dependence and distribution of chl-*a* within our study region. Additional LAC (local area coverage) data giving high resolution single day images of chlorophyll distribution for segments of the AMLR survey area have also been obtained.

Drifter Buoy Deployment: In cooperation with the Global Drifter Program (P. Nieler, SIO), we deployed 20 drifter buoys (10 each for Leg I and Leg II) to determine paths and rates of ocean currents in the AMLR study area.

Non-routine CTD Stations: Time permitted us to obtain additional data during both Legs I and II in regions of specific interest to describe the distribution of phytoplankton. At the end of Leg I, a transect including 7 CTD stations along 59.75°S between 56 and 59°W was followed by a transect along the Shackelton Fracture Zone to measure bathymetry. On the return to Cape Shirreff at the beginning of Leg II, one CTD cast was made in the Drake Passage (Station CWZ). These CTD casts included measurements of PAR, transmissometer, and fluorometer, and included chlorophyll measurements from water bottle samples. One additional station during Leg II, X10-07, was made to fill in a gap for a station transect in which a phytoplankton bloom had developed. These data will be used to study processes involved with bloom dynamics.

TENTATIVE RESULTS AND CONCLUSIONS

Overview of Phytoplankton Distributions in the AMLR Survey Areas January-March

***West Area*:** Chlorophyll-*a* concentrations at 5m averaged 0.26 ± 0.45 mg Chl m^{-3} (n = 49), and values integrated to 100m were 16 ± 13 mg Chl m^{-2}. For this area, chlorophyll concentrations were well below our 12-year average (5 meter being 0.85 ± 0.33 mg Chl m^{-3}; 100m integrated being 56 ± 22 mg Chl m^{-2}).

***Elephant Island Area*:** Chlorophyll-*a* concentrations at 5m averaged 0.30 ± 0.27 mg Chl m^{-3} (n = 93), and values integrated to 100m were 21 ± 15 mg Chl m^{-2}. For this area, chlorophyll concentrations were well below our now 13-year average (5 meter being 0.93 ± 0.43 mg Chl m^{-3}; 100m integrated being 57 ± 24 mg Chl m^{-2}).

***Joinville Island and South Areas*:** For the Joinville Island Area, too few stations were made to make any historical comparisons (5m chlorophylls averaged 0.27, n = 3, and 0.37, n = 4, mg Chl m^{-3} for Legs I and II, respectively). For the South Area, chlorophyll-*a* concentrations at 5 m averaged 0.44 ± 0.22 mg Chl m^{-3} (n = 36), and values integrated to 100 m were 23 ± 8 mg Chl m^{-2}. For this area, chlorophyll concentrations were well below our 12-year average (5 meter being 1.75 ± 0.74 mg Chl m^{-3}; 100m integrated being 84 ± 41 mg Chl m^{-2}).

Chlorophyll concentrations generally increase between Legs I and II (Table 1). Although concentrations were low for all areas in the AMLR survey area, chlorophyll concentrations did increase slightly during Leg II (Figure 1). Satellite imagery (Figure 2) shows this same trend, with moderate chlorophyll concentrations in the AMLR survey area (and

Bellingshausen/Scotia Seas) during December, 2002, that decreased during January, 2003; chlorophyll concentrations increased again somewhat during February to subside during March, the end of the austral summer.

	No. of Years	Area	Average Number of Stations	Mean Surface, mg Chl m^{-3}	Median Surface, mg Chl m^{-3}	Mean Integrated, mg Chl m^{-2}	Median Integrated, mg Chl m^{-2}
Leg I	13	EI	58 ± 14	0.75 ± 0.31	0.63 ± 0.25	48 ± 17	44 ± 15
	11	SA	11 ± 4	1.27 ± 0.6	1.14 ± 0.52	66 ± 23	59 ± 20
	11	WA	17 ± 11	0.69 ± 0.29	0.57 ± 0.35	47 ± 15	45 ± 19
		2003 EI	39	0.21 ± 0.18	0.15	18 ± 10	18.0
		2003 SA	17	0.41 ± 0.19	0.37	22 ± 8	19.0
		2003 WA	25	0.12 ± 0.12	0.05	13 ± 8	9.0
Leg II	13	EI	57 ± 13	1.04 ± 0.6	0.80 ± 0.49	66 ± 35	55 ± 29
	11	SA	11 ± 5	1.89 ± 1.65	1.91 ± 1.94	106 ± 93	92 ± 78
	11	WA	18 ± 13	0.99 ± 0.48	0.78 ± 0.59	65 ± 34	58 ± 32
		2003 EI	48	0.37 ± 0.31	0.25	24 ± 18	19.0
		2003 SA	19	0.47 ± 0.24	0.41	24 ± 8	21.0
		2003 WA	23	0.35 ± 0.55	0.07	19 ± 16	12.0

Table 1. Comparison of surface and integrated (100 meter) chlorophyll concentrations in the three different AMLR survey regions between 2003 and the 1990-2003 mean (median) seasonal values. For all regions and both legs, 2003 chlorophyll concentrations were below average.

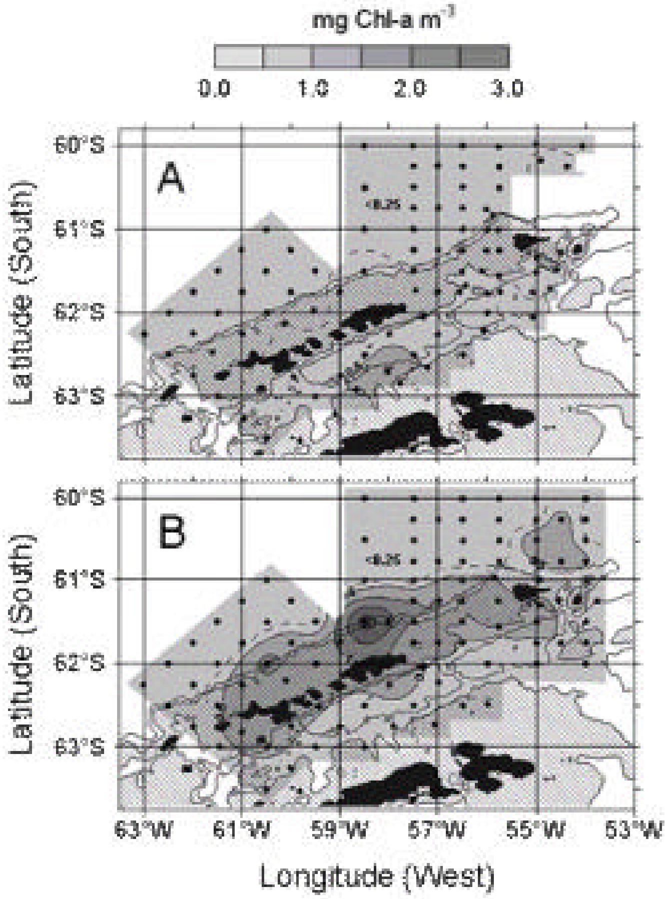

Figure 1. Distribution of 5 meter chlorophyll concentrations (methanol extraction) and positions of stations (filled circles) for (A) Leg 1 and (B) Leg II of the AMLR 2002/2003 ship survey. The 0.25 mg Chl-a m^{-3} contour is shown as a broken line. The cross hatched areas are shelf waters with depths <500 meters. The 1000 meter depth contour is also shown (continuous line).

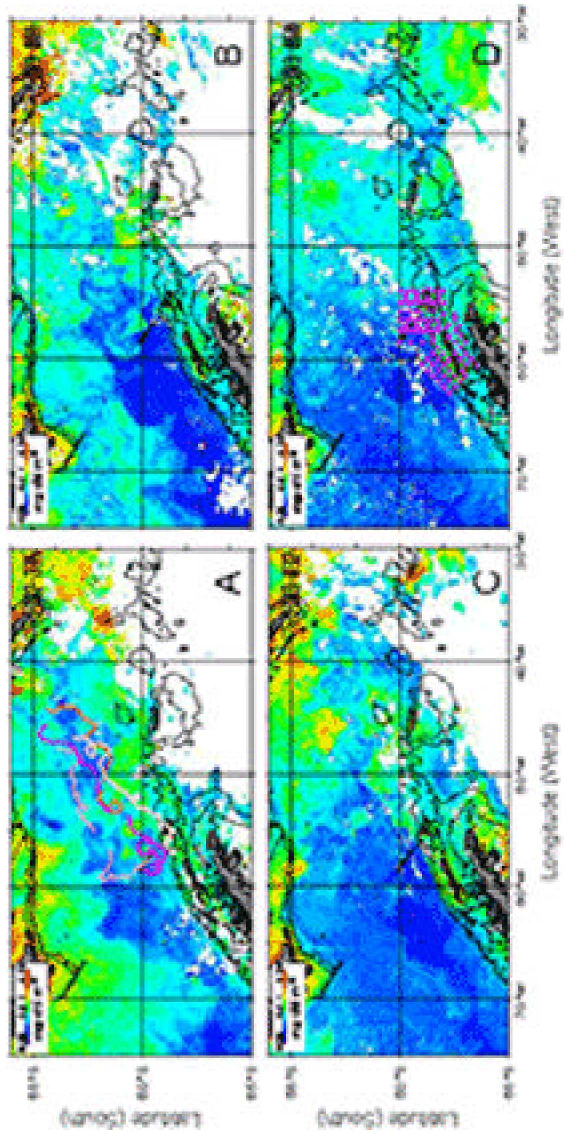

Figure 2. Monthly averages of surface chlorophyll (derived by SeaWIFS CC4x4 algorithm) dissolution in the Bellingshausen and Scotia Seas obtained by SeaWIFS satellite for (A) December, 2002, (B) January, 2003, (C) February, 2003, and (D) Marach, 2003. In (A), tracks are shown of four drifter buoys released in January and distance traced through mid-April (~4 months). In (D), station positions (peak squares) are shown for Leg 2 of the 2003 survey.

Ocean Surface Currents and Circulation

Twenty drifter buoys were released this year during the AMLR oceanographic survey, 10 for each of Legs I and II. A primary purpose for these releases was to examine how the Shackleton Fracture Zone (SFZ) interrupted the eastward flow of the Antarctic Circumpolar Current (ACC). Patterns of the drifter tracks were generalized into 5 categories (Figure 3).

Buoys released north of the shelf break in the Antarctic Circumpolar Current (ACC) drifted east northeastward and either were

- deflected southeastward towards the north of Elephant Island (Figure 3A) or
- deflected northwestward (Figure 3B).

In both cases, after passing the SFZ, these drifter buoys were realigned to the general east northeastward flow of the ACC.

- Buoys released within the shelf (<500m) and shelf-break (500-1000m) region between King George and Elephant Islands (Figure 3C) were either caught in a southwest current north of King George Island (blue trace), a southeast current that hugged the southern shores of Elephant Island (red trace), or a southeast current into the Bransfield Strait (green trace); these drifters were eventually captured by an east northeasterly current.
- Three drifters released at the shelf-break north of King George Island took a southwest direction (Figure 3D) with two (red and blue traces) entering the Bransfield Strait via the Nelson Strait (between Nelson and Robert Islands). One of these (blue trace) left the Bransfield Strait north of King George Island and was entrained by the general east northeasterly flow of the ACC.
- Two drifter buoys released in the shelf region north of Livingston Island took a west southwest course (Figure 3E), with one drifter entering the Bransfield Strait south of Snow Island (blue trace).

From the collected tracks of these 20 drifter buoys, a description of the general pattern of current flow within the AMLR survey area for the 2002/2003 field season can be made (Figure 3F). The SFZ marks a major obstruction in the flow of ACC as stated by others (see Stein, 1988). Drifter buoys exited the Bransfield Strait north of King George Island to flow southwest along the northern shores of the South Shetland Islands (Stein, 1988). Some of this current re-entered the Bransfield Strait between King George and Livingston Islands, and a remainder entered the Bransfield Strait south of Snow Island. Bransfield Strait water (e.g., Water Type IV) originates at the southwest entrance of the strait as a complex blend of Bellingshausen and Weddell Seas water, as well as coastal waters (Stein, 1988; Hofmann et al., 1996). Stein also described an eddy (e.g. his Figure 10) southeast of Elephant Island, similar in locality to where one of our drifters became entrained for about two months (green trace, Figure 3C).

Several of the drifter buoys survived passage through the Scotia Sea (Figure 2A). Although at the time of this writing the drifters had reached of the distance to South Georgia, the distances traveled shown in Figure 2A took between 43 and 86 days. Drifter buoys released in the ACC ranged between 11-15 km d^{-1} east northeast in speed by straight line distance. Drifter 39141 travelled 900 km in 65 days, which would extrapolate to the distance between Elephant Island and South Georgia in less than 100 days. There have been efforts made to determine whether krill found in the South Georgia Island area might originate from the South Shetland Island area (Hofmann et al., 1998; Fach et al., 2002). From modeling, these authors suggested that krill might be transported across the Scotia Sea in 3-4 months. The direct results of our drifter buoy data indicate this is a reasonable estimate of time for krill transport.

Analysis of Bloom Development

On February 14, a high resolution, local area coverage (LAC) SeaWiFS image of chlorophyll distribution (taken four days prior) was received on board ship. An additional CTD station (X10-07 at 61.5 °S and 58 °W) was occupied on February 14, 2003, to obtain more data on this bloom. Drifter buoy data indicated that this bloom was associated with a frontal system between Bransfield Strait and Drake Passage waters.

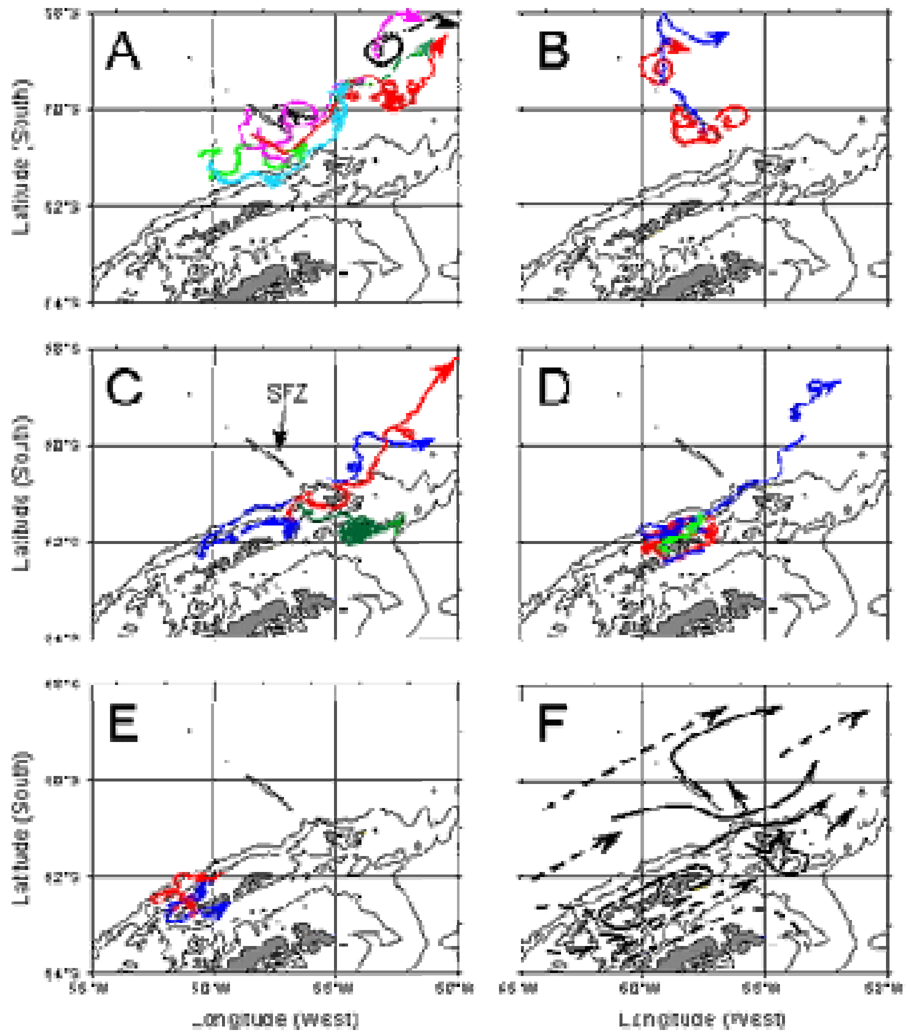

Figure 3. Tracks of buoys released January-March, 2003. Drifter buoys generally moved in an east northeast direction, but their tracks could be grouped into 5 patterns. (A) Releases north of the shelf-break in the ACC were apparently deflected by the Shackleton Fracture Zone (SFZ) so that the buoys passed between the SFZ and Elephant Island. (B) Releases near the SFZ moved northwestward. (C) Releases between King George and Elephant Island in shelf and shelf-break waters were entrained in a northeastward flowing current. In addition, one buoy entered the Bransfield Strait and apparently remained within an eddy southeast of Elephant Island. (D) Releases similar to (C) but nearer to King George Island flowed southwest and entered the Bransfield Strait between Livingston and King George Islands. (E) Releases in shelf and shelf-break waters north of Livingston Island flowed southwest and entered the Bransfield Strait south of Livingston Island. (F) Generalized patterns of surface currents (solid lines with arrows indicating direction) from this study. Broken lines with arrows indicate the

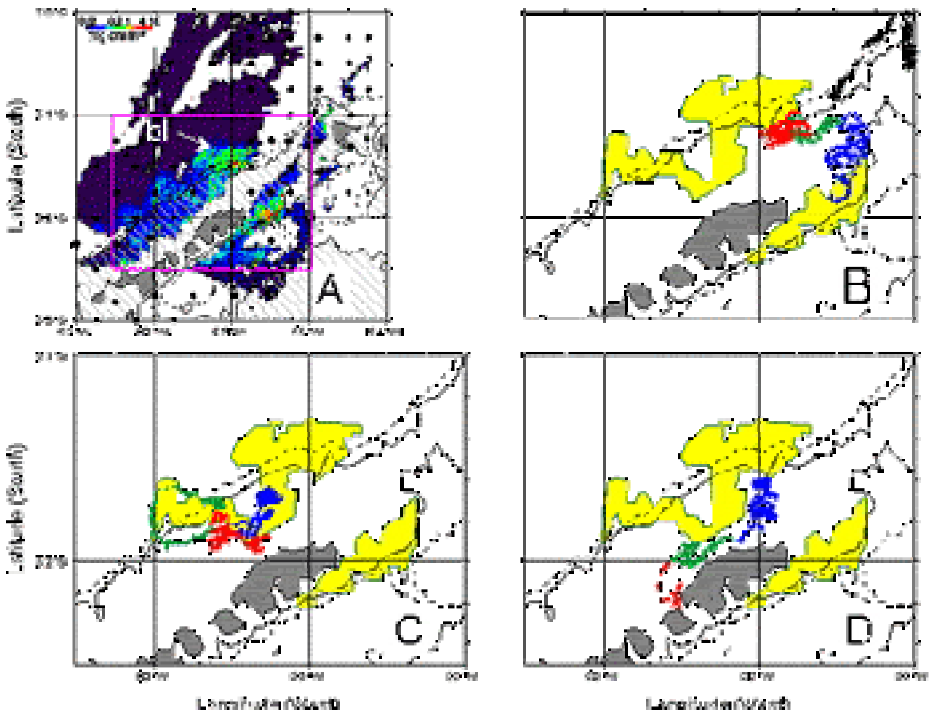

Figure 4. Surface currents as indicated by drifter buoy tracks in relation to location of a phytoplankton bloom in shelf waters between King George and Elephant Island. (A) High-resolution local area coverage (LAC) SeaWiFS image for February 10, 2003. (Julian day 41) that shows two blooms (the southern bloom is separated from the northern by a strip of low chlorophyll containing water). The bloom discussed in the text is indicated by bl. Non-colored areas are where no data was obtained due to cloud cover, and filled circles show station positions (B,C.D) Enlarged area indicated as pink box in (A), showing buoy drifter marks in relation to regions showing of elevated chl-a concentrations (shown in yellow). The time periods of the drifter tracks are shown as a function of time, with blue being Julian days 26-35, green for Julian days 36-45, and red for Julian days 46-55. Drifter 39110 is shown in (B), in addition to drifter 39096, the path of which (black trace) is shown for Julian days 26-35 as it drifted toward Elephant Island. Path of drifter 39131 is shown in (C). Path of drifter 39119 is shown in (D). Contour lines represent 500 (hatched area in A) and 1000 meter depth.

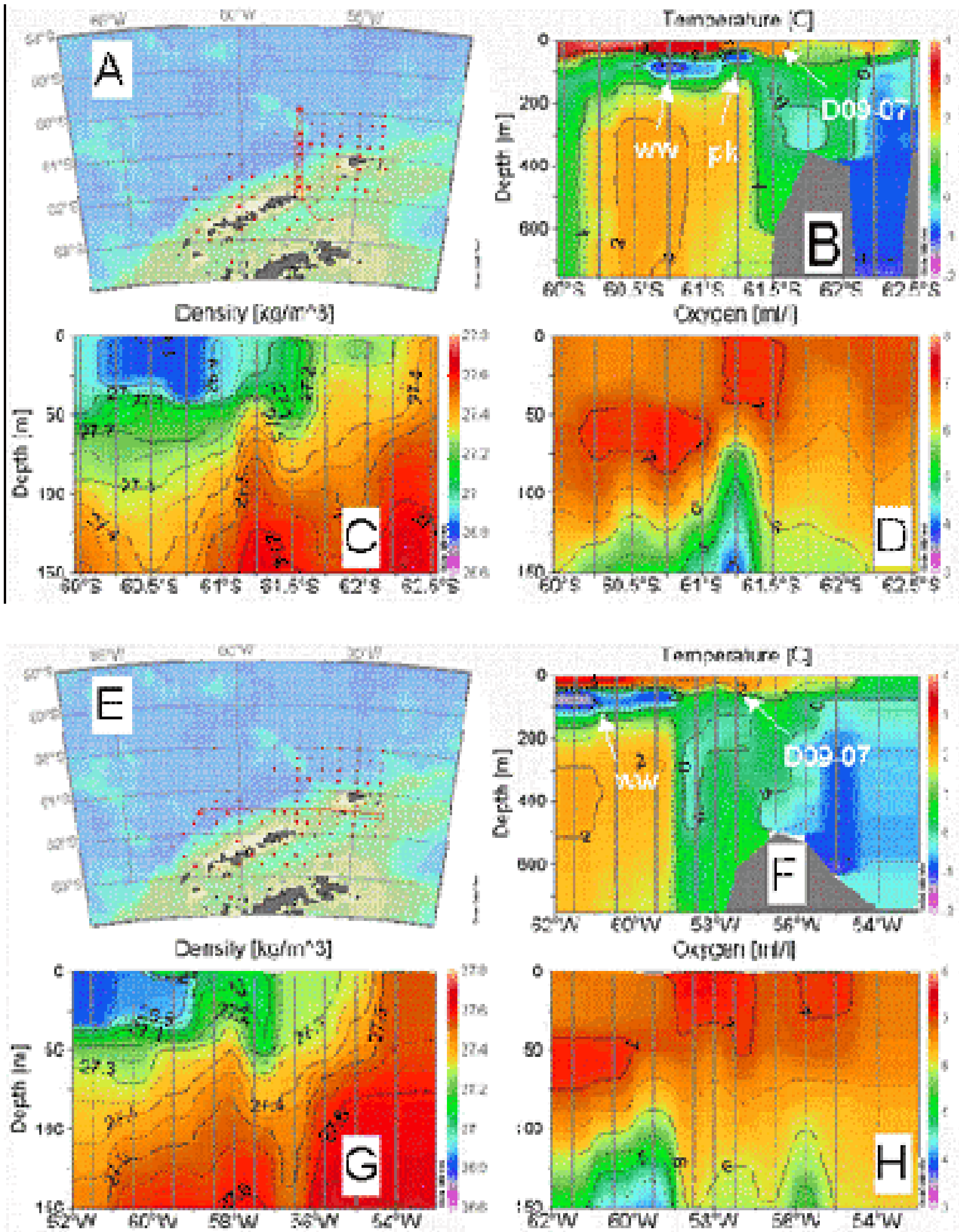

Figure 5. Interpolated (generated by Ocean Data View, Schlitzer, 2002) temperature (ºC), density (sigmal-theta, kg/m^3) and oxygen (ml/L) data of latitudinal (A-D) and longitudinal (E-H) sections through a bloom, The juncture of these sections occurred at station D09-07. Winter Water (ww) characteristic of Water Type I (ACC) and station D0906 (pk) as discussed in the text are shown. See Figure 6 for phytoplankton concentrations relating to these sections.

Data relevant to this phytoplankton bloom are shown in Figure 5 (temperature, density, and oxygen) and Figure 6 (extracted chl-a, fluorometric, and transmissometry). These data lend additional support to the suggestion that this bloom (measuring >1 mg Chl m^{-3}) did occur at a front with mixing between waters of Water Types I and IV. It should be noted that for Figures 5A-D and 6A-D, the series of stations taken from the shelf and southward were sampled approximately 7-8 days after the northern portion of the transect; for Figures 5E-H and 6E-H, stations were sampled over a 9 day period. A latitudinal section made through the bloom area (bl in Figure 6B), corresponded to 1 mg chl m^{-3} at 5 m measured at station D09-06. This section shows the ACC (e.g., Water Type I; Amos and Lavender, 1991; Deemer et al., 2001) to the north, characterized by warm surface waters (>2 ºC; Figure 5B) and a layer of Winter Water (ww in Figure 5B) with low temperature (~-1 ºC) and salinity (<34 $^{o}/_{oo}$) at about 75 m (Figures 7B-D). This is in contrast to water of the Bransfield Strait that lies to the south (Figure 5B), having cooler (<2 ºC) and saltier (~34 $^{o}/_{oo}$) surface waters with temperatures approaching -1 ºC below ~300 m (Figures 7B-D). Water Types II and III are mixtures of Bransfield Strait and ACC waters (Amos and Lavender, 1991; Deemer et al., 2001). Water Type II is similar to Water Type I in Temperature/Salinity space (Figure 7B) and water column profiles (Figure 7C-F), but has a higher temperature minimum (-1-0 ºC) with corresponding higher salinity (>34 $^{o}/_{oo}$). Water Type III was found over the shallow sill of the Loper Channel (between Elephant Island and King George) and north to the shelf break. It was characterized by having a modest temperature minimum (~0 ºC; "Bloom" in Figure 7B, C). A longitudinal section (Figures 5E and 6E) through the bloom area (bl in Figure 6F) included values of 1.7 mg chl m^{-3} at station X10-07 and 2.3 mg chl m^{-3} at station D11-07 (see Figure 7A for locations of these stations). Both temperature and salinity profiles (Figure 7B-D) show that ACC waters lay to the west of this section and Bransfield Strait waters lay at the eastern edge of the plot. Water Type III was also found over the sill and westward to the shelf-break in this section.

The sections for water density (Figure 5C, G) indicate that denser water had welled up at the juncture of ACC and Water Type III. This also corresponded with much lower oxygen concentrations below ~60 m (Figures 5D, H) as compared with surrounding waters and the northern and western boundries of the bloom (Figure 6B-D, F-H). Highest oxygen concentrations were in near surface waters that most likely corresponded to increased photosynthesis of the bloom, as well as in Winter Water of the ACC.

The temperature minimum at station D09-06 (pk in Figure 5B) of -1.08 ºC was at 55 m (heavy green line in Figure 7C) and had a salinity of 34.06 (heavy green line in Figure 7D). The temperature verses salinity relationship (Figure 7B) indicated that this was of Water Type I (e.g., ACC) water. However, blooms are not typical for this water type (Holm-Hansen et al., 1997), and this station had >1 mg chl m^{-3} at 5 m. Station D09-06 was also unusual in that 1) it had a temperature minimum at approximately 20 meters shallower than is typical of Water Type I (Figure 5B); and 2) the oxygen concentration at this temperature minimum was 6.55 ml/liter. The Winter Water in ACC is much richer in oxygen concentration (see Figures 5D, H).

Our biological data (Figures 6B-D) indicated that this pocket of cold water at station D09-06 was probably derived from Winter Water. Winter Water in the ACC for the AMLR survey area is characterized by a chlorophyll fluorescence maximum (fm in Figures 6C, G) near the temperature minimum (see Figures 7B, E; Holm-Hansen et al., 1997). Although this fluorescence maximum does correspond to a chlorophyll maximum, the *in vivo* fluorescence yield per unit chlorophyll (in proportion to *in situ* PAR) is 2-3 times higher for ACC than of other water types in the survey area (Holm-Hansen et al., 2000). Our data indicated that the *in vivo* fluorescence yield per unit chlorophyll relative to PAR for 40 and 50 m samples at station D09-06 were not significantly different than those of Winter Water and were higher than those of Bransfield Strait water.

We think it likely that the formation of this bloom in the waters between King George Island and Elephant Island was due to injection of iron into the euphotic zone by upwelling generated along a frontal system in shelf and shelf-break waters. This interpretation would be consistant with previous data from AMLR studies which have shown the enhancement of phytoplankton biomass in a frontal system to the north of Elephant Island (Helbling et al., 1993). Also, that addition of iron to ACC waters results in an increase of phytoplankton biomass (Helbling et al., 1991; Holm-Hansen et al., 1994).

DISPOSITION OF THE DATA

All chlorophyll and CTD-interfaced sensor data obtained during these cruises have been archived with AERD, Southwest Fisheries Science Center. HPLC samples will be processed by Dr. B.G. Mitchell under his NASA SIMBIOS project, and made available to AMLR participants.

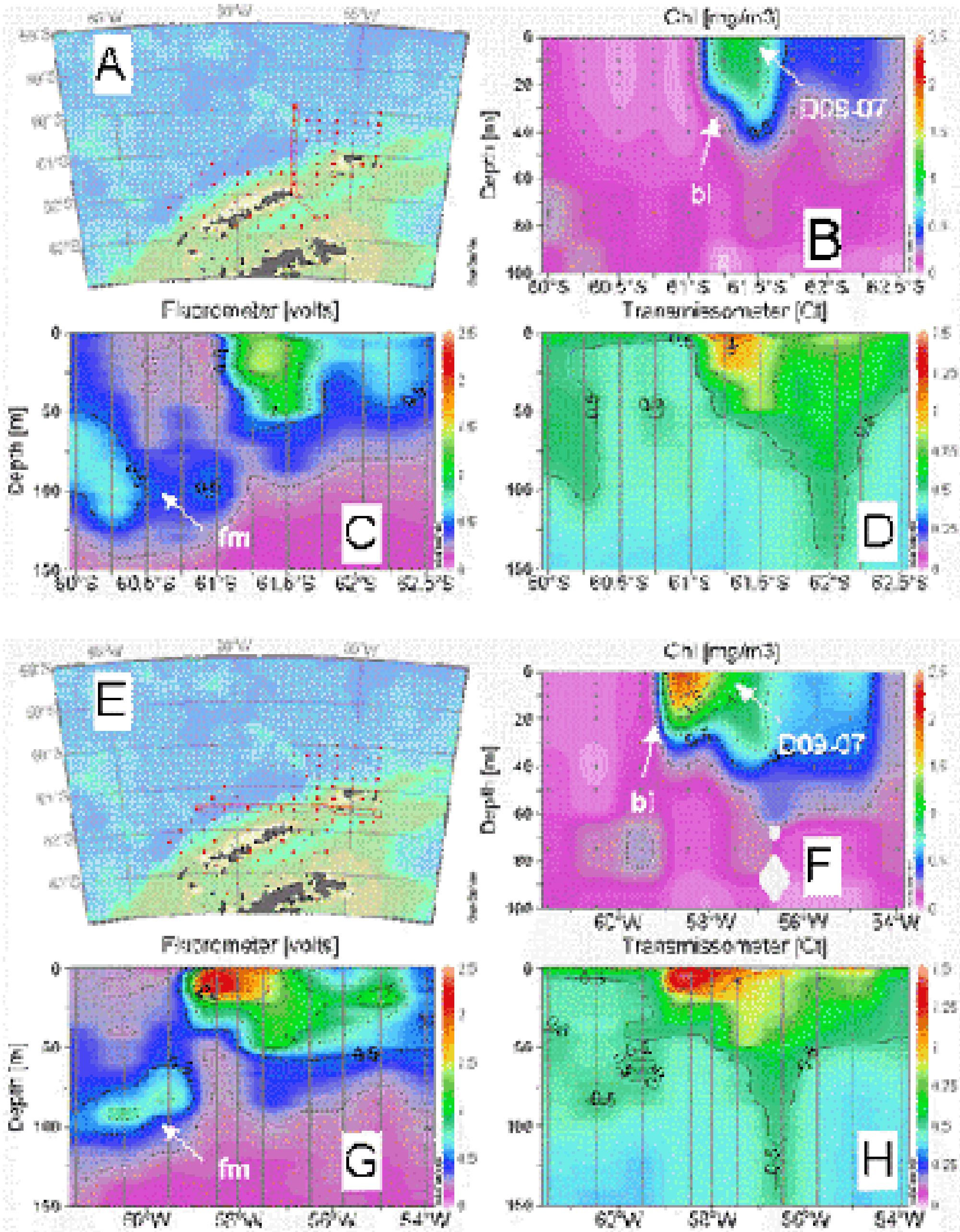

Figure 6. Interpolated (generated by Ocean Data View, Schlitzer, 2002) chlorophyll (from bottle samples, mg m^{-3}), fluorometric (volts) and beam transmission (C_t) data of latitudinal (A-D) and longitudinal (E-H) sections through a bloom (bl). The juncture of these sections occurred at station D09-07. Winter Water characteristic of Water Type I (ACC) is shown with a chlorophyll fluorescence maximum (fm). See Figure 5 for physical properties relating to these sections.

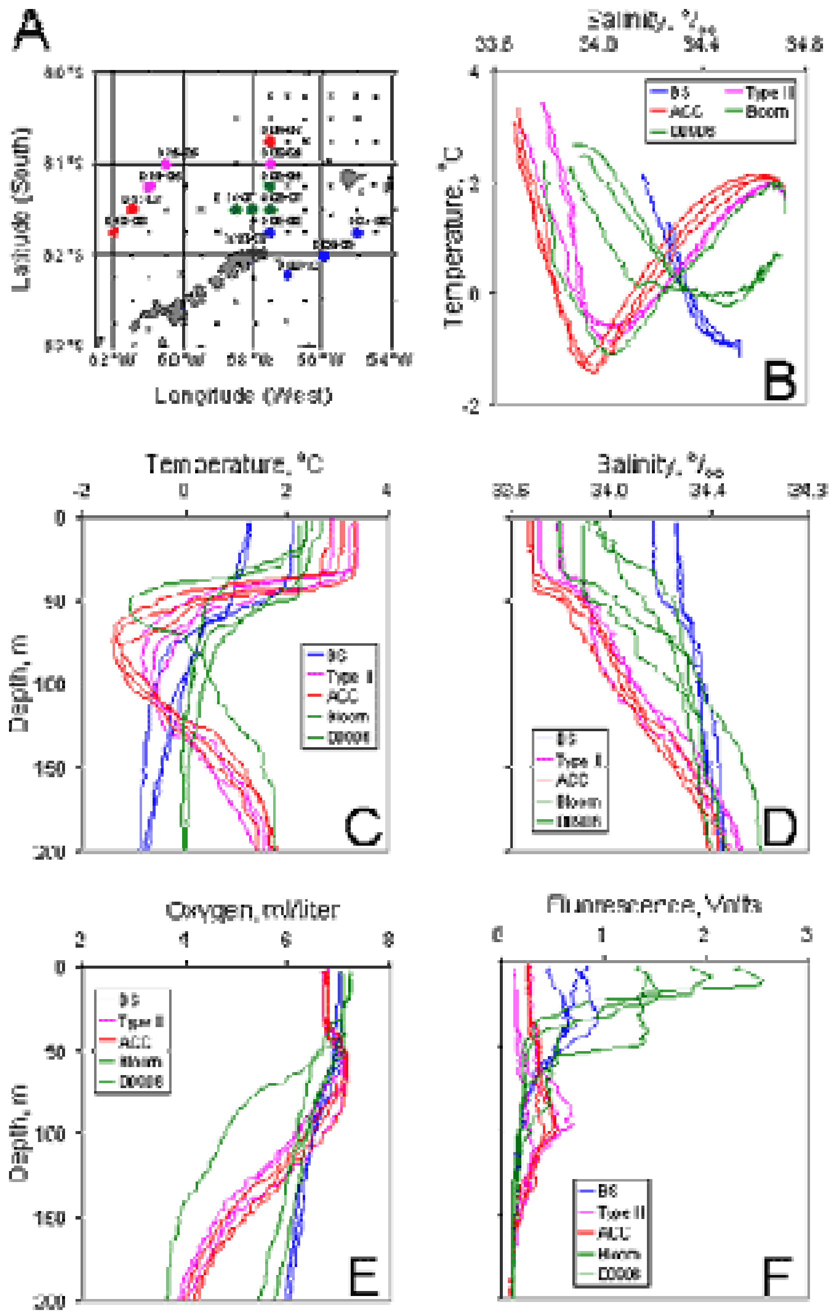

Figure 7. Water column characteristics at selected stations in the AMLR survey area (A) for Bransfield Strait (blue), ACC (Water Type I, red), Water Type II (pink) and four stations encompassing the bloom (green), with other stations indicated as X. Temperature verses salinity relationship in (B), with profiles for (C) temperature, (D) salinity, (E) oxygen, and (F) chlorophyll fluorescence. In B-F, colors represent waters as in (A), with station D09-06 (pk in Figures 5,6) with the heavy green line. Note the different shapes of fluorescence profiles for Water Types I and II compared with bloom with Bransfield Strait Water.

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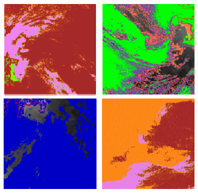

MARINE, PHYSICAL, HYDROPRAPHICAL, AND CHEMICAL PROPERTIES AND PHYTOPLANKTON OF THE ANTARCTIC PENINSULA: A TIME SERIES 1990-2002

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TASK/THEME: 3B

SUMMARY

During the past decade the National Oceanographic and Atmospheric Administration (NOAA) has funded the U.S. Antarctic Marine Living Resources Program (AMLR) to conduct an intensive multi-disciplinary oceanographic program during the summer season (January –March) in the region around Elephant Island, Antarctica. The grid of approximately 100 oceanographic stations has been sampled twice each year (with the exception of 1997 and 2000) from 1990 through 2002. During Jan-Feb, 2000, the US AMLR group participated in a multi-national, synoptic cruise survey of the entire Scotia Sea, with Leg II of year 2000 having a much reduced sampling routine. For 2000/01 and 2001/02, similar station positions were made for both Legs I and II, although the station names were changed starting in January 2002 to simplify the nomenclature of naming the ever increasing number of new stations. Also, beginning with year 2000, both the physical oceanography and phytoplankton components of the US AMLR cruises were significantly trimmed down, resulting with a great reduction in the types of data collected. The primary objectives of the AMLR program are to improve our understanding of (i) the factors that influence krill (*Euphausia superba*) abundance and distribution and (ii) the impact of varying krill abundance on higher trophic levels (e.g., fish, birds, seals, whales). The abundance of krill is thought to be dependent upon the availability of food (phytoplankton) reservoirs that, in turn, are dependent upon the complex hydrography of this region. Hence, phytoplankton biomass and distribution, and the factors that influence rates of primary production were also included in the field work of the AMLR program, for which our group at SIO has investigated since 1990.

The AMLR program is the only long-term oceanographic program in the Antarctic with a standard sampling grid, and this program will continue in the foreseeable future. Therefore, our data encompassing phytoplankton and their physical environment are especially valuable with respect to studying trends of a primary food stock in relation to both inter-annual and long-term climate variability, since this would influence populations of marine birds and mammals. Insight to the causal factors or processes responsible for variability of phytoplankton productivity in the AMLR survey region may be resolved by analysis of a sufficiently detailed database incorporating phytoplankton, zooplankton, physical, optical, and chemical data of the upper water column. Unfortunately, such has been beyond the scope of the AMLR program until now. The central goal of this project was to process available physical, hydrographic, chemical, optical, and phytoplankton data obtained during the past 12 years of AMLR field studies into a relational database format. Here we describe the general format of the AMLR Survey Database, Ver1.0.

The Databases

Two series of observations are documented by this database. The first included vertical profiles of temperature, depth, oxygen, and photosynthetically available radiation (PAR), as well as biological and chemical properties from discrete water samples from fixed stations. Generally, there were two Legs during the AMLR survey season, with one and sometimes two surveys conducted each Leg. Station positions and their designation varied 1990-1993, and station names again changed in 2002. Starting in 1994, major surveys for Legs I and II were called “A” and “D” and minor surveys “B” and “C”, respectively. Occasional extra CTD casts were made if time permitted, and designated “X”. For years 1990-1992, two Legs were made for each year, and also designated “A” and “D”; for 1993, Leg II was designated “E”. For 1997, serious problems developed with the ship, therefore Leg II was aborted; during January through mid February, 2000, the multi-vessel “synoptic survey” was made of the Scotia Sea, therefore *only* Leg II data were of the AMLR survey area and included with this database. During early survey years, station numbers consisted of two digits, while those of later years consisted of three digits. To enable fluency of the database, for stations with having two digit numbers, a prefix of “0” was added. Beginning in 2002, a complete revamping of station numbers was made, for which there is no logical cross-reference that can be made except by comparing coordinates.

The second series of observations includes underway measurements of sea temperature, salinity, beam transmission and fluorescence obtained from the ships continuous flow intake system located approximately 5 meters below surface. These were complimented by continuous measures air temperature, barometric pressure, true wind speed/direction, PAR, and ship/speed position (GPS navigational information and output from the ship’s gyro compass) were indexed to GMT date and time. These data are found in the database named **AMLR_UW.mdb**. Relative humidity was also recorded, however these data were not incorporated into this database, because readings were consistently over 100% for most years. The underway data collection system consisted of :

- digital outputs from a Seabird SBE21 thermosalinograph, a Coastal Environmental Systems WeatherPak 2000, a Furuno GPS Navigator GP-30-35, the ship’s GPS system, and the ship’s gyro compass. Both the thermosalinograph and WeatherPack were calibrated by their manufacturers prior to each cruise.
- analog outputs from a Turner Designs Model 10 fluorometer;
- a Fluke Data Bucket used for analog to digital signal conversion;
- a Digi 16-port serial adapter.

All CTD/carousel casts were made with a Sea-Bird SBE-9/11 PLUS CTD/carousel water sampler. A Data Sonics altimeter was used to guide the CTD/carousel to within 5m of the bottom on the shallow stations. Raw CTD data were corrected for time-constant differences in the primary and oxygen sensors. Parameters were then derived and binned to produce 1-meter depth-averaged profiles for analysis. Only data from the downcast of the CTD were considered for these continuous data. Water samples were collected at each station for salinity checks using a calibrated Guildline Autosal. These CTD data are found in the database **AMLR_CTD.mdb**. As the area covered by the AMLR surveys grew, sectors were defined by geographical location: Elephant Island Area, South Area, West Area, Joinville Island Area, and Blue Water Zone (BWZ, located in the central Drake Passage).

The carousel bottles for water samples were fired during the upcast at the CTD station. Until 2000, the cast was halted during the upcast at a targeted depth, and bottles fired; since 2000, bottles have been fired “on the fly” at the targeted depth.

The nomenclature of the databases is straight forward. For all tables in **AMLR_Phyto.mdb** and **AMLR_CTD.mdb**, either an *AMLR_ID* or *UpcastID* (in the case of **AMLR_CTD.mbd**, this is named *DowncastID*) column is defined. For most tables in **AMLR_Phyto.mdb**, both columns are included. The *AMLR_ID* allows cross-referencing of all depth-related data with the station information (e.g., table *CTDStation_Data* data in **AMLR_Phyto.mdb**). The *AMLR_ID* is “cruise-year-station”, for example AMLR2000_A042 would be station A042 during the AMLR 1999/2000 field season. All stations 1990-2001 have a nomenclature reflecting Leg (e.g., A-E, M, X) following a three-digit station number (early years having 2-digit station numbers have had “0” prefixed to them). For 2002, station numeration changed, and was replaced by a 4-digit station number. The columns labeled *UpcastID* in **AMLR_Phyto.mdb** are the *AMLR_ID* appended with a 3-digit targeted bottle firing depth, for example AMLR2000_A042-015 would be the 15 meter targeted depth for station A042 during the 1999/2000 field season. The column labeled *DowncastID* in **AMLR_CTD.mdb** is similar having a 3-digit text appended that represents the 1 meter binned depth measured during the downcast. For both *UpcastID* and *DowncastID*, the 3-digit depth is replaced by a 4-digit depth for depths >999 meters. Therefore, *UpcastID* and *DowncastID* can also be cross-referenced for query purposes. Additionally, the table *Chl-Continuous Flow* in **AMLR_Phyto.mdb**, consisting of continuous flow phytoplankton pigment data, can be cross-referenced with data in **AMLR_UW.mdb** adding columns *Date* + *Time* for query purposes.

Methods of Instrument Calibration

Fluorometric Chlorophyll

Chlorophyll concentrations reported in **AMLR_Phyto.mdb** were obtained by filtering 100 ml seawater sample through 25 mmWhatman GF/F filters, with pigments on the filters extracted in 10 ml 100% MeOH. Chlorophyll concentration is porportional to the fluorescence yield measured on a calibrated fluorometer. For values reported 1990-1995, fluorescence was measured with a Turner Designs TD-10, those reported 1996-2002 measurement was made using a Turner Designs TD-700. For all years,

Chlorophyll = Factor X (Rb – Ra)

And

Phaeopigment = Factor X (τ * Ra – Rb)

Where Rb and Ra are fluorescence values before and after addition of 10N HCl, respectively, and τ is an acid factor relating the unit change in fluorescence yield of pure chl-a upon acidification. The factor of calibration for the TD-700 changed with time. As the regression between these factors and time was significant (p<0.05), it was decided that this provided a more accurrate estimate than a single factor for a single year. To test this decision, a comparison between chl-a derived by HPLC (measured 2000-2002) and our values was made. Our values were 97% those obtained by HPLC, and compared well with standard acetone extraction values that were 93% of the HPLC chl-a values. With respect to acetone extraction values, MeOH appears to provide slightly better extraction qualities.

Transmissometers

Different transmissometers were used both for continuous flow and CTD casts. For continuous flow measurments during underway measurements, a Sea Tech Transmissometer was used. A Sea Tech transmissometer was also used for CTD casts 1990-1999 and 2001 Leg I. These Sea Tech transmissometers measured beam transmission at 660nm. For CTD casts during 2000, 2001 Leg II, and 2002, two Wet Labs Sea Star transmissometers were used: one measured 660nm and the other measured 440nm beam transmission. Historical calibration records for the Sea Tech transmissometers used for CTD casts were either missing or did not correspond to measures made. To estimate beam transmission ($C_{(t)}$) of CTD casts 1992-2001, it was assumed that "pure" seawater was measured at the deepest depth of each individual CTD cast >500 meters; for casts <500 meters, the previous valid cast value was used. The voltage measured at this depth by the transmissometer was considered = 100% seawater = ~"pure" H_2O. Values of 100% transmission were obtained from R. M. Pope and E. S. Fry ("Absorption spectrum (380-700 nm) of pure water. II. Integrating cavity measurements," *Appl. Opt.,* **36**, 8710-8723, 1997); with a 25 cm path, % transmission values were used as 440nm = 99.84%, 660nm = 90.26. Raw voltage data for CTD transmissometers were not available 1990 – 1992, but %Transmission values were, and it was assumed that these represented calibrated estimates. Calibration records for the continuous flow transmissometers were usually logged in the underway comments. For those years that these records were missing, air calibration factors were determined from voltages logged during cleaning times of the transmissometer windows. Calibration records exist for the Wet Labs Sea Stars and were used to estimate $C_{(t)}$. In all cases,

$C_{(t)}$ = -4 X (ln(%Transmission/100)) ,

where

% Transmission = Volts X (%T_{H2O}) X $(100\%Volts - 0\%Volts)^{-1}$

and

@ 440nm, % T_{H2O} = 99.84%,

@ 660nm, % T_{H2O} = 90.26%

Fluorometers. For all years where used, a Sea Tech Fluorometer was mounted on the CTD Carousel to measure chlorophyll fluroescence with depth. Maximum output voltage was 5 volts and occurred at 6-7 mg Chlorophyll m^{-3}. A Turner Designs Model-10 flurometer was connected to the continuous flow system for underway fluoresence measures. The recorded output consisted of two scaling factors as well as voltage, and these values were multiplied together to yield a "relative units" value as presented in **AMLR_UW.mdb**.

PAR Sensors

For 1994-1999, incident irradiation as reported in this **AMLR-UW.mdb** was measured by a Biospherical Instruments (BSI) Model QSR-240 (scaler sensor). Underway PAR reported here for 2000-present was measured using the Weather Pak. Although voltages exist for PAR for surveys earlier than 1994, neither instruments nor their calibration factors were known, therefore these data were omitted.

For measure of PAR at depth, a BSI cosine PAR sensor Model QCP-200L was used. Biospherical Instruments has recently admitted a large error made in their calibration values given to us over the years. The new PAR values using these new calibration factors have issues which are yet to be resolved. For the 2001 and 2002 field seasons, casts simultaneous with the CTD casts were made using the BSI PRR-800, a free-fall profiling radiometer that incorporates a recently calibrated cosine PAR sensor. Comparison of of PAR obtained by the PRR-800 with with that estimated by the QCP-200L (from data obtained during upcasts at >20 meter depths to eliminate ship shadow influence) will be used for quality control purposes.

Known Issues

Known issues of the databases presented as of 7/1/2003 are:

- Underway data for 1990 does not exist. Underway data 1992 had corrupted temperature and salinity data. PAR sensor type (and calibrations) 1991-1993 unknown, hence voltages cannot be converted. The raw underway data for 2000 was found corrupted.
- Values of PAR from CTD casts may be in error. Recalibration by BSI was done Spring, 2003, however issues remain and quality control needs to be done.
- $C_{(t)}$ 1990 – 1993 were based on %Transmission given in existing files, not on raw data. These appear too high. Investigation of this problem should be made. $C_{(t)}$ 2000 – 2002 using C-Star transmissometers is being re-evaluated by G. Mitchell et al., with their final corrections expected Summer, 2003.
- Tight quality control of older data needs to be continued.

THE CENTER FOR STOCK ASSESSMENT RESEARCH (CSTAR)

Marc Mangel
University of California, Santa Cruz

TASK/THEME: 4B

SUMMARY

The Center for Stock Assessment Research (CSTAR) was formed in 2001 with the objective of undergraduate, graduate, and post-graduate training in the science associated with the problems of assessing the numerical abundance, spatial distribution, size distribution and reproductive status of commercially important fish species.

Work at CSTAR focuses on using mathematical, statistical, and computer models to solve important environmental and ecological problems. The work is grounded in data, and also seeks to expand the base of basic knowledge that supports rigorous application of science to real-world problems. Furthermore, research on marine fisheries conducted by CSTAR members allows testing theoretical predictions via natural and human experiments on a scale that is appropriate for understanding the dynamics of ecosystems. Such large-scale experiments are rarely available to the scientific community. The foci of research in the Center for the period 2001-2006 are spatially explicit population dynamics, environmental variability and population processes, and risk analysis.

During the project period, CSTAR membership included

UCSC

Suzanne Alonzo (Post-doctoral fellow)

Megan Atcheson (Senior thesis student)

Michael Bonsall (University Research Fellow, Imperial College, UK; visitor in winter/spring 02-03)

Sigrun Elliasen (Ph.D. student, University of Bergen; visitor spring 03)

Teresa Ish (MS Student, Ocean Sciences and California Sea Grant Fellow)

Holly Kindsvater (Undergraduate research student and assistant to the Director)

Yasmin Lucero (PhD student, Ocean Sciences and NMFS/Sea Grant Fellow)

Marc Mangel (Professor, Applied Mathematics and Statistics, UCSC, Co-director)

Steve Munch (Post-doctoral fellow UCSC)

Kate Siegfried (PhD student, Environmental Studies)

Melissa Snover (National Research Council Post-doctoral fellow)

Andi Stephens (PhD student, Ocean Sciences)

Chris Wilcox (PhD. Environmental Studies 2002; currently post-doctoral fellow at University of Adelaide).

Nick Wolf (Scientist, MRAG Americas, working at UCSC)

NMFS/SCL (all NMFS Scientists)

Edward Dick

Xi He

Alec MacCall (Co-director)

Stephen Ralston

NMFS/PFEL (NMFS Scientists unless otherwise indicated)

Cindy Bessey

Jeff Hinke

Melissa Snover (National Research Council Post-doctoral fellow)

George Watters

Effective training requires a vibrant intellectual life that consists of courses, research, seminars and scientific interactions. Our students took a wide variety of courses (described in detail below) and conduct a wide range of research projects; we mounted a monthly seminar series in winter and spring terms and held an internal meeting in the fall term.

APPROACH, EVALUATION AND METHOLODOGY

CSTAR is a training program, so that the students take courses. During the project period, CSTAR students (and in some cases, post-doctoral fellows) took the following courses

Fall 2002

Computer Engineering 107: Mathematical Methods of Systems Analysis (Stochastic)

Environmental Studies 201A: Keywords and Concepts

Engineering 156: Linear Statistical Models

Ocean Sciences 200: Physical Oceanography

Winter 2003

Engineering 206: Bayesian Statistics

Engineering 215: Mathematical Biology

Environmental Studies 201B: Keywords and Concepts

Ocean Sciences 242: Ocean Ecosystems

Spring 2003

Biology 252: Community Ecology

Engineering 223: Time Series

Environmental Studies 201 M,N: Research in Environmental Studies

Ocean Sciences 220: Chemical Oceanography

Part of training is an active seminar series, since it contributes so much to intellectual life. In the fall term, we held an internal, day-long meeting in which all members talked about their current research projects. During winter and spring terms, we held a public seminar series, in conjunction with the Department of Applied Mathematics and Statistics, in Applied Theoretical Ecology with the following speakers:

- January 13: Per Lundberg, Lund University (on sabbatical at NCEAS): Of birds and benthos: on environmental variability, monitoring and community composition
- February 10: Larry Crowder, Duke University: Quantitative approaches to sea turtle bycatch: Protecting animals with ocean-sized habitats
- February 28: Sarah Newkirk, Stanford University: Property Rights in EEZ Fisheries.
- March 10: Russ Lande, UCSD: Accounting for stochasticity and uncertainty in sustainable harvesting strategies
- March 14 Daniel Promislow, University of Georgia: Thinking About Longevity; New evolutionary perspectives on an old age problem
- April 8: Gunnar Steffanson, Univ. of Iceland and Marine Research Institute, Reykjavik: A statistical approach to multispecies models of the marine ecosystem
- April 14: Colette St. Mary, University of Florida. Estimating: Population Demography. Considering Its Implications For Management
- May 12: Elizabeth Marschall, Ohio State University, Using optimality models to investigate patterns of energy allocation in fish

JIMO funding provides the core for the CSTAR operation (including release time from standard undergraduate courses for the Director, a post-doctoral scholar, an undergraduate assistant for the Director, and core support facilities for the various activities), but to be fully supported, other funding needs to be found too. During the project period, CSTAR funds were leveraged with other grants and contracts so that the UCSC members were funded as follows:

Suzanne Alonzo

Megan Atcheson.

Michael Bonsall

Sigrun Elliasen

Teresa Ish

Holly Kindsvater

Yasmin Lucero

Marc Mangel

Steve Munch

Kate Siegfried

Melissa Snover

Andi Stephens

Nick Wolf

CSTAR funding is used to cover various ancillary costs of the research operation (ethernet connections, software maintenance, printing and photocopying). Overall, we have established a program of research and training that if it were fully funded by CSTAR would be more than 3 times the current budget.

RESEARCH ACCOMPLISHMENTS AND RESULTS

SUZANNE ALONZO

Alonzo and Mangel have developed a general framework using an individual-based simulation model to determine the effect of life-history pattern, sperm production, mating system and management strategy on stock dynamics. We have applied this general approach to the specific question of how size-selective fisheries that remove mainly males will impact the stock dynamics of a protogynous population with fixed sex change compared to an otherwise identical dioecious population. The first paper resulting from this research has been submitted and reviewed by Fishery Bulletin (submitted October 2002, reviews received April 2003) and we are in the process of revising the manuscript and will send the revised manuscript back to the editor in the next few weeks for his final decision regarding publication.

MEGAN ATCHESON

In 2002-2003 Ms. Atcheson designed and executed a senior thesis on the life history variation, growth and smolt transformation in Steelhead Trout (Oncorhynchus mykiss). This was a multi-faceted thesis including both theoretical and empirical aspects. First, she developed a conceptual framework for steelhead trout based on the literature. This framework was then used to develop hypothesis tested in the lab at the National Marine Fisheries Service Santa Cruz Laboratory in collaboration with Susan Sogard. The research focused on the influence of size and growth rate on smolt transformation.

MICHAEL BONSALL

During a five-month research stay at UCSC, Bonsall and Mangel developed models to explore how physiological structure predicts mortality trajectories, with longevity and mortality of the rockfish in mind. We use two different approaches. In the first, we use the method of linear chains to treat mortality that arises as the result of multiple physiological processes. In the second, we assume that mortality is the result of damage associated with growth and metabolism. Both approaches lead to a rich diversity of predicted mortality trajectories. We also developed a model to explore how the diversity and mechanisms of diversification can be explain in terms of life history trait trade-offs. In particular, we have explored how natural mortality rate (longevity) might affect competitive ability and consequently patterns of coexistence between species. We have shown how the diversity and diversification of species can be influenced by natural morality rate. We have shown how selection on uncorrelated life history traits can lead to patterns in these life history traits as evolution proceeds.

SIGRUN ELIASSEN

Ms. Eliassen earned a Masters degree in Zoological ecology from the Department of Zoology, University of Bergen, Norway (2000). Currently she is a PhD student at the Department of Fisheries and Marine Biology, University of Bergen. Her PhD-project on “Hedonic models of fish behavior” aims at developing a method for modeling adaptive behavior in complex and changing environments. During a 4-month research stay at UCSC, she and Mangel collaborated on models of learning and adaptive foraging behavior.

TERESA ISH

Ms. Ish completed a M.S. thesis in Marine Science, “Conceptual Tools for Managing Two Monterey Bay Fisheries”. She currently has one paper in review, co-authored by Marc Mangel, EJ Dick, and Paul Switzer. She was also the recipient of the Young Investigator Award at the Fourth Mote Symposium. In fall 2002, Ms. Ish worked, in conjunction with Ms. A. Stephens, on the development of effort allocation models for bocaccio, using recreational data. Ms. Ish began work at the NMFS/SCL in summer 2003.

HOLLY KINDSVATER

Ms. Kindsvater is undergraduate assistant to Director Mangel. In addition, she has been continuing research on her senior thesis project. She is exploring the dynamics of marine organisms whose populations are subject to intake by power plants (entrainment). Her model includes a putative compensatory reserve of larvae, but also incorporates density-dependent processes in adult stages. The resulting multi-generational stock recruitment relationship will lend insight into the dynamics of marine populations in different states (for example, those subject to fishing pressure and entrainment, which is the case for some California rockfish populations)

YASMIN LUCERO

In her first year as a graduate student Ms. Lucero has completed courses on Fisheries Conservation and Management, Introduction to Probability, Theory, Bayesian Statistics, Physical Oceonagraphy, Dynamics of Marine, Ecosystems, Chemical Oceanography, Ocean Ecosystems and Mathematical, Biology. She has begun research on coastal pelagic fishes in the California Current. This includes developing a simple population model for Sardines (*Sardinops sagax*) and Anchovies (*Engraulis mordax*). This model incorporates predation/cannibalism dynamics between the species, and the presence of temporally variable nursery habitat.

STEPHAN MUNCH

Dr. Munch is a post-doctoral research fellow currently involved in several research projects with Mangel, members of CSTAR, and other researchers. He is developing Bayesian methods for analyzing stock-recruit data with Dr. Thanasis Kottas of the Department of Applied Mathematics and Statistics of UC Santa Cruz. With Nick Wolfe (Mangel lab), he is studying compensatory growth using Bayesian dynamic linear models. He is also developing a dynamic optimization approach to understanding when compensatory growth should occur given costs of growth, size dependent mortality, and seasonal time constraints. He has had two papers, based on his dissertation at SUNY Stonybrook, accepted for publication this year. One (Munch and Conover 2003) is a demonstration of intermediate term costs of growth in Atlantic silversides, to be published in Evolution later this year. The second (Munch et al. 2003) presents a method for estimating the size dependence of growth and mortality from size frequency data, which is to be published in the August issue of Ecology. He is currently working on extending this method to looking at mortality in eight species of juvenile rockfish, in collaboration with Dr. Steve Ralston of the NMFS lab, Santa Cruz and Kate Siegfried (CSTAR graduate student).

KATE SIEGFRIED

Ms. Siegfried completed the first year of course work for the Environmental Studies graduate requirements. This included an experimental design course, a grant-writing course, one advanced reading group (which read *The Evolution of Life Histories*, by Stephen C. Stearns), and two courses that contained six three-week modules covering ecology, political economy, political ecology, natural resource economics, agroecology and conservation biology, and global change.

She also completed three quantitative courses: linear statistical models, mathematical biology, and probability theory. Her research effort focused on estimating mortality from size-frequency distributions of rockfish, and estimating prior distributions for life history parameters such as growth and mortality from elasmobranch data. She also carried out an extensive literature review on the topics of elasmobranch management and aging. In the spring, she was awarded a $1500 departmental grant, which will support a visit to the NMFS, Panama City Laboratory and she served on the departmental seminar committee throughout the academic year.

MELISSA SNOVER

Dr. Snover began working with CSTAR in October 2002. Working with George Watters (NMFS/PFEL) and Mangel, Snover is developing a model for coho salmon growth and maturation rates. This model provides proximate and ultimate causations for early maturation in this species of salmon. They are using a form of the von Bertalanffy curve where net linear growth rates are described by E-kL, E relates to the animal's rate of anabolism, k is the growth coefficient and relates to the rate of catabolism and L is length. Making the assumption that k is set at an early point in an individual's development and remains constant throughout life, faster growth in freshwater, or higher k, results in larger smolts. For seawater growth, it is assumed that all smolts from the same source experience approximately the same ocean conditions and food availability; therefore the E term is constant. Hence, net linear seawater growth rates decrease with larger values of k. Larger smolts have a decreased capacity for growth and cannot attain large sizes, an ultimate causation of early maturation. Fitness functions incorporating freshwater and seawater survival, body size, probability of mating (males only), and gonadosomatic indices (males only) are also being developed. Curves resulting from these functions demonstrate that the largest smolts will maximize reproductive fitness by maturing early. Intermediate- and small-sized smolts maximize fitness by maturing at three and four years, respectively. Snover is currently preparing drafts for two manuscripts from the research done so far

ANDI STEPHENS

The relevant coursework taken by Ms. Stephens included Introduction to Probability Theory, Bayesian Statistics, Mathematical Biology, and Mathematical Methods for Engineers. She passed the PhD Qualifying Exam and her thesis proposal has been accepted. Under the direction of Alec MacCall, Teresa Ish and she completed an initial

investigation of a new method for statistical analysis of recreational catch of rockfish. With Marc Mangel, she worked on an age-structured model and risk analysis for Gulf of Maine salmon populations.

She has been awarded a Science Fellowship by the Center for Informal Learning and Schools.

NICK WOLF

During the last nine months, Mr. Wolf has been collaborating with Mangel to develop a series of models representing alternative hypotheses to explain the decline of the Steller sea lions' western population. He began his investigation in late September of 2002 by constructing a series of deterministic population models and fitting them to the available population-wide census data. At the Mote symposium in November, he met with other population biologists to discuss these early results. He spent the next few months familiarizing himself with the Steller sea lion literature, compiling census data from individual rookeries, and re-writing the population models to include process uncertainty and incorporate censuses from individual rookeries in years when only part of the declining (western) population had been censused. With this model, Mr. Wolf intended to produce a “landscape” of anomalous mortality and fecundity rates across the geographic range of the declining population and compare it to the spatial and temporal distributions of fishing activity, predator sightings, or other local factors in order to test various hypotheses proposed to explain the decline. Mr. Wolf attended David Draper’s class in Bayesian statistics during the first quarter of 2003 and became well versed in the art of confronting alternative models with data, producing likelihood distributions, and converting them to posterior probability distributions for the parameters of interest.

After a particularly fruitful meeting with CSTAR speaker Gunnar Stefansson in April, Mr. Wolf realized that a better way to test the alternative hypotheses might be to formulate them as a series of explicit functions relating local mortality and/or fecundity rates to local conditions via generalized linear models. The approach will then be to solve for the spatially and temporally constant parameters in these functions, rather than solving for the vital rates themselves. He is currently working out the implementation of observational uncertainty in the latest version of the model.

CONCLUSIONS AND RECOMMENDATIONS

The overall objective of CSTAR is to provide training in quantitative population and community ecology to enhance the pool of qualified scientists available to NMFS. The current project period is the first full year of CSTAR operation. In that year we have already placed one student (E.J. Dick) in a permanent NMFS position (harvest analyst at the NMFS/SCL), have another (Teresa Ish) who is beginning contract work at the NMFS/SCL in summer 2003, postdoctoral scholar Suzanne Alonzo received an offer from Yale University, and two postdoctoral scholars (Steve Munch and Melissa Snover) who are being considered for a new position at the NMFS/SCL. We have also provided quantitative training to two undergraduates (Megan Atcheson and Holly Kindsvater), both of whom will go on to graduate school. In academic year 2003-04, the continuing students (Yasmin Lucero, Kate Siegfried and Andi Stephens) will be joined by two new PhD students (EJ Dick and Anand Patil). In the upcoming year, we have a slate of 9 external seminars, sabbatical visitor Dr. K. Lorenzen (Imperial College) and a return visit by Dr. M. Bonsall.

In short, CSTAR is on a very fine trajectory towards excellence in research and training and we anticipate that CSTAR students and post-docs will set the standard for NMFS research 5-10 years hence.

GENETIC POPULATION STRUCTURE OF CENTRAL CALIFORNIA COASTAL SALMONID POPULATIONS

R. Bruce MacFarlane
University of California, Santa Cruz

TASK/THEME: 4B

SUMMARY

Genetic data have long been recognized as valuable components of any biological management plan, as they provide information that cannot be obtained in any other way. In spite of the precarious position of California's coastal salmonid stocks, little is known about their biology, especially population genetic structure. The cooperative research in this study is providing a comprehensive picture of genetic population structure of steelhead, coho and chinook salmon in California.

OBJECTIVES AND APPROACH

The specific objectives of this study are to:

- Determine the relationship of extant runs of coho salmon, chinook salmon and steelhead in different watersheds with one another.
- Identify appropriate broodstock for hatchery operations.
- Confirm/identify the source of broodstock used in hatchery operations within the region.
- Evaluate whether there are significant differences between naturally reproducing fish and fish introduced through hatchery releases and stocking programs.
- Evaluate interactions (e.g. hybridization), and consequences of such interactions, between naturally produced and hatchery-raised fish.
- Estimate the demographic trajectory, rates of straying and recent effective population sizes of extant salmonid runs for multiple year classes.
- Evaluate interyear and interbasin variability in population genetic composition.
- Evaluate inbreeding and outbreeding depression and identify the components involved in such declines in fitness.
- Archive and catalogue salmonid samples for use by other research and management teams.
- Use novel molecular genetic methods to assess impacts of pinnipeds on salmon populations.

During this project period, we have continued the study of the relationships among extant steelhead runs in coastal California streams and rivers using molecular genetic techniques. In the last reporting period, tissue samples were collected from approximately 5000 fish from 40 watersheds, DNA was extracted, catalogued and archived, and a standardized set of 18 microsatellite DNA markers was developed and tested extensively. In this reporting period, we finished genotyped and quality control of all 18 microsatellite markers in approximately 4500 fish, representing most of the salmonid-bearing coastal California streams and rivers between the Klamath River and Monterey County.

Extensive analyses of the data have been undertaken. Among them are the construction of genealogical relationships, estimates of straying rates and inbreeding, and tests of population differentiation, linkage and Hardy –Weinberg equilibrium. The demographic trajectory of all stocks studied was also evaluated.

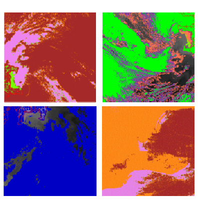
A set of 12 microsatellite markers for coho salmon were partially developed in the last reporting period. In the present period, testing was completed, the set of markers changed to accommodate new information and genotyping of almost 500 fish completed. Preliminary applications of these 12 markers included an evaluation of potential donor stocks for a restoration effort in the Russian River and the selection of 150 individuals for broodstock in the Scott Ck. (Santa Cruz Co.) coho salmon captive broodstock program. Moreover, the data have been used to identify the source of founders for a recent colonization event in Marin County, CA. In the next reporting period, the dataset will be expanded by 50% to include 18 microsatellite markers (for increased statistical power) and the number of individuals analyzed will double.

ACCOMPLISHMENTS

1. Genotyping with 18 microsatellite genes of approximately 4500 steelhead trout
2. Extensive analyses of 18 microsatellite dataset for steelhead trout, including stray rates and inbreeding coefficients.
3. Determination of demographic trajectory for more than 40 stocks of steelhead trout in coastal California.
4. Further development of standardized sets of microsatellite DNA markers for coho salmon and chinook salmon.
5. Evaluation of coho salmon genetics for captive (hatchery) broodstock and reintroduction programs in Scott Creek (Santa Cruz Co.) and the Russian River (Sonoma Co.).

CONCLUSIONS

The preliminary results of this multiyear project have provided a much clearer picture of population genetic structure for coastal steelhead trout population than was previously possible. This has led directly to the formulation of an appropriate model for delineation of management units in the Endangered Species Act Technical Recovery plan for these ESA listed populations. The use of genetic methods to select individuals for inclusion in captive broodstock programs is a major advance that will provide a hedge against extinction and maintain effective population size. It is recommended that the research program continue as outlined.



COOPERATIVE STUDIES OF PACIFIC COAST SALMON: NMFS/UCSC

Peter Adams
University of California Santa Cruz, California

TASK/THEME: 4B

BACKGROUND

The entire area of salmonid anadromous fish habitat within California is covered by one or more Endangered Species Act (ESA) listing of salmonids. This is the largest environmental conservation effort ever attempted. The underlying science needed for recovery of these salmonids is only in the most preliminary stage of development. This is the first part of a long-term agreement to provide the salmon science needed to recover these species. These studies, which are essential for the conservation and management of Pacific Coast salmon and steelhead, are conducted by the University of California, Santa Cruz (UCSC) and NOAA Fisheries, Southwest Fisheries Science Center, Santa Cruz Laboratory (SCL) through a collaborative research effort of the Joint Institute of Marine Observations (JIMO). This cooperative project combines the unique talents of UCSC basic researchers with the applied researchers of NOAA Fisheries.

There were three general parts to the multi-disciplinary program:

- Compiling relevant life history data and conducting field surveys on critical salmon populations.
- Development of a central information database for threatened and endangered coastal salmon and steelhead populations.
- Statistical modeling to predict the level of change in threatened and endangered salmon and steelhead populations that can be detected with current data.

The work was conducted at UCSC, SCL, and in coastal watersheds of California, including those that transverse the UCSC campus.

SUMMARY OF STUDIES

Field Studies of Coho Salmon: Contributions to Statistical Survey Design and Ecological Understanding of Coastal Salmonids

For the past four years, researchers from UCSC and NOAA Fisheries have conducted an ongoing, intensive study on the South Fork Noyo River (Mendocino County) to collect data on juvenile distributions (Figure 1), habitat usage (Figure 2), outmigration timing, adult abundance, distribution, origin (hatchery vs. wild), run-timing and straying. These studies were initiated in response to the lack of comprehensive, rigorously and recently collected data for salmonid populations from coastal California. These studies have provided rich data sets that have supported development of improved survey designs and sampling protocols. Researchers are developing a rigorous statistical framework for new abundance surveys, which will include an improved habitat unit selection scheme, bias-adjusted abundance estimators, explicit variance estimators, and characterization of the conditions under which such surveys can be expected to perform well. These developments will improve the quality of juvenile abundance data throughout the West Coast. These data have also supported other studies designed to examine the statistical power of different approaches to monitoring salmonid abundance. The field data has provided the basis for investigation of ecological questions, such as the relationship of juvenile distributions to adult spawner distributions over a range of population densities, and the prevalence of a life-history variant of coho salmon recently reported for the California part of the species' range.

Juvenile salmonid abundance and distribution were similar in 2001 and 2002, but differed from results found in 2000. Coho salmon were almost four times more abundant in 2001 and 2002 than in 2000 (Table 1). Young-of-the-year (YOY) steelhead were most abundant in 2000, with numbers decreasing by around 40% in 2001 and 2002. Steelhead ages 1+ and >1+ were most abundant in 2000 and 2001, with a slight decrease observed in the 2002 counts. Juvenile coho salmon and steelhead were encountered in the highest numbers in the South Fork and the North Fork of the South Fork, Noyo River.

Figure 1. UCSC and NOAA Fisheries researchers measuring salmon and steelhead habitat in a coastal basin.

Figure 2. UCSC field biologist counting juvenile coho salmon and steelhead in a coastal basin.

Assembly and Analysis of Population Presence and Trend Data for Coho Salmon

Coho salmon are listed as “threatened” under the federal Endangered Species Act throughout their entire California range. The paucity of reliable time-series data on coho salmon population abundance within California has hindered status assessments and recovery efforts for coho salmon in the region. Because of the lack of long-term abundance records, previous status reviews have relied primarily on comparisons between the historical and current distribution of coho salmon within the state. Researchers from UCSC and NOAA Fisheries have assembled and continue to update data on the distribution of coho salmon across their California range from the mid-1980s to the present. We have developed a database containing more than 9,000 survey observations of coho salmon presence or absence in the Central California Coast (CCC) and Southern Oregon/Northern California Coast (SONCC) Evolutionarily Significant Units (ESUs) for the period 1986-2001. These data indicate that over the past 15 years, coho salmon have occupied between 40% and 60% of historical streams in the CCC and SONCC ESUs (Figure 3), and that populations are at or near extinction in several major watersheds in the CCC ESU. The data have been used in formal status review updates prepared by NOAA Fisheries scientists, which provide the scientific basis for Endangered Species Act listing decisions, and are expected to play an important role in salmon recovery planning efforts.

Statistical Analysis of Data on Salmon Distributions

This project includes statistical analysis of data collected for various life history stages of Pacific salmon in the Noyo River (Mendocino County) and Prairie Creek (Humboldt County). These data have been collected to investigate population dynamics and to provide a basis for examining ways to improve methods for monitoring salmon populations. Recent and ongoing analysis includes evaluation of sampling at different life history stages (e.g. spawning adults, redd counts, and surveys of juvenile abundance) to capture changes in population size in the Noyo River, and analysis of patterns in the use of different habitat types by juvenile coho salmon as a function of population size in Prairie Creek. The first project is expected to provide useful guidance regarding the type of data that is most useful for analysis of population trends as well as working towards an understanding of how to relate different types of data across populations. The second project is expected to contribute directly to the design of sampling surveys able to detect changes in population status without requiring a comprehensive abundance estimate.

Relationships Between Resident and Anadromous Forms of Rainbow Trout

Rainbow trout exhibit both non-migratory (resident) and anadromous (steelhead) life history forms. Steelhead are listed under the ESA, but resident forms are not. However, the reproductive relationship between the two forms has been difficult to study, in part because juveniles of the two forms co-occur and look identical. UCSC and NOAA Fisheries researchers are using otolith (Figure 4) strontium to calcium (Sr/Ca) ratios to discern between life history forms and to estimate the proportion of fish which are descended from females of the alternate life history form, and thus the degree of reproductive isolation. To date, over 900 samples have been collected from resident and steelhead hatcheries in California. These samples are being analyzed to compile a reference dataset, confirm anadromy of steelhead broodstock, and evaluate the use of scales and fin rays as non-lethal alternatives to the otolith-based method. Preliminary results confirm that progeny of steelhead and residents can be distinguished based on Sr/Ca ratios (Figure 5). Results also have revealed variation among hatcheries and watersheds in northern California, and have documented alternation of life history type among generations in hatchery fish. These results will be applied to studies of natural populations and move fishery managers toward the long-term goal of understanding the role of resident forms in the establishment and persistence of ESA listed steelhead populations in California.

Southern and Central California Ssteelhead Distribution Surveys

The current regional distribution of steelhead in Southern California and the South-Central California Coast finds its southern range limit in Southern California, where it is considered to be at high risk of regional extinction. The South-Central California Coast steelhead populations are listed as ‘threatened’ according to the ESA, while the Southern California steelhead populations are listed as ‘endangered.’ The original NOAA Fisheries status review in 1996 (which led to the listings) and subsequent updates have all mentioned the high level of uncertainty about the status of these fish, due to lack of data. To help improve this existing paucity in the data, a group of NOAA Fisheries scientists and UCSC biologists conducted a systematic survey of the coastal stream basins in Southern and South-Central California (Summer 2002), where both populations of steelhead were known to exist historically. Existing reports of recent occurrence were summarized, and new data were collected, so as to document presence or absence in each basin. The group also examined basins with no documented history of steelhead occurrence whenever practical. In all, the group estimated presence/absence for 82 coastal basins in which the fish were known to occur historically, and 64 basins with no prior record of steelhead occurrence. The data suggest that steelhead are still widely distributed, but have been lost from at least half their basins in the Southern California region. The study decreased the uncertainty about the current geographic range of these two populations, and is expected to play an important role in the recovery planning process.

GIS Support for Technical Recovery Planning and Research-Monitoring Efforts

This project has entailed the assembly and implementation of a GIS, covering the range of salmonid anadromy throughout California and parts of Southern Oregon. Developed by UCSC researchers, with input from NOAA Fisheries scientists, it is being used as a tool to support spatially explicit analyses in the course of technical recovery planning for listed Pacific salmon and steelhead. Tasks have included: (1) assembling relevant data from diverse sources, including digital elevation models, precipitation models, hydrological and geological layers, barriers, and land cover/land use; (2) developing products, such as watershed delineations, comparative statistics, and distance matrices for use in analysis of population structure; (3) implementing a dynamic segmentation model for data assembly, display and analysis; (4) developing models to predict habitat characteristics as a function of stream gradient and precipitation inputs; and (5) assembly of data on the distribution of Pacific salmon and steelhead from published and grey literature and solicited from local experts. These data and products are currently being applied to support technical recovery planning and to support design of research projects intended to fill critical gaps in our knowledge base of Pacific salmon and steelhead in California.

Literature Database

This effort involves identifying, acquiring, and cataloging information from various sources relevant to Pacific salmon and steelhead and making it accessible in a searchable literature database. Researchers from UCSC, working closely with NOAA Fisheries researchers, have cataloged well over 3,500 reports, datafiles, publications, and other information useful for various Endangered Species Act activities being conducted by NOAA Fisheries. The items are cataloged in a searchable database (ProCite) and copies of most of the information are available at SCL. In addition, many of these reports and data sets are available in electronic form.

PUBLICATIONS, REPORTS, AND PRESENTATIONS

Bjorkstedt, E.P. Implications of competition in common habitats for the dynamics of stage-structured metapopulations. Presentation at the 5th Annual Salmon Ocean Ecology Meeting, February 11-12, 2003.

Boughton, D.A. Recovery under the Endangered Species Act. Presentation at the 21st Salmonid Restoration and Urban Streams Conference, March 28-29, 2003. San Luis Obispo, CA.

Boughton, D.A. A regional overview of southern steelhead. Presentation at the 21st Salmonid Restoration and Urban Streams Conference, March 28-29, 2003. San Luis Obispo, CA.

Donohoe, C.J., and Adams, P.B. Microchemical analysis to discriminate between threatened and endangered rainbow trout and steelhead (*Oncorhynchus mykiss*). Presentation at the 2003 Monterey Bay National Marine Sanctuary Symposium, California State University, Monterey Bay, March 15, 2003. Monterey, CA.

Donohoe, C.J., and Adams, P.B. Use of otolith microchemistry to infer migration histories of *Oncorhynchus mykiss*. Presentation at the 21st Salmonid Restoration and Urban Streams Conference, March 28-29, 2003. San Luis Obispo, CA.

Donohoe, C.J., and Adams, P.B. Evaluation of Sr/Ca ratios in three structures as records of individual and maternal migration history in rainbow trout (*Oncorhynchus mykiss*). Presentation at the Annual Meeting of the Western Division of the American Fisheries Society, April 14-17, 2003. San Diego, CA.

Lindley, S.L., and Mohr, M.S. 2003. Modeling the effect of striped bass (*Morone saxatilis*) on the population viability of Sacramento River winter-run chinook salmon (*Oncorhynchus tshawytscha*). Fishery Bulletin 101:321-331.

Lindley, S.L. State-space models and their application to salmonid population viability analyses. Presentation at the NMFS BiCoastal Salmon Population Viability Analysis Workshop, April 29-30, 2003. Gloucester, MA.

Lindley, S.L. *In Press.* Estimation of population growth and extinction parameters from noisy data. Ecological Applications.

Newman, K., and Lindley, S.L. Modeling the population dynamics of Sacramento River winter-run chinook salmon using adult escapement and juvenile production estimates. Presentation at the Interagency Ecological Program Workshop, California Water and Environmental Modeling Forum Annual Meeting, February 25-27, 2003. Pacific Grove, CA.

NOAA Fisheries. 2003. Draft: Preliminary conclusions regarding the updated status of listed ESUs of West Coast salmon and steelhead. Northwest Fisheries Science Center, Seattle, WA and Southwest Fisheries Science Center, Santa Cruz, CA. Available at: http://www.nwfsc.noaa.gov/cbd/trt/brt/brtrpt.html

Schick, R.S., Lindley, S., and Bjorkstedt, E. Assessing quantitative relationships between Chinook salmon and GIS-derived habitat data. Presentation at the Interagency Ecological Program Workshop, California Water and Environmental Modeling Forum Annual Meeting, February 25-27, 2003. Pacific Grove, CA.

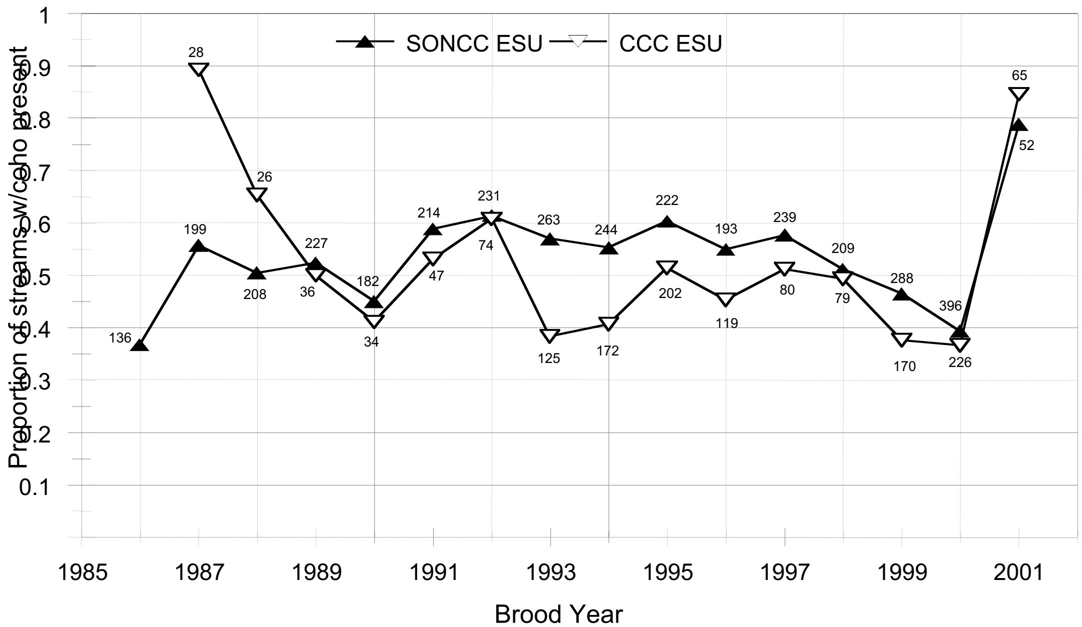


Figure 3. Proportion of streams surveyed for which coho salmon presence was detected within the Southern Oregon/Northern California Coast (SONCC) and Central California Coast (CCC) Evolutionarily Significant Units by brood year.

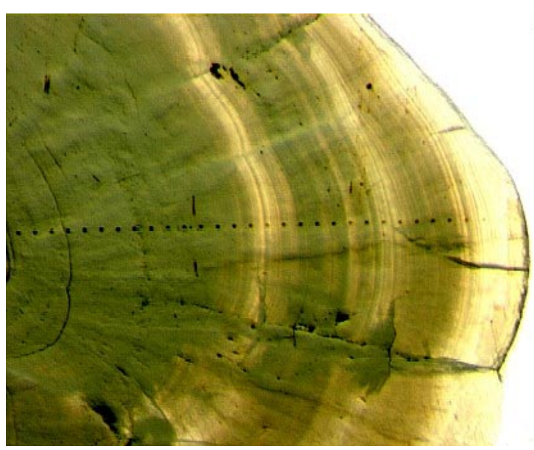


Figure 4. USCS and NOAA Fisheries researchers use otoliths (ear stones) from rainbow trout to determine migratory history. This figure shows a cross-section of an otolith that was scanned for the presence and distribution of the element - strontium (Sr).

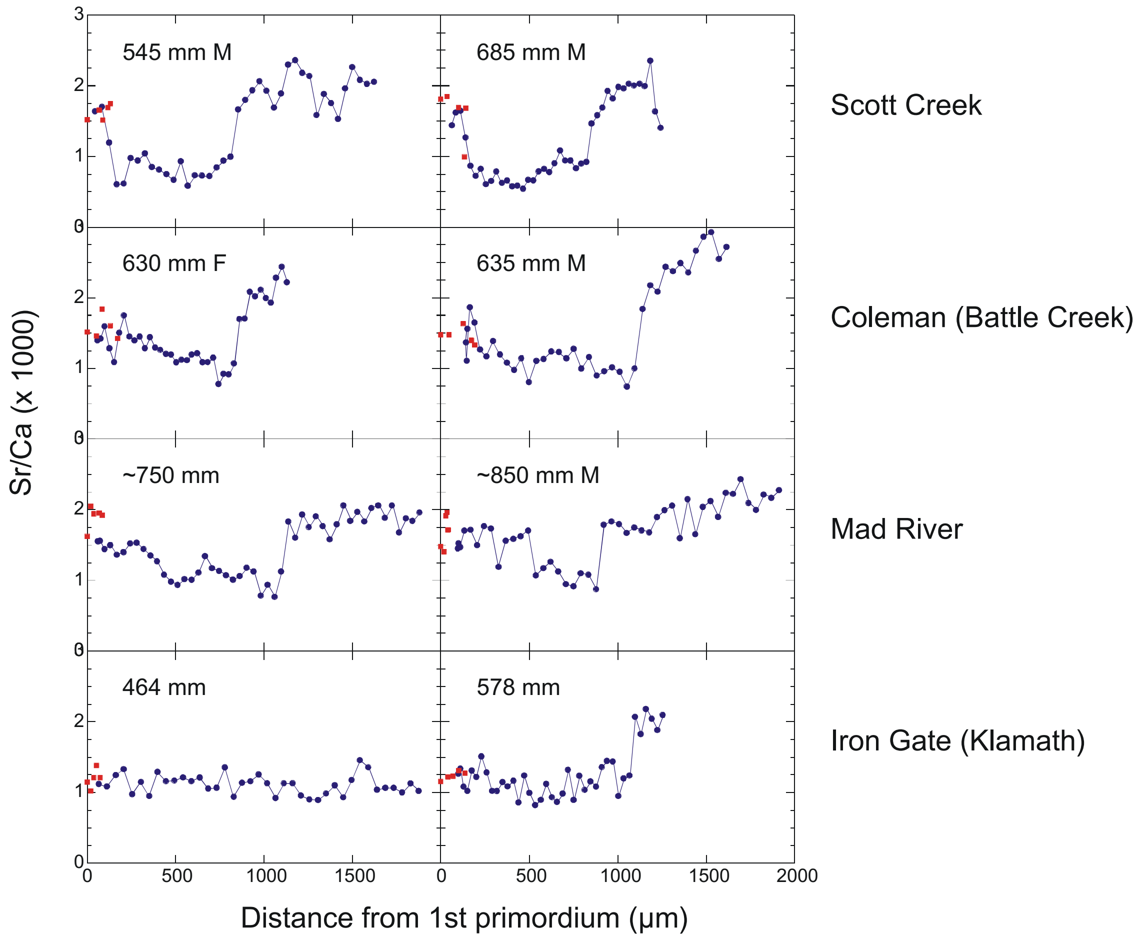
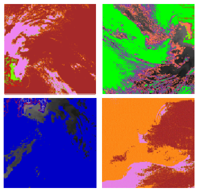


Figure 5. Cross-otolith variation in Sr/Ca ratios of 8 adult rainbow trout, collected from four steelhead hatcheries in California. Patterns suggest that the upper 6 fish were steelhead and the progeny of steelhead mothers, fish at lower left was a resident and progeny of a resident mother, and fish at lower right was a steelhead and progeny of a resident mother. (M=male, F=female)

Table 1. Summary by stream of coho salmon and steelhead observed in pools and runs during the summer months of 2000, 2001 and 2002 for the juvenile salmonid distribution surveys in South Fork Noyo River and tributaries, Mendocino County, California. Note: These numbers do not represent abundance estimates. They are based on single-pass snorkel observations of pools and runs (riffles were not snorkeled).

	2000					2001					2002				
	Stream	Coho	Steelhead			Stream	Coho	Steelhead			Stream	Coho	Steelhead		
Stream	Length (m)[a]	salmon	YOY	1+	>1+	Length (m)[a]	salmon	YOY	1+	>1+	length (m)[a]	salmon	1. Y	1+	>1+
South Fork	9627	3205	3516	613	160	9573	9538	1231	572	213	9501	7779	1751	211	85
Reach 2[b]	1812	885	936	153	36										
Reach 2[b]	2020	500	567	486	56										
N. Fk. of S. Fk.	9294	804	5446	1367	258	11206	7485	4260	1141	364	13819	4687	3955	737	137
Gonzo Creek	222	0	2	0	0	258	258	1	0	0	313	0	1	0	0
Brandon Gulch	876	0	243	20	6	841	0	0	7	1	2396	0	528	28	9
Grover Creek	912	0	166	15	3	925	2	7	13	3	1058	4	1	4	0
Peterson Gulch	408	0	0	1	0	619	1	0	0	0	840	19	0	0	0
Bear Gulch	2251	50	10	27	20	2199	14	379	96	6	2504	300	417	32	32
Parlin Creek	8203	203	1632	270	67	8100	293	63	146	81	7985	2284	724	72	37
Reach 1[b]	1749	200	462	133	40										
Reach 1[b]	1730	176	245	87	33										
Moe Creek	1008	1	119	24	5	1128	0	1	15	5	1190	0	5	11	0
Larry Creek	531	0	3	0	0	596	0	0	1	0	585	0	0	0	0
Curly Creek	912	0	70	2	3	952	0	0	0	4	1005	0	0	0	0
Pipe Gulch	592	0	26	21	10	652	1	50	19	2	933	0	40	16	3
Road 320 Creek	89	0	1	0	0	122	0	0	0	1	341	16	3	1	1
Shooter Creek						300	1	9	2	0	320	0	3	1	0
Rhody Creek						278	0	0	0	0	271	0	1	0	0
Culi Creek											239	3	2	1	2
Total	34925	4263	11234	2360	532	37747	17336	6000	2012	682	43299	15092	7431	1114	280

a - Stream length represents the total length of the pools, runs, and riffles (no fish counts in riffles).
b - Two reaches (South Fork, Reach 2 and Parlin Creek, Reach 1) were surveyed twice in 2000 to assess seasonal changes in fish distribution, stream lengths and fish counts of these repeat counts not included in totals.



ESTUARINE AND OCEAN PHYSIOLOGICAL ECOLOGY OF SALMON

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TASK/THEME: 4B

SUMMARY

Salmonid stocks (chinook salmon, *Oncorhynchus tshawytscha*, coho salmon, *O. kisutch*, and steelhead, *O. mykiss*) from California′ s Central Valley and coastal streams have declined to low levels in the past several decades. All four of California=s Central Valley chinook runs are either listed or candidates for listing by the U. S. Endangered Species Act. Likewise, coastal chinook, coho, and steelhead Evolutionarily Significant Units are in jeopardy of expirpation. Although freshwater habitat loss and degradation undeniably impact salmon populations, estuarine and ocean conditions contribute to the interannual variability in growth and survival. Climatic and oceanographic forcing, ranging from localized short-term phenomena to ocean-basin interdecadal scales, affects environmental conditions and biological productivity that, in turn, influence salmon population dynamics. Effects of environmental perturbations are likely to elicit different responses in California salmon, species at the southernmost extent of their ranges, than in the more studied populations inhabiting the Pacific Northwest.

Effective management of salmonid stocks and their ecosystems requires greater knowledge of the estuarine and oceanic factors regulating Pacific salmon stocks. This is particularly true for the critical early life cycle phases during the first months in the marine environment. The need for basic biological data and the influences of environmental factors on survival and health have been identified as high priority research needs by the Pacific Fishery Management Council (Research and Data Needs 1998-2000, PFMC, September 1998) as well as the scientific community (Estuarine and Ocean Survival of Northeastern Pacific Salmon, Proceedings of the Workshop, April 1997; NMFS Estuarine and Ocean Salmon Strategic Research Plan, April 1998). The results of the proposed study will improve understanding of salmon physiological ecology and help focus conservation and management efforts on the most effective options for this socio-economically valuable resource. Additionally, essential salmonid habitat (e.g., areas of abundance, intense feeding, etc.) in coastal ecosystem will be identified.

OBJECTIVES

The goal of this study is to determine spatial and temporal variability of physiological processes, ecological interactions, and the influences of environmental factors on juvenile salmon in estuaries and the coastal ocean of California. Specific experimental objectives are to determine:

- seasonal abundance, distribution, and movement patterns
- association with oceanographic features (e.g., coastal jets, upwelling centers, eddies)
- age and growth
- energy status
- physiological condition and metabolic rates
- stock origin (natural/hatchery, natal stream)
- trophic relationships
- associated fish communities
- relationship to environmental conditions (primary and secondary productivity, temperature, salinity, and hydrodynamics [freshwater outflow, upwelling, current patterns])

ACTIVITIES

University of California, Santa Cruz (UCSC), and NOAA Fisheries researchers collect salmon, prey, and environmental data in estuaries and coastal waters to determine spatial and temporal variability in salmon dynamics and the influences of environmental factors on abundance, distribution, growth, fitness, and survival. Field trips and cruises are conducted throughout the year, but concentrated effort occurs from spring to early fall when juvenile salmon are emigrating through estuaries and initiating the ocean phase of their life cycle. At selected locations salmon are captured by trawl or seine and either measured, tagged, and released or taken to the laboratory for analysis or experimentation. Trophic relationships are assessed by collecting depth-stratified plankton and neuston samples in conjunction with salmon collections. Hydrosondes, *in situ* data loggers, and external databases (e.g., USGS and NOAA) are used to acquire environmental data. In the laboratory, salmon morphometric data are recorded and tissue samples analyzed to determine age, growth, energy status, feeding, physiological condition, metabolic activities, genetic identification, and stream of origin. In some cases, fish will be placed in tanks and experiments conducted to determine responses to environmental variables. Data from these analyses will be used to model salmon-environmental relationships to improve our understanding of the influences of estuarine and coastal ocean conditions. UCSC laboratory research assistants and graduate students from UCSC team with NOAA Fisheries biologists to collect salmon, plankton, and environmental data in the field and conduct laboratory experiments and analyses.

APPROACH, EVALUATION AND METHODOLOGY

Studies were organized into three units: large estuary (San Francisco Estuary), small estuaries (Redwood, Gazos, Scott, Willow Creeks), and coastal ocean. The San Francisco Estuary was sampled during May and June, the period of estuarine usage by Central Valley fall-run chinook salmon. Juvenile salmon, plankton, and hydrologic data were collected at the estuary entrance (confluence of the Sacramento and San Joaquin Rivers) and exit (Golden Gate). A small surface trawl was towed to collect juvenile salmon. Depth-stratified plankton samples were obtained by a Tucker trawl fished below the surface and below the pycnocline. A Manta net was used to sample the surface neuston. Vertical profiles of hydrologic data (temperature, salinity, dissolved oxygen, pH, and turbidity) were obtained by the use of a hydrosonde. Salmon and plankton were returned to the laboratory for analyses. In the laboratory, juvenile salmon are examined, measured, and tissues subsampled for further analyses. Otoliths are removed and used to determine age and growth history. Stomach contents are quantified and speciated. Carcasses are used to determine protein, water, and lipid classes' concentrations. A small sample of caudal fin was saved for later genetic analysis.

The small estuary study has been expanded this year. Previously, annual patterns of coho salmon and steelhead abundance were recorded by snorkel surveys. Loggers recorded continuous temperature data. This year, we have initiated additional analyses. Fish were collected by seine and length and weight data recorded. Small gill samples were taken to measure Na^+,K^+-ATPase, an indicator of seawater readiness. A small sample of caudal fin was saved for later genetic analysis. Other components, including feeding and prey composition, thermal history by temperature tag, metabolic rates by respirometry and enzyme assays, and age and growth determinations by otolith analysis will be implemented within the year. Environmental data, as above for the San Francisco Estuary study, and the open/closed status of the estuaries are recorded.

Juvenile salmon distribution and development in the coastal ocean are assessed by three cruises each year and from collections at the Golden Gate. Cruises were conducted in June and September 2002 and March 2003 in an area between Pt. San Pedro (south of the Golden Gate) and Ft. Ross (north of Bodega Bay) and the 100-m depth contour. Juvenile salmon were captured with a 264 Nordic Rope Trawl towed at the surface. Depth-stratified plankton and neuston samples, and vertical CTD profiles of temperature, salinity, chlorophyll fluorescence, and water clarity, were obtained at trawl locations and at a series of stations on transects from near the coast to off the shelf within the study area. Juvenile salmon were removed from the net and frozen. By-catch was enumerated and standard lengths and weights of a subset of each species were recorded. Laboratory examinations, measurements, and analyses as described for salmon collected in San Francisco Estuary were performed on ocean-caught juveniles.

RESEARCH ACCOMPLISHMENTS AND RESULTS

During the past annual cycle, we collected 510 juvenile chinook salmon: 317 from the San Francisco Estuary and 193 from the coastal ocean. While emigrating through the estuary the mean growth was 2.3 mm in fork length and 0.95 g in weight, within the range found in previous years (1995-2001). Age and growth rate data are not available yet. Otoliths have been prepared for analysis, but have not been read. Thus, instantaneous growth and migration rates cannot be calculated presently. Juvenile salmon condition (K-factor), unlike previous years, did not decline while transiting the estuary. In all previous years, K declined significantly. In 2002, the juvenile condition index was

1.12∀0.01 at estuary entry, and was 1.13∀0.01 for juvenile salmon leaving the estuary at the Golden Gate. There was a depletion of stored lipids in salmon emigrating through the estuary. Variable energy dynamics have been seen in previous years. In some years there were increased triacylglyercol (TAG) concentrations, in others a decrease, and in still others TAG levels remained unchanged. Other results from the 2002 San Francisco Estuary study are incomplete. But evaluation of existing data suggests that the 2002 chinook salmon year class fared well while transiting the estuary. We performed an analysis of the relationships among salmon growth, energy status, and environmental factors for the 1995 to 1999 year classes while in San Francisco Estuary. A principal component analysis revealed that zooplankton biomass and residence time in the estuary, were the most important environmental variables explaining growth and energy status. Further, there is a statistically significant inverse relationship between growth rate and TAG concentration, consistent with the lipostatic regulation of growth theory.

Juvenile salmon collected in the coastal ocean revealed an abundance and distribution pattern similar to the past two years. During the June cruise, 105 juveniles were caught in 13 trawls, representing a CPUE of 8.1/tow. All the juveniles caught in June were within the Gulf of the Farallones; no salmon were captured in six trawls north of Pt. Reyes. In September, 74 subyearling chinook salmon were caught in 20 tows for a CPUE of 3.7/tow. The change in CPUE reflects greater dispersal, and perhaps mortality, of the yearclass as salmon move away from the source estuary, in this case, San Francisco. Further, 46 of the 74 young salmon were caught north of Pt. Reyes indicating northward movement on the continental shelf. As in all past years, energy reserves declined following ocean entry. However, in 2002 the decline was significantly less than in other years. The TAG concentration for fish leaving the estuary was 33.6 mg/g and was 29.93 mg/g for ocean-caught juveniles. A manuscript describing and explaining growth and energy dynamics of juvenile salmon in the coastal ocean during the 1998 El Niño is in preparation.

Other aspects of the estuarine and ocean study not yet developed sufficiently to present data are progressing. Results from weekly non-lethal sampling of juvenile steelhead and coho salmon in the Scott Creek estuary reveal differences in growth between hatchery-produced and natural fish of both species and differences between species in their time-course for saltwater adaptation. Additionally, this project supports Rachel Barnett Johnson's Ph.D. dissertation research on the production source, spatial structure and connectivity of chinook salmon stocks in California using otolith microchemical analysis. During the present reporting period, collection of otoliths was completed and chemical analytical protocol development has started.

CONCLUSIONS AND RECOMMENDATIONS

This project is an ongoing study. Interim results indicate that residence in the large San Francisco Estuary has a variable influence on juvenile chinook salmon growth and development. Little growth has been observed while in the estuary in all years, but energy dynamics and now condition have varied. Interannual variability of environmental conditions during the period of juvenile salmon residence undoubtedly plays a role in their development. Although results from past years show a relatively short residence time, the time spent varies among years and is inversely related to freshwater outflow. Best growth and energy status occur when residence times are longer and there are high concentrations of zooplankton. Water temperature does not appear to have a substantial influence on growth or energy reserves.

Once juvenile chinook salmon from California's Central Valley exit the San Francisco Estuary and start the ocean phase of their life cycle, growth rates are enhanced, condition increases, and lipid reserves are depleted. This strategy, promoting growth at the expense of energy reserves, may be beneficial for survival and a result of evolutionary propensity to take advantage of the high biological productivity of the upwelling-driven central California coastal ecosystem.

We recommend continuing the San Francisco Estuary study through 2004 to acquire ten years of salmon and environmental data, allowing a robust analysis of the influence of environmental factors on juvenile salmon growth and development. The study should be repeated when environmental conditions change, such as during a drought.

The coastal ocean study should be continued for at least three more years in order to gather enough data to be able to understand the distributional patterns and the importance of oceanographic features and conditions on juvenile salmon growth and development.

The small estuaries study is just starting. The study should be continued until adequate knowledge of spatial and temporal variability of growth and physiological fitness, and the environmental conditions beneficial or detrimental to these processes, is gained.

SHIP TIME – NEW HORIZON

Robert A. Knox
Scripps Institution of Oceanography

TASK/THEME: 5B

The objectives were to provide ship time and shipboard technical support services to three NOAA projects:

1 Cowcod Reserve Survey in February 2002 on Scripps Research Vessel (R/V) *New Horizon*

2 Northeast Pacific GLOBEC (Global Ocean Ecosystems Dynamics) cruises on Scripps R/Vs *New Horizon* and *Roger Revelle*.

3 Cowcod Reserve Survey in February 2003 on Scripps R/Vs *New Horizon* and *Robert G. Sproul*

Ship and technical support were provided as planned. Reports on scientific results and accomplishments, research collaborations, awards, outreach activities and publications will derive from the corresponding scientific projects.

OPERATIONAL VOLCANIC ASH AVIATION HAZARDS: ANALYSIS OF MT. CLEVELAND AND MT. HEKLA ERUPTIONS

James J. Simpson
Scripps Institution of Oceanography

TASK/THEME: 3C

SUMMARY

The original objective of this project was to examine the failure of NOAA operational satellite-based airborne volcanic ash detection algorithms in support of both commercial and civil aviation. After this part of the project was successfully completed, the National Weather Service (NWS) asked for additional help in two other areas: a) Alaskan climate and NOAA's roll out of its new Climate Reference Network (CRN) in Alaska; and b) improving stream flow prediction in NWS's River Forecast Center (RFC) in the Anchorage Forecast Office.

APPROACH / EVALUATION / METHODOLOGY

A combination of satellite-based retrievals of application-specific analyses products, atmospheric advective / diffusion modeling and statistical analyses of large *in situ* data sets was used. Where appropriate, mathematical methods of data fusion were used to blend results from the three basis types of analyses / data types. Forecasting needs for a specific application were identified jointly by scientists at UC San Diego / Scripps Institution of Oceanography and the operational meteorological agencies (U.S. National Weather Service, Canadian Meteorological Center). Results were

compared with operational needs to determine possible failure nodes of an operational analysis and to make specific recommendations for improvement. Throughout this process, operations personnel were involved to help evaluate results in specific forecasting / operational needs areas.

RESEARCH, ACCOMPLISHMENTS AND RESULTS

Airborne Volcanic Ash Detection

Six scientific papers resulted from the satellite-based airborne volcanic ash analyses performed as part of this project. The full citation and abstract for each of these papers is given below. NOAA recently elected to fund the development of a new system to test and evaluate a Volcanis Ash Coordination Tool (VACT) by NOAA's Forecast System Laboratory, Boulder, Colorado, Lynn Shernetz Principal Investigator. This VACT tool is based on the Simpson *et. al* (2001) analyses of the eruption of MT. Cleveland, Alaska.

In addition, Dr. Simpson was a lead instructor for the National Weather Service's Airborne Volcanic Ash Aviation Safety Workshop held in Anchorage, Alaska May, 2002. This workshop was attended by multiple / international representatives from interested government agencies and from operations people (*e.g.*, chief pilots, meteorologists, operational officers) from various international / regional airlines.

Complete references and abstracts for the six international peer-reviewed papers resulting from this component of the study appear below.

James J. Simpson, Gary Hufford, David Pieri and Jared Berg, "**Failures in Detecting Volcanic Ash from a Satellite-Based Technique**," *Remote Sensing of Environment*, vol. 72, pp. 191-217, 2000.

Abstract. Immediate and accurate detection of airborne volcanic ash is an operational imperative of the aviation industry, especially jet aircraft. Ash encounters place passengers aboard these aircraft at severe risk and significantly impact via forced rerouting, both the safety and profit margins of freight carriers due to their limited fuel supply. Moreover, the airlines can suffer high economic costs for repair and replacement of equipment. Operational detection and tracking of volcanic ash by most national weather services has relied heavily on a split window differencing technique of thermal long-wave infrared channels on currently operational satellites. Unfortunately, prior work on volcanic ash detection has not emphasized the dynamical interaction between the erupting volcano and the effects of overlying atmospheric water vapor, phreatic and phreatomagmatic water sources. Six volcanic ash eruptions from around the globe were chosen for study because they have wide variation in ambient atmospheric water vapor, available ground and surface water and different magma types. Results show that the present differencing technique is not uniformly effective in properly classifying volcanic ash pixels in the satellite scene and often falsely interprets meteorological clouds as volcanic ash clouds and conversely. Moreover, it is not always a robust early detector, an operational aviation requirement. Seasonal variability in global integrated atmospheric water vapor, coupled with the geographical distribution of currently active volcanoes, suggests the concerns discussed herein with regard to six specific eruptions, have applicability to the global aviation industry. Operational implications are discussed and a strategic proposal is presented on necessary steps to improve detection.

Keywords – *Airborne Volcanic Ash, Satellite, Aviation Safety*

James J. Simpson, Gary L. Hufford, David Pieri and Jared S. Berg, "**Response to 'Failures in Detecting Volcanic Ash from a Satellite-Based Technique,'"** *Remote Sensing of Environment*, vol. 78, pp. 347-357, 2001a.

Abstract. Prata et al. (2001) state that our analysis (Simpson et al. 2000) "suffers from a fundamental flaw in its methodology and numerous errors in fact and interpretation." We assert that Prata et al. (2001) are incorrect. Our original analysis, augmented herein, shows that from an aviation safety perspective, their T_4-T_5 volcanic ash detection algorithm does not meet the requirements of the aviation industry. For arbitrary satellite scenes, their algorithm: 1) underdetects airborne volcanic ash; 2) yields numerous false alarms; and 3) does not satisfy the five minute warning imperative mandated by the aviation industry. Independent evidence and unique in situ validation data from the NASA DC-8 encounter with volcanic products from the recent Hekla eruption further support our original analysis and conclusions. Factors affecting the usefulness of their algorithm within the context of aviation safety, include but are not limited to, ambient atmospheric water vapor, ground and juvenile water in the magma as well as its chemical composition, cloud cover, atmospheric ice crystals, and the general applicability of the theoretical assumptions underlying their T_4-T_5 volcanic ash detection algorithm. The new analyses presented herein, as well as those of Simpson et al. (2000), show that new approaches are needed to address the complex problem of accurate and rapid detection of airborne volcanic ash.

Keywords – *Airborne Volcanic Ash, Satellite, Aviation Safety*

James J. Simpson, Gary L. Hufford, David Pieri, René Servranckx, Jared S. Berg and Craig Bauer, "**The February 2001 Eruption of Mount Cleveland, Alaska: Case Study of an Aviation Hazard**," *Weather and Forecasting*, vol. 17, pp. 691-704, August 2002a.

Abstract. Mt. Cleveland, Alaska (52°49'N, 169°57'W), located on Chuginadak Island, erupted on February 19, 2001. The atmosphere-volcanic plume interactions, which occurred as part of this event, led to several serious encounters of commercial aircraft with the ash. A number of continental and oceanic air traffic control areas were affected. Here, a detailed case study of the eruption, subsequent movement of the airborne plume and operational response are presented. The likelihood of future such encounters may be reduced as a result of lessons learned from this event. Some potential new assets for improving our detection/response to the airborne volcanic ash hazard to aviation also are discussed.

Keywords – *Mt. Cleveland, Airborne Volcanic Ash, Water Vapor, Ice, Atmospheric Shear*

D. Pieri, C. Ma, J. J. Simpson, G. Hufford, T. Grindle and C. Grove, "**Analyses of *in-situ* Airborne Volcanic Ash from the February 2000 Eruption of Hekla Volcano, Iceland**," *Geophysical Research Letters*, vol. 29, no. 16, pp. 19-1 – 19-4, 2002b.

Abstract. A McDonald-Douglas DC-8 NASA research aircraft inadvertently flew into an airborne volcanic ash plume from the 26 February 2000 eruption of Hekla Volcano. Filter samples from the aircraft were compared with normal use and pristine clean filters using SEM, energy-dispersive x- ray spectrometer, and Nicolet FTIR spectrophotometer analyses. These analyses confirm that the DC-8 encountered airborne volcanic ash from Hekla Volcano. This result is supported by independent onboard heated aerosol observations at the time of the encounter. The analyses further demonstrate the ambiguous nature of the dual band thermal IR (split window) method for detecting volcanic ash from the point of view of aviation safety. They also highlight the utility of in situ aircraft filter-based observations of volcanic aerosols for scientific purposes.

Keywords – *Airborne Volcanic Ash, Aerosol, Engine Damage, Aviation Safety, Validation, SEM analysis, geochemical analysis*

J. J. Simpson, G. L. Hufford, R. Servranckx, J. Berg and D. Pieri, "**Airborne Asian Dust: Study of Long-Range Transport and Implications for the Detection of Volcanic Ash**," *Weather and Forecasting*, vol. 18, pp. 121-141, April 2003a.

Abstract. The transport of fine-grained Asian dust from its source (e.g., Gobi Desert, Mongolia) to North America is a common springtime phenomenon. Because of its chemical composition (silicon, iron, aluminum, and calcium) and its particle size distribution (mean aerodynamic diameter 2-4μm), Asian dust produces a negative signal in the split-window T_4-T_5 algorithm, as does airborne volcanic ash. The split-window algorithm is commonly used by operational Volcanic Ash Advisory Centers. Thus, it is important to find ways to differentiate between airborne Asian dust and airborne volcanic ash. Use of Total Ozone Mapping Spectrometer aerosol and sulfur dioxide indices, in conjunction with the split-window method, can mitigate the possibility of a false airborne volcanic ash alarm. Asian dust also is important for other reasons. Thus, meteorological agencies should monitor it because: 1) it can be transported thousands of kilometers from its source region and thus is of global interest (e.g., effects on radiative forcing) and 2) fine-grain particles pose a potentially serious public health hazard.

Keywords – *Asian Dust, Health Hazard, False Airborne Volcanic Ash Signal, Satellite*

Gary L. Hufford, Leonard J. Salinas, James J. Simpson, Elliot G. Barske and David C. Pieri, "**Operational Implications of Airborne Volcanic Ash**," *Bulletin of the American Meteorological Society*, vol. 81, pp. 745-755, April 2000.

Abstract. *Volcanic ash clouds pose a real threat to aircraft safety. The ash is abrasive and capable of causing serious damage to aircraft engines, control surfaces, windshields, and landing lights. In addition, ash can clog the pitot-static systems which determine wind speed and altitude and damage sensors used to fly the aircraft. To ensure aviation safety, a warning system should be capable of a five minute response time once an eruption has been detected. Pilots are the last link in the chain of safety actions to avoid or mitigate encounters with volcanic ash. For the pilots to be effective, the warning and safety system must meet their needs. The ability to issue accurate and timely warnings, advisories, and forecasts requires a rapid means to detect and continually track the ash cloud and*

smooth coordination between many agencies. The current operational ash detection technique uses satellite remote sensing. Potential problems with this technique and the potential impact of these problems on aircraft safety are discussed.

Keywords – *Volcanic Ash, Operational Forecasting, Aviation Safety*

Climate Analyses for Alaska

A climatological surface temperature and precipitation analysis was needed for a wide variety of forecasting issues in Alaska. We analyzed the recently available PRISM data set for seasonal and longer variability in surface temperature and precipitation.

As part of NOAA's new Climate Reference Network, the need arose to determine the optional site for new and improved climate sensors in Alaska. Optional site selection is important for at least three separate reasons: 1) to cover regions of Alaska not currently observed (*e.g.*, high mountain regions like the Brooks Range); 2) to locate sensors in regions of largest climate uncertainty; and 3) to optimize the design with careful attention to cost as limited funds are available for the Alaskan component of the Climate Reference Network. A second climate analysis, which compared modeled surface temperature and precipitation from two different models (the ANUSPLIN and the PRISM model); was conducted to determine regions of Alaska with maximum and minimum uncertainty in our knowledge of space / time variation in long-term surface temperature and precipitation. In addition, specific recommendations for the roll out of NOAA's Climate Reference Network were given in the manuscript (see below) based on this study.

Finally, Dr. Simpson gave invited key note presentations at two recent meetings conducted by NOAA in Alaska: 1) Alaska Climate Reference Network Kickoff Workshop – March 25-26, 2003 Anchorage, Alaska; and 2) Alaska Region Climate Services Workshop, June 10-12, 2003, Fairbanks, Alaska. These presentations were based on the two papers cited below, which resulted from the climate analysis component of this study.

James J. Simpson, Gary L. Hufford, Michael D. Fleming, Jared S. Berg and Justin B. Ashton, "**Long-term Climate Patterns in Alaskan Surface Temperature and Precipitation and Their Biological Consequences**," IEEE *Transactions on Geoscience and Remote Sensing*, vol. 40, pp. 1164-1184, May 2002c.

Abstract. Mean monthly climate maps of Alaskan surface temperature and precipitation produced by the Parameter-elevation Regression on Independent Slopes Model (PRISM) were analyzed. Alaska is divided into interior and coastal zones with consistent but different climatic variability separated by a transition region; it has maximum interannual variability but low long-term mean variability. Pacific Decadal Oscillation (PDO)- and El Niño Southern Oscillation (ENSO)-type events influence Alaska surface temperatures weakly (1-2°C) statewide. PDO has a stronger influence than ENSO on precipitation but its influence is largely localized to coastal central Alaska. The strongest influence of Arctic Oscillation (AO) occurs in northern and interior Alaskan precipitation. Four major ecosystems are defined. A major eco-transition zone occurs between the interior boreal forest and the coastal rainforest. Variability in insolation, surface temperature, precipitation, continentality and seasonal changes in storm track direction explain the mapped ecosystems. Lack of westward expansion of the interior boreal forest into the western shrub tundra is influenced by the coastal marine boundary layer (enhanced cloud cover, reduced insolation, cooler surface and soil temperatures). In this context, the marine boundary layer acts in an analogous fashion to the orographic features which form the natural *boundaries of other Alaskan ecosystems. Variability in precipitation may play a secondary role.*

Keywords - *Arctic Hydrology, Surface Temperature, Precipitation, Arctic Climate, Climographs, Boreal Forest, Alaska, ENSO, Pacific Decadal Oscillation, Arctic Oscillation, Tundra*

James J. Simpson, Gary L. Hufford, Chris Daly, Jared S. Berg and Michael D. Fleming, "Two Views of Alaskan Surface Temperature and Precipitation: Implication for the Development of an Improved Operational Climate Monitoring System," *Weather and Forecasting*, submitted 2003b.

Abstract. Mean monthly climate maps of surface temperature and precipitation in Alaska produced by the ANUSPLIN and PRISM models were analyzed. Differences and similarities between the two sets of maps were determined and possible reasons for these differences are given. These differences do not affect the observed large-scale patterns of climatic variability. Alaska is divided into interior and coastal zones with consistent but different climatic variability separated by a transition region; it has maximum interannual variability but low long-term mean variability. Both data sets support the earlier four major ecosystems and ecosystem transition zone identified by Simpson et. al (2002). Differences between the two data sets provide guidance for an improved operational climate services program currently under implementation by the U.S. National Weather Service. Finally, the PRISM model

data set provides the best currently available spatial coverage of Alaskan long-term mean monthly surface temperature and precipitation.

Keywords - *Arctic Hydrology, Surface Temperature, Precipitation, Arctic Climate, Climographs, Boreal Forest, Alaska*

Snowmelt / River Ice Hydrology

Stream flow river forecasting is especially difficult in Alaska for a variety of complex reasons (*e.g.*, spring breakup can be sudden and swift; extratropical storms can produce sudden intense and extensive rainfall). Based on a recent work (see reference and abstract below), several improvements in operation stream flow forecasting are now possible. Based on these studies, we are currently developing a program with the RFC Alaskan Region to incorporate some of the concepts into their operational stream flow forecasts. A global climatological analysis of atmospheric water vapor, based on a combined *in situ* and remote sensing data set, also was performed. This study provides information useful for both improved airborne volcanic ash detection and hydrologic stream flow prediction.

James J. Simpson, Michael D. Dettinger, Frank Gehrke, Timothy J. McIntire, and Gary L. Hufford, "**New Approaches to Snow Pack/Snowmelt Hydrology: Hydrologic Scales, Cloud Variability, Remote Sensing and Models**," *Weather and Forecasting*, submitted 2003c.

Abstract. Accurate prediction of available water supply from snowmelt is needed if the myriad of human, environmental, agricultural, and industrial demands for water are to be satisfied, especially given legislatively imposed conditions on its allocation. Robust retrievals of hydrologic basin model variables (e.g., insolation, areal extent of snow cover) provide several advantages over the current operational use of either point measurements or parameterizations to help meet this requirement. Insolation can be provided at hourly time scales (or better if needed during rapid melt events associated with flooding) and at 1 km spatial resolution. These satellite-based retrievals incorporate the effects of highly variable (both in space and time) and unpredictable cloud cover on estimates of insolation. The insolation estimates are further adjusted for the effects of basin topography using a high resolution digital elevation model (DEM) prior to model input. Simulation of two Sierra Nevada rivers in the snowmelt season of 1999 indicate that even the simplest improvements in modeled insolation can improve snowmelt simulations with 10-20% reductions in root-mean-squared errors. Direct retrieval of areal extent of snow cover may mitigate the need to internally calculate this variable, something which on physical grounds is undesirable and often leads to under estimation or over estimation of the volume of the water in many operational model reservoirs. Agencies responsible for accurately predicting available water resources from the melt of snowpack (e.g., both Federal (the U.S. National Weather Service's River Forecast Centers (RFCs)) and state (the Californian Department of Water Resources)), can benefit by incorporating concepts developed herein into their operational forecasting procedures.

Keywords – *Snowpack, Snowmelt Hydrology, Hydrological Scales, Cloud Variability, Remote Sensing, Models, Insolation, Areal Extent of Snowcove.*

James J. Simpson, Jared S. Berg, Chester J. Koblinsky, Gary L. Hufford and Brian Beckley, "**The NVAP Global Water Vapor Data Set: Independent Cross-Comparison and *Multiyear Variability*,**" *Remote Sensing of Environment*, vol. 76, pp. 112-129, 2001b.

Abstract. Space-time variability in the global distribution of atmospheric total column water vapor (tcwp) greatly impacts the hydrologic cycle. NASA's Water Vapor Project (NVAP) produced a global 1 degree x 1 degree tcwp data set for use as a tool to investigate, among other things, atmospheric variability. An independent cross comparison of the NVAP tcwp product was performed using the TOPEX / POSEIDON (T/P) Topex Microwave Radiometer (TMR) data and the European Centre Medium-range Weather Forecasts (ECMWF)-based range delay data set produced by Météo-France (MF) and distributed with T/P data. When these T/P range delay data are converted to tcwp, they show that NVAP is biased dry and ECMWF/MF is biased wet relative to the independent TMR measurement. Although the absolute accuracy of the NVAP tcwp product is uncertain, results indicate its relative accuracy is sufficient for variability studies. Empirical Orthogonal Function analysis and spectral analysis applied to this dataset show that seasonal variability over the annual cycle accounts for about 20% of the variance (EOF1). An ENSO signal is found in the annually demeaned data; the magnitude of the cross correlation between the temporal amplitude of EOF1 and the Niño 3.4 (SST) time series is 0.9. Comparisons also were made between the NVAP patterns of variability in tcwp and independent re-analysis and interpretation of numerical model generated atmospheric fields. In general, there is good agreement between the NVAP data and the re-analysis fields. Finally, specific recommendations are made for: 1) improvement of the NVAP data set upon re-analysis; and 2) use of the NVAP data, in place of ECMWF/MF-based range delay data, for T/P retrievals when TMR data are not available if and when

T/P data are re-analyzed. This latter recommendation is especially important for regions of the tropical Indo-Pacific (e.g., Indonesia) where islands can interfere with valid TMR retrievals.

Keywords – *Atmospheric Water Vapor, TOPEX/Poseidon, ENSO, Seasonal, Annual and Interannual Variability*

CONCLUSIONS AND RECOMMENDATIONS

Overall Conclusions

This project has produced ten scientific papers. Results from these efforts are being transitioned into NOAA / National Weather Service operational forecasting methods.

Based on this work, continued cooperative programs with the National Weather Service Alaska Region are currently being implemented.

Study-Specific Recommendations

From "The February 2001 Eruption of Mount Cleveland, Alaska: Case Study of an Aviation Hazard":

The fundamental objective is clear: to keep aircraft and volcanic ash completely separated. Uncertainty is a major impediment to achieving this and is likely to remain so in the foreseeable future. Still it is our hope that as a result of this case study the following recommendations may help to reduce uncertainty for the benefit of aviation safety and operational response efficiency:

1. More frequent and detailed volcanic ash PIREPS are needed. When ash is present, they should clearly indicate both the flight level / location / time at which the report is made AND the level(s) / location / time where the odor / ash were encountered. In specific situations and geographical areas, PIREPs of "no ash" would also provide valuable information in defining the extent of the ash cloud.

2. Conduct a thorough study of the spectral characteristics of airborne volcanic ash to identify the optimal wavelengths for sensors on future satellites.

3. Regular coordination and response exercises should be conducted between adjacent VAACs and Meteorological Watch Offices.

4. Investigate the possibility of assessing qualitatively the real-time potential for a long lived ash plume based on the amount of horizontal spreading of the plume as a function of time in the dispersion model.

From "Airborne Asian Dust: Study of Long-Range Transport and Implications for the Detection of Volcanic Ash":

The following conclusions and recommendations are proposed:

1. Asian dust events, especially in springtime, occur frequently. Chinese National Academy's records show that during the 17th century, there were 0.3 to 1.0 sand storms in Inner Mongolia per year, but by 1990, the annual rate had increased to 3.0 to 5.0 per year (http://www.lakepowell.net/asiandust.htm). Multiple dust events occurred January to May during 1997 – 2002 (http://info.nies.go.jp:8094/kosapub).

2. Satellite and lidar observations clearly show transport of dust to the North Pacific atmosphere and over North America. Model results corroborate this.

3. Large particles of dust do not reach North America due to gravitational settling.

4. Asian dust which reaches North America, typical aerodynamic diameter of 2-3 μm, is derived largely from crustal rocks and minerals dominated by the elements Si, Fe, Al, and Ca.

5. The particle size distribution and chemical composition of the Asian dust are near optimal to produce a strong negative signal in the "split-window" T_4-T_5 airborne volcanic ash detection algorithm used by most operational VAACs. An inverted arch, characteristic of airborne volcanic ash, is also produced. Unless the VAAC meteorologists are trained to recognize and correctly interpret these characteristics of Asian dust, a false VAAS could be issued. The mis-identification of lofted dust vs. volcanic ash has important operational impacts (potential false volcanic ash alert). Moreover, accurate and rapid detection of dust may help to warn flight

operations in potentially affected airports about possible decreased visibility, especially in China, Korea, and Japan. It also has air safety (potential health) implications should dust get into the cabin.

6. Simultaneous use of TOMS aerosol and sulfur dioxide indexes with the T_4-T_5 "split-window" retrieval can help to distinguish Asian dust from volcanic ash. Unfortunately, TOMS data are only available during daylight hours and may not be received in "real-time" by some VAACs. The area covered by the negative T_4-T_5 signals may also help distinguish Asian dust from volcanic ash (very large relative to that of a newly erupted volcanic ash plume, at least in the early stage).

7. Meteorological and environmental agencies which share responsibility for "air quality" advisories need to monitor the distribution of Asian dust because of its potential public health hazard.

8. Analogous dust events occur in other hyper-arid regions (*e.g.,* Sahara).

9. The possible short- and long-term impacts of desert dust on aircraft should be examined and documented. Would these be significant enough to warrant the issuance of advisory messages by VAACs as is already the case for volcanic ash?

10. Experimental instruments (*e.g.,* MODIS) may prove useful, especially if TOMS data become unavailable.

From "Two Views of Alaskan Surface Temperature and Precipitation: Implication for the Development of an Improved Operational Climate Monitoring System":

To better achieve its new climate services objectives, NWS has begun a study to optimize the design of an improved Alaskan climate observing system in support of its new Climate Services program. Based on the analyses presented in Simpson *et. al* (2003b) and those of Simpson *et al*. (2002c), we offer the following suggestions for consideration by NWS:

1. Variability in surface temperature and precipitation is not uniform throughout Alaska. Therefore, we believe that a uniformly-spaced observing grid is not appropriate.

2. The regions of largest uncertainty in Alaskan climate variables are in some of the most remote places in Alaska (*e.g.*, the Brooks Range, the North Slope, the Wrangell - St. Elias Mountains, portions of interior Alaska and western Canada, the Aleutian Islands). Upgrading an Alaskan climatic observing network should emphasize the instrumentation (with satellite– telemetry capability) of such remote and totally undersampled areas.

3. In locating new observing stations, attention should be given to the vast upland areas of the Alaska interior. In winter, the interior atmosphere is often decoupled vertically, due to persistent inversions. It is possible that large-scale atmospheric variations such as ENSO and PDO will affect low-lying areas within the inversion layer very differently than upland areas in the free atmosphere above this layer. Currently, observational data represent low-lying areas almost exclusively.

4. Precipitation gauges in Alaska should be shielded to minimize undercatch. Undercatch of precipitation, especially during winter, is now known to be a source of significant measurement uncertainty, which can confound analyses of precipitation amount and variability both in space and time.

5. Given the magnitude and cost of the task, partnerships should be actively sought with other agencies which share similar needs and objectives. For example, partnering with the U.S. Department of Agriculture's National Resources Conservation Service as it rolls out its Soil and Climatic Analysis Network (SCAN) seems prudent.

6. A common set of climate quality instruments, calibration, analyses and reporting procedures also should be adapted by partnering agencies. This would help to minimize a potential "grab bag" of intercalibration issues and other uncertainties which, if unresolved, could limit the usefulness of the intended climatic services network.

7. Care should be exercised to avoid placing sites in convenient but unrepresentative locations (*e.g.*, near airports) simply because they are easy to access and maintain or meet other objectives. Observations and sites suitable for aviation simply may be inadequate for climate studies.

8. Common metadata standards should be defined and implemented by the partnering agencies to ensure easy access and use of climate data by the community.

9. Electronic delivery of data should be encouraged. All data belong in the public domain.

JOINT PROJECT AGREEMENT CONCERNING CSRC SYSTEM

Yehuda Bock
Scripps Institution of Oceanography

TASK/THEME: 2D

SUMMARY

The next semi-annual Coordinating Council meeting is scheduled for Friday, May 16, 2003 at the PG&E headquarters in San Francisco, CA. The last meeting was held on October 18, 2002 at Scripps Institution of Oceanography in La Jolla. Copies of the October meeting minutes are available on the CSRC website at

http://csrc.ucsd.edu/input/csrc/csrcMtgMinutesOct2002.pdf.

The Fall 2002 CSRC Director's report from the meeting is available for download from

http://csrc.ucsd.edu/general/reports.html.

At the fall Coordinating Council meeting a Work Plan Committee was formed. Members of the committee included Dave Stone (chair), Don D'Onofrio, Larry Fenske, Greg Helmer and Marti Ikehara. In late 2002, the Work Plan Committee requested that interested parties and groups help them develop a plan for FY03/04. Individuals were asked to fill out and submit a "Priority Survey" to the Committee with their ideas of CSRC goals and available funding. The individual responses were tallied and compiled into the "Priority Survey Summary", which was used to provide guidance and direction to the Council in prioritizing its goals for the upcoming year. The summary is available for download at

http://csrc.ucsd.edu/input/csrc/workPlanPrioritySurveySummary.pdf

and the FY03/04 Work Plan is available at http://csrc.ucsd.edu/input/csrc/csrcWorkPlan2003_04.pdf.

The Work Plan served as the basis for the CSRC FY04 (July 1, 2003 to June 30, 2004) funding proposal that was submitted to NGS on April 2, 2003.

Both Cecilia Whitaker and Jim Swanson have been developing GPS users email lists that can be used to send information and updates to interested parties. Cecilia's list currently numbers over 200 and Jim's includes another 196.

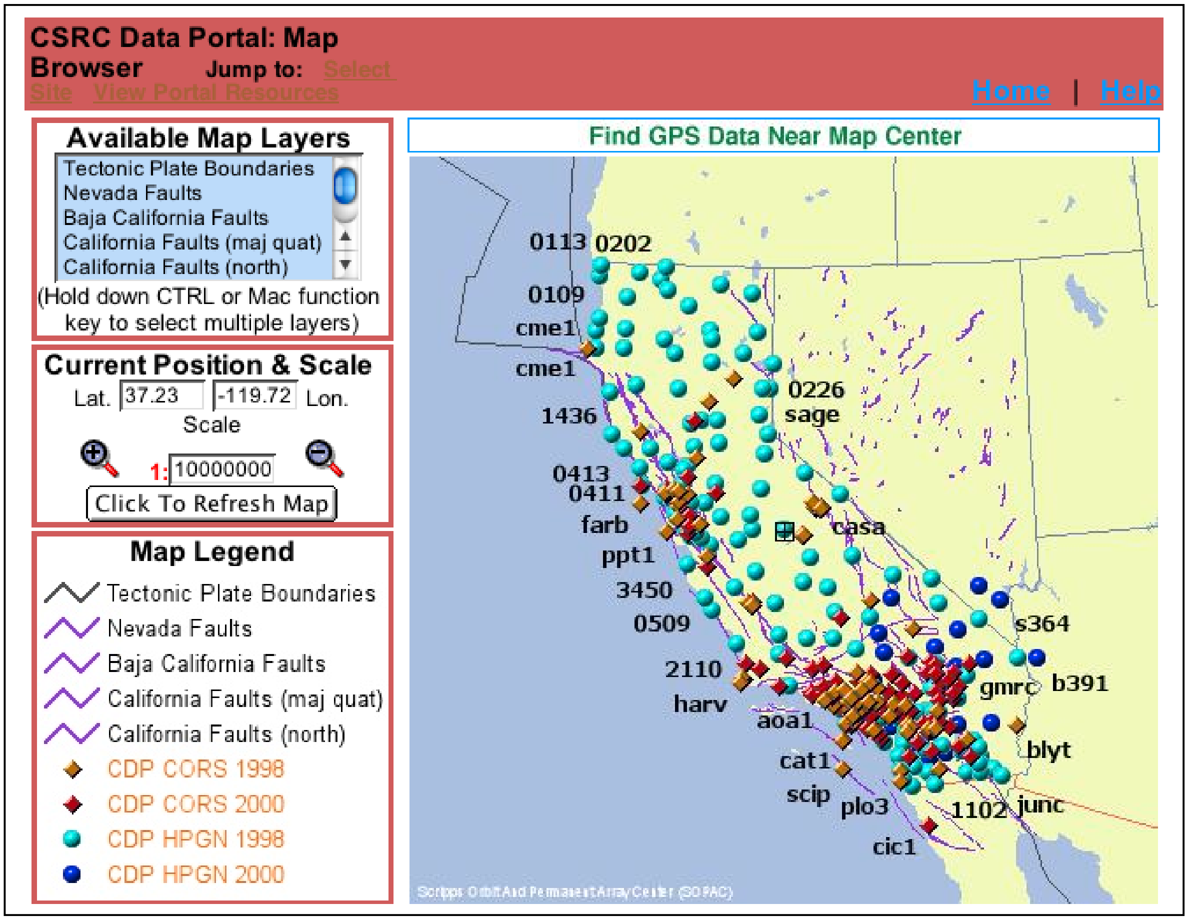
CALIFORNIA SPATIAL REFERENCE NETWORK MASTER PLAN

On March 12, 2003, CSRC received notice from NGS that the Master Plan for a Modern Geodetic Control Network is "fully acceptable to NGS". Copies of the final Master Plan are available on the CSRC website at http://csrc.ucsd.edu/input/csrc/csrcMasterPlan.pdf. This task is complete.

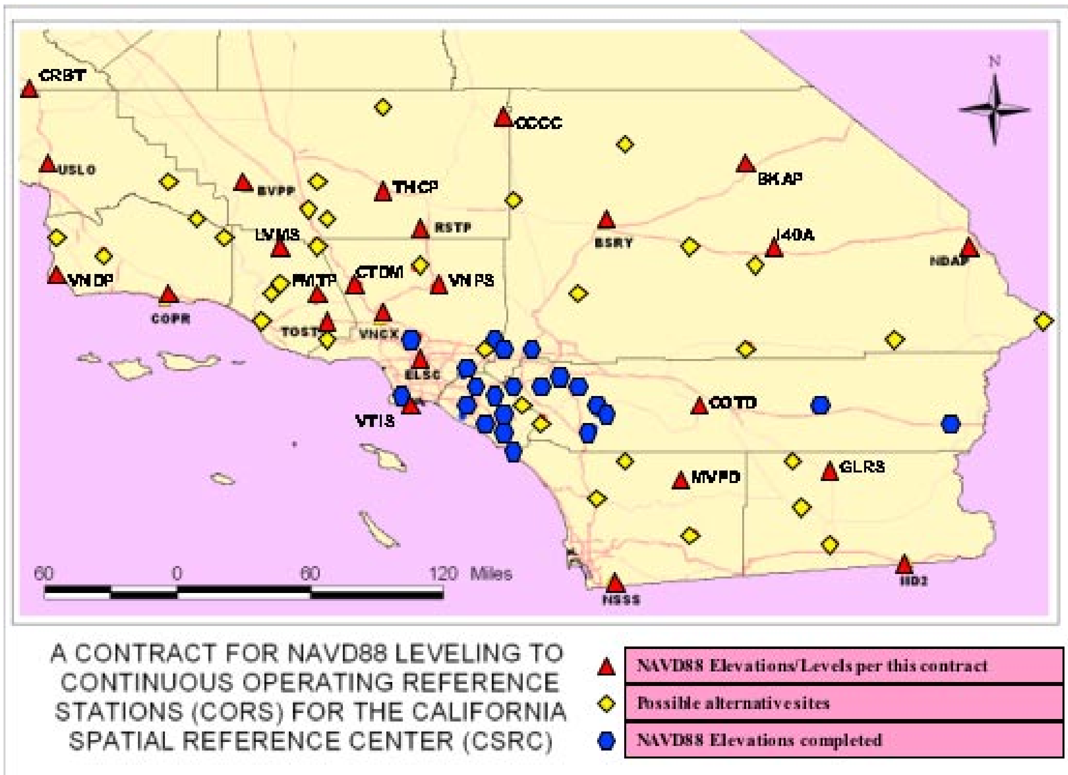
CALIFORNIA CORS DATA PORTAL & DATA DISSEMINATION

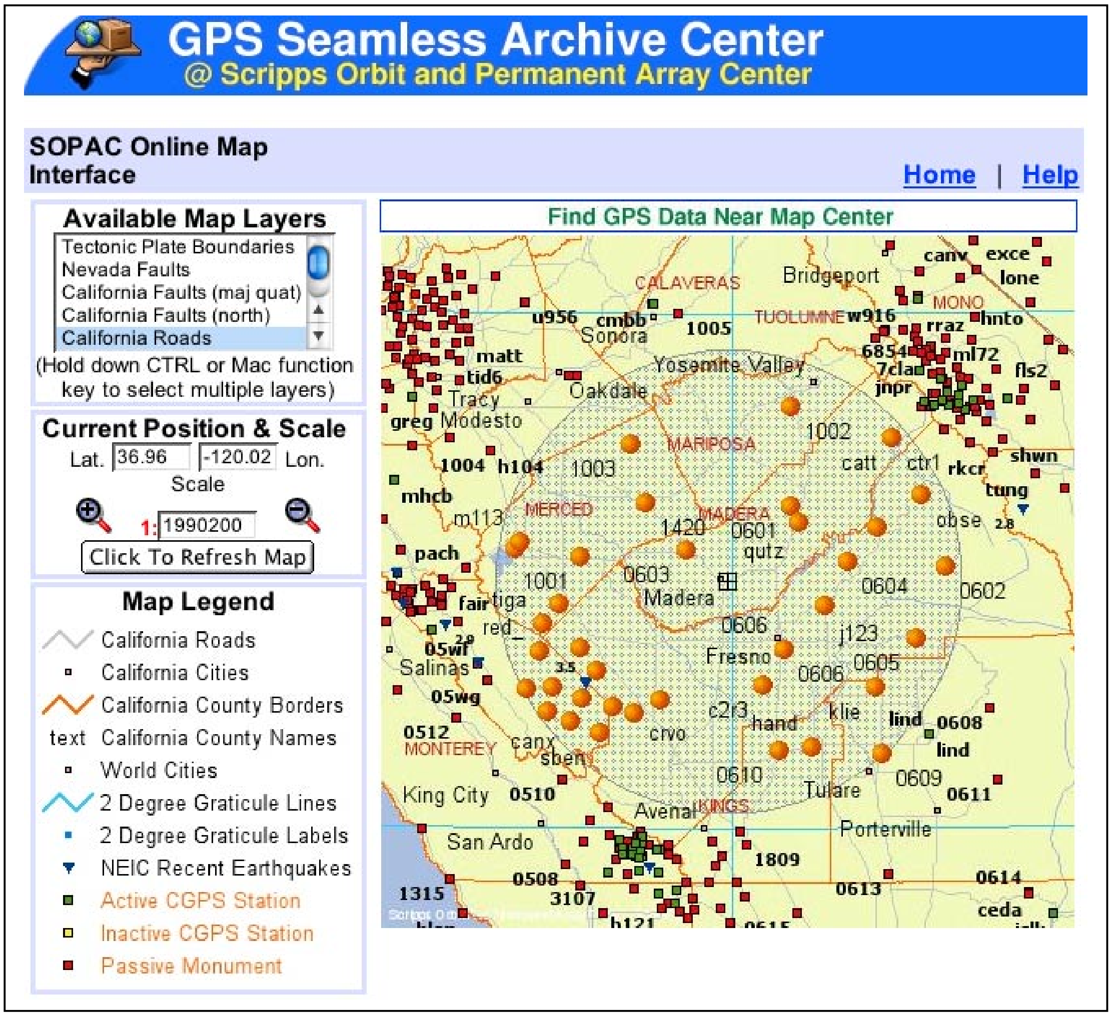
All aspects of the CSRC data portal have been updated to include the HPGN 1998 monuments adjusted by the CSRC. The site locations are available on an interactive map by entering the data portal http://csrc.ucsd.edu/cdp/, choosing the Map Browser and selecting from the "Available Map Layers" (see example below).

CSRC Data Portal (CDP) map with new interface displaying all CORS and HPGN sites from 1998 and 2000 (post Hector Mine earthquake) adjustments performed by the CSRC for Caltrans.



The map interface has also been completely redone on all CSRC and SOPAC maps. With the GPS Seamless Archive (GSAC) developed by SOPAC for UNAVCO, a user will be able to navigate the CSRC map browser, delineate windows (boxes or circles – see example below) and collect sets of monuments/data files matching their interests. This is made possible through the fusion of SOPAC's map interface and use of GSAC "content". CSRC is the first major client of the GSAC.





Example of the use of the new SOPAC map interface to locate CORS and GPS monument locations in Northern California within a 100 km radius of the map center. Map generated by SOPAC's GSAC Center, which is accessible through the CSRC Web Pages (http://csrc.ucsd.edu/).

HEIGHT MODERNIZATION: CORS NAVD88 HEIGHTS IN SOUTHERN CALIFORNIA

Cecilia Whitaker has researched and created a plan of CORS to level to in the 10 Southern California counties (see figure below). She worked with Larry Fenske to complete a final draft of the contract and leveling specifications/procedures. A meeting to discuss the Request for Proposal (RFP) details and the process with the UCSD Purchasing/Subcontract Officer (Robert Beiner) was held at Scripps on March 27, 2003. It was decided that the contracting process would be much the same as the South San Francisco Bay Area Project, except that the RFP will be more widely advertised. The RFP was posted on the CLSA and CELSOC web sites, as well as in the California Contracts Register. Notice that the RFP was also sent to the GPS Users and CELSOC Members email lists.

Scripps Purchasing Office put together the RFP for this work and the selection committee members have been chosen. The RFP was issued on April 21, 2003, with proposals due by May 21, 2003. The contract should be awarded by the end of June, 2003.

In accordance with University policy, the Cost per Quality Point (CPQP) method will be used to award all contracts until CSRC receives terms and conditions from NGS that state otherwise.

Cecilia and Larry have also put together a training document titled "Specifications and Procedures for Second Order, Class II Geodetic Leveling to Establish Elevations on CORS".

It is available from the CSRC website at http://csrc.ucsd.edu/input/csrc/corsLevelingSpecs.pdf

HEIGHT MODERNIZATION PROJECTS

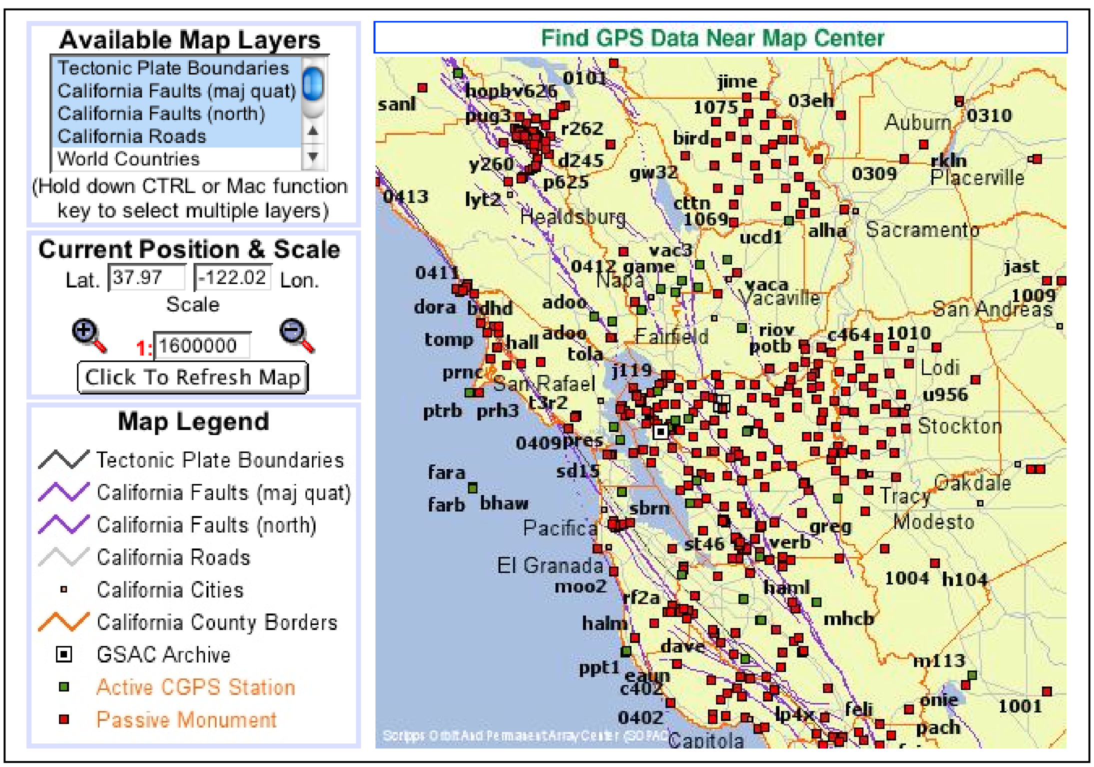
The CSRC has now completed several height modernization projects in northern California.

The team of Johnson-Frank & Associates, Inc. completed the South San Francisco Bay Height Modernization Project and submitted their final report on December 2, 2002.

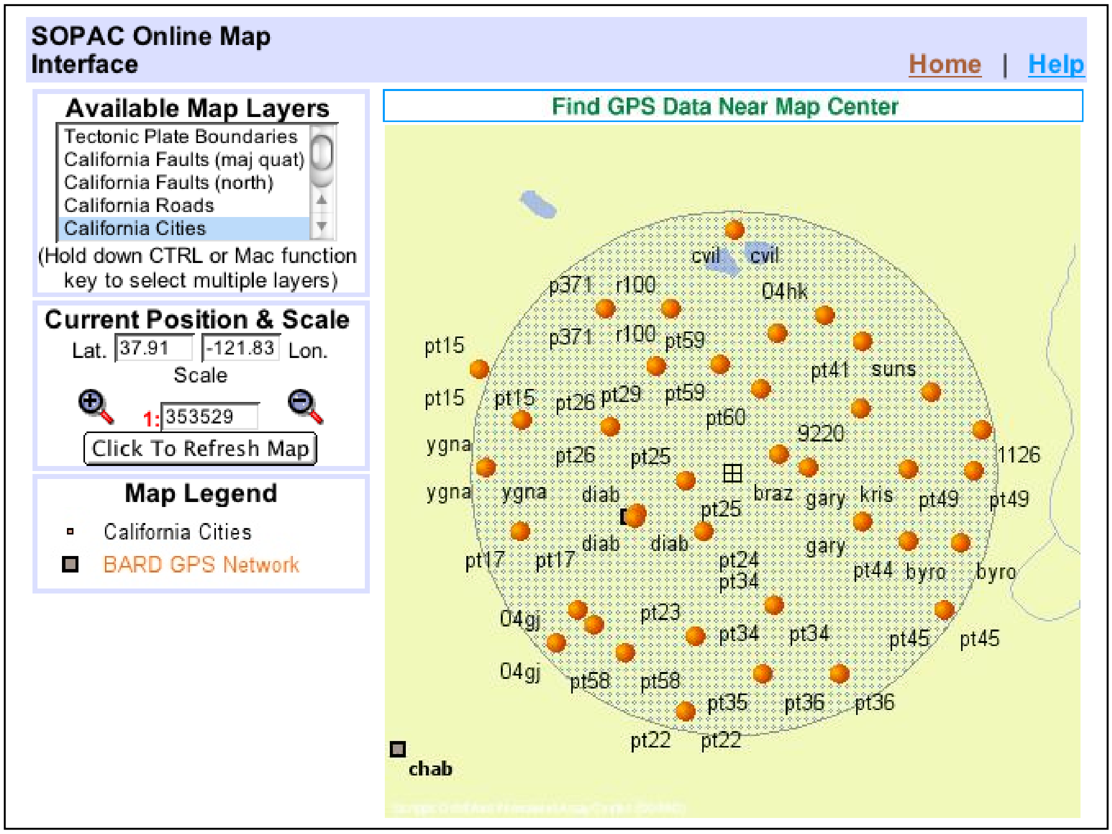
In addition, the CSRC staff has completed the Contra Costa project and Yolo County 2002 projects.

We have also received the results from the Tuolumne County project and will integrate them into the SOPAC/CSRC database.

The CSRC has contracted for the services of Mr. Mike Potterfield to assist us with streamlining future height modernization projects, in all their aspects. We are now in the process of reviewing all completed projects, integrating them into the SOPAC/CSRC database, and posting them on the CSRC Web Site. We are also evaluating the 1999 and 2002 Yolo Projects for subsidence.



Location of height modernization monuments and CORS (CGPS stations) in Yolo County, Contra Costa County, and the San Francisco Bay Area. Map generated with SOPAC/CSRC map interface using GSAC information.



In this example, a GSAC user locates all passive monuments and BARD sites in a 20 km radius about the map center (in Contra Costa County).

REAL TIME, HIGH-RATE GPS NETWORKS

Orange County Real Time Network (OCRTN)

On February 20, 2003 John Canas and the staff at the County of Orange-Geomatics/Land Information Systems hosted a CSRC meeting/Real Time Network Forum in Santa Ana, CA. Surveyors from the San Francisco Bay Area, as well as Riverside, San Diego and San Bernadino counties were invited to come and get an overview of the Orange County Real Time Network (OCRTN) and its implications for other real-time networks that are in the planning stages. The meeting was well attended and the Bay Area participants were pleased and encouraged by what they saw and heard. Jim Swanson is continuing to work with the UC Berkeley and the Bay Area Real Time Network (BARTN) committee members to develop a plan for that area (see overview of BARTN below).

Typical wireless RTK system used in OCRTN. The system is being used with off-the-shelf Ashtech, Trimble, and Leica RTK receivers. The user only requires a wireless modem to make the connection to the OCRTN data server, thus avoiding the need for setting up a base station and eliminating the line-of-sight radio limitations of conventional RTK surveying.

At the meeting on February 20th, John Canas announced that the Orange County Real Time Network (OCRTN) was considered “operational.”

To review the two operational phases of OCRTN:

Phase 1: Streaming raw high-rate (1 sec) GPS data from continuously operating reference sites (CORS) to central facility in Santa Ana. These data are available to anyone in raw (MBEN) or RINEX formats for post-processing from the SOPAC/CSRC archive.

Phase 2: Generating and making available real-time data (1-2 s latency) via the wireless Internet to anyone at no cost (free) for real-time kinematic (RTK) surveying and various forms of dynamic positioning in Orange County, operated by Geomatics/Land Information Systems.

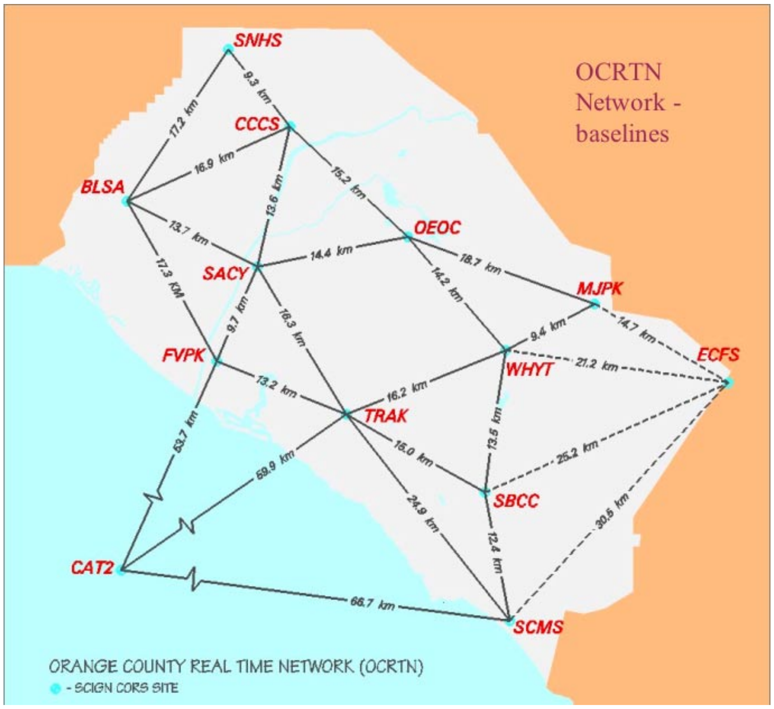
At the present time, there are a growing numbers of operational users of the OCRTN for wireless RTK surveys:

- Government Agencies: County of Orange, Caltrans
- Private Sector: RBF, Hunsaker and Assoc., Mesa GPS
- GPS Dealers: Servco, Trimble, GPS West Inc.

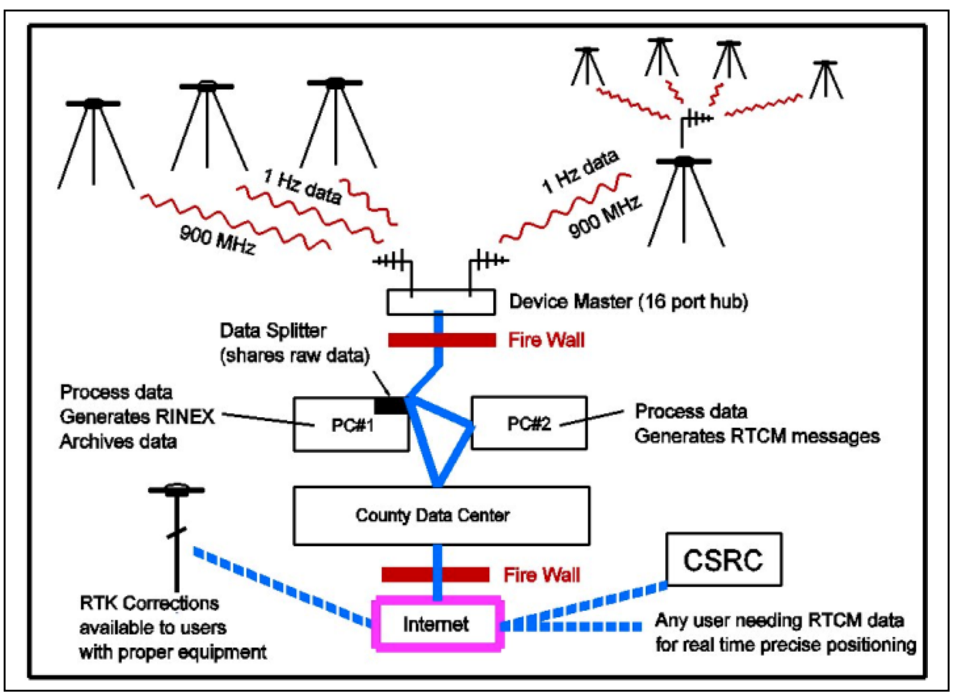
There is also research being performed on these data in the areas of seismology and intelligent transportation.

Remaining tasks include:

1. The site at Los Alamitos (BLSA) has been constructed and is flowing data through a wireless modem to OCRTN. This solution is not optimal because of data latency (up to 1 minute) associated with the wireless service provider. We are evaluating other options.
2. We have developed a buffering scheme to ensure against loss of data. We are now testing this solution at BLSA. If successful we will deploy at the other OCRTN sites.
3. We are testing the practicality of streaming data by telephone modem from the two remaining sites in Orange County (SNHS and CCCS).



Map of OCRTN and Network Baselines. All sites provide 1 Hz data except for SNHS and CCCS in the north part of the county, and ECFS that will be part of the Riverside County real time effort.

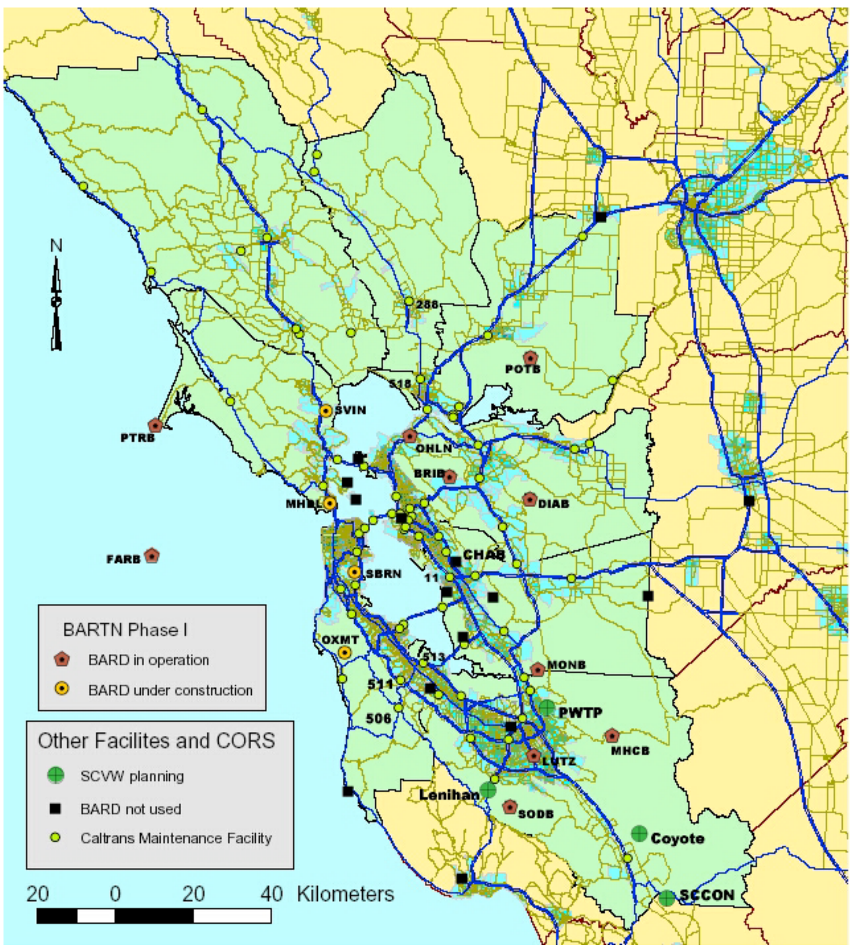


BAY AREA REAL TIME NETWORK (BARTN)

Bay Area Real-Time Network

Jim Swanson has been working with Mark Murray of Berkeley Seismological Laboratory (BSL) and with surveyors from Caltrans District 4, East Bay Municipal Utility District (EBMUD), Santa Clara Valley Water District (SCVWD), and other Bay Area public agencies to develop a plan for a real time network. EBMUD is developing a real time CORS near the West End of the Bay Bridge and are testing wireless communications with BSL. SCVWD surveyors have received funding to develop four CORS in southern Santa Clara County. Nelson Aguilar and AJ Burgess of Caltrans District 4 have been working with Jim to assess Caltrans maintenance facilities in Napa, Alameda, and San Mateo Counties for possible new CORS.

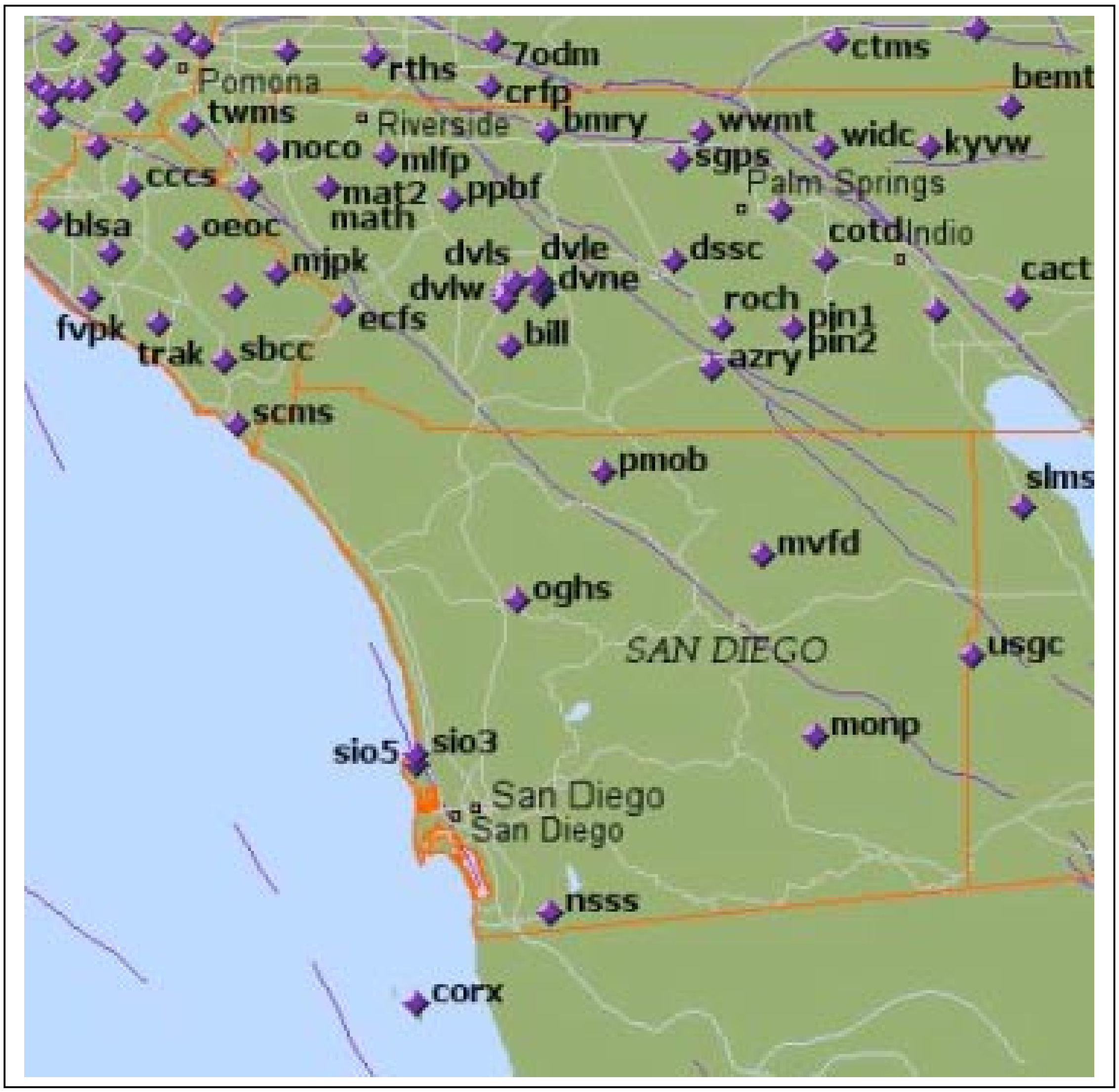
Jim Swanson organized a Bay Area Real Time Network (BARTN) meeting on November 15, 2002 at EBMUD with participation of approximately 50 representatives from public and governmental agencies located in and around the Bay Area. The most tangible outcome of this meeting was A Bay Area Real Time Network (BARTN) coordinating committee was formed with members from the above-mentioned agencies. On February 20, 2002, the committee members traveled to the Orange County Surveyors Office in Santa Ana, California for a CSRC meeting/Real Time Network Forum. John Canas and his staff provided an overview of the Orange County Real Time Network (OCRTN) and its implications for other real-time networks.



Latest plan for the establishment of BARTN. A real time network that encompasses the Bay Area's major population centers would cover an area of approximately 8400 square kilometers (3200 square miles). The area under consideration would include portions of nine Bay Area counties: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma. These counties also make up Caltrans District 4.

Riverside County Real Time Network

The CSRC is working to expand the southern California real-time network into Western Riverside County, in collaboration with the Riverside County Flood Control and Water Conservation District, the Surveyor's Office of the Riverside County Transportation Department, and the Southern California Integrated GPS Network. As in OCRTN, the central facility will receive data continuously from the upgraded SCIGN sites. The data will be analyzed for integrity, stored on data servers, and RTCM data will be provided by means of wireless links to support RTK surveys. The data will be collected in parallel at SOPAC/CSRC and archived. A user will be able to compute orthometric heights in the field, based on NGS geoid models and corrector surfaces computed from the CORS sites as orthometric heights are determined for these sites. This approach will be tested in Orange County, which has an extensive horizontal and vertical control network.



Area of Focus for Riverside County Real Time Network

A meeting was held in Santa Ana (hosted by John Canas) on April 23 to discuss an MOU between the counties and SCIGN concerning real-time networks, with participants from CSRC, Orange County, Riverside County, San Diego County, Los Angeles County, San Bernardino County, and City of Los Angeles. At this meeting we discussed progress and issues related to the Riverside County and Orange County efforts. These include the requirement for sufficient data buffering issue to maintain one week's worth of data at the sites in the event of a large earthquake or other emergencies, site communications, site upgrades, interaction among the parties, and leveraging other projects such as UCSD's HPWREN and RoadNet projects. In direct support of this effort Scripps investigators (Bock and Frank Vernon have been awarded a contract from NASA's SENH (Solid Earth and Natural Hazards) program for a three-year grant entitled: "Development of a Real-Time GPS/Seismic Displacement Meter: Applications to Civilian Infrastructure in Orange and Western Riverside Counties, California." The first year funding totaling $189,470 have been awarded, and funds totaling $40,000 have been allocated by the two Riverside County agencies.

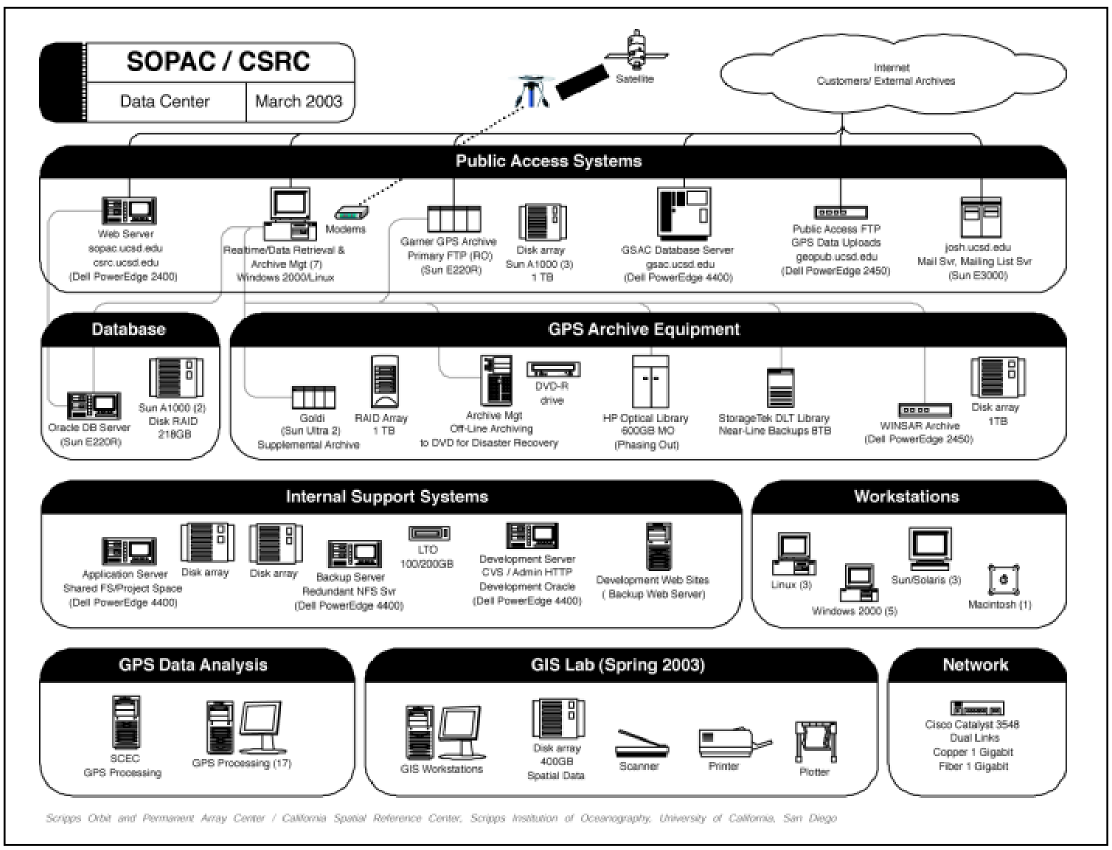
A significant outcome of meeting in Santa Ana was the formation of a working committee to oversee the development of the Riverside County Real Time Network (RCRTN).

Height Modernization: Interferometric Synthetic Aperture Radar (InSAR)

We investigated different methods of unwrapping the interferometric phases, also investigating how to filter the data in order to maximize the unwrapped area while minimizing any filter-generated artifacts. A total of 291 unwrapped phases were then generated. These phases were initiated at the pixel containing the SCIGN station USC1. Ongoing work includes attempting to establish a least-squares method and model for phase at each point in the InSAR time series (rather than between the two times making up each pair), and including GPS tropospheric and positional information into this analysis.

CSRC Facilities

The CSRC staff continues to upgrade and make changes to the CSRC computer facility (see below). A summary of the recent progress is provided as Attachment 1.



EDUCATION AND OUTREACH

CSRC representatives attended and participated in numerous meetings and conferences in efforts to provide information and to foster cooperation on projects between agencies and groups.

November 14, 2003 – Jim Swanson and Dave Zilkoski met with Corps of Engineers staff working on the Hamilton Wetlands Restoration Project in Marin County.

November 15, 2002 - Jim Swanson and Dave Zilkoski met with California Coastal Commission staff at a California Coast Height Modernization meeting set up by Becky Smyth.

November 15, 2002 – Yehuda Bock, Greg Helmer, Jim Swanson and Don Donofrio attended the Bay Area Real Time Network (BARTN) meeting and introduced the plan to approximately 50 representatives from public and governmental agencies located in and around the Bay Area.

November 26, 2002 - Don D'Onofrio gave a short presentation to the Tuolumne County Board of Supervisors regarding the height modernization project.

December 2, 2002 – Jim Swanson met with Santa Clara Valley Water District staff to discuss CORS installation in the district.

December 9, 2002 – Jim Swanson attended the BARTN advisory committee meeting to discuss the plan.

December 13, 2002 – Northern California GPS Users Group Meeting

January 24, 2003 – Jim Swanson gave a presentation on CSRC, San Joaquin Valley height modernization and real time networks at the Fresno State University Geomatics Engineering Conference

February 4, 2003 – Jim Swanson made a presentation to the Caltrans District 6 Executive Staff

February 20, 2003 – Real Time Network Forum in Santa Ana, CA

February 20-22, 2003 – Cecilia Whitaker gave three presentations on CSRC and CORS use to the Western Federation of Surveyors and Washington State Land Surveyors Association joint conference. Washington surveyors were very interested in starting a "WSRC".

February 26, 2003 – Jim Swanson, Don D'Onofrio and Marti Ikehara met with Caltrans to collaborate on leveling work that Caltrans is planning for the San Joaquin Valley.

February 27, March 6, 2003 – Cecilia Whitaker gave two evenings of presentations on CORS/CSRC to students at the University of Riverside GPS program.

March 9-12, 2003 – Jim Swanson and Art Andrew gave presentations at the CLSA conference

March 11, 2003 – Cecilia Whitaker gave a presentation on using CORS for vertical surveys at the CLSA.

March 12, 2003 – Don D'Onofrio and Greg Helmer gave presentations at the CLSA conference.

March 14, 2003 – Northern California GPS Users Group Meeting

April 3, 2003 - Greg Helmer reported on the "State of CSRC" as part of the "State of NGS" meeting hosted by the Riverside County Flood Control District

April 16, 2003 – Jim Swanson made a presentation to the Humboldt County Chapter of CLSA.

April 26, 2003 – CLSA Board meeting in Sacramento, CA

April – May, 2003 – Cecilia Whitaker taught a University of Riverside class on GPS and CORS/CSRC as part of their GPS program.

ATTACHMENTS

ATTACHMENT 1 - SOPAC/CSRC COMPUTER EQUIPMENT REVIEW

GARNER ARCHIVE

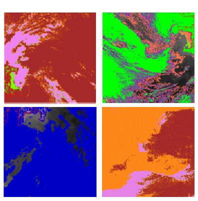
Approximately one terabyte of storage has been added to the CSRC Garner public GPS archive in the last six months. The new storage space is mirrored in two separate physical locations using lower cost, lower performance equipment. As data ages, they are relocated from higher performance equipment to the new lower performance equipment in order to provide space for high demand data.

NETWORK

In order to facilitate reliable GPS data transfers and web presence, a fiber gigabit ethernet link was added to the CSRC computer center. The new fiber connection is three hops over the UCSD campus backbone to the Internet. This new link supplements an existing copper gigabit ethernet connection, which is four hops from the Internet. The new ethernet link is a component of a plan to increase network reliability and provide direct gigabit network connections to high performance hosts such as the garner GPS archive.

DATABASE

An Oracle database system supports the automated GPS archival system, CSRC website, and CSRC data portal on a 7/24 basis. The database was moved to a new server and a new version of the Oracle RDBMS software. The database schema went through a complete analysis and reconfiguration to improve performance and efficiency. New database schemas were added to the database server to support a new refined GPS timeseries/coordinates service. The database is also being used to support spatial queries through the GSAC.



IMPLEMENTATION OF A REAL-TIME PRECIPITABLE WATER CAPABILITY USING THE GLOBAL POSITIONING SYSTEM

Yehuda Bock and Peng Fang
Scripps Institution of Oceanography

TASK/THEME: 2D

SUMMARY

This project is a continuation of the previous project (FY2001) under the same title. The objective for this project period (FY2002) was to reliably realize the goal of generating the precipitable water estimation with a latency of 2-3 hours, while maintaining the high quality (<= 1.5mm RMS) of the Integrated Precipitable Water (IPW) estimates.

In order to achieve this goal, a sliding window (SWIN) data processing procedure, developed during 1998-1999, was refined through intensive testing at SIO. Peng Fang then ported it to the FSL/NOAA Boulder facility during a one-week visit at the end of 1999. This SWIN system is capable of processing GPS data with arbitrary session lengths, at arbitrary starting times, in a very flexible network configuration, which is important for future expansion. The system is

particularly suited to carry out near real-time data processing using inexpensive single- or multi-CPU PC platforms running on a variety of UNIX operating systems. The IPW segment has been installed at FSL, where full-scale production is carried out, and SIO, where a subset of the network is processed for verification purposes. The supporting segment, also using the SWIN scheme, is only installed at SIO. This segment generates precise GPS orbits and orbit prediction on an hourly basis. The requirements for such a system are extremely challenging, and include: 1) a steady supply of high quality raw observations; 2) well distributed global network; 3) short processing time, and 4) fully automated quality control procedures [Fang et al., 2001]. Soon after deploying the system at FSL, both the IPW production and orbit supporting segments were in operation. The IPW estimates from this system were later assimilated into the operational Numerical Weather Prediction (NWP) model at the weather forecasting division of FSL with positive impact during severe weather in the U.S. [Gutman and Benjamin, 2001]

The operational system up-time, including both the production segment at FSL and the orbit-supporting segment at SIO, has been maintained as high as 99%. Over the past year, the system was down only on a few occasions due to global data supply problems, network communication problems, or a rare hardware failure, which are beyond SIO's control. In order to combat hardware failure problem, a failover system was developed. The accuracy of SIO hourly predicted orbits (next 24 hours) are generally at the 20-30 cm level, which is about the level of the best post-processed orbit some years ago when ground-based GPS meteorology started.

Throughout the course of deployment and operation, SIO has provided frequent and timely technical support to FSL. This includes scientific and technical consultation, system diagnosis via remote access, processing of table updates and modification of procedures to suit special needs or to improve efficiency/reliability. In addition, SIO also participated in special experiments as a part of on-going research activities.

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PUBLICATION SUMMARY			
	JIMO LEAD AUTHOR	NOAA LEAD AUTHOR	OTHER
Peer-Reviewed	24	4	32
Non Peer-Reviewed	40	0	41
TOTAL	64	4	73

FY03 SUMMARY			
Author	**Peer Reviewed**	**Non Peer Reviewed**	**TOTAL**
JIMO Lead Author	24	40	64
NOAA Lead Author	4	0	4
Other Lead Author	32	41	73
TOTAL	60	81	141

FY '03 EMPLOYEE SUMMARY (for those having some component of NOAA funding)

Title	Number of Employee's
Research Scientist	11
Project Scientist	5
Visiting Researcher	1
Post Graduate Reseacher	8
Academic Specialist	6
Staff Research Associate	4
Development Engineer	5
Senior Electronics Technician	1
Marine Technician	2
Coder, Sr	1
Computer Reseource Specialist I	1
Laboratory Assistant	1
Information Technology Analyst	16
Business Officer	2
Financial Analyst	2
Financial Specialist	4
Administrative Assistant	8
Graduate Student Researcher	9
Undergraduate Assistant	7
TOTAL	**94**