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VARIATIONS

Leaving a Legacy

by David M. Legler, Director

One the challenges of CLIVAR is encouraging and guiding studies that not only investigate processes important for the understanding and prediction of climate changes, but provide a legacy that is more than a collection of dense observations over a limited region and time period. The North American Monsoon Experiment, NAME, took place nearly 3 years ago and is now focusing on the synthesis of its results, its legacy of improved observational requirements and improved forecasting capabilities. As NAME winds down, advance planning for a new study, VOCALS, is underway. VOCALS will explore the challenging ocean-atmosphere dynamics of the southeast Pacific and will consider both the physical as well as biogeochemical processes leading to changes in cloud formation and upper ocean heat budgets in an attempt to improve coupled model simulations in this notoriously difficult region. These are just a few of the studies currently in place or in planning stages. Consult the U.S. CLIVAR web pages for information on other studies.

Continued on Page Two

IN THIS ISSUE

The VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS)

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VOCALS is one of the principal activities of the WCRP/CLIVAR VAMOS panel, and has links with the GEWEX Cloud System Study (GCSS) group. The Southeast Pacific (SEP) climate is a tightly coupled system involving poorly understood interactions between clouds, aerosols, marine boundary layer (MBL) processes, upper ocean dynamics and thermodynamics, coastal currents and upwelling, large-scale subsidence, and regional diurnal circulations (Fig. 1). This unique system is very sparsely observed, yet its variations have important impacts on the global climate. There are also great economic impacts, with the regional fisheries representing almost one-fifth of the worldwide marine fish catch.

The Andes Cordillera are barriers to zonal flow in the South Pacific, resulting in strong winds parallel to the coasts of Chile and Peru (Garreaud and Muñoz 2005), which drive intense coastal upwelling, bringing cold, deep, nutrient/biota rich waters to the ocean surface. As a result, sea-surface temperatures (SSTs) are colder along the Chilean and Peruvian coasts than at any comparable latitude. The cold SSTs, in combination with warm and dry air aloft helped by orographic effects of the Andes (Richter and Mechoso, 2006), support the largest and most persistent subtropical stratocumulus deck in the world. The presence of this cloud deck has a major impact upon the earth's radiation budget.

Several fundamental problems are barriers to the understanding of SEP's weather and climate: These problems include the serious difficulties in the quantification of the indirect effect of aerosols upon cloud radiative properties (e.g. Lohmann and Feichter 2005). Also, coupled atmosphere-ocean general circulation models (CGCMs), have troublesome systematic errors in the SEP, notably (Fig. 2) too warm SSTs and too little cloud cover (e.g. Mechoso et al. 1995).

The principal program objectives of VOCALS are: 1) the improved understanding and regional/global model representation of aerosol indirect effects over the SEP; 2) the elimination of systematic errors in the region of coupled atmospheric-ocean general circulation models, and improved model simulations and predictions of the coupled climate in the SEP and global impacts of the system variability. Program documents and information can be found at www.eol.ucar.edu/projects/vocals/.

The VOCALS Strategy

VOCALS is organized into two tightly coordinated components: 1) a Regional Experiment (VOCALS-REx), and 2) a

Continued from Page One

A little over a year ago U.S. CLIVAR constituted some short-term Working Groups that would work collaboratively on focused and pressing scientific challenges and needs. The efforts of these Working Groups can be found on the U.S. CLIVAR web site. The Ocean Salinity Working Group is finishing their written findings and the MJO Working Group efforts were highlighted at the recent WGNE Systematic Biases workshop. Two other Working Groups were recently initiated. Drought is a major focus of U.S. CLIVAR and the Drought Working Group activities (described in this article) will complement the DRICOMP funded activities, which were recently solicited. Please check the respective Working Group web pages for further information and how to get involved.

The recently released US Ocean Research Priorities Plan and Implementation Strategy (http://ocean.ceq.gov/about/docs/orpp12607.pdf) includes, as one of its Near Term Priorities, the Atlantic Meridional Overturning Circulation (MOC). U.S. CLIVAR and the agencies will be working with the community to develop implementation plans for this initiative. More information will follow in the next Variations and on the U.S. CLIVAR web site.

Variations

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Modeling Program (VOCALS-Mod). Extended observations (e.g. IMET surface buoy, satellites, cruises) will provide important additional contextual datasets that help to link the field and the modeling components. The coordination through VOCALS of observational and modeling efforts will accelerate the rate at which field data can be used to improve simulations and predictions of the tropical climate variability. VOCALS is primarily sponsored by NSF and NOAA with contributions from the Office of Naval Research (ONR), DOE, and international partners.

VOCALS Scientific Issues

a.Aerosol-cloud-drizzle interactions in the marine PBL

In addition to responding to large-scale dynamics, cloud optical properties over the SEP are also impacted by atmospheric aerosols (Huneeus et al. 2006), with contributions from both natural and anthropogenic sources. Cloud droplet effective radii are small off the coast of Chile and Peru, implying enhanced cloud droplet concentration, particularly downwind of major copper smelters whose combined sulfur emissions total 1.5 TgS yr^{-1}, comparable to the entire sulfur emissions from large industrialized nations such as Mexico and Germany (Source:GEIA). Regional changes in surface and TOA radiation caused by the enhanced effective radii are as high as 10-20 W m^{-2}, with significant, but currently unknown, implications for the ocean heat budget.

The East Pacific Investigation of Climate (EPIC) field study (Bretherton et al. 2004) found evidence that drizzle formation, enhanced by the depletion of aerosols (Wood 2006) in the clean MBL, can drive remarkably rapid transitions which drastically reduce cloud cover (Stevens et al. 2005). Although low clouds and the dynamical and microphysical processes controlling their thickness and coverage are a cornerstone of the climate of the SEP, our knowledge of clouds in this region is so far limited to surface and spaceborne remote sensing. There are no in-situ observations of these clouds with which to test hypotheses concerning their physics and chemistry. VOCALS observations will seek to quantify the controls on cloud condensation nuclei (CCN) formation and growth, in concert with the IGBP's Surface Ocean Lower Atmosphere Study, SOLAS.

b. Systematic biases in atmosphere-ocean GCMs

CGCMs have difficulties in simulating marine stratocumulus clouds (Ma et al. 1996; Kiehl and Gent 2004; Wittenberg et al. 2006). This is attributable, in part, to the inadequate representation of MBL processes (turbulence, drizzle, mesoscale organization) in atmospheric models, and to a poor representation of cloud microphysical processes (i.e. aerosol processes, including their transport from continental sources and their removal by drizzle). Studies using CGCMs (Ma et al. 1996, Gordon et al. 2000) demonstrate that the accurate prediction of the optical properties of low clouds over the SEP is required in order to simulate the strong trade winds and the observed SST distribution.

The OGCM components of CGCMs also have difficulties with coastal upwelling, and the offshore heat and nutrient transport by the associated mesoscale eddy field (Penven et al. 2005, Colbo and Weller 2006).

Mean advection velocities in the upper ocean in the SEP are weak (few cm s^{-1}). The upper ocean, therefore accumulates and expresses locally the influences

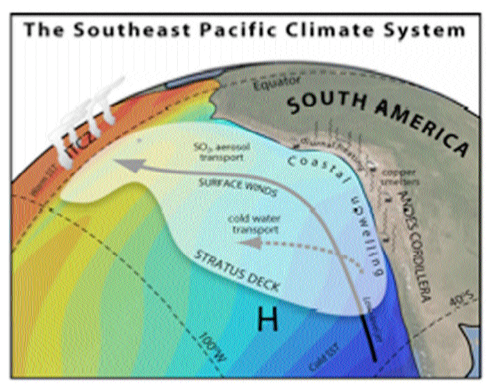

Figure 1. Key features of the SEP climate system.

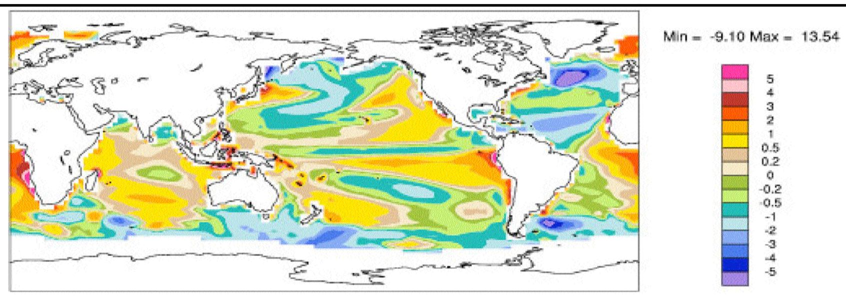

Figure 2. Annual mean sea-surface temperature biases in CCSM3 1990 control run (Collins et al. 2006)

of lateral fluxes associated with eddies (e.g. Penven et al. 2005), and vertical mixing events associated with atmospheric forcing transients (Wijesekera and Gregg 1996). Mesoscale ocean eddies 50-200 km across can affect SST well offshore by fluxing cold water from the coastal upwelling regions (Fig. 3). Eddies could also impact the ocean-atmosphere flux of dimethylsulfide (DMS), an important precursor gas for cloud condensation nuclei. Eddy heat flux divergence may account for roughly 40 W m^{-2} net heat flux into the ocean over the remote SEP (Colbo and Weller 2006). Mesoscale eddies are poorly observed and understood, and are barely resolved in coupled ocean-atmosphere climate models (Canuto and Dubovikov 2005). Observations at the IMET buoy (20°S, 85°W) show that another challenge for OGCMs is vertical mixing at the base of the upper layer by near-inertial oscillations, which can entrain fluid from the cool, fresh intermediate water below.

VOCALS-Mod posits that alleviation of the difficulties with the simulation of stratocumulus and coastal upwelling/ocean heat budget will result in major improvements in GCM performance. These improvements include the alleviation/elimination of the double-ITCZ biases that characterizes contemporary CGCMs. There is evidence that this bias has a negative effect on the CGCM performance in the prediction of ENSO and its remote impacts.

c. Interactions between the SEP with remote climates

There is consensus that climate variability in the SEP can imprint a signature in large-scale fields via teleconnections. Previous work has provided indications that features of tropical precipitation patterns are strongly influenced by the SEP (Ma et al. 1996; Large and Danabasoglu 2006). The pronounced annual cycle in the equatorial cold tongue is also considered to originate from the SEP (Mitchell and Wallace 1992). Atmospheric disturbances in the SEP with an asymmetric structure propagate westward in the form of Rossby waves (Xie 1996), and oceanic disturbances similarly propagate westward as Rossby waves and eddies (Chelton et al. 2006). However, the mechanisms of interaction are not well understood.

4. VOCALS-REx

a. Goals

VOCALS-Rex will collect datasets required to address a set of issues that are organized into two broad themes: (1) aerosol-cloud-drizzle interactions in the marine boundary layer (MBL) and the physicochemical and spatiotemporal properties of aerosols; (2) chemical and physical couplings between the upper ocean, the land, and the atmosphere. The overarching goal for work in the first theme is a better understanding of processes that influence cloud optical properties (cloud cover, thickness, and particle size) over the SEP. The goal of the second theme refers to the roles that oceanic upwelling, mesoscale eddies and other transient upper oceanic processes play in determining the characteristics of the sea surface temperature distribution across the SEP. The hypotheses and testing strategies are presented in full in the VOCALS Scientific Program Overview (see www.eol.ucar.edu/projects/vocals/).

b. Aerosol-cloud-drizzle theme

A comprehensive suite of in-situ and remotely sensed cloud and boundary layer measurements will be performed using the aircraft platforms and the ships. Aircraft missions will focus upon understanding the processes that control precipitation, including the role of atmospheric aerosols, their transport from the land to the ocean, and their depletion by the clouds themselves. A key goal is to better link aerosol microphysical variability with the variability in the radiative properties of the clouds by performing closure studies that not only link cloud microphysics with aerosol microphysics, but also link the cloud optical properties (measured with aircraft and satellite remote sensing) to the underlying aerosol variability. SOLAS studies will seek to relate this aerosol variability to the marine sources and sinks of sulfur-containing gases and particles.

c. Coupled ocean-atmosphere-land theme

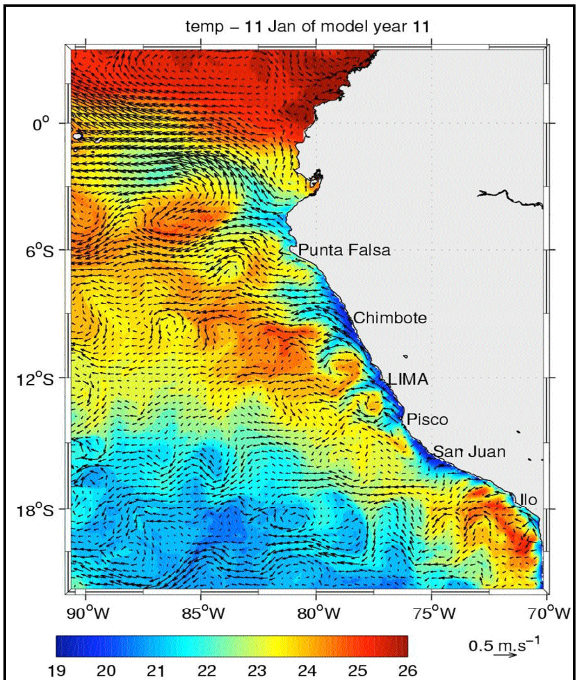

Figure 3. SST and surface current variability associated with the mesoscale ocean eddy field in a regional ocean model.

A ship towing the SeaSoar platform will be used to conduct a survey of the mesoscale eddy field at several distances from the coast. Detailed measurements of the microscale variability of the upper ocean will be used to explore the connections between the ocean mixed layer and the ocean beneath. Chilean and Peruvian coastal components are expected to provide key data on the nature of the upwelling and the initiation of the mesoscale eddies. Links between the variability in oceanic upwelling and the biogenic production of important aerosol precursor gases (e.g. DMS) will be explored using DMS flux measurements. In addition, the role of the land at modifying the diurnal cycle (Garreaud and Muñoz 2004) and synoptic variability of clouds and low level winds will be explored.

An additional key VOCALS-REx goal is to use the unparalleled combination of cloud measurements and other observational datasets to critically evaluate the accuracy of current and future satellite cloud microphysical retrieval algorithms.

d. Strategy

VOCALS-REx will have an intense observing period during October-November 2008. The observational platforms during the period will comprise aircraft (chiefly the NSF C-130, the CIRPAS Twin Otter, the DOE G-1, and possibly the UK BAe-146), research ships (the NOAA Ronald H Brown (RHB), and possibly a second ship), a land site in Chile, and Peruvian and Chilean coastal cruises. Figure 4 shows a map of the VOCALS-REx study region and platforms involved. VOCALS-Rex activities have been carefully designed to complement and enhance a suite of enhanced long-term observations in the SEP. These include an uninterrupted six year record from the IMET instrumented surface buoy (85°W, 20°S), annual buoy maintenance cruises (in 2001 and then in 2003-2006), and regionally-subsetted satellite data.

VOCALS-Mod

- Goals: A principal goal of VOCALS is to improve model simulations of key climate processes using the SEP as a testbed, particularly in coupled models that are used for climate change projection and ENSO forecasting. VOCALS-Mod, therefore, provides the context for VOCALS and will directly benefit from the observations collected in the field campaign. The principal objectives of VOCALS-Mod are (1) improving the understanding and simulation of diurnal, seasonal, inter-annual, and inter-decadal variability in the SEP; (2) improving the understanding and simulation of oceanic budgets of heat, salinity, and nutrients in the SEP and their feedbacks on the regional climate; (3) developing the capability for simulation of cloud optical properties (coverage, thickness, and droplet size) and the effect on these properties of aerosols emitted in the region; (4) elucidating the interactions between the SEP climate and remote climates. VOCALS-Mod will provide modeling support for VOCALS-REx through real-time forecasts and data assimilation. The research methodology in VOCALS-Mod will be organized into several themes:

- Downscaling to the VOCALS-Rex study region: Global reanalysis data will be used as forcings for Regional Atmospheric Models (RAMs) and Regional Ocean Models (ROMs), the output of which will provide invaluable regional context in which to interpret VOCALS-REx field data.

- Ocean mesoscale eddy structure and transports: High resolution ROMs will be used in conjunction with the VOCALS-REx oceanographic mesoscale survey and satellite data to determine the horizontal and vertical eddy structure, eddy heat/freshwater/biota transports from the coastal upwelling region to the remote SEP, and interactions between the eddies, the mixed layer and the deeper ocean.

- Aerosol-cloud-drizzle-ocean interactions: VOCALS-REx data will be used to constrain and refine parameterizations of aerosol scavenging, cloud fraction and cloud microphysical processes used in participating AGCMs and RAMs.

- Diagnostic studies of the regional climate system: RAMs, ROMs and Regional Ocean-Atmosphere Models (ROAMs) will be used to investigate the coupling between the atmosphere, ocean and land in the SEP region.

- Modeling biogeochemical processes: VOCALS will accelerate the process by which a representation of the interactions between ocean biota and the climate system are included in climate models.

- Development of a Multi-Scale Simulation and Prediction (MUSSIP) System: VOCALS-Mod will use a Multi-Scale Simulation and Prediction (MUSSIP) system based on a RAM coupled to an eddy-resolving ROM embedded within a global climate model or forced by reanalysis data.

- Strategy: The VOCALS modeling vision is based on the concept of a multi-scale hierarchy of models reflecting the multiscale nature of processes in the SEP and the multiscale hierarchy of VOCALS observations. VOCALS-Mod will coordinate activities carried out at operational centers (NCEP), research laboratories (NCAR, GFDL) and universities, with the goal of using VOCALS observational datasets both to evaluate model performance and to inform physical parameterization development. Use of the operational modeling systems will provide insight into the time evolution of errors and their dependency on the analysis employed for initialization; use of research modeling systems will facilitate the realization of hypothesis-testing experiments. The collaborations established willl make available the hierarchy of numerical models needed to address the broad range of space and time scales of processes in the VOCALS region.

The VOCALS Legacy

VOCALS has been conceived with the overarching goal of improving large scale coupled ocean-atmosphere model simulations and predictions of the SEP climate system. This will be achieved with a coordinated modeling and observational program, in which datasets are identified, generated and shared through a VOCALS-wide data archive. Datasets generated will be made available to the broad modeling community as soon as quality control is completed. A multi-scale simulation and prediction system will be developed. VOCALS will pave the way for field campaigns in the stratocumulus regions in the eastern tropical Atlantic, which influence the western

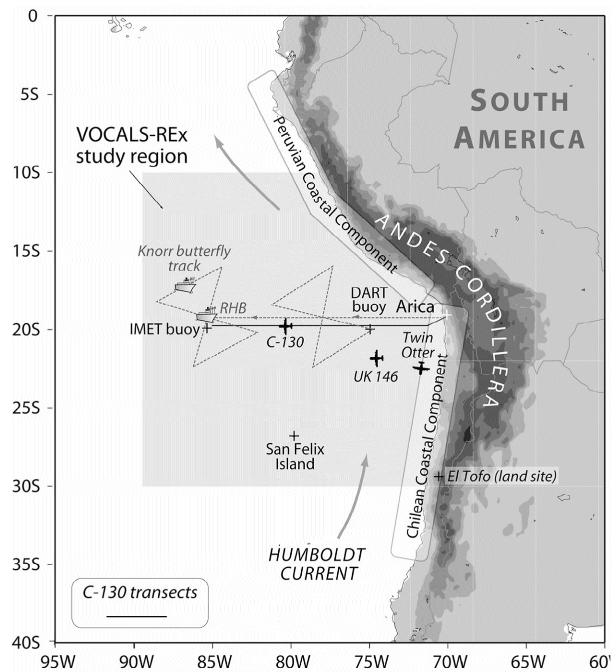

Figure 4. VOCALS-REx study region and key platforms/components involved. The RHB will make stationary measurements at 3 locations (20S and 75, 80, and 85W). Ideally, a second ship will make butterfly patterns with the SeaSoar platorm to survey ocean mesoscale variability. The C-130 will make cross-sectional measurements along 20S out to 85W, and conduct flights to study the sturcture of pockets of open cells (POCs). The other aircraft will work mainly in the near-coastal zone to examine aerosol, cloud and drizzle variability. The Chilean and Peruvian coastal components will involve coastal ship sampling of the upper ocean and marine boundary layer. The Chilean land site will be used to examine the chemical and physical properties of the air masses that are advected from Chile over the SEP.

African summer monsoon. In addition, VOCALS will provide education and training for both U.S. and regional climate scientists.

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The U.S. CLIVAR Working Group on Long-term Drought

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Siegfried Schubert, NASA Goddard Space Flight Center, co-chair

U.S. CLIVAR recently formed a Working Group to provide funding agencies and existing scientific steering groups with specific guidance on research needs for improving prediction and monitoring tools for long-term (multi-year) droughts and to energize initial drought activities. Such droughts have tremendous societal and economic impacts on the United States, and many other countries throughout the world. Estimates of the costs of drought to the United States alone range from \$6-\$8 billion annually with major droughts costing substantially more (e.g., \$62B in 1988 according to NOAA). The Dust Bowl drought of the 1930s, which at its maximum extent covered much of the continental U.S. (Fig. 1) is ranked as one of the top 10 domestic weather-related disasters of the 20th century. Recent population increases in water-limited regions has increased vulnerability to drought at the same time that climate change projections suggest that drought conditions may become more extreme in the 21st Century, particularly in the southwestern United States (NRC, 2007).

Several agencies including NOAA and NASA are in the planning phase for implementing the National Integrated Drought Information System (NIDIS, 2004) authorized by law in December 2006. The vision for NIDIS is a dynamic and accessible drought risk information system that provides users with the ability to determine the potential impacts of drought, and the decision support tools needed to better prepare for and mitigate the effects of drought. As the designated lead agency, NOAA is developing an interagency implementation plan. NASA is also engaged in planning for NIDIS as part of an overall strategy to implement key aspects of the international Global Earth Observation System of Systems (GEOSS) strategic plans.

While NIDIS has a strong focus on the U.S., it is clear that drought is a global phenomenon, both in terms of the forcing elements and the potential commonality of local processes that operate to make some regions more susceptible to drought than others. As such, confidence in our understanding of drought processes (remote and local forcing, feedbacks, etc.) will be significantly advanced by efforts to properly analyze and simulate regional drought wherever it occurs. Recent studies (e.g., Hoerling and Kumar 2003; Schubert et al. 2004; Seager et al. 2005) suggest that such simulations are feasible using current global models (Fig. 2). There are, however, still major uncertainties about the relative roles of the different ocean basins, the strength of the land-atmosphere feedbacks, the role of deep soil moisture, the nature of long-term SST variability, the impact of global change, as well as fundamental issues about predictability of drought on multi-year time scales.

The primary objective of the U.S. CLIVAR Working Group is to facilitate progress on the understanding and prediction of long-term (multi-year) drought over North America and other drought-prone regions of the world, including an assessment of the impact of global change on drought processes. The specific tasks of the Working Group will be to: 1) coordinate and encourage the analysis of observational data sets to reveal antecedent linkages of multi-year droughts; 2) propose a working definition of drought and related model predictands of drought, 3) coordinate evaluations of existing relevant model simulations, 4) suggest new experiments (coupled and uncoupled) designed to address some of the uncertainties mentioned above, and to contribute to NIDIS-related drought risk assessment; 5) examine the prospects for using land data assimilation products for operational monitoring, assessment and hydrological applications; and 6) organize an open workshop in 2008 to present and discuss the working group results and consider results from the community.

As initial products, the Working Group is compiling a list of recent papers on drought research, and an inventory of accessible data sets for observational studies. These products (still under development) can be obtained through the Working Group's web page at http://www.usclivar.org/Organization/drought-wg.html. The Working Group has also initiated discussion of a working definition of drought (including onset and demise) for use by both the prediction/research and applications communities. The goal of this effort will be to

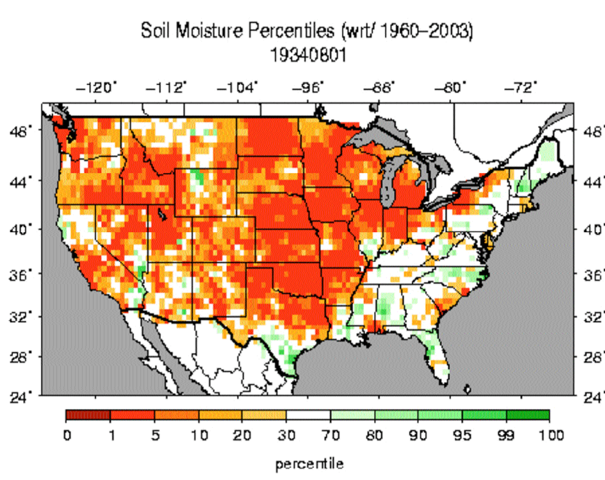

Figure 1. Spatial extent of the Dust Bowl drought of the 1930s in August 1934. Percentiles are for soil moisture relative to the 85-year period 1915-2003. From University of Washington Surface Water Monitor, available online at: http://www.hydro.washington.edu/forecast/monitor.

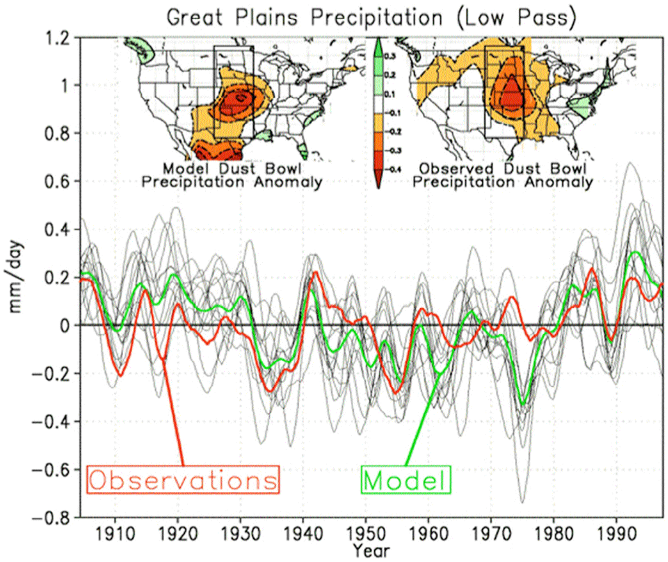

Figure 2. Time series of precipitation anomalies averaged over the U.S. Great Plains region (30°N to 50°N, 95°W to 105°W), from Schubert et al. (2004). A filter has been applied to remove time scales shorter than about 6 years. The thin black curves are the results from 14 ensemble members from C20C global model runs. The green solid curve is the ensemble mean. The red curve is based on observations. The maps show the simulated (left) and observed (right) precipitation anomalies averaged over the Dust Bowl period (1932 to 1938, units mm/day).

define drought in a way that is quantifiable and verifiable for the purpose of model prediction experiments, as well as for drought monitoring and early warning, and facilitating communication between the applications and modeling/research communities.

The working group will help coordinate key aspects of the long-term drought research agenda outlined in the recent drought workshop recommendations (e.g. Schubert et al. 2005). It will interact with the developing NIDIS program to communicate current drought prediction and attribution capabilities. The Working Group will work with the NIDIS community and the relevant funding agencies to develop guidance on drought research needs, based on assessments of prediction capabilities and input we will seek concerning stakeholder-driven prediction priorities. It will advocate the coordination of efforts among the agencies to advance drought prediction research in ways that will maximize the utility for NIDIS development.

The long-term drought problem can be an important umbrella issue to bring together the relevant research expertise of the International CLIVAR program (with its focus on large scale and ocean-atmosphere coupling), and GEWEX (focusing on regional scales and land-atmosphere coupling). What is the role of the land (e.g., deep soil moisture, snow, vegetation)? What is the role of the different ocean basins, including the impact of ENSO, the PDO, the AMO, and longer term warming trends in the global oceans? To what extent can drought develop independently of ocean variability due to year-to-year memory inherent to the land?

The Working Group will recommend and promote a set of idealized experiments coordinated among different models to address some of the key issues outlined above (e.g., role of different ocean basins, deep soil moisture, etc.). Specific details about the experiments and diagnostic analyses are beginning to be developed. The Working Group will coordinate with research institutes and universities active in drought research to ensure that the relevant simulations are well documented and accessible to the community.

New simulations will build upon the climate variability and change attribution activities funded by NOAA/CDEP, the attribution and prediction capabilities at various universities and research institutes, and take advantage of the many long term coupled model runs that have been conducted as part of the IPCC climate change assessment process. The upcoming DRICOMP (http://www.usclivar.org/DRICOMP-AO.html) model assessment research opportunity represents an important component of this effort. Additional activities of the Drought Working Group can be monitored on its web page: http://www.usclivar.org/Organization/drought-wg.html).

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The Path to Improving Predictions of the North American Monsoon

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The North American Monsoon System (NAMS) is considered to be the principle organizing structure for the warm season limate of southwestern North America. Like its global, though often larger, counterparts in Asia, Australia, Africa and South America, the NAMS exhibits marked seasonal reversals in land-ocean thermal contrasts, low and mid-tropospheric wind fields, atmospheric moisture convergence patterns, atmospheric stability and, consequently, precipitation. The seasonal onset, intensity and decay of summer rains drive a host of ecological and societal dependencies ranging from water resources to wildland fire threat to rangeland forage production to energy supply and demand to estuarine fisheries (cf Ray et al., 2007; Aragón and García, 2002; Gochis et al., 2006, 2007a). However, also like its global counterparts, prediction skill of warm season rainfall on seasonal to interannual timescales remains critically low. This lack of skill translates into a persistent vulnerability of the aforementioned dependencies. The 2006 summer monsoon, which brought persistent heavy rainfall to the U.S.-México border region (Sonora, Chihuahua, Arizona and New Mexico) and tens of millions of dollars in damages, served as a timely reminder of this vulnerability (cf FEMA, 2007, CLIMAS, 2006).

The NAME Program:

The North American Monsoon Experiment (NAME) is a continental-scale process study now in its seventh year that was conceived to directly address the issue of improving predictions of warm season precipitation in North America. The NAME program is jointly sponsored by Climate Variability and Predictability (CLIVAR) and Global Energy and Water Cycle Experiment (GEWEX) research efforts. The underlying hypothesis of NAME is that the structure and evolution of the NAMS provides a physical basis for determining the degree of predictability warm season precipitation over much of North America. A fundamental first step towards improved prediction is the clear documentation of the major elements of the monsoon system and their variability within the context of the evolving Ocean-Atmosphere-Land (O-A-L) annual cycle (Higgins and Gochis, 2007). To achieve this NAME employs a multi-scale (tiered) approach with focused monitoring, diagnostic and modeling activities in the core monsoon region, on the regional-scale and on the continental-scale (Fig. 1). (Additional detail on NAME background information and motivating science questions can be found in Higgins et al., 2006 and NAME-SWG, 2007).

Central to the NAME research effort is a list of science questions posed on the three tiers of the NAME study domain. These questions are aimed at improving the understanding and simulation of 1) warm season convective processes over complex terrain (Tier I), 2) the modes and drivers of intra-seasonal variability (Tier II) and, 3) the response of the NAMS to oceanic and continental boundary conditions (Tier III). The timeline for NAME activities (Fig. 1) encompasses planning, data collection and principle research phases. A progressive aspect of NAME has been that modeling and data assimilation activities were engaged early in planning process in order to guide the observational strategy of a large Enhanced Observing Period (EOP) or, field campaign, which was conducted during the summer of 2004. This coordination insured that the field data collected not only would serve as valuable data for conducting exploratory and diagnostic analysis, but would also directly address problematic modeling issues that had arisen through numerous prior modeling

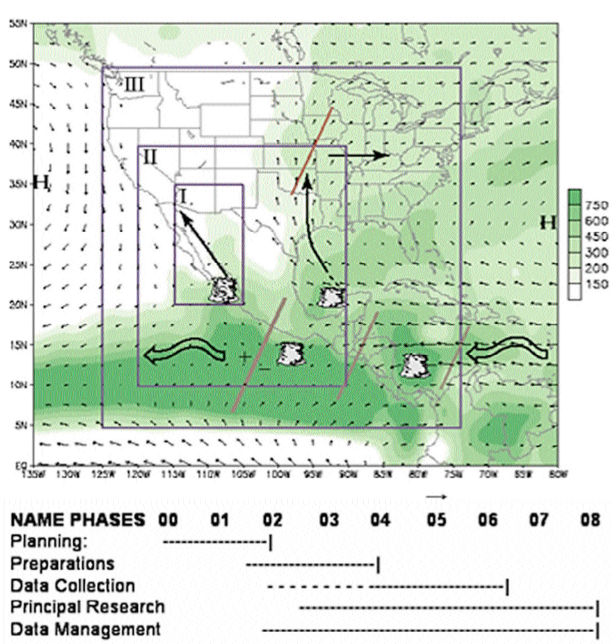

Figure 1. Multi-tiered research domain developed for NAME. Important features of the monsoon climate are also depicted. Digonal red lines indicate eastward (mid-latitude) and westward (tropical) propagating transients known to imact monsoon behavior. Wind vectors indicate the mean 925hPa wind field from the NCEP/NCAR reanalysis. Green shading indicates merged satellite estimates and raingauge observatins of precipitation in millimeters. The timeline for NAME program, beginning in 2000, is also shown. (Adapted from Higgins et al., 2006)

studies. These issues included the structure and evolution of regional moisture flux patterns over the Gulf of California (GoC), air-sea interactions over the GoC and Eastern Pacific, the diurnal cycle of precipitation, upscale organization and propagation of convection, the influence of low-and mid-latitude transients on precipitation episodes and coupling between the land-surface and the atmosphere. The NAME 2004 EOP was organized and conducted by an international coalition of university and agency scientists, and forecasters from México, the U.S. and central America. More than 20 different types of instrument platforms, including surface meteorological stations, radars, aircraft, research vessels, satellites, wind profilers, rawinsondes, pibals, rain gauge networks, soil moisture sensors and GPS integrated water vapor retrieval antennae were deployed within the Tier I and II regions in Figure 1. (Higgins and Gochis, 2007)

The remainder of this article provides a brief overview of the key findings from the 2004 EOP as well as a discussion on current activities aimed at improving predictions of warm season precipitation over North America. Given the brevity of this summary only a few topics are highlighted. The summary provided below along with much of the work cited is contained in a forthcoming special issue in the Journal of Climate on NAME due to be published during the late-spring of 2007, and in meeting reports from the NAME SWG from 2005 and 2006 available through the official NAME website

(http://www.eol.ucar.edu/projects/name/)

Key Findings from 2004 EOP:

Regional circulation structures around the Gulf of California (GoC):

Owing to marked deficiencies in the pre-existing operational sounding network over the NAMS region, characterization of the atmospheric circulation in the Gulf of California region was greatly enhanced during the 2004 NAME EOP. Time mean analyses of NAME 2004 observations, conceptualized in Figure 2, show strong low-level convergence and upper-level divergence along the crest of the Sierra Madre Occidental (SMO) (Johnson et al., 2007). This direct circulation structure, centered over western

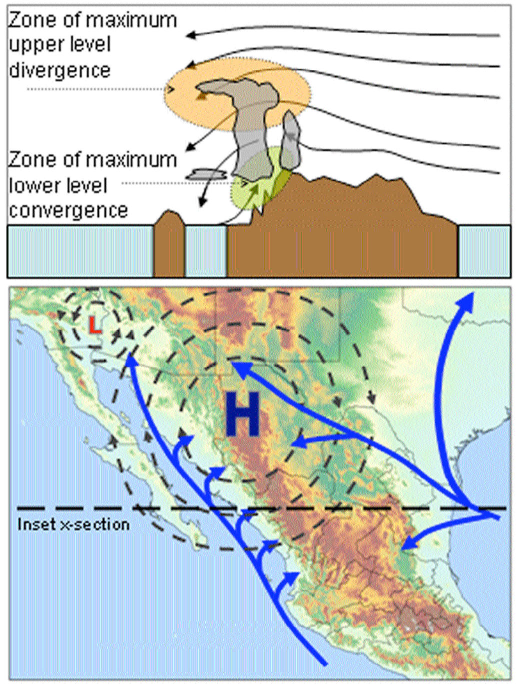

Figure 2. Schematic of regional circulation features of the North American Monsoon. Heavy blue lines in plan view designate principle moisture pathways. 'H' an d 'L' indicate climatological positions of hte upper-level monsoon anticyclone and hte low-level desert thermal low, respectively. Cross-section in top figure is approximated from heavy black dotted line on map. Cloud structures in grey shading approximate those structures diagnosed from various precipatation studies conducted as part of NAME. (Adaped from Johnson et al., 2007, Higgins et al., 2006, Nesbitt and Gochis, 2007).

México, is considered to be the principle driver of the NAMS. Peripherally, strong subsidence was found to persist over the Gulf of California as a result of return flow from sea-breeze/terrain circulation and from flow descending over the SMO (Johnson et al., 2007; Zuidema et al., 2007). Despite the enhanced observing network present during 2004, significant uncertainty in the vertical humidity structure over the complex terrain exists due to lack of surface meteorological and atmospheric observations.

Flow over the GoC and the western coast of the Mexican mainland was typified by nocturnal low level southeasterly flow and daytime low-level westerly flow inland towards the SMO. Easterlies tend to persist at middle and upper levels fostering a light to moderately sheared environment over the principle convective region of the western slope of the SMO. Divergence, vertical motion, heating and moistening profiles derived from analyses of the special observations are all consistent with a convectively-dominated dynamical system (Johnson et al., 2007). Nevertheless, stratiform precipitation structures were frequently observed during nighttime hours and are assumed to play an important role in modifying the regional thermodynamic structure over and around the GOC (Johnson et al., 2007; Zuidema et al., 2007; Williams et al., 2007).

Climatologically, inverted troughs and other synoptic transients such as tropical easterly waves, and westerly mid-latitude troughs are critical features of the NAM (Douglas and Englehart, 2007). Inverted troughs, propagating along the southern limb of the summertime subtropical anticyclone, help advect moisture and provide dynamical support by means of large scale ascent and orographic lift in otherwise dry regions such as the central Mexican Plateau. In addition to having a late onset, synoptic variability during 2004 summer monsoon was characterized by a reduced number of inverted troughs and nearly twice the climatological number of midlatitude westerly troughs (Douglas and Englehart, 2007). The westerly troughs during 2004 were implicated in drier-than-normal conditions in Arizona and northern Sonora but wetter than normal conditions in eastern New Mexico. On interannual timescales the dominance of a particular transient regime significantly influences summer rainfall patterns (Douglas and Englehart, 2007).

Characteristics of Precipitation:

Forcing of the diurnal cycle of winds

Calendar of CLIVAR and CLIVAR-related meetings

Further details are available on the U.S. CLIVAR and International CLIVAR web sites: www.usclivar.org and www.clivar.org

Variability of the American Monsoons (VAMOS-10)
2-5 April 2007
Santiago, Chile
Attendance: Invited
Contact: http://www.clivar.org

Int'l Oceanographic Data and Information Exchange (IODE)
16-20 April 2007
Trieste, Italy
Attendance: Open
Contact: http://www.iode.org

CLIVAR Indian Ocean Panel Meeting
23-25 April 2007
South Africa
Attendance: Invited
Contact: http://www.clivar.org

Seventh Workshop on Decadal Climate Variability
30 April-3 May 2007
Kona, Hawaii
Attendance: Open
Contact: http://www.decvar.org/workshops_conferences.php

Ocean Observataions Panel for Climate-12
30 April-4 May 2007
Melbourne, Australia
Attendance: Invited
Contact: http://www.clivar.org

AGU Joint Assembly
21-25 May 2007
Acapulco, Mexico
Attendance:Open
Contact: http:// www.agu.org

WCRP Workshop on Seasonal Prediction
4-8 June 2007
Barcelona, Spain
Attendance: Open
Contact:
http://www.wmo.ch/web/wcrp/AP_SeasonalPrediction.html

NOAA Climate Observation Annual Review
5-7 June 2007
Silver Spring, Maryland
Attendance: Open
Contact: http://www.oco.noaa.gov

Pacific Science Congress XXI Symposium on Global Change, Asian Monsoon and Extreme Weather and Climate
12-16 June 2007
Okinawa, Japan
Attendance: Open
Contact: http://www.psc21.net

12th Annual Community Climate System Model (CCSM) Workshop
18-21 June 2007
Breckinridge, CO
Attendance: Open
Contact: http://www.ccsm.ucar.edu

IEEE Oceans '07
18-21 June 2007
Aberdeen, Scotland
Attendance: Open
Contact: http://www.oceans07ieeeaberdeen.org/

IUGG 2007
2-13 July 2007
Perugia, Italy
Attendance: Open
Contact: http://www.iugg2007perugia.it/

U.S. CLIVAR Summit
23-25 July 2007
Annapolis, Maryland
Attendance: Invited
Contact: www.usclivar.org

Application of Remotely Sensed Observations in Data Assimilation
23 July - 10 August 2007
College Park, Maryland
Attendance: Open
Contact:http://www.essic.umd.edu

AMS Air-Sea Interaction Conference
20-24 August 2007
Portland, Oregon
Attendance: Open
Contact: http://www.ametsoc.org

Layered Ocean Model Meeting
20-23 August 2007
Bergen, Norway
Attendance: Open
Contact: www.clivar.org

CLIVAR Working Group on Ocean Model Development
26-27 August 2007
Bergen, Norway
Attendance: Invited
Contact: http://www.clivar.org

2nd International Conference on Earth System Modeling
27-31 August 2007
Hamburg, Germany
Attendance: Open
Contact: http://www.mpimet.de/icesm

CLIVAR SSG-15
11-14 September 2007
Geneva, Switzerland
Attendance: Invited
Contact: http://www.clivar.org

AMS Conference on Satellite Meteorology and Oceanography and Ocean Vector Winds Science Team
24-28 September 2007
Amsterdam, Netherlands
Attendance: Open
Contact: http://www.conferences.eumetsat.int

PICES 16th Annual Meeting: The Changing North Pacific: Previous patterns, future projections and ecosystem impacts
26 October - 5 November 2007
Victoria, British Columbia
Attendance: Open
Contact: http://www.pices.int/meetings

is supplied by land-sea contrasts and the heating of elevated terrain and these circulations significantly influence the diurnal cycle of precipitation. As a result, precipitation character (e.g. frequency, intensity and duration) is often related to variations in local (O~1-10 km) and regional (O~10-100 km) terrain features, land-sea contrasts and access to abundant atmospheric moisture (Gebremichael et al., 2007; Gochis et al., 2007b; Janowiak et al., 2007; Lang et al., 2007; Vivoni et al., 2007). Numerous studies now confirm a precipitation climatology in which precipitation forms most frequently and earliest in the afternoon over the highest terrain, albeit with comparatively light intensity, and less frequently and later during the evening but with heavier intensities over the low elevation coastal regions. While a large fraction of the regional precipitation climatology is dominated by events whose entire life cycles occur over the complex terrain of the SMO, a secondary, 'disturbed' regime is now recognized under which organized, propagating precipitation events move away from topography (Lang et al., 2007). Radar composite products collected during 2004 also capture the complex interactions between the regional circulation, the land-sea breeze and propagating organized precipitation events over the GoC. Notably, precipitation over the GoC is about 12 hours out of phase with precipitation occurring over the SMO (Lang et al., 2007; Zuidema et al., 2007). Long-lived stratiform precipitation structures, characterized by strong brightband signatures in radar and vertically-pointing profilers, are very significant and, at times, a dominant mechanism for precipitation (Lang et al., 2007; Williams et al., 2007). Retrievals from NOAA wind profilers and space-borne radar show a relatively strong dependence on microphysical structures, in particular brightbanding (Williams et al., 2007). Strong spatial and temporal variations in cloud thermal and microphysical characteristics present significant challenges in estimating precipitation from remote sensing platforms (Nesbitt and Gochis, 2007).

Ocean-Land-Atmosphere Coupling:

Onset of the 2004 monsoon was associated with the southeasterly advection of warm water from the tropical East Pacific Ocean into the GoC (Zuidema et al., 2007). Throughout the summer, oceanographic observations near the mouth of the GoC documented that strong solar heating, ocean heat advection and nighttime cloudiness over the Gulf provide a positive feedback resulting in net surface heating despite a large evaporation component. Furthermore, periodic, strong advection of warm water from the southeast during atmospheric moisture surge events also appears to contribute to a surge-memory effect as the recently advected water contributes to the latent and sensible fluxes within the Gulf region. Capturing the complex, transient behavior of the GoC heat and moisture source will be essential for improving model simulations and highlights the importance of resolving the Gulf in free running climate models.

Strong latitudinal and terrestrial gradients in terrestrial hydrology and ecology are found throughout the monsoon region. These variations act as a dynamic assimilator of atmospheric processes yet their influence as an atmospheric driver (ie the nature of the land-atmosphere feedback) remains uncertain (Vivoni et al., 2007; Watts et al., 2007; Zhu et al., 2007). During 2004, tower flux and soil moisture measurements were made in a variety of ecotones (transition areas between two adjacent ecosystems). From a vegetation biome perspective tropical deciduous forests respond much more quickly and strongly to precipitation than other semi-arid communities (Watts et al., 2007). Notably, the tropical deciduous forests exhibit slower decay of evapotranspiration fluxes under moisture stress than many other communities effectively resulting in a 'quick learning-long forgetting' behavior. On seasonal and interannual timescales antecedent land surface conditions across southwestern North America affect the timing of the onset of monsoon precipitation by modulating the land-sea thermal contrast (Grantz et al., 2007, Zhu et al., 2007). These anomalies are largely established in response to antecedent cold-season precipitation anomalies which vary greatly from year to year. This regional forcing acts in concert or competition with large-scale teleconnective forcing provided by remote and near shore sea surface temperatures (Grantz et al., 2007, Gochis et al., 2007a).

Towards Improving Predictions

Transferring this emerging understanding of the NAMS into improved predictions of warm season precipitation will not be easy. Fundamental limitations still exist in the observing system over parts of México, in particular the SMO, the intra-America Seas region, and the tropical oceans in general. Poor treatment of convection in models and limited understanding of role of terrestrial forcing will continue to inhibit rapid increases in seasonal and interannual forecast skill from dynamic models. However, as part of NAME, progress is being made on defining which observations are critical to improving model initializations and forecasts. Assimilation of NAME 2004 special soundings into NCEP model-based data assimilation systems indicates that impacts of the soundings are most pronounced at low levels in the atmosphere and mainly in the core monsoon region of northwestern México and the southwestern U.S. where the sounding data were collected (Mo et al., 2007). Enhanced sounding observations also had a significant and beneficial impact on depicting the structure of the Gulf of California low-level jet. However, additional data impact studies of the NAME 2004 enhanced observations, such as sea surface temperatures, rain gauge observations, and soil moisture measurements, on atmospheric analyses are needed. These studies will, over time, contribute to the development of an observing system design for the NAMS which is key deliverable from the NAME program.

Comparatively less progress has been made in addressing NAME research questions in Tiers II and III compared to Tier I. While this is understandable, given the focus of NAME

2004, the research issues in Tiers II and III need to have greater priority in the future in order to make progress on warm season precipitation forecasts. The 2004 monsoon highlighted the significant dependence of monsoon precipitation, in many regions, on transient synoptic features. For instance, moisture surge activity appears to be enhanced during active phases of the Madden Julian Oscillation (Johnson et al., 2007; Lorenz and Hartmann, 2006). Similarly, Mestas-Nunez et al. (2007) show that variability in the transport from the key moisture source region of the intra-America Seas is linked to changes in summertime precipitation patterns over the central and eastern U.S. It has become clear that there are complex interactions between tropical easterly waves, upper-level inverted troughs, cold fronts, cut-off lows, open troughs, and GoC moisture surges that are not well understood despite the fact that they are critically important in the prediction of warm season precipitation.

As NAME enters into its modeling and prediction phase many significant challenges remain. Some of these are 'grand challenge' issues, such as the representation of convection in models or land-ocean-atmosphere coupling, that extend well beyond NAME. More importantly, in order to improve predictions of warm season precipitation, NAME will need to engage a variety of strategies aimed at detecting critical environmental processes that modulate the warm season circulation and improving the representation of these processes in empirical and dynamical prediction models. One way forward, as mentioned previously, is to design and maintain a robust climate observing system across the southern North American cordillera, the GoC and the intra-America Seas regions. This need has also been identified in the context of other climate variability and climate change research efforts recently articulated by Diaz et al. (2006) and Diamond and Helfert (2007).

Second, NAME must also engage efforts to provide added value to existing forecast methodologies in order to create more usable warm season forecast products. One way NAME is addressing this issue is by developing the NAME Forecast Forum which will consolidate a variety of operational and experimental forecast products of monsoon activity. This new effort will build upon the success of the NAME Model Assessment Project (NAMAP see Gutzler et al., 2006 for details), which has documented the attributes and shortcomings of several leading global and regional models in the simulation of monsoon circulation and precipitation features. More detail on this effort will be forthcoming in the coming months though interested parties are encouraged to contact the authors directly. Another way for NAME to add value to existing forecasts is by improving the application of dynamical and statistical-dynamical downscaling techniques in seasonal forecasts. While such approaches clearly can not correct for erroneously forecasted climatic structures, they can serve to better transfer information captured in forecasted climate modes to smaller scale, regional climate processes such as variable precipitation characteristics across complex terrain. As has been the case from the beginning of NAME, it will be through a synthesis of multi-disciplinary activities that measured progress in improved understanding of the monsoon system will be transferred into improved prediction capabilities.

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Analyzing the Variations of the Global Ocean Energy Cycle

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The Earth's climate is an energy cycle that converts absorbed solar radiation into heat and associated terrestrial radiation and into the circulations of the atmosphere and ocean. A key exchange of energy within the system, which also couples the circulations of the atmosphere and ocean, is between the surface and the atmosphere, primarily through evaporation cooling of the surface and precipitation heating of the atmosphere, forming a water cycle intimately linked to the planetary energy cycle. Because of Earth's spherical shape, rapid rotation and elliptical orbit about the sun, the solar heating is neither uniform nor constant. Because of the turbulent nature of the atmospheric and oceanic motions that transport heat and water with very different characteristic times scales, the response of the system is neither steady nor in instantaneous balance. Although some statistics of the variations of energy and water exchanges among the several climate system components may be static, the energy-water cycle is fundamentally dynamic.

Basic questions about the climate are: how variable is the climate with a "statistically steady" forcing (natural variability) and how sensitive is the climate to systematic changes in the forcing (climate change)? The latter is determined by numerous feedback processes that operate to alter the exchanges of energy and water within the system and with the outside but, in the truly dynamic climate system, the former is also influenced by these same processes. To learn the answers to these questions, therefore, we must observe the varying relationships amongst the components of the climate system and diagnose the variations of their exchanges of energy and water to determine how they regulate and modulate the climate response to forcing. For this purpose, the observations must have a combination of high space-time resolution and global, long-term coverage that can only be provided, in practice, by systematic satellite observations. The former is required to resolve accurately the energy and water exchange variations at the weather-process-level and the latter is required to provide enough examples of the different possible configurations of the climate system to understand the range of multi-variate, non-linear relationships that are produced by the interactions of the processes.

To describe the complete energy-water cycle requires measurements of the thermodynamic state of all the climate components and the hydrodynamic state of the atmosphere and ocean, as well as all the properties of them that affect the energy and water exchanges. The state is described by the 4-dimensional distribution of temperature, humidity and winds in the atmosphere, of the temperature, salinity and currents in the ocean and the temperature and "water content" of the land and ice. To calculate the exchanges of energy requires determination of the tendencies of the state variables and their atmospheric and oceanic transports which are functions of spatial derivatives of these variables. Additional properties that are needed to calculate radiative exchanges are the gas composition of the atmosphere (including the main greenhouse gases), aerosols, clouds and surface spectral albedo/emissivity. The main additional quantities to determine the water cycle are precipi-

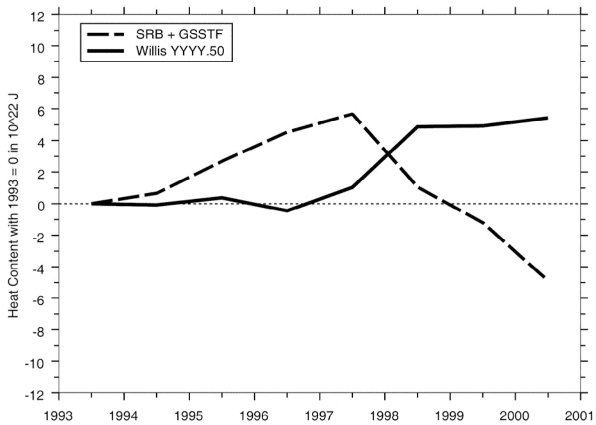

Figure 1. Comparison of the decadal-scale anomaly in net surface fluxes and the variations of annual upper-ocean heat content.

tation (rain and snow), evaporation, water storage on the land as snow/ice and in the deep acquifer, as well as water runoff from the land to the ocean.

The state of the ocean has been observed very sparsely for the past many decades but only recently have these data been compiled to provide a comprehensive description of the state and circulation of the ocean. The World Climate Research Program (WCRP) was established, in part, to coordinate activities to develop a number of datasets that were missing for describing the energy-water cycle [GARP 1975]. Among the first WCRP activities were projects to determine the thermodynamic state of the world ocean (the World Ocean Circulation Experiment, WOCE) and to study the coupling between the tropical oceans and global atmosphere (Tropical Ocean Global Atmosphere, TOGA). These studies are continuing as part of the Climate Variations (CLIVAR) project. Several other projects, now collected under the Global Energy and Water Experiment (GEWEX), have produced a collection of cloud, precipitation, aerosol and radiative flux products that can provide important information about ocean-atmosphere exchanges of energy and water (Table 1, see Rossow et al. [2006]). A newer initiative under GEWEX includes a project (SeaFlux) to determine the turbulent fluxes of heat and water at the ocean surface [Curry et al. 2004].

As one illustration of analyses that can be done with this set of data products, Figure 1 shows the decadal variations (anomaly relative to 1993) of the global mean heat content of the upper ocean, diagnosed from buoy and satellite observations (Willis et al. [2004], updated, private communication), compared with the heat content variation inferred from the total surface energy fluxes, based on the GEWEX Surface Radiation Budget product (SRB, Stackhouse et al. [2001]) and the GSSTF2 turbulent fluxes [Chou et al. 2003]. Such a diagnostic approach for the heat budget has been advocated by Pielke [2003]. Levitus et al. [2000] has compiled a longer record of ocean heat content. Given the "large" uncertainties associated with these data products, it is no wonder that these results do not yet agree but the magnitude of the differences is much smaller than expected. Moreover, the surface flux products have known sources of uncertainty that can be worked on to improve them; in particular the surface latent heat flux products based on satellite microwave measurements appear to have an excessively strong increase (cooling) over this time period associated with known problems of calibration.

Using six different combination-datasets (two different surface radiative flux products, ISCCP-FD and SRB [Stackhouse et al. 2001] and three different surface turbulent flux products, GSSTF2, HOAPS [Grassl et al. 2000] and WHOI [Yu et al, 2004]), we can estimate the mean meridional heat transport of the global oceans (Figure 2), where the error bars indicate the spread of estimates obtained from these different data combinations (cf. Zhang and Rossow [1997]). The uncertainties are particularly significant in the southern oceans and are primarily caused by differences among the turbulent flux data products (cf. Chou et al. [2004]) rather than the surface radiative flux products (cf. Zhang et al. [2006]).

Anomalies in the total (atmosphere plus ocean) meridional energy transport over the past two decades inferred from the ISCCP-FD reconstruction of top-of-atmosphere radiative fluxes, which agrees very well [Zhang et al. 2004] with directly inferred anomalies at lower latitudes from ERBE [Wong et al. 2006]. The uncertainties in the surface fluxes currently preclude a definitive separation of these features into separate atmospheric and oceanic contributions, but the association with ENSO events is clear, although variable. The higher latitude location of the transport anomalies in 1998/99, as contrasted with generally lower latitude anomalies during other events, suggests the possibility that the former event was dominated by a change in atmospheric heat transport while the earlier events were dominated by changes in oceanic heat transport. If the quality of these products can be improved by further evaluation and

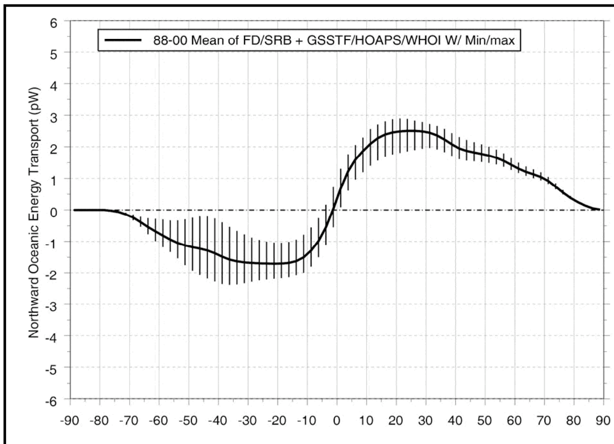

Figure 2. Mean meridional heat transport by the global ocean inferred from six different combinations of two radiative flux and three turbulent flux products.

systematic re-processing, then this difference could be investigated further.

To stimulate more extensive analyses of the variations of the global energy-water cycle and the processes that influence them, as well as re-processing of these products to improve thei reliability, the GEWEX Radiation Panel is organizing a complete set, at least one dataset for each of the components of the energy-water cycle, in two forms. The first is a summary of the datasets in the form of monthly mean global maps, all in the same grid covering the same time period, posted on and downloadable from the GRP website:

(http://grp.giss.nasa.gov/gewexdsets.html). The second is providing access to the original versions of these datasets (with a variety of map grids, sampling intervals and periods covered), starting with the four GRP products for radiation, precipitation, clouds and aerosols, on an active server to be hosted by NCDC. The online summary is now available and the datasets are being assembled for the server and should be available by the end of in 2007. This collection could form the core of a larger climate dataset, if datasets are added by other components of the World Climate Research Program such as CLIVAR.

E&W Cycle Element (*Dataset Names*)	Period Covered	Sampling Spatial (km)	Time (hrs)
Atmospheric State			
**TOVS (no winds)*	1979-current	280	24
**NCEP/NCA*	1948-current	280	6
ERA-40	1963-2003	280	6
Clouds			
**ISCCP*	1983-2005	280	3
SOBS	1971-1996	280-560	3-24
Ozone			
TOMS	1978-2003	110	24
**SBUV*	1978-2005	280	24
SAGE II	1979-2005	560	month
Trace Gases			
CO2, CH4, etc...	1958-current	Global	month
Aerosols			
**GACP (ocean only)*	1981-2004	280	month
**NOAA aerosol (ocean only)*	1995-2005	110	24
SAGE II (strat.)	1984-2005	560	month
Radiation			
NIMBUS-7 (TOA)	1978-1985	280	12
ERBE (TOA)	1984-2002	280	24
CERES (TOA)	2000-current	110	3
**SRB (TOA-SRF)*	1983-2004	110	3
**FD (TOA-SRF)*	1983-2005	280	3
Precipitation			
**GPCP*	2002-current	280	3
**GPCP*	1997-current	280	24
**GPCP*	1979-current	280	pentad
Surface Fluxes			
GSSTF2 (oceans)	1988-2000	280	day
HOAPS (oceans)	1988-2002	50	pentad
WHOI (oceans)	1981-2002	110	day
Oceanic State			
**Reynolds (SST)*	1982-2005	110	week
**World Ocean Atlas*	1948-1998	110-560	month
**WOCE*	1990-1997		
Ocean Surface Winds			
Wentz	1987-2005	110	24
Ocean Currents			
T/P-Jason	1992-2005	50-110	5-day
GRACE	2002-2005		
Key Supporting Datasets			
Baseline Surface Radiation Network	1994-2005	35 sites	5 min
Global Precipitation Climatology Center	1951-2004	50	month
Global Runoff Data Center	1970-2005	4500 sites	daily

Table 1. Some available global, long-term datasets that can be used to quantify variations of the global energy-water cycle. Most of these are being produced or studied in GEWEX activities; references and relevant web site addresses for these datasets can be found on the GEWEX Radiation Panel web site at http://grp.giss.nasa.gov/gewexdsets.html). Additional products (not all mentioned below) are being studied in CLIVAR activities. Asterisks indicate datasets to be provided on the NCDC active server.

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U.S. CLIVAR Western Boundary Current Working Group

In January 2007, the U.S. CLIVAR Western Boundary Current Working Group began. A primary objective of the working group is to encourage better understanding of the climate implications of the western boundary current atmosphere-ocean interaction, which will in turn improve the decadal and longer timescale predictability of the climate system.This working group topic is timely because the Kuroshio Extension System Study (KESS) and CLIVAR Intermediate Mode Water Dynamic Experiment (CLIMODE) groups are just beginning their analysis work, so the synthesis of those analyses could be shaped by encouraging joint group meetings. In addition, high-resolution satellite observations (with lengthening data records) and more accurate ocean and climate models are spurring increased interest in the midlatitude western boundary current regions.

The working group will seek answers to the following science questions:

- How does air-sea interaction compare in the western North Atlantic and North Pacific? What are the implications of the differences?
- What is the nature of atmosphere-ocean interaction in western boundary current regions? On what temporal and spatial scales does this occur? Is there predictability in the system?
- To what extent are coupled models getting the interaction right? Can we identify specific problems in ocean or atmosphere models? Is there a "coupled" interaction? What numerical experiments need to be done to test hypotheses?
- To what extent does air-sea interaction extend beyond the boundary layer and influence broader climate variability in both the atmosphere and ocean? What role do stratiform and convective clouds play in the atmospheric response?

Additional information regarding the Western Boundary Working Group can be found at: http://www.usclivar.org/Organization/wbc-wg.html

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