The NASA Seasonal-to-Interannual Prediction Project (NSIPP)

NASA/Goddard Space Flight Center

Progress Report

February 15, 2000

The NASA Seasonal-to-Interannual Prediction Project (NSIPP) Annual Report for 1999

GOAL

To develop an assimilation and forecast system based on a coupled atmosphere-ocean-land-surface-sea-ice model capable of using a combination of satellite and in situ data sources to improve the prediction of ENSO and other major S-I signals and their global teleconnections.

OBJECTIVES

Demonstrate the utility of satellite data, especially surface height (altimeter), air-sea flux observations (scatterometer, microwave) and soil moisture (microwave), in a coupled model prediction system.

Aid in the design of the observing system for short-term climate prediction by conducting OSSE's and predictability studies.

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Funded by NASA/ESE: Global Modeling and Analysis Program
Physical Oceanography Research and Analysis Program.

Summary Highlights

T3E procurement: Support of NCCS, HQ and GSFC management procured 512 T3E processors for NSIPP and science team in February 1998 and additional 512 processors in January 2000.

CGCM simulations: 40 year run on T3E highlights problems with annual cycle of equatorial SST and zonal surface stress.

Tier 1 Forecasts: 1981-98 without data assimulation, 12-month hindcasts show useful skill in Niño3 prediction for 7 months; 1993-99 with TAO data assimilation show useful forecast skill to at least 12 months.

Tier 2 Forecasts: Predictability study; forecasts for JFM 1998 and 1999.

AGCM/Land simulations: Influence of soil moisture on predictability of summertime precipitation over North America.

Ocean Data Assimilation: Implemented parallel EnKF on T3E; parallel OI with TAO measurements; EnKF with synthetic altimetry.

AGCM development: Test of prognostic cloud liquid water scheme; atmospheric boundary layer modifications give improved wind stress; stretched grid tested over Amazon.

LSM development: Catchment development with tests in Red-Arkansas basin; improved snow model.

Ocean Model simulations: Poseidon model analysis of surface heat budget along the equator; intercomparison with MICOM, MOM, Gent-Cane.

Background

Understanding and predicting seasonal-to-interannual climate variations is an essential goal within the overall NASA strategy for climate research. The NASA Seasonal to Interannual Prediction Project (NSIPP) has been established as a core research and development activity at the Goddard Space Flight Center (GSFC) to develop the use of existing and planned remote observing systems together with in situ observations for experimental predictions of seasonal-to-interannual climate variations. By focusing on the application of remotely sensed observations, NASA expects to make unique contributions to the USGCRP to CLIVAR/GOALS and GEWEX international research programs.

The NSIPP approach is based on the premise that coupled ocean-atmosphere-land general circulation models (CGCMs) offer the best prospect for predicting tropical sea surface temperature (SST) anomalies and of extending the prediction of global precipitation and temperature anomalies. The NSIPP CGCM is comprised of the Aries atmospheric model, the Poseidon quasi-isopycnal ocean model and the Mosaic land surface model (LSM), all developed at Goddard. The key to tropical forecasts lies in initialization of the upper ocean, and the key to summertime precipitation forecasts over the continental U.S. lies in the initialization of soil moisture; therefore, ocean and land surface data assimilation are essential elements in NSIPP's strategy.

The NSIPP CGCM and ocean data assimilation system have been implemented on a scalable parallel architecture currently, a T3E parallel system with 512 nodes. This environment allows finer resolution global simulations than have been run previously. Initial coupled simulations are being tested at 2 degrees for the atmosphere and 2/3 degree for the ocean, and finer resolution models ranging from 0.5 degree for the atmospheric GCM and 1/3 degree for the ocean GCM are being run experimentally. The use of ensembles, in both simulations and assimilation/forecasts, is integral to NSIPP's approach and is facilitated by the T3E.

NSIPP expects to produce routine experimental ENSO predictions for the tropical Pacific region within the next year. Subsequently, NSIPP will broaden its activity to include prediction of the global response to ENSO forcing in the Pacific basin and will also examine the predictability of other major climate variations on seasonal-to-interannual time scales. In addition, the SST from the coupled predictions will be used to force coupled atmosphere-land surface predictions using models with high resolution in specific areas for investigation of the downscale impact of large scale tropical SST anomalies. These predictions will be conducted using ensembles to characterize the uncertainty of the forecasts.

In the coming year we expect to assess the utility of remotely-sensed sea surface height for initializing the tropical oceans for coupled predictions and the impact of remotely-sensed surface salinity in ENSO prediction by undertaking observing system simulation experiments. We will continue to use SSM/I - based surface wind analyses for ocean initialization and expect to assess the added value of TRMM precipitation products and of the high resolution vector winds from QuikSCAT when quality research products are available. We will also investigate how to make best use of remotely-sensed soil moisture from SMMR within the framework of the Mosiac Catchment land surface model.

Summary of Activities, June 1997 - October 1999

The primary focus in the initial phase of NSIPP has been towards getting the coupled model ready for forecasts. This has entailed implementing and testing the model and assimilation codes in the parallel environment of the T3E, diagnosing performance problems with the component models as well as identifying climate drifts in the CGCM which does not employ flux corrections.

CGCM Experiments

Within the last year, a 40-year coupled simulation was conducted to investigate the coupled model performance at both seasonal and interannual time scales. The model drift stabilized within 20 years with cold equatorial Pacific SST, and warm temperatures in the region of the ITCZ and in the equatorial Atlantic. As is typical in CGCMs, the annual cycle in the eastern equatorial Pacific was poor weak in amplitude and lagging in phase by about 4 months. This problem was traced to errors in the zonal surface stress along the equator; hence the AGCM development described later. The model produced interannual variability in the tropical Pacific Ocean resembling El Niño (Figure 1) in spite of the problems in phase and amplitude of the seasonal cycle. However, the biennial component of the signal is too strong relative to the quadrennial component.

SST Anomaly from Model Climatology (1991-2020)

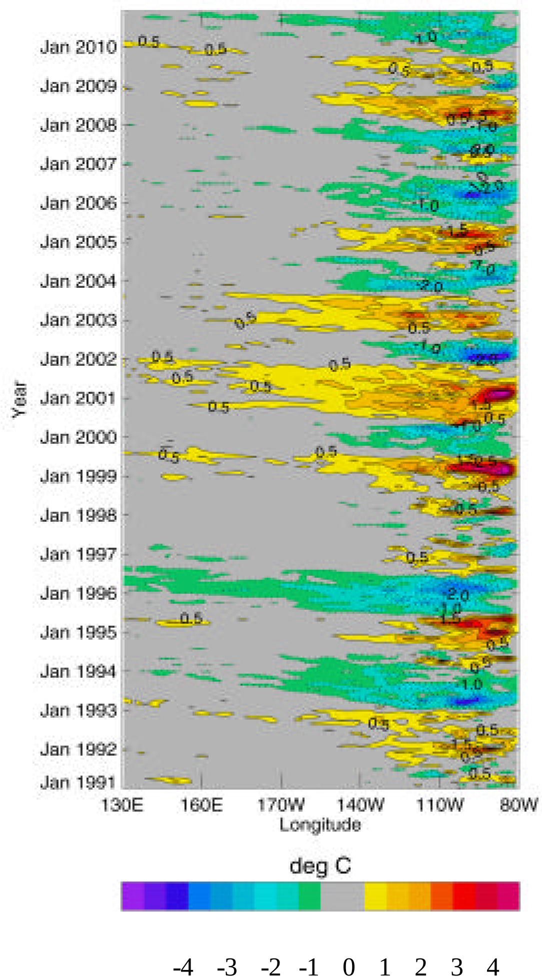


Figure 1: Interannual SST anomaly along the equatorial Pacific (averaged from 2ºS to 2ºN) from the initial 40-year coupled simulation. The time series is shown for the last 30 years of the run.

Eventually, biases in the CGCM simulations affect the capability to forecast phenomena like ENSO. To identify which of these biases are most important to improve the forecast system, a series of forced and coupled experiments were conducted with the atmospheric and ocean models. Observed SST and wind stress forced the models for the period 1981-1998. In forced mode, the ocean model produces El Niño events with the correct amplitude and phasing of SST anomalies and realistic subsurface behavior. In comparison with observations, the atmospheric model also does well in simulating interannual wind stress anomalies in response to anomalous SST, especially at the western and central equatorial section for the zonal component and at the mean Intertropical Convergence Zone location for the meridional component. However, correlations between observed and simulated wind stress drop remarkably in the eastern Pacific. When the ocean model is forced with the atmospheric model wind stress, the eastern Pacific equatorial subsurface during warm (cold) ENSO events is significantly colder (warmer) than when the ocean is forced with observed stresses. It is clear that this bias can have a negative impact on the coupled model's forecast skill. After coupling, even when the coupled atmospheric state remains close to the forced one, the subsurface ocean in the eastern Pacific tends to cool because of errors in the meridional structure from the ocean model. Eventually, cold subsurface temperature anomalies affect SST and the evolution of the coupled model diverges from reality. Hindcast experiments with the coupled model show that this is indeed the case.

CGCM Forecasts (Tier 1)

During the past year a baseline suite of coupled hindcasts without ocean data assimilation was completed. These retrospective hindcasts showed useful skill (i.e., anomaly correlation scores of at least 0.6) for 6-to-7 months with the ocean initialized by forcing with remotely sensed surface winds from the SSM/I sensor on the DMSP satellites and remotely sensed SST from AVHRR. Much of this skill is associated with the slow evolution of El Niño related signals below the ocean surface. NSIPP's goal is to extend this skill out to 18 months by providing better initial states of the subsurface ocean using TOPEX altimeter data as well as by improving the ocean and atmospheric models.

The coupled model was initialized with states from the uncoupled simulations starting every two months from 1981-1998 (4 warm and 3 cold events) and then allowed to evolve freely for 12 months (see Figure 2). The forecast drift, calculated as the mean 12 month evolution computed from the entire period of the experiment, was subtracted from each forecast before assessing forecast skill. The Niño3 SST index for the 1997-1998 event is shown in Figure 3. Despite a warming tendency that occurs in experiments initialized as far back as August 1996, the onset phase of this event is not captured (a similar behavior is found for the 1982-1983 event - see Figure 2). Nevertheless, the model captures the decline phase of this ENSO quite well (as during the 1982-83 event). In the experiment starting in June 1997 the Niño3 temperature anomaly returns back to zero very quickly before a slight increase towards the end of this experiment. For the runs initialized in August and October 1997 an initial decrease in the temperature anomaly is also followed by a significant increase. In all cases, this increase leads to an unrealistic maximum around June 1998. The initial drop in Niño3 SST is due to a shallowing thermocline associated with meridional advection driven by erroneous atmospheric wind stresses and with biases in the ocean structure. Meanwhile, an eastward slow propagation of the warm central Pacific SST signal is responsible for the warming that occurs after the initial cooling, with a local intensification of the warm signal in the eastern Pacific. A subsurface cold signal in the thermocline propagated slowly eastward and was responsible for the observed cooling during Spring 1998. This work identified local cooling in the Eastern Pacific as an important factor that limits hindcast skill of ENSO events.

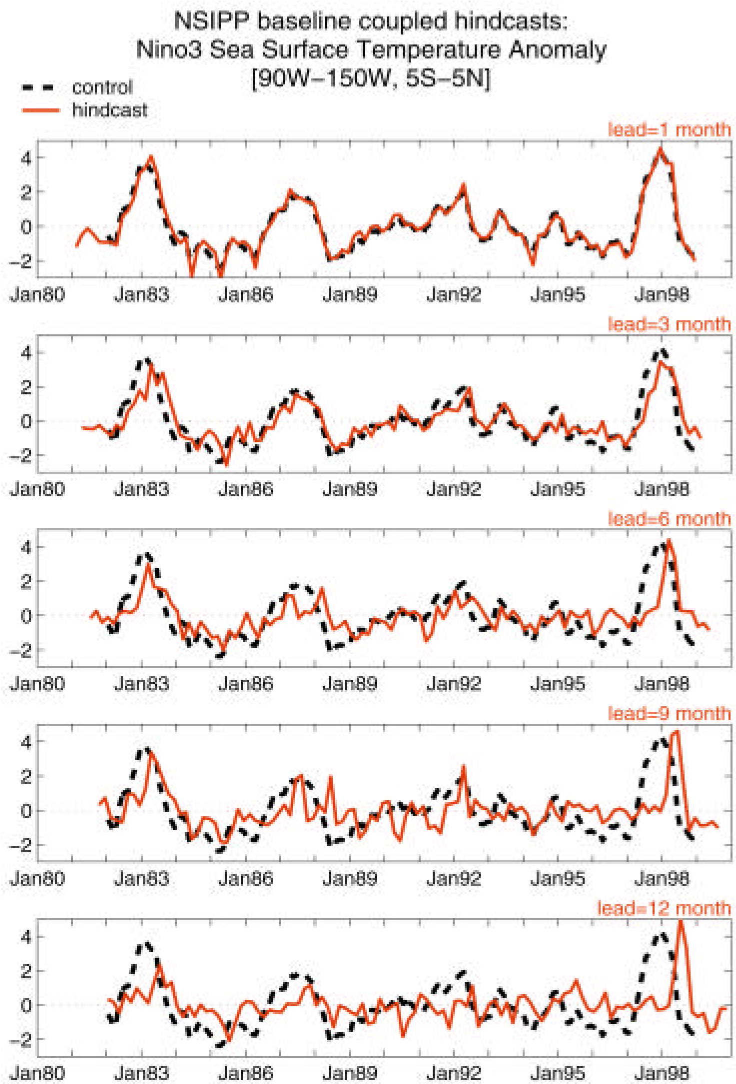


Figure 2: NSIPP baseline forecast, as for Figure 2. Here the Niño3 forecast is shown at various lead times for forecasts from 1981 to the present (Jan. 2000).

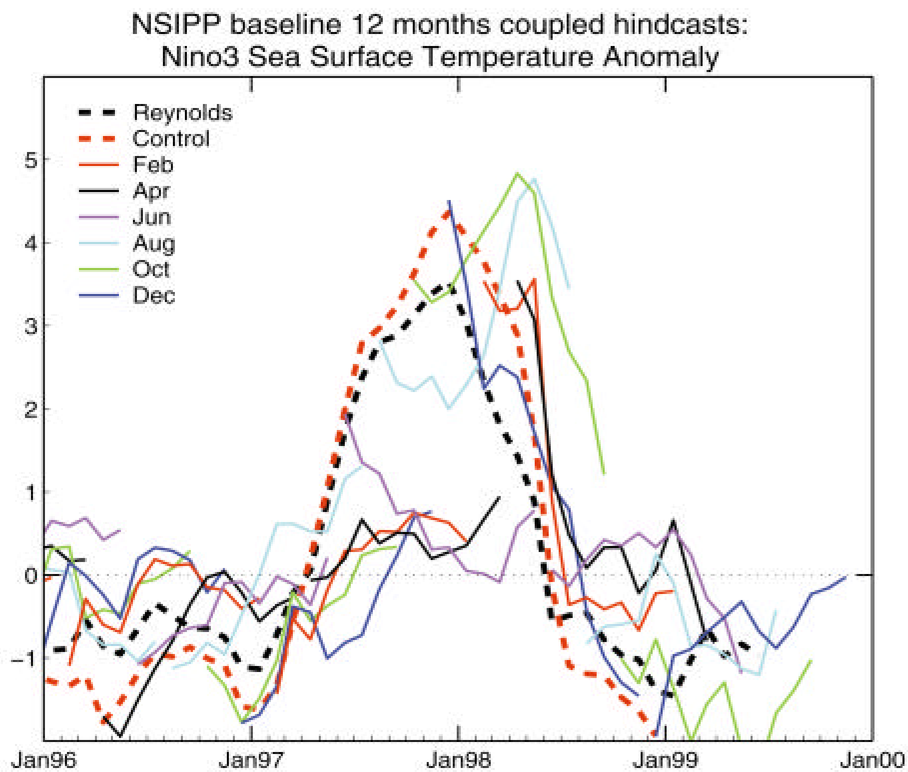
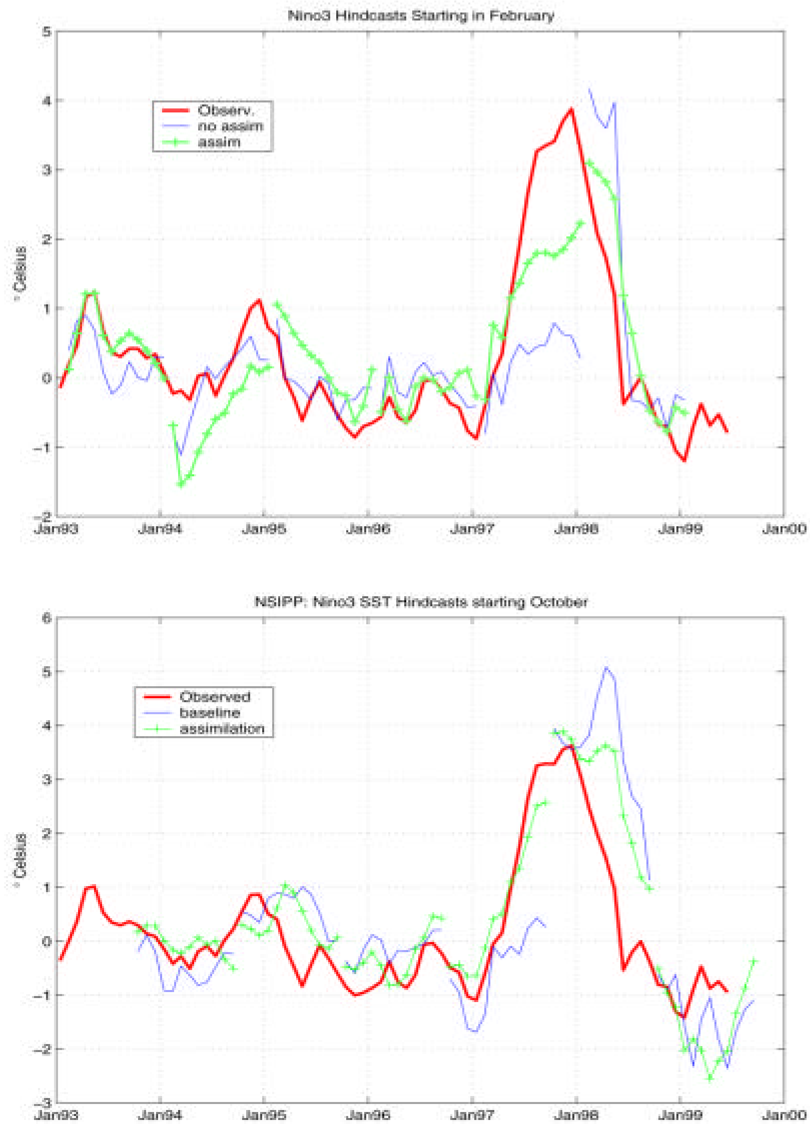


Figure 3: The NSIPP baseline forecast for 1996-99. The ocean model is initialized with observed wind forcing without assimilation. The atmosphere is forced by observed SST prior to coupling. Monthly SST anomalies for Niño 3 are shown for 12-month forecasts starting every second month. The dark dashed line is observed SST anomaly. The light dashed line is the SST anomaly from the forced ocean simulation.

The first tests of initializing the ocean state by assimilating TAO temperatures employed a rudimentary optimal interpolation (OI) scheme wherein the data were assimilated level-by-level. The forecast error covariance was assumed gaussian, with a 10 degree zonal decorrelation length scale and a 3 degree meridional scale. Consistent with the results of NCEP, ECMWF, and others, even this simple scheme has proven very effective in improving the forecast skill (Figure 4). Analysis indicates that this is due primarily to improvement of both the mean and anomalous thermocline in the eastern basin and to the larger thermocline anomalies in the initial state.



Hindcasts starting from February initial conditions

Hindcasts starting from October initial conditions

Figure 4: Comparison of 12 month forecasts with and without ocean data assimilation during initialization. During assimilation, daily averaged TAO temperature are assimilated every 5-days by calculating super observations.

<u>Tier 2 Predictability Studies</u>

We have continued to participate in the U.S. Dynamical Seasonal Prediction (DSP) activity organized by Dr. J. Shukla. Results are to be reported in a forthcoming special issue of *Q.J. Roy. Met. Soc*. Building on the DSP experience, we have focused on the nature of the middle latitude unpredictable "noise" in seasonal wintertime (JFM) forecasts. The results suggest that the noise is modulated by ENSO. In particular, forecasts of the 1983 warm event show considerably less noise in the Pacific/North American region than forecasts for the 1989 cold event (Figure 5). An analysis of the noise shows that it gains energy from the Pacific jet, and that the energy transfer is greater for the 1989 retracted jet compared with the extended jet during 1983. We further show that the spatial structure of the noise is dominated by the PNA pattern. This work, in partnership with Dr. Grant Branstator at NCAR and a member of the NSIPP Science Team, was presented at the Fourth International Conference on Modeling of Global Climate Change and Variability.

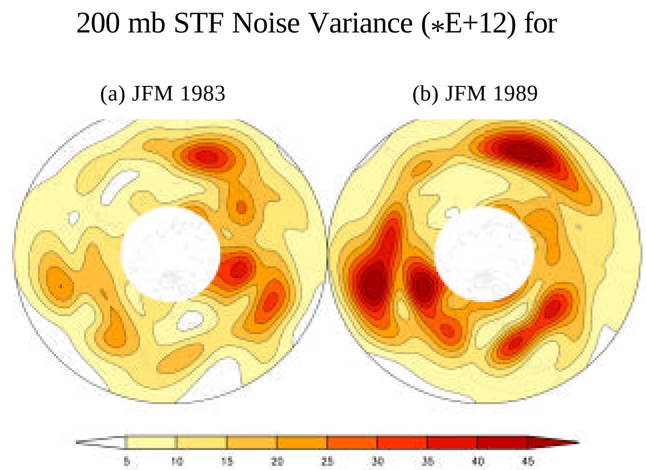


Figure 5: Noise variance for 200mb streamfunction from an ensemble of AGCM runs forced by observed SST. The left-hand figure is for winter 1983, right-hand figure is for winter 1989.

<u>Coupled AGCM-LSM Predictability Experiments</u>

Through a suite of ensemble experiments, we have analyzed the relationships between precipitation variability and land surface processes in the AGCM. We found that precipitation variability in the AGCM can be treated as a simple linear system, such that the total precipitation variance (σ_p) is a simple linear function of the variance ($\sigma_{p\text{-}sst}$) induced by variable SSTs, the variance ($\sigma_{p\text{-}atm}$) induced by chaotic atmospheric dynamics, and an amplification factor (a_L) associated with land-atmosphere feedback: $\sigma_p = a_L(\sigma_{p\text{-}sst} + \sigma_{p\text{-}atm})$. Thus, the land surface acts as a simple amplifier of precipitation signals induced by SST variations and atmospheric chaos. A strong land contribution to precipitation variability is not necessarily inconsistent with a strong correlation between continental precipitation and SST anomalies.

These experiments also address the impact of a seasonal soil moisture forecast on the seasonal precipitation forecast. The main result is shown in Figure 6. The precipitation statistics from two ensembles have been transformed into an index that describes the robustness of precipitation response to the specified boundary conditions. If, at a given point, all members of an ensemble produce basically the same timeseries of precipitation, then this index has a value close to 1, and we say that precipitation at that point is tied strongly to the surface boundary conditions -- precipitation is predictable if the surface boundary conditions are themselves predictable (at least for the GCM climate). If, on the other hand, the different ensemble members produce very different timeseries of precipitation, then the index is close to zero, and the potential for predictability is low. In this case, chaotic atmospheric dynamics overwhelms any control on precipitation imposed by the boundary conditions. These results are reported in a paper to appear in the inaugural issue of the *J. of Hydrometerology*. They also appeared on the cover page of the *Bull. Am. Met. Soc.* Much of this research is also funded as an EOS IDS investigation by Koster and Suarez.

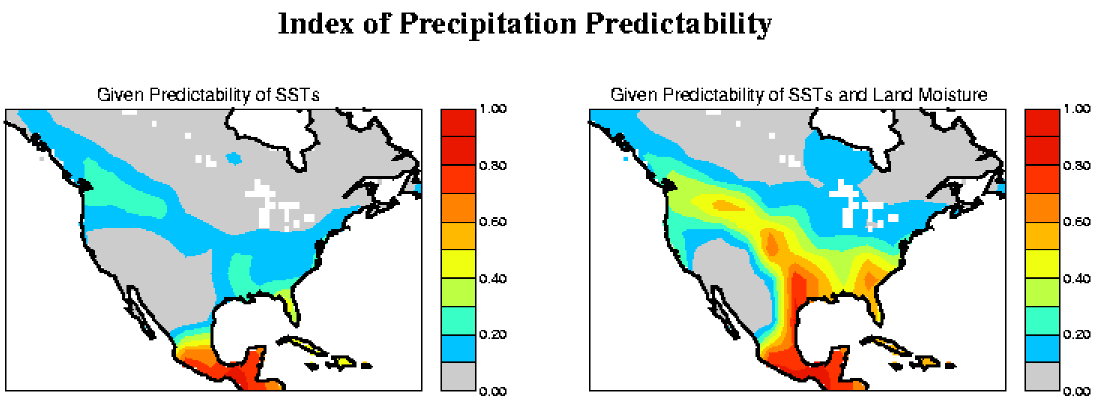


Figure 6: The left plot shows a "robustness" index over North America as computed from an ensemble in which only SSTs are specified. Notice that foreknowledge of SSTs would contribute to the predictability of precipitation only in the tropical areas. The right plot shows this index as computed from an ensemble in which both SSTs and land surface moisture conditions are specified. Given foreknowledge of land surface moisture conditions, precipitation would be predictable over a significant part of midlatitude North America.

Ocean Data Assimilation

As noted above, much of the predictability of tropical Pacific SST is associated with the persistence and propagation of ocean thermocline anomalies. Thus, one of NSIPP's most important elements is the development of the ocean data assimilation system for Poseidon, compensating for model and forcing errors during the initialization procedure. We are now testing two assimilation systems that we have implemented on the parallel architecture of the T3E. The two systems, optimal interpolation (OI) and the ensemble Kalman Filter (EnKF), share as much common software as possible. Although the implementation is for the global model, to date we have concentrated testing on the tropical Pacific. The implementation is multivariate, allowing the use of altimeter data to correct the subsurface temperature, salinity and currents.

The OI implementation requires a prior (fixed) estimate of the forecast error covariance. In addition to the simple specification of a univarite gaussian covariance, we have estimated multivariate, anisotropic, inhomogeneous covariance functions through Monte Carlo experiments. These covariances are, in essence, those that would be obtained from a dataless EnKF where the system noise is estimated from an ensemble of AMIP integrations. An example of these covariances is shown in Figure 7. They are being tested in identical twin experiments where the impact of multivariate corrections is being compared with temperature-only corrections. Assimilation of TAO observations is also underway.

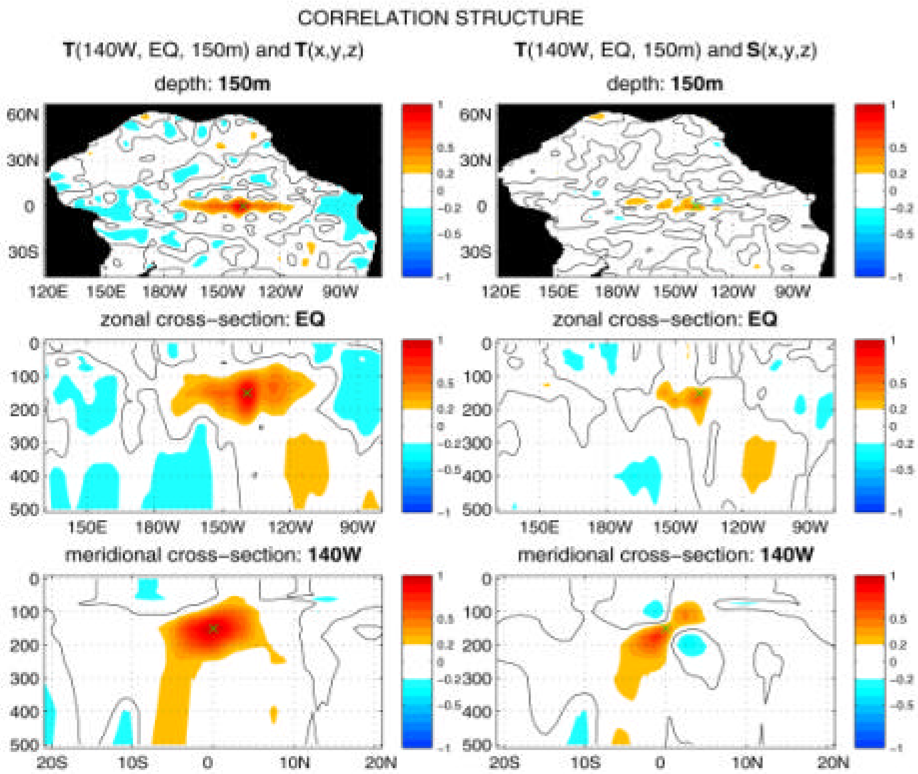


Figure 7: Sample cross-covariances of errors in temperature at 140°W on the equator at a depth of 150m with temperature (left panel) and salinity (right panel) for selected depths and sections. These error covariances have been estimated from Monte Carlo simulations using different atmospheric forcing data sets.

Although the OI system has the advantage of requiring significantly fewer parallel computing resources than the EnKF, it has the disadvantage that it relies on the assumption that the error-covariance distribution is asymptotic (in time). In contrast, the EnKF relies on real-time ensemble integrations of the model to evolve a time-dependent estimate of the error-covariance matrix together with the model flow. *Our EnKF implementation is truly state of the art: it is the first implementation of a sophisticated data assimilation scheme which at the same time (a) provides time dependent error-covariance estimates, (b) is implemented on a massively parallel computing system and (c) is applied to a realistic GCM.*

The parallel EnKF has been applied to the assimilation of temperature data from the TAO array. The resulting analyses have been shown to reproduce the development of the 1997-1998 El Niño better than the model forced by SSM/I winds but with no data assimilation. The method is currently being tested in the framework of identical-twin experiments simulating the assimilation of TOPEX/Poseidon altimetry. Figure 8 shows the impact of the assimilation of synthetic TOPEX data with the EnKF on the model estimates of the temperature, salinity and horizontal current fields in the tropical Pacific ocean. It shows that when altimetry is assimilated, the temperature errors in the thermocline are about 35% lower than the corresponding errors from an ensemble integration of the ocean model without assimilation. For salinity, the errors in the tropical thermocline are reduced by about 25%; for the zonal and meridional currents, by about 30%.

We are in the process of comparing the respective merits of the OI and EnKF data assimilation systems for the initialization of NSIPP's coupled ocean-atmosphere climate forecasting system. As noted earlier, the simple OI assimilation using gaussian covariance functions has proven very effective in the ocean initialization. The results from the identical twin experiments with the EnKF indicate that the simultaneous assimilation of TOPEX altimetry and TAO temperature will further improve the initial conditions for the ocean model.

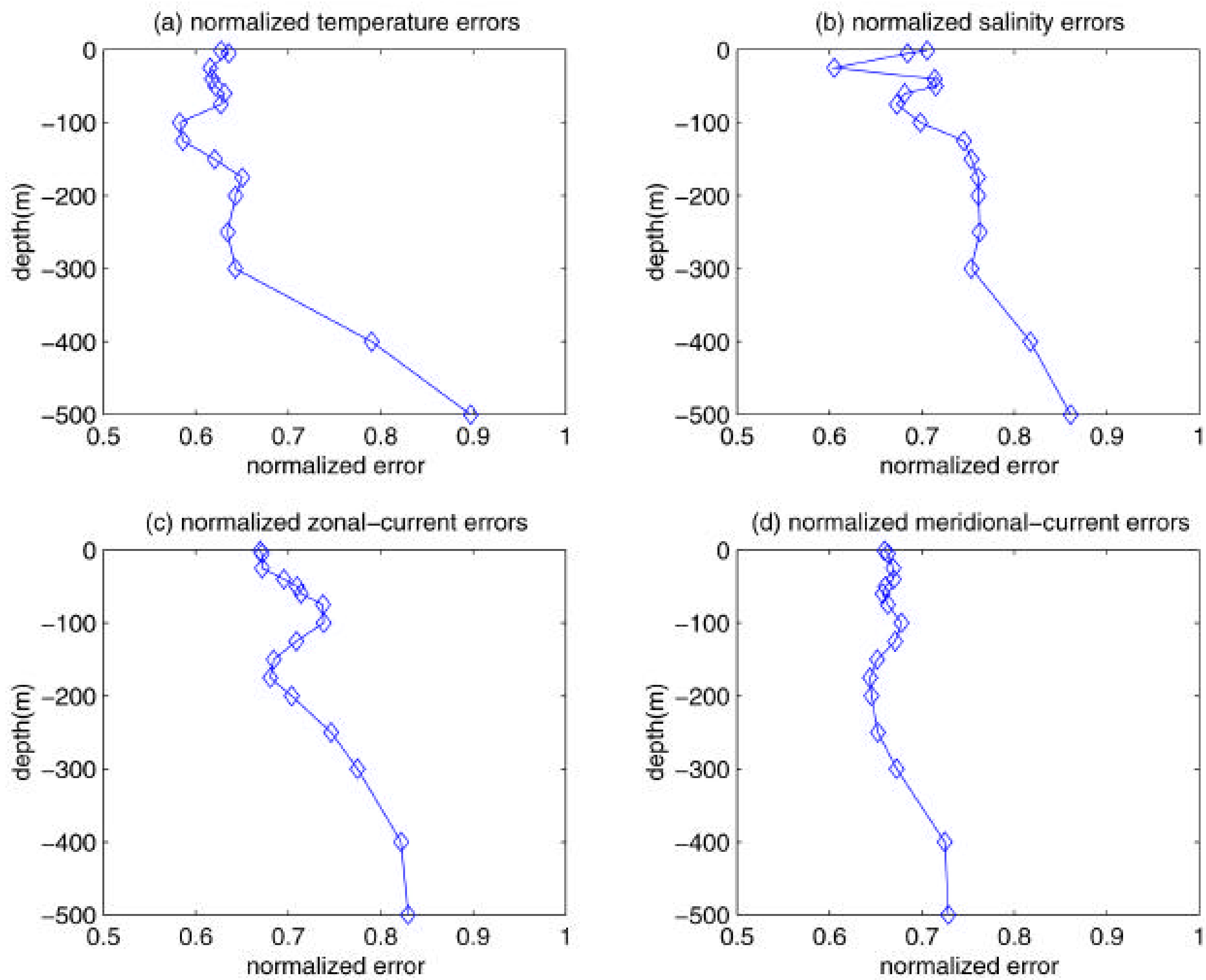


Figure 8: Ratio of the rms errors after 60 days of assimilation of synthetic TOPEX altimetry with the EnKF to rms errors without assimilation: (a) temperature, (b) salinity, (c) zonal current, and (d) meridional current. The rms error profiles are averaged over the tropical Pacific ocean. A normalized error equal to 1.0 would signify that the assimilation of surface altimetry has no impact on the subsurface model estimates. Normalized errors lower than 1.0 signify that the assimilation has a positive impact.

In a complementary effort, the adjoint model of the thermodynamic sub-model of the Poseidon ocean model has been successfully assembled to assimilate the Reynolds weekly mean sea surface temperature data in an effort to back out the surface heat fluxes and the optimized ocean temperature initial conditions. These fields will eventually be used in the ocean initialization for coupled ENSO prediction.

AGCM Development

During the last year a preliminary prognostic cloud liquid water scheme has been implemented in the NSIPP AGCM. The source terms for liquid water have been completed. These include cloud production by large scale condensation and subgrid scale variations in water substance and temperature, as well as production of clouds by convection. The major work left to be done in this area is to validate the parameterization of microphysical losses of cloud due to evaporation and conversion to precipitation.

Also during the last year, the AGCM's simulation of wind stress has been improved over tropical oceans. A detailed diagnosis of the AGCM's momentum budget in the tropics showed that the momentum budget of the tropical marine atmosphere in the AGCM is more complicated than commonly assumed. The conventional picture involves a simple balance between surface stress and pressure gradient force within the atmospheric boundary layer (ABL). In the AGCM, significant additional contributions come from vertical advection of momentum, and pressure gradient forces above the ABL. We are in the process of determining whether these additional momentum sources would be reliably detectable in current analyses. In any case, substantial improvements in the model's simulation of equatorial wind stress were obtained by 1) adding vertical resolution below 700 mb, i.e., in the ABL and trade wind layer; 2) removing some approximations in the model's ABL parameterization; and 3) removing cumulus friction in the ABL. The improvements due to 1 and 2 are not difficult to understand. However, the negative impact of cumulus friction (3) is perplexing. We believe it may be related to an incomplete parameterization of cross-cloud pressure gradients in the current scheme. The comparison of model and observed annual cycle of zonal wind stress and the SST response in the corresponding forced ocean model along the equator is shown in Figure 9.

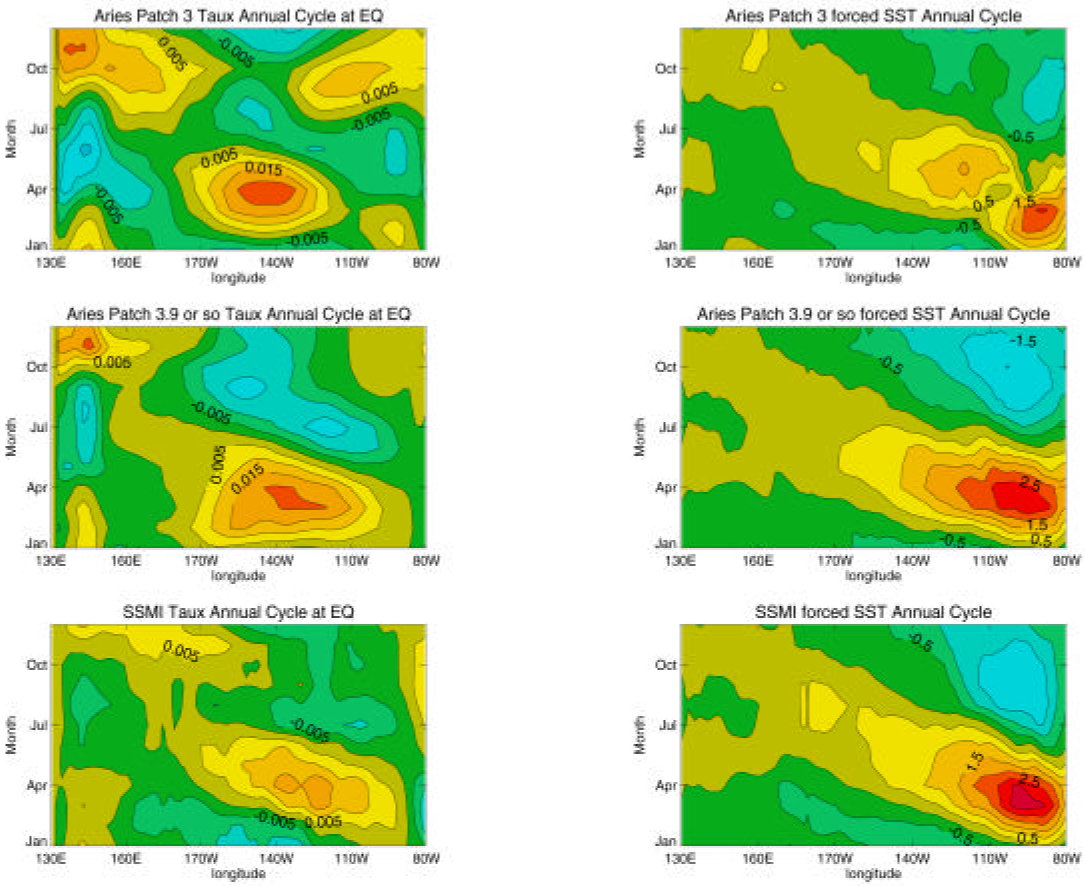


Figure 9: Left-hand panel shows zonal wind stress along the equator from the original AGCM (top), the improved AGCM (middle) and from Atlas SSMI winds using Large and Pond drag coefficients (bottom). The right-hand panel shows the SST from OGCM simulations forced by the winds to the left. The SST is from a 15-year integration, averaged over the last 5 years. Surface head flux was from COADS climatology in concert with a relaxation to Reynolds climatology with dQ/dSST from COADS.

LSM Development

Work on the catchment LSM continues. The aim of this effort is to improve seasonal and interannual variability in GCM simulations through an improved representation of subgrid scale land-atmosphere water and energy fluxes. The fundamental hydrologic unit is the watershed, and topography-induced soil moisture heterogeneity within the watershed is treated statistically at little computational cost. The analytic form of the TOPMODEL equations is used to produce consistent predictions of baseflow out of the watershed and the saturated fraction within it, the latter having a direct impact on calculated evapotranspiration and surface runoff. A working version has been tested in two venues --- over the Red-Arkansas basin, using forcing established for the PILPS 2c intercomparison study, and over North America as a whole, using forcing from the ISLSCP Initiative 1 CD-ROM. Comparisons of simulated results versus observations suggest that this model framework is capable of reproducing observed evaporation and runoff rates over large spatial scales. In the collaboration with GISS, we support Dr. Marc Stieglitz at LDEO/GISS to undertake additional model development: the incorporation within the catchment LSM of 1) ground physics so as to better simulate the temporal evolution of ground temperatures (including soil freezing) at depth and across horizontal space, and, 2) a simple three layer snow model. In addition, we are supporting a collaboration with Dr. Manfred Owe (Code 974) to develop a remotely sensed soil moisture data set from SMMR. The initial investigation compares a satellite time series with in situ observations in the U.S. and the results are promising. A comparison with LSM-generated fields is underway.

Ocean Model and Data Analysis

To validate the performance of the Poseidon OGCM, we undertook a controlled experiment intercomparison with MOM (a level model, comparison experiment undertaken by Dr. Dave Behringer, NCEP) and the Gent-Cane sigma coordinate model (comparison experiment undertaken by Dr. Ragu Murtugudde, UMD). The intercomparison focused on the mean and seasonal cycle in the tropical Pacific. All models, with comparable horizontal and vertical resolution, were consistent in their biases, showing the influence of forcing errors. Overall, Poseidon performed as well as, or better, than the other models in the amplitude and phase of SST, surface currents, and equatorial undercurrent magnitude.

We have also performed a fairly extensive model intercomparison between Poseidon and MICOM, another layer-formulated model, in which the configurations and forcing were roughly analogous. The models have similar basic responses to the annual cycle, although the phasing can differ by 1-2 months. Equatorial current transports are generally in line with observations within the limit of the observational errors. The intercomparison shows that the current reduced gravity configuration of Poseidon is not a significant limitation in the tropics or southern subtropics. With the data from the intercomparison we showed that the exchange between the North Pacific subtropical and tropical gyres is highly seasonal, and demonstrated a possible mechanism (seasonal thermocline expansion) for the interior exchange. The models reproduce the observed intergyre exchange both spatially, and in magnitude. This mechanism may influence the decadal variability in the ENSO system.

We have begun to look at the influence of higher frequency forcing to the model thermohaline fields. The use of higher frequency daily wind observations (from Dr. R. Atlas's SSMI analysis) alone has a 1-2º C impact in the model SST, and appears to influence subsurface temperature and salinity distributions also. The higher frequency forcing sets appear to reduce scatter in the water mass properties of the current systems for reasons which are as yet unknown.

Mechanisms controlling the variation in sea surface temperature (SST) climatology and during the 1994-1995 warm event in the equatorial Pacific were also investigated using Poseidon model simulations. The climatological budgets from Poseidon were consistent with published analysis of TAO observations. In early 1994 in the western basin the initial warming was related to enhanced external heating and reduced cooling effects of both vertical mixing and horizontal advection associated with weaker than usual wind stress. In contrast to large El Niño events where the SST anomaly is largest in the eastern basin, during the 1994-95 event the largest positive SST anomaly was observed in the mid-basin. Also in contrast to major El Niño events where the anomaly is not due to anomalous external heat flux, the 1994-95 anomaly in the western and mid-basin was associated with both anomalous heat flux and zonal advection, both associated with weak easterly stresses.

NSIPP has supported Dr. Paul Schopf to implement the barotropic mode with arbitrary bottom topagraphy. This development is complete and we are currently merging this software with our existing code.

AGCM Stretched Grid Simulations

Within the ambit of the NASA LBA-Hydrology project, this project focuses on understanding the roles of land-surface processes and the two-way interactions between regional and large-scale atmospheric, land-surface, and oceanic processes in the interannual and seasonal variability of the atmosphere in the Amazon region.

The most innovative aspect of this study is the use of the stretched-grid approach in the AGCM. The stretched-grid consists of setting fine horizontal resolution in the Amazon Region and increasingly coarser resolution elsewhere. In this configuration, the GCM simulations can be thought of as regional climate model simulations for the Amazon Region. We have performed long-term GCM simulations using a stretched horizontal grid configuration. Successful simulations with grids that have a 1 degree (0.5 degree) horizontal resolution in the region of interest, stretching to 4 degrees (4 degrees) at the antipodal region. These simulations are four (eight) times less costly than their uniform resolution counterparts. The simulations on the stretched grids reproduce the general circulation climatology as well as the 2.5 x 2.0 degree ARIES GEOS benchmark simulations (Figure 10).

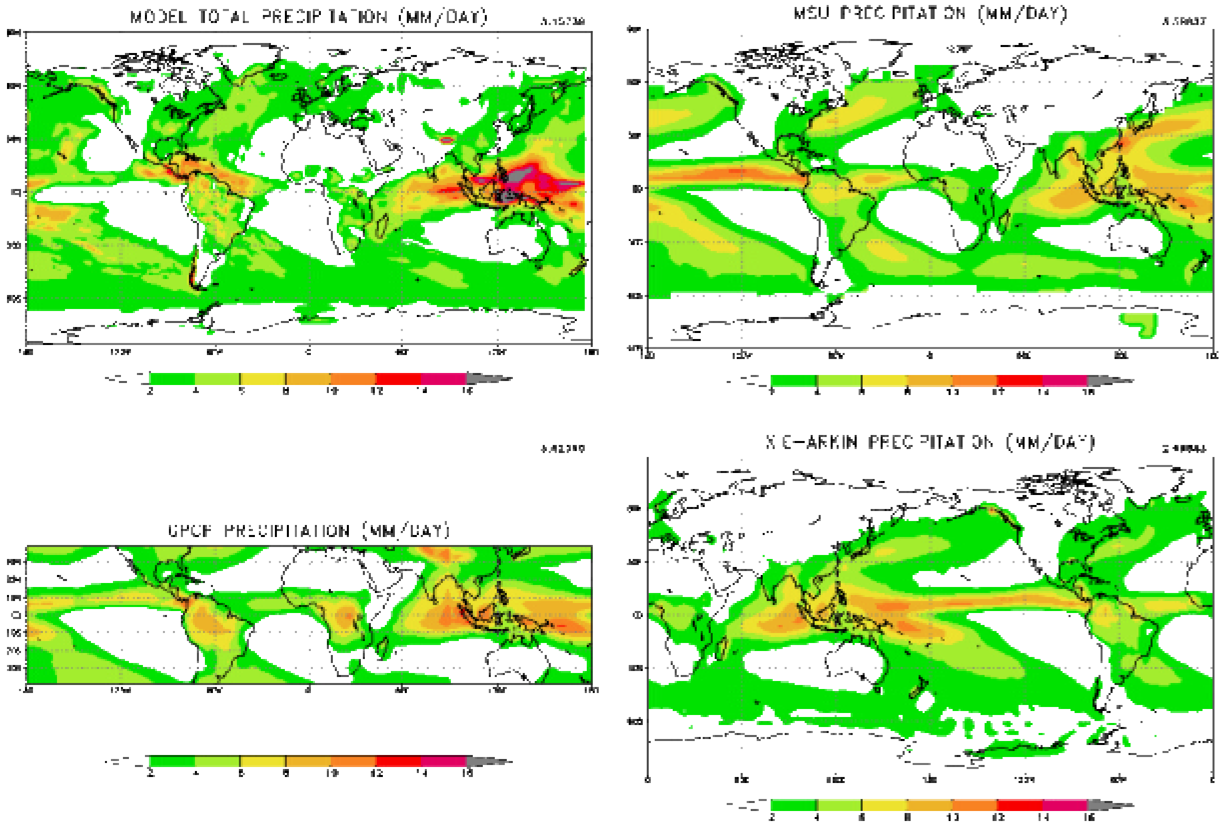


Figure 10: Precipitation from the AGCM in stretched grid implementation compared with available climatologies from observations.

Collaborations

Both Paul Schopf (GMU) and Marc Stieglitz (LDEO) visit NSIPP several times a year to consult on the ocean and land models, respectively, and their continued development. Bill Dewar (FSU) and Trevor McDougall (CSIRO) visited NSIPP for 2 weeks in June 1999 to learn the Poseidon ocean model and collaborate on tests of its vertical coordinate and numerics. Ming Cai and Eugenia Kalnay (UMD) have developed a strong interaction with NSIPP for testing ensemble breeding methods. The collaboration with Grant Branstator (NCAR) has been very productive with his early comparisons of the NSIPP AMIP integration with that from NCAR's GCM3. This has now expanded into an investigation of the noise in the ensemble Tier 2 hindcasts. Collaborations with other NSIPP science team investigators continue to evolve.

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NSIPP Publications, 1998-1999

Draft Manuscripts

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NSIPP Science Team

In November 1998 a Science Team of 8 funded collaborations was chosen from a competitive response to an Announcement of Opportunity to collaborate with and support the NSIPP core effort at Goddard. An introductory Science Team Meeting was held in May, 1999. In addition, NSIPP provides funds for a small number of collaborations essential to the core effort. These investigations are summarized below.

CGCM and AGCM Diagnostics
Grant Branstator, NCAR and M. Chen, Iowa State University, *Diagnosis and simulation of the South-east Asian-induced wavetrain that occurs during tropical Pacific cold and warm events.*

Sumant Nigam, University of Maryland, *Dynamical diagnosis of the NSIPP atmospheric and coupled model simulations*.

John Roads, Scripps Institution of Oceanography, *Seasonal and Atmospheric predictions*.

Chunzai Wang, NOAA/AOML/U. Miami, *Studies of western Pacific Interannual Anomaly patterns toward improved ENSO prediction*.

Land Surface Model Development and Land Assimilation
Paul Houser, GSFC, and Jay Famiglietti, University of Texas, *Optimal land initialization for seasonal climate predictions*.

Ocean data assimilation and coupled forecasting
Eugenia Kalnay, University of Maryland, *Ensemble ocean-atmosphere perturbations with growing ENSO modes using breeding*.

Thorsten Markus, JCET/GSFC/UMBC, *Improved Surface Heat and Salt Fluxes at polar latitudes through the assimilation of satellite measurements.*

Ocean Model Development
William Dewar, Florida State University, *Thermodynamics in layered models*.

NSIPP Associate Investigators

Paul Schopf, George Mason University, *Development of the Poseidon Ocean Model for NSIPP*.

Marc Stieglitz, Lamont Doherty Earth Observatory, *Land surface model development for NSIPP*.

NSIPP Science Team Abstracts

Project Title: Diagnosis and Simulation of the Southeast Asian-Induced Wavetrain that Occurs During Tropical Pacific Cold and Warm Events

Principal Investigator: Grant Branstator

PI Organization: National Center for Atmospheric Research

CO-I: Dr. Mike Chen, Iowa State University

Abstract

In a preliminary study, the PIs have discovered that atmospheric circulation anomalies associated with tropical Pacific cold and warm events consist of not only the well-known large scale wavetrain that emerges into the Northern Hemisphere from the central Pacific but also consist of a second wavetrain whose origin appears to be near tropical Southeast Asia. This secondary wavetrain is composed of elements whose scale is approximately half the scale of the highly studied central Pacific wavetrain but it extends completely across the Pacific and affects short term climate over the United States. Given the association of this secondary wavetrain with tropical warm and cold events, and given its important role in determining the influence on the US of these tropical events. The PIs will continue and expand their investigation of this feature as part of NSIPP.

Results from this investigation will contribute to the NSIPP effort by emphasizing the global nature of the ENSO and US seasonal forecast problems, by helping to define the minimum domain needed for NSIPP Tier 2 seasonal forecasts to be successful over the US, by documenting physical processes needed to correctly predict ENSO's influence over the US, by evaluating NSIPP core atmospheric models and indicating ways in which they can be improved, and by describing and diagnosing hitherto unrecognized features of the natural circulation that seasonal-to-interannual forecasts are attempting to predict.

Project Title: Dynamical Diagnosis of the NSIPP Atmospheric and Coupled Model Simulations

Principal Investigator: Sumant Nigam

PI Organization: University of Maryland, College Park

Abstract

This effort will undertake a comprehensive diagnosis of the NSIPP atmospheric and coupled model integrations with focus on: a) improvements in atmospheric process parameterizations, particularly those associated with tropical circulation regimes, and b) analysis of NSIPP's multidecadal integrations, and applications to diagnostic studies of seasonal-to-interannual (S-I) variability and predictability.

The goal of the proposed dynamical diagnosis is to enhance the representation of observed modes of recurrent seasonal-to-interannual variability in the NSIPP model runs, so that useful S-I predictions can be obtained from this coupled model.

Project Title: Seasonal Atmospheric and Oceanic Predictions

Principal Investigator: John Roads

PI Organization: University of California, San Diego

Abstract

The goals of this effort are to show:

1. to what extent the NSIPP ocean and atmospheric simulations and predictions are skillful and possible paths toward utilizing and improving them;

2. that the NSIPP assimilated ocean initial state contributes to increased ocean forecast skill over our current initialization methods;

3. that the NSIPP ocean SST forecasts used as boundary conditions on our atmospheric models provide increased atmospheric forecast skill over our current boundary forcing using persistent SSTs;

4. that knowledge of the atmospheric initial state will provide a noticeable increase in skill, which will provide some incentive to merge the NSIPP ocean and atmospheric assimilation efforts;

5. that NSIPP seasonal forecasts can be improved immediately through statistical downscaling, and ultimately through dynamical downscaling, over certain regions.

Project name: Studies of Western Pacific Interannual Anomaly Patterns toward Improved ENSO Prediction

Principal Investigator: Dr. Chunzai Wang

PI Organization: University of Miami

Abstract

Since the observed western Pacific anomaly patterns are robust features of ENSO in nature and therefore may affect ENSO forecasting skill, it is important to know whether or not they appear in NSIPP general circulation models (GCMs). The proposed work is to analyze these patterns in NSIPP GCMs and satellite observations, in an attempt to improve ENSO predictions based upon

the incorporation of these western Pacific patterns. The analyses will include calculations of El Niño/La Nina composites, calculation and comparison of ENSO indices over the entire tropical Pacific, and empirical orthogonal function calculations. Satellite data to be analyzed are sea level derived from satellite altimeters, surface winds derived from existing and planned scatterometers, SST derived from the AVHRR observations, OLR and ocean color from satellite observations, along with in situ measurements (sea level from tide gauges, surface winds from FSU, subsurface temperature from XBTs).

Project Title: Optimal Land Initialization for Seasonal Climate Prediction

Principal Investigator: Paul R. Houser and James S. Famiglietti

PI Organization: GSFC and University of Texas at Austin

<u>Abstract</u>

This effort will to explore the optimal initialization of NSIPP's land system using relevant remotely-sensed observations within a land data assimilation framework. This development will greatly increase our skill in land surface, weather, and climate prediction, as well as provide high-quality land surface *assimilated data fields* that are useful for subsequent research and applications. Analysis of the constant confrontation of model predictions with observations at various time and space scales will provide an opportunity to improve our understanding and assessment of the space-time structure of land-atmosphere interaction, the relationship between model estimates and observations of land surface conditions, and the role of *interannual* hydrologic and climatic variability.

Project Title: Ensemble ocean-atmosphere perturbations with growing ENSO modes using breeding

Principal Investigator: Eugenia Kalnay
Co-I's: Zoltan Toth, Ming Cai and Herve LeTreut

PI Organization: University of Maryland, Department of Meteorology

<u>Abstract</u>

This effort will develop breeding techniques for ensemble coupled forecasts using the NSIPP coupled ocean-atmosphere model. The aim is to generate initial perturbations to the coupled state which project in the ENSO modes. Breeding will create, at a very low computational and developmental cost, perturbations of the coupled system which are the leading Lyapunov vectors for the ENSO mode.

Project Title: Improved Surface Heat and Salt Fluxes at Polar Latitudes through the Assimilation of Satellite Measurements

Principal Investigator: Thorsten Markus and Donald J. Cavalieri

PI Organization: UMBC/JCET

Abstract

The objective of this project is to improve the parameterizations of the sea ice component in the NSIPP atmosphere and ocean models through the assimilation of satellite passive microwave data. In winter, turbulent heat fluxes over open water can be two orders of magnitude greater than over the perennial ice cover. Thus, small-scale openings in the sea ice cover, not detectable in the model, can dominate regional heat budgets leading to quite different rates of oceanic ventilation which can significantly alter the stratification of the polar surface water masses. Daily maps of sea ice concentration, motion, and snow depth will be calculated using state-of-the-art sea ice algorithms for both polar regions. These data will be assimilated into thermodynamic models providing accurate maps of daily albedos, atmospheric heat fluxes and oceanic heat and salt fluxes for the investigation of seasonal and interannual variabilities and for incorporation into the NSIPP models.

Project Title: Ocean Model Development

Principal Investigator: William K. Dewar

PI Organization: Florida State University

Abstract

This effort addresses three issues central to the modeling of physically consistent ocean thermodynamics and the use of the full equation of state in a layered model. These issues are, ordered by emphasis, mixed layer modeling, diapycnal mixing parameterizations and surface definition. The first topic addresses the development of mixed layer models in density coordinates, thereby making the surface layer consistent in construction with the interior. This obviates the need for unphysical parameterizations joining the surface to the interior in layered models. For the second topic we will oversee implementation of our diapycnal mixing algorithms in the Poseidon ocean model used by NSIPP. The third topic involves the use of neutral surface concepts in the development of a vertical coordinate for use in Poseidon.

NSIPP Associate Investigator Abstracts

Project Title: Development of the Poseidon Ocean Model for the NASA Seasonal to Interannual Prediction Program

Principal Investigator: Paul Schopf

PI Organization: George Mason University

Abstract

This proposal covers work needed to make enhancements to the Poseidon ocean model which is an integral part of the coupled climate model to be used for the climate prediction system. Specifically, the work aims to extend the global upper ocean model to include a barotropic component and to efficiently handle integration over arbitrary basin geometry.

Project Title: Land Surface Model Development for NSIPP

Principal Investigator: Marc Stieglitz

PI Organization: Lamont Doherty Earth Observatory of Columbia University

Abstract

The aim of this effort is to improve seasonal and interannual variability in GCM simulations through an improved representation of subgrid scale land-atmosphere water and energy fluxes. The fundamental hydrologic unit is the watershed and topography-induced soil moisture heterogeneity within the watershed is treated statistically at little computational cost. The analytic form of the TOPMODEL equations is used to produce consistent predictions of baseflow out of the watershed and the saturated fraction within it, the latter having a direct impact on calculated evapotranspiration and surface runoff. Attention is focused in two areas: The incorporation within Catchment LSM of 1) ground physics so as to better simulate the temporal evolution of ground temperatures (including soil freezing) at depth and across horizontal space, and, 2) a simple three layer snow model.