Improving Short-term Climate Forecasts with Satellite Observations

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***Abstract*— Understanding and predicting seasonal-to-interannual climate variations is a central goal within U.S. climate research. At NASA's Global Modeling and Assimilation Office, we are developing a coupled model forecast system to optimize the use of existing and planned satellite data, together with *in situ* observations, for experimental predictions of short-term climate variations. Our focus is on using satellite data to initialize the ocean and land surface, the slower components of the climate system that have the potential memory to enhance climate prediction.**

Keywords-component; El Niño, satellite data, seasonal forecasts

I. INTRODUCTION

A primary goal of the U.S. Climate Change Science Program is to address scientific questions relating to climate variability: to improve our understanding of the causes of the dominant modes of natural variability, changes in their frequency and/or intensity that may be associated with long-term climate change, and to improve our ability to predict El Niño and other seasonal-to-interannual modes. Climate variability from subseasonal to interannual time scales has an enormous economic impact worldwide. One of the strongest responses to the equatorial El Niño signal lies over the continental U.S., hence much benefit is to be gained by predicting such variations in a timely manner.

During the late 1990's, data from NASA's latest generation of earth observing satellites, unprecedented in volume and accuracy, came online and provided the first global views of climate variability. The integrated view provided particularly from NASA's satellite altimeter and scatterometer stimulated efforts, such as those in the Global Modeling and Assimilation Office (GMAO), to use satellite data to enhance seasonal prediction capabilities.

II. SOURCES OF PREDICTABILITY

The longer temporal scales of the ocean and land surface are the key sources of memory in the coupled climate system that promise skill in predicting short-term climate variability. The focus within the GMAO is on optimizing the use of satellite altimeter data and evaluating the impact of planned satellite observations such as surface salinity data from Aquarius. Predictability experiments and hindcast tests that use observed precipitation to precondition the soil moisture distribution have also been conducted. The results indicate that the key to summertime precipitation forecasts over transition zones between dry and humid areas in tropical and mid-latitude regions (such as the central U.S.) lies in the initialization of soil moisture [1]. Given these results, the GMAO system also focuses on the initialization of the land surface model, with developments undertaken for assimilation of soil moisture estimates from AMSR-E.

III. THE FORECAST SYSTEM

The current implementation of the GMAO coupled general circulation model (CGCMv1) uses the NSIPP1 atmospheric model [2], the Poseidon quasi-isopycnal ocean model [3], and the Mosaic Land Surface model [4]. The CGCM is freely coupled (i.e., flux corrections are not employed) once per day. The CGCM and ocean data assimilation systems have been implemented for scalable parallel architectures. Coupled simulations are run at $2° \times 2.5° \times 34$ layers for the atmosphere and $1/3° \times 5/8° \times 27$ layers for the ocean.

Each month an ensemble of experimental predictions of 12-months' duration is conducted. Beginning in 1999, eighteen-member ensemble predictions have been conducted by adding perturbations of both the atmosphere and ocean to the initial conditions generated by integration/assimilation. For earlier periods, to generate a climatology for forecast calibration, six-member ensembles were used.

Results from six-member ensemble hindcasts (re-forecasts) for the 1997/98 El Niño event are shown in Figure 1. The CGCMv1 forecast system shows significant skill at forecasting the onset and decay of the 1997/98 El Niño, without a false positive forecast in early 1996. Forecasts starting earlier than February 1997 indicated a warm event, but underestimated the amplitude. The forecast from 1 February 1997, prior to the westerly wind events that triggered the strong equatorial Kelvin wave in observations, shows a strong event although the amplitude stops growing in the last 3 months of the 12-month forecast. The forecast from April 1997, consistent with the poorer performance of the coupled system at this time, shows greater spread within the ensemble, but still indicates a strong event.

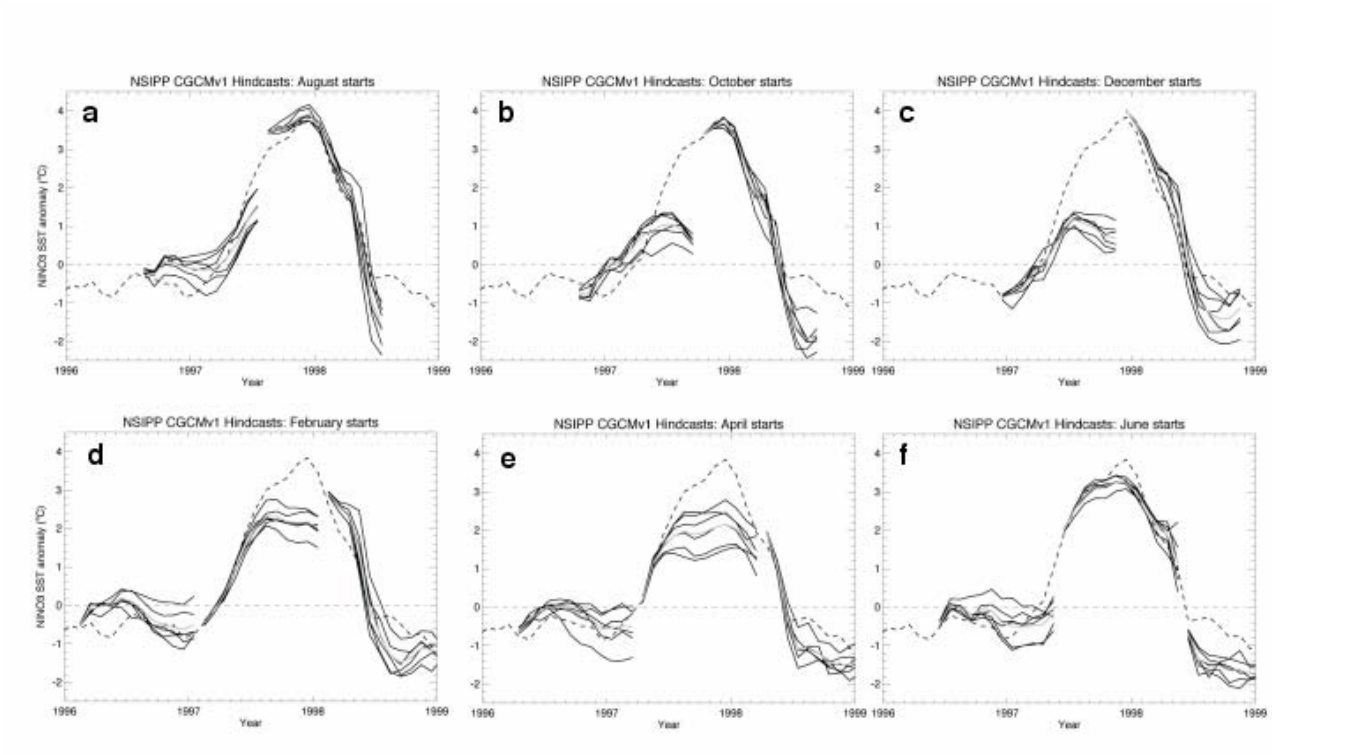

Figure 1. Retrospective 12-month hindcasts of Niño-3 SST anomalies during 1997/98, as a function of forecast start date: a) August starts, b) October starts, c) December starts, d) February starts, e) April starts, and f) June starts. The dashed line is the observed SST anomaly.

IV. Initializing the Ocean

For the baseline set of coupled forecasts shown above, the ocean is initialized globally by assimilating *in situ* temperature profiles using an optimal interpolation method. No altimeter data are used. The remotely sensed sea surface height from Topex/Poseidon (T/P, 1992-2006), and now from Jason (launched in 2001), provides unprecedented views of the global ocean variability. Figure 2 shows the sea surface height anomaly from Topex/Poseidon at the height of the 1997/98 El Niño.

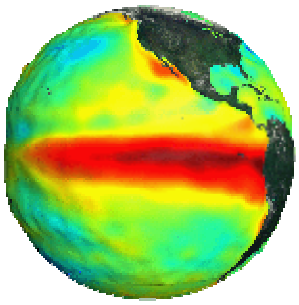

Figure 2. Sea surface height anomalies from Topex/Poseidon. Warm colors indicate positive anomalies. During the height of the 1997/98 El Niño, anomalies in the eastern equatorial Pacific were near 40cm.

Since the altimeter provides a measure of surface height variation, ocean data assimilation is key to mapping that information to the subsurface so as to initialize the ocean component of the coupled model. In the GMAO ocean assimilation system, surface height anomalies are assimilated using an ensemble Kalman filter (EnKF) which accounts for the presence of forecast-model biases compared with the satellite data [5].

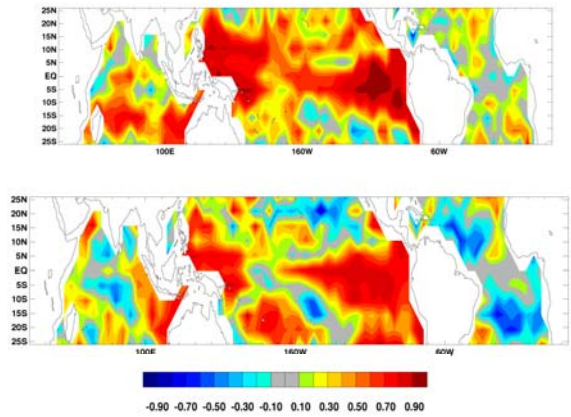

Figure 3. Anomaly correlation between 3-month forecast sea surface height anomalies and Topex/Poseidon anomalies from a set of ensemble forecasts initialized in May each year from 1993 to 2002. Upper figure is from forecasts with the ocean initialized with T/P data. Lower figure is from forecasts initialized with *in situ* data only.

When the T/P data and *in situ* temperature data are assimilated to initialize the ocean, seasonal hindcasts of sea level made with the coupled model are generally better than those initialized with optimal interpolation of temperature observations alone. Particular improvements in the first season (month 3) of the forecast are outside the equatorial Pacific waveguide where the Tropical Ocean Atmosphere (TAO) mooring array provides good initial conditions. Improvements are also evident in the other tropical ocean basins (Figure 3).

V. Initializing the Land Surface

Theoretical predictability studies [1] have shown the potential for soil moisture initialization to improve forecasts of summertime continental precipitation and surface air temperature over several regions of the globe. In the absence of a satellite mission to provide global measurements of soil wetness, we have used instead observed and analyzed fields of precipitation and other surface fluxes to initialize the land surface model used in the coupled system. A series of experiments using the atmosphere-land only components showed that the land initialization does cause a small but statistically significant improvement in one-month forecasts of precipitation and air temperature in the region of the U.S. Great Plains [6]. For precipitation, the increases in forecast skill appear strongest in May through July, whereas for air temperature, they are largest in August and September. Land initialization appears to contribute the most to monthly precipitation forecast skill. In 2004, the GMAO coupled forecast system was modified to include initialization of the atmosphere and land surface. The results for the first month of forecast surface temperature are shown in Figure 4, comparing with observations from NOAA's Climate Prediction Center and with forecasts made when the land surface and atmosphere are not initialized. The results in the coupled system are consistent with those from the uncoupled system, with improvements later in the season.

VI. Summary

Since the dramatic influence of the large El Niño event of

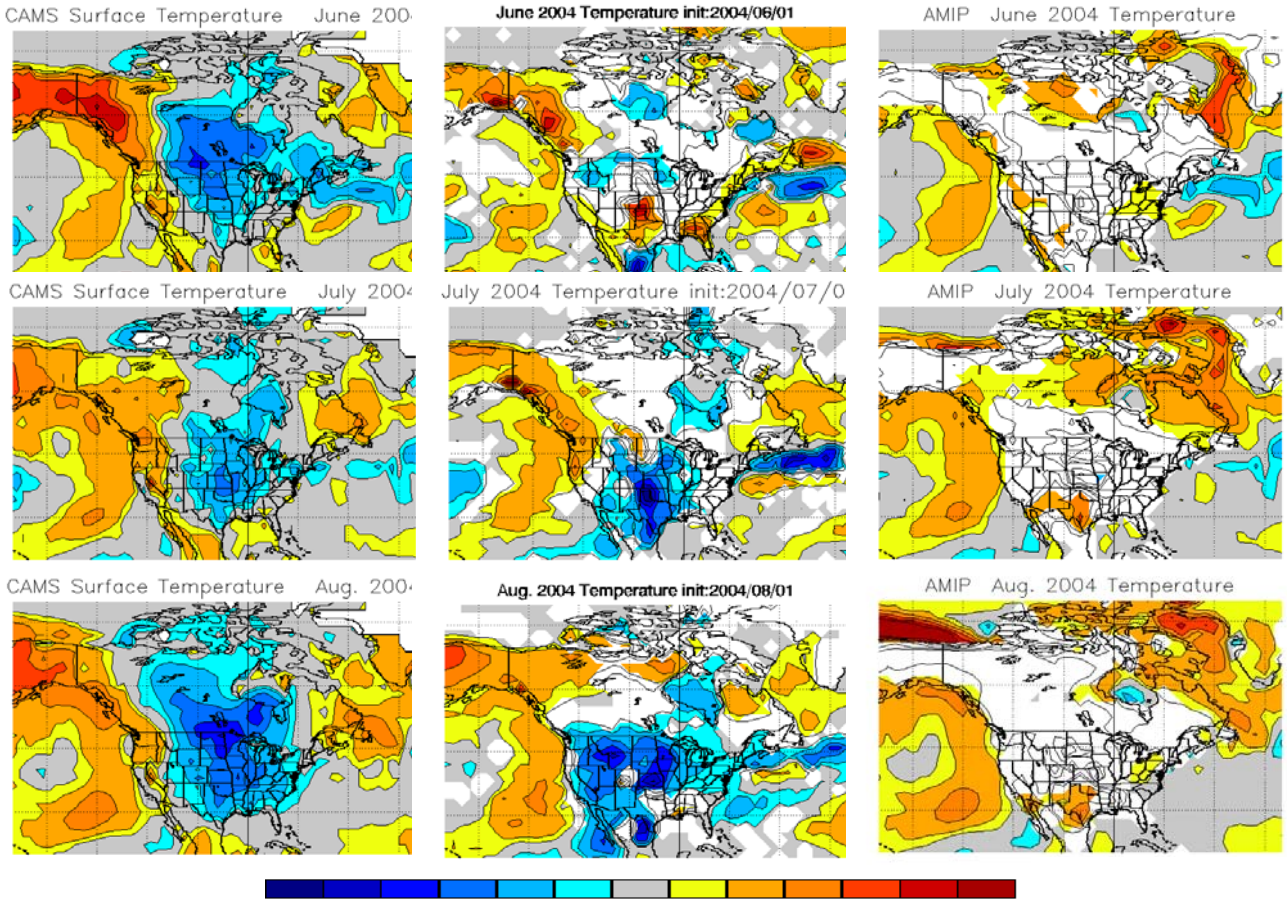

Figure 4. Forecast surface temperature during the first month of the coupled forecast. Leftmost panels are analyses of observations. Center panels are from forecasts where the atmosphere and land surface have been initialized. Rightmost panels are from forecasts where the land surface and atmospheric initial conditions are from atmospheric model runs over observed sea surface temperatures. The top row is for June 2004; center row is July 2004; bottom row is August 2004.

1982-83, which was not anticipated in any forecast, scientists have increased their efforts to forecast anomalous sea surface temperature patterns in the tropical oceans and their impact in other areas of the globe. Significant advances have been made in forecasting the evolution of strong warm and cold events once they have been initiated. These advances have arisen from an enhanced tropical ocean observing system, improvements in the computer models used for forecasts, and from the satellite data available for initializing the components of the coupled system. The observing system includes NOAA's TAO moored buoys, which provide information on subsurface ocean temperatures, surface temperatures from AVHRR, MODIS, and AMSR-E, the surface altimetry from Topex/Poseidon and Jason. The surface winds from scatterometry and the remotely sensed measurements of precipitation used to force the ocean and land surface models during initialization are also important developments in the observing system. In spite of these advances, it remains a challenge to forecast events prior to their initiation and to forecast weak conditions. In addition, although the responses to El Niño or La Niña episodes are strong and widespread, the differences in responses from region to region and between events make forecasting the details a challenge. Yet these details are important if the forecasts are to be useful for practical applications such as water management and agricultural planning. The challenge for seasonal prediction is to understand the mechanisms that contribute to extreme climate anomalies, and the factors and feedbacks that provide potential to enhance prediction of these anomalies.

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REFERENCES

[1] R.D. Koster et al., "Regions of strong coupling between soil moisture and precipitation," Science, vol. 305, pp. 1138–1140, 2004.

[2] J.T. Bacmeister, and M. J. Suarez, "Wind-stress simulations and the equatorial momentum budget of an AGCM," J. Atmos. Sci., vol. 59, pp. 3051–3073. DOI: 10.1175/1520-0469, 2002.

[3] P. Schopf and A. Loughe, "A reduced-gravity isopycnic ocean model–hindcasts of El-Niño," Mon. Wea. Rev., vol. 123, pp. 2839–2863, 1995.

[4] R.D. Koster and M.J. Suarez, "Energy and water balance calculations in the Mosaic Land Surface Model." NASA Tech. Memo. 104606, Vol. 9, 59pp., 1996.

[5] C.L. Keppenne, M.M.Rienecker, N.P. Kurkowski, D.D. Adamec, "Ensemble Kalman Filter assimilation of temperature and altimeter Data with bias correction and application to seasonal prediction", Nonlin. Proc. Geophys., vol. 12, pp. 491–503, 2005.

[6] R.D. Koster, et al., "Realistic initialization of land surface states: Impacts on subseasonal forecast skill", J. Hydrometeor., vol. 5, pp. 1049–1063, 2004.