Seasonal forecasting at NASA's Seasonal-to-Interannual Prediction Project (NSIPP)

Michele M. Rienecker and Max J. Suarez

NASA/Goddard Space Flight Center
Greenbelt, MD 20771, USA
Michele.M.Rienecker@nasa.gov, Max.J.Suarez@nasa.gov

Abstract

Understanding and predicting seasonal-to-interannual climate variations is a central goal within NASA's 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 remotely sensed data together with in situ observations for experimental predictions of seasonal-to-interannual climate variations. Here we describe the performance of the NSIPP Version 1 forecast system which is now used each month for 12-month forecasts of the global coupled ocean-atmosphere-land-surface state.

1. The forecast system

The current implementation of NSIPP's coupled general circulation model (CGCMv1) uses the NSIPP1 atmospheric model (Bacmeister et al. 2000, Bacmeister and Suarez 2002), the Poseidon quasi-isopycnal ocean model (e.g., Schopf and Loughe 1995), and the Mosaic Land Surface model (Koster and Suarez 1996). The CGCM is freely coupled once per day; flux corrections are not employed. 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, NSIPP produces experimental coupled predictions of 12-months' duration, with the start date of the 1st of the month. Eighteen-member ensemble predictions are conducted by adding perturbations of both the atmosphere and ocean to the initial conditions generated by integration/assimilation. For coupled forecasts the ocean is initialized globally by assimilating *in situ* temperature profiles using an optimal interpolation method. The assimilation analysis is produced daily and includes an adjustment to the model's salinity state using the water mass preservation procedure of Troccoli and Haines (1999). More sophisticated methods, such as the Ensemble Kalman filter (EnKF), are in test phase (e.g., Keppenne and Rienecker 2002). The atmosphere and land surface are initialized from an AMIP simulation over observed (Reynolds) sea surface temperature (SST). In addition to the (Tier 1) forecasts using the CGCM, the forecast SST anomalies are used with a climatological SST in atmosphere-land (Tier 2) predictions. The latter have been conducted because of the drift problems usually encountered with coupled models. We will show below that the latest version of the NSIPP forecast system has reduced these drifts substantially so that the two-tiered system may not be necessary.

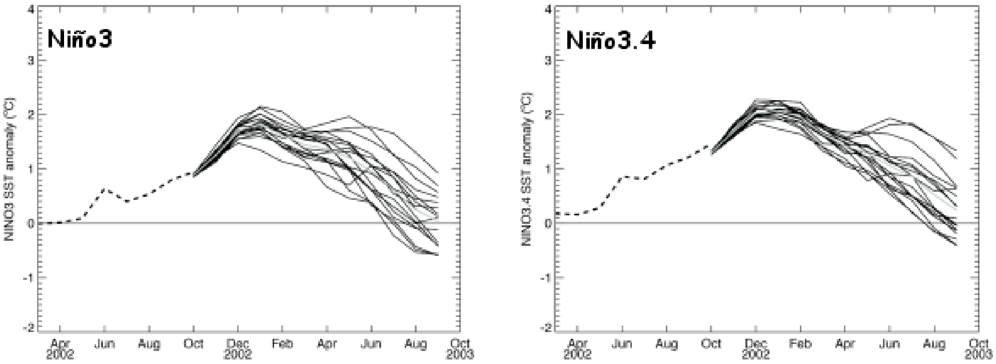

Figure 1: Niño-3 and Niño-3.4 forecast SST anomalies from the CGCMv1 forecast initialized on 1 October, 2002. The dashed line is observed (Reynolds) SST anomaly. The anomalies are computed relative to a climatology calculated over 1993 to 2001.

The latest forecast, initialized on October 1, 2002, is for moderate El Niño conditions. Both Niño-3 and Niño-3.4 indices (Figure 1) peak in December 2002 -- January 2003, and display little spread between ensembles during the first 6 months. The forecast amplitude is higher in Niño-3.4 than in Niño-3, with a tighter ensemble. The timing of peak warm conditions has been consistent from hindcasts conducted since April 2002, although the amplitude of the ensemble mean has varied by about 0.5°C.

2. Model drift and validation through hindcasts

In forecast mode, the CGCMv1 undergoes a markedly reduced shock and climatological drift compared with CGCMv0, which we have used in regular forecasts since January 2000. The drift is exemplified by that in the Niño-3 index, shown as a function of starting month in Figure 2. In the first 6 months of the forecast, biases are significant only for forecasts starting earlier than August. All forecasts seem to undergo a drift during July. The initial shock (estimated as the drift in the first month of the forecast) is usually less than 0.5°C. The drift is indicative of the reduced annual cycle in the free coupled model – higher SST during the cold phase and lower SST during the warm phase. The drift is also low outside the equatorial Pacific wave guide and the associated global precipitation patterns are quite realistic (not shown).

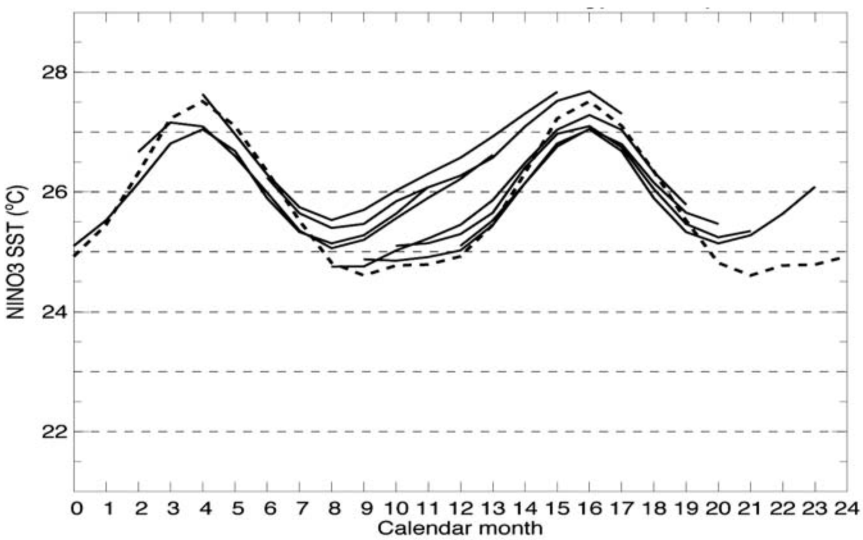

Figure 2: Climatological drift of Niño-3 SST as a function of forecast start month. The drift is calculated from 6-member ensemble forecasts conducted for a duration of 12 months from 1993 to 2001. The dashed line is a climatology of Reynolds SST calculated over the same time period.

The CGCMv1 forecast system was first used for a real-time forecast in September 2002. We are currently conducting retrospective forecasts for 1993 through to the present. Forecast anomalies are calculated relative to the climatological drift for the forecast start month. The forecast skill as a function of start month and year can be assessed by the comparison of April and September starts in Figure 3. The first 9 months of the forecast are shown. Generally, the spread of the ensemble is tighter for strong events, and during strong events the spread is wider for April starts. There are obvious forecast failures for April starts: those in 1995 and 2001, with a strong false La Niña for the former and strong false El Niño for the latter. The event of 1995 seems to be tied to an overly strong surface wind response that amplified the negative subsurface temperature anomalies present in observations. The event of 2001 seems to be tied to erroneously strong positive subsurface temperature anomalies generated by the ocean data assimilation system. Otherwise, the forecast system performs well, with a 0.7 correlation with observed anomalies at 9 month leads.

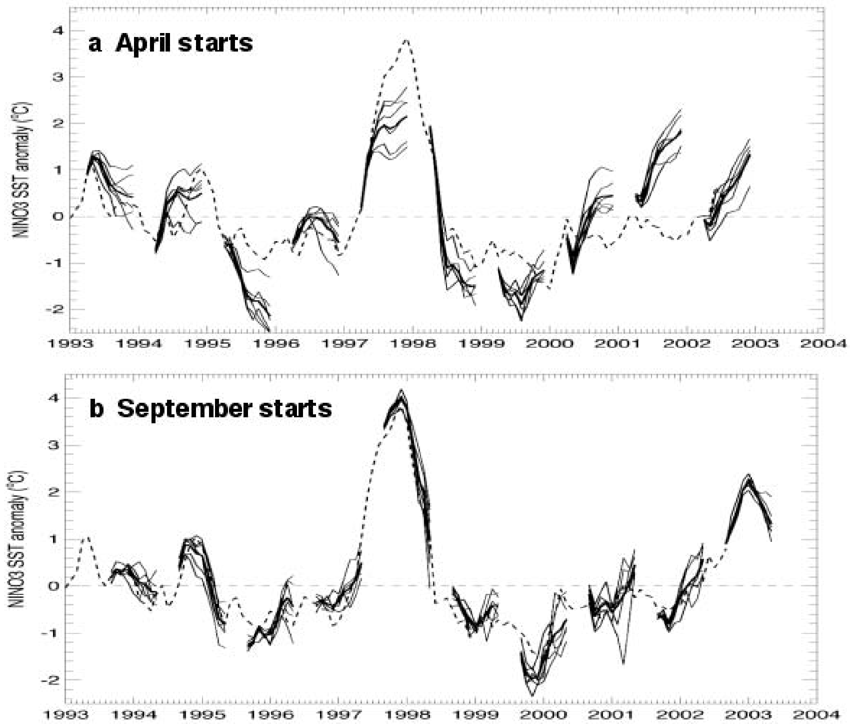

Figure 3: Retrospective hindcasts of Niño-3 SST anomalies conducted for April and September starts. The six-member ensemble mean is shown by the heavy solid line. Individual ensemble members are shown by the thin solid lines. The dashed line is the observed SST anomaly. The first 9 months of the 12-month forecast are plotted.

3. Forecasts of the 1997/98 El Niño

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 (Figure 4). 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. Most forecast systems seem to forecast the decay of the event very well. Our system does very well also at the timing of the decay.

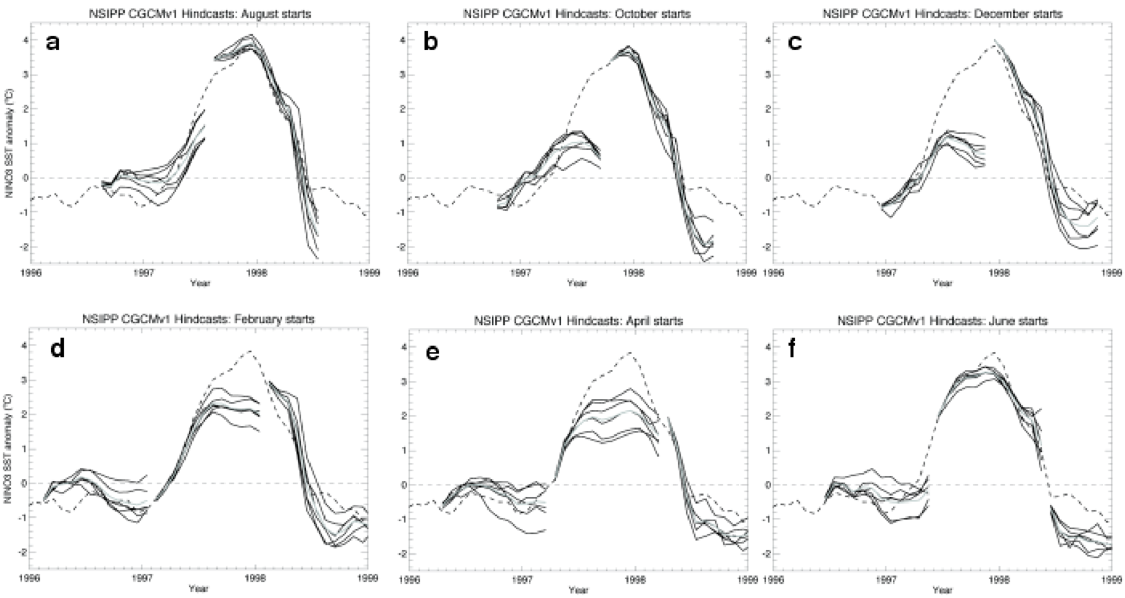

Figure 4: Retrospective 12-month hindcasts of Niño-3 SST anomalies during 1997/98, as a function of forecast start date: a) August starts, b) October starts, c) December starts, d) February starts, e) April starts, and f) June starts. The dashed line is the observed SST anomaly.

4. The atmospheric response in the coupled forecast

The atmospheric response to the forecast SST anomalies was analyzed for the 9 years of the hindcasts. Figure 5 shows the anomaly pattern correlation between a one-season forecast of precipitation and the CMAP observations in a tropical band from 30°S to 30°N. The correlation exceeds 0.7 during the 1997/98 event ,and for four of the nine years exceeds 0.5. To assess the relative effects of errors in forecast SST and in atmospheric response, correlations are also shown for an AMIP run using the same AGCM as was used in the coupled forecasts. These show that, for years with significant tropical Pacific SST anomalies, the improvements from a perfect prediction of SSTs would have been marginal. Significant improvements, however, occur during weak ENSO conditions (1996, 2000, 2001).

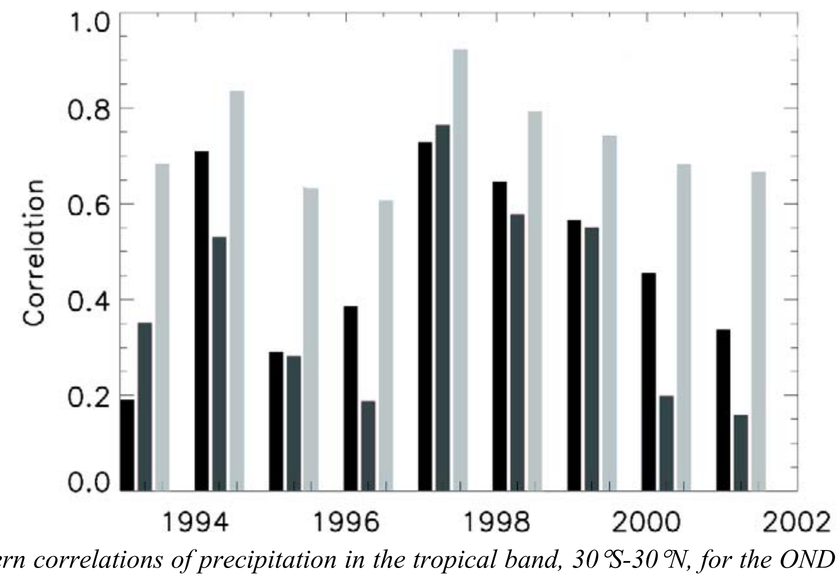

Figure 5: Pattern correlations of precipitation in the tropical band, 30°S-30°N, for the OND season. Three values are shown for each year. The central (dark grey) bar for each year is the correlation between the CGCMv1 forecast precipitation and CMAP. The forecast was initialized 1 September each year. The left-most (black) bar is the correlation between CMAP and an AMIP simulation with the same AGCM. The light bar is the measure of potential predictability assessed from the AMIP ensemble (see text)

These correlations need to be compared with some measure of potential predictability. To do this we compute the correlations between an AMIP ensemble and a single AMIP integration withheld from the ensemble (i.e., assuming perfect foreknowledge of SST and a perfect AGCM). The figure shows that additional skill could be achieved, particularly during non-ENSO years. It also shows that interannual fluctuations in realized skill closely follow the potential predictability..

5. Future Developments

NSIPP's ultimate goal is the use of satellite data in the prediction of SST patterns and the teleconnection patterns of precipitation and surface temperature over continental regions. One of the strongest responses to the equatorial El Niño signal lies over the continental U.S. However, predictability studies (e.g., Koster et al. 2000) indicate that the key to summertime precipitation forecasts over transition zones between dry and humid areas in tropical and midlatitude regions (such as the central U.S.) lies in the initialization of soil moisture. Hence, NSIPP places high emphasis on modeling land surface hydrology and also on initialization of the land surface state for boreal summer forecasts. New predictability experiments and preliminary hindcast tests that use observed precipitation to precondition the soil moisture distribution are confirming the earlier results of the impact of soil moisture on summertime precipitation and surface temperature. Thus, in addition to assimilation of surface height observations from the Topex/Poseidon and Jason altimeters, NSIPP is developing the capability to assimilate soil moisture data from Aqua's AMSR.

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