Background:

Our original proposal called for the completion of a large number of hindcast experiments using a coupled atmosphere-ocean general circulation model (GCM) to help evaluate the global predictability of sea surface temperature (SST), near surface air temperature, and precipitation. The coupled GCM (CGCM) in the proposal had the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model Version 3 (MOM3) as the ocean GCM (OGCM) component model and the ECHAM4.5 model of the Max-Planck Institute for Meteorology (MPI) as the atmospheric GCM (AGCM) component model. Initial conditions for the OGCM, which provide the memory of the system, came from a state of the art ocean data assimilation system (ODA) product produced by GFDL. The approach outlined in the proposal is called a one tier forecasting system because both the SST forecast, which provides the major boundary forcing for the AGCM, and the AGCM fields themselves such as near surface temperature and precipitation are obtained from the same set of integrations. A one tiered forecast system has the potential to provide the most accurate forecasts of global precipitation and near surface temperature anomalies since all of the degrees of freedom of the real coupled system are modeled. Several groups had reported promising initial results using small numbers of cases employing the one tiered approach. On the other hand, errors in the component models can lead to misrepresentation of some of these degrees of freedom and contribute to a poorer forecast then can be obtained from models with fewer degrees of freedom and fewer errors. As described below, the preliminary results that we obtained as well as similar results from one of our collaborators has convinced us to modify our work plan while retaining our original goal.

Description of Experiments Performed Using the CSL Allocation:

The proposal that was submitted described work that is part of a collaborative project between the International Research Institute for Climate Prediction (IRI) and several other research institutions collectively known as the network of Applied Research Centers (ARCs), which is funded by the National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs (OGP). Each of the groups involved in this project was supposed to perform an identical set of hindcasts for the period 1980-1999, all using the same OGCM component model and initial state as described above. The only difference between the different coupled models was the AGCM component model. The goal of this project was to evaluate the predictability of SST, near surface air temperature, and precipitation globally using one tiered coupled GCMs. By performing identical experiments with several forecasting systems which differed only in the AGCM component model we hoped to be able to provide a rigorous test of the one-tiered approach. Unfortunately, only one of the ARCs, the Center for Ocean Land Atmosphere (COLA) interactions has performed the prescribed experiment to date. On the other hand, the results obtained by COLA and IRI are extremely similar and given the difference in systematic error between the two coupled models (and personal communication from colleagues) we feel the results are representative. We describe here
the experiments that have been performed using the IRI CSL allocation. We note those cases where related experiments were performed but did not use IRI CSL resources.

**Direct Coupled Experiments Using the High Resolution Version of MOM3:**

The first set of experiments used the originally proposed version of MOM3 which has meridional resolution of 0.33° within 10° of the equator with a taper zone from 10° to 20° over which the resolution linearly increases to 1°; poleward of 20° the meridional resolution is 1°. The zonal resolution is uniform everywhere and is 1°. The model has 40 vertical layers with the upper 21 layers having a thickness of 10 meters. This model resolution was chosen because of its ability to accurately simulate the equatorial and coastal upwelling in the tropical Pacific when forced with observed estimates of the surface fluxes. Unfortunately, AGCM fluxes are significantly different from the observed estimates, and as will be described in the next section, a lower resolution OGCM which is still equatorial wave resolving produces very similar answers at less computational cost. Using this coupled configuration the following experiments were performed:

40 – One year hindcasts using the coupled model with ECHAM4.5 AGCM. These hindcasts were performed for initial conditions (ICs) for each January and July 1 for the period 1980-1999.

40 – One year hindcasts using the coupled model with COLA AGCM. Same hindcast experiments as above. COLA was given enough computer time for approximately 30 of these integrations from the IRI account to help them complete this work.

20 – Years of coupled integration using the ECHAM4.5 AGCM version of the coupled model were required during the initial development phase of the coupled model.

**Direct Coupled Experiments Using the Medium Resolution Version of MOM3:**

The second set of experiments used a coarser resolution version of MOM3 that is considered to be adequate for resolving equatorial waves but somewhat less accurate then the higher resolution version in representing upwelling in the tropics especially along the coast. This version has meridional resolution of 0.5° within 10° of the equator with a taper zone from 10° to 20° over which the resolution linearly increases to 1.5°; poleward of 20° the meridional resolution is 1.5°. The zonal resolution is uniform everywhere and is 1.5°. The model has 25 vertical layers with the upper 10 layers having a thickness of 15 meters. Using this configuration the following experiments have been performed:

40 – One year hindcasts using the coupled model with ECHAM4.5 AGCM. These experiments were identical to those described above but used the coarser resolution OGCM. All of these integrations were performed on CSL computers. COLA performed a similar set of experiments with their own computer time.

22 – Years of coupled integration using the coupled model with ECHAM4.5 AGCM were performed as part of the development of the coupled model. This included an extended integration to characterize the models intrinsic interannual variability.
AGCM Only Experiments Using ECHAM4.5:
Several AGCM only experiments were performed in association with our coupled experiments. These are as follows:

20 Year spinup run for the ECHAM4.5 AGCM. This run used the surface temperature from the GFDL ODA interpolated to the AGCM Gaussian grid as the boundary condition for an AGCM AMIP2 type integration from 1979 to 2000. The purpose of the integration was to develop a set of AGCM restart files for the coupled forecasts in which the AGCM had been brought into equilibrium with the SST it will feel when the hindcast is started. This is an attempt to minimize the oceanic Kelvin wave initial shock which can be generated in the equatorial Pacific when a coupled model integration is started.

Ensemble of three 17 year (1979-1995) AMIP2 integrations using the ECHAM4.5 AGCM with a modified land surface scheme. These experiments were to evaluate the ability of the modified land surface scheme in simulating the global anomalies of near surface temperature and precipitation in comparison to the control model which is used in the coupled simulation and was also used in a suite of 10 AMIP2 runs. The modified land surface scheme was not found to improve the simulated precipitation and temperature anomalies. If the opposite had been true we would have changed the AGCM component model in our coupled model.

Summary of Results:
We present here a few figures showing some of the points elucidated above. Figure 1. shows a comparison of the hindcast skill at 3 and 6 month lag for all July 1 IC experiments in the 1980-1999 period from the coupled model using the ECHAM4.5 AGCM. Results from the coupled model using the COLA AGCM are very similar (Ed. Schneider, personal communication). The shading scheme has been chosen to highlight anomaly correlations greater then 0.6 which is the community accepted lower bound for skillful forecasts. A comparison of the results from the coupled experiments using the high and medium resolution OGCMs shows little difference. Further, there is almost no skill outside the central and eastern near equatorial Pacific.

Figure 2. shows the hindcasts of equatorial Pacific SST for the July 1, 1986 and July 1, 1987 IC cases compared with the observed anomalies. Both versions of the coupled model have some fidelity to observations. However, the coupled model version with the higher resolution OGCM is much noisier and does not pick up the warm to cold transition in early 1988 correctly.

Figure 3. shows hindcasts for the same period but for the January 1 IC cases. Clearly, the model is not as successful for these cases. In particular, neither version is able to capture the onset of the warm event in late 1986. Also, both versions have trouble continuing the warm event beyond late spring 1987.

This type of seasonality of forecast skill depending on IC starting time is found in almost all models and has come to be called the ‘spring predictability barrier’. In the
next section we discuss our approach to improving forecasts which start in Northern Hemisphere winter and spring.

Work in Progress:

Given the results described above we have modified our work plan from the original proposal. The first modification was to switch to the coarser resolution OGCM which is considerably less expensive computationally but provides adequate resolution for the problem we are studying. Currently, we are working on two aspects of the coupled forecast system that we hope will improve the ability of our coupled model to predict SST both in the tropical Pacific and elsewhere. First, we are generating an ocean initial state using the coupled GCM (ECHAM4.5 AGCM) rather than using the GFDL ODA product. Recent work by Kirtman and Schneider (1996) and Chen et al. (1995) has shown improved forecast skill in the tropical Pacific when using initial ocean states obtained using simple empirical data assimilation schemes. These simple schemes effectively act as filters for the ocean state and are found to retain only the large scale and low frequency component of the ocean subsurface temperature anomalies. We are currently generating a similar empirical ODA product with our coupled model and will redo the hindcast experiments with this data. The second modification we are making is to develop an anomaly coupled model. Most of the SST anomalies outside of the tropical Pacific are in large part driven by the anomalous heat flux. Unfortunately, the current AGCMs, including very good ones like ECHAM4.5, have large enough errors in their heat flux formulation that the SST errors that result when coupling can prevent proper simulation of interannual variability. Our hope is that the global anomaly coupled model will enhance skill in forecasting SST in other regions.

We are currently working with our IRI applications colleagues to define the needed level of forecast skill for near surface temperature and precipitation anomalies. In particular, we are working with Marianne Hopp on forecasting severity of Dengue Fever on seasonal to interannual time scales. We are also working with Heidi Cullen in trying to forecast relevant metrics for predicting reservoir levels in parts of Brazil which are of use to the local officials associated with managing the hydroelectric power facilities.

Additional Use Of CSL Resources:

We would also like to note that we have made extensive use of the “standby” time available on the IBM and Compaq systems to perform several supplementary AGCM only experiments. In particular, we have found that the predictability of near surface temperature and precipitation for the ECHAM4.5 is not significantly improved by using a higher horizontal resolution (T63) version of the model. We have found the standby queues to be an excellent resource that helps us to get some work done while at the same time using GAUs that would otherwise go unused.

Usage Issues:

We give these as bullets as that seems most appropriate.

1. One of our scientists, David DeWitt, took the MPI course taught by Jim Tuccillo of IBM. Dave found the course material and Jim’s presentation to be excellent. We are very glad to see NCAR offer such courses to the user community.
2. On several instances we have made use of the Consulting group and we find their help to be very thorough and useful. In particular, we extend our thanks to Dick Valent, Dan Anderson, and George Fuentes (system administration). We appreciate the time it takes to provide individual help when having to deal with the many hundreds of users that NCAR has.

3. We would like to thank Bo Connell and Ginger Caldwell for answering our numerous and sometimes redundant questions about our account. We always receive timely attention to our requests.

4. The web-based help pages are great for teaching new users how to use the different platforms. We have found the documentation to be well organized and concise with the most basic information separated from more advanced topics so that one does not need to read through irrelevant material to find what one is looking for.

5. The front end machines, like utefe and babyblue provide a useful way for users to debug their programs before having to run through the queue on the bigger machines. Please keep these machines.

Overall, we have been very happy with the NCAR CSL program and are very grateful to have been able to participate in it. We hope to be able to continue to do so in the future.
References


Figure Captions

Fig. 1. Top panels show the anomaly correlation at three month lag for the ECHAM4.5 plus MOM3 coupled experiments for the version using the high (left panel) and medium resolution (right panel) versions of the OGCM. Bottom panels are the same as the top except for at six month lag. Shading levels are as indicated on the figure and the thick black contour is for the value of 0.6.

Fig. 2. Top panels show the evolution of near equatorial SST anomalies for the period July 1986 to June 1987. The left (right) panel is for the ECHAM4.5 plus MOM3 coupled model using the medium (high) resolution OGCM. The middle panel is for the observed anomalies. Contour and shading intervals are $0, \pm 0.5, 1, 1.5, 2, 2.5, \text{ and } 3.0^\circ\text{C}$. The bottom panels are the same except for the period July 1987 to June 1988.

Fig. 3. Same as Fig. 2 except that forecasts begin on January 1 as opposed to July 1. Top panel figures are for the period January 1986 to December 1986 while the bottom panel figures are for January 1987 to December 1987.