Project no. GOCE-CT-2003-505539

Project acronym: ENSEMBLES

Project title: ENSEMBLE-based Predictions of Climate Changes and their Impacts

Instrument: Integrated Project

Thematic Priority: Global Change and Ecosystems

D1.11: Scientific report/paper documenting the improved seasonal hindcast skill of the ECHAM5/OM1 coupled model in the ENSEMBLES stream 1 simulations, relative to DEMETER and the model improvements responsible

Due date of deliverable: Feb 2008
Actual submission date: May 2008

Start date of project: 1 September 2004  Duration: 60 Months

Organisation name of lead contractor for this deliverable: IFM-GEOMAR

Revision 1
Abstract

The seasonal forecasting skill of the IPCC version of the ECHAM5/MPI-OM model is investigated in an extensive suite of hindcasts: Four hindcast per year of at least seven months length, with nine ensemble members, extending from 1960 till present. These experiments represent the STREAM2 simulations for ENSEMBLES (Stream 1 are subset of these). Hindcasts are initialised using a coupled assimilation scheme in which SST data are nudged into the climate model in the tropical band. No other observations are used. The model's seasonal forecast skill is demonstrated to be comparable to that of other state-of-the art GCMs.

The hindcast setup adopted here is similar to that used in a previous set of hindcasts with an earlier version of the model that were performed for the DEMETER project. The skill of those hindcasts was markedly poorer than the latest set. The skill improvement is demonstrated to be due to the reduction of model systematic bias, and not to difference in ocean initialisation.

Model Description

The IPCC version of Max-Planck Institute for Meteorology (MPI) climate model is used in this project (ENSEMBLES version hereafter). The model consists of the ECHAM5 atmospheric general circulation model (GCM) coupled to the MPI-OM ocean GCM coupled with the OASIS3 software. ECHAM5 is run with T63 horizontal resolution, and 31 vertical levels. MPI-OM uses a curvilinear grid with a 1.5° average horizontal resolution, and 40 vertical levels. No flux adjustment is applied in the model.

The previous version of the model was used to perform seasonal forecasts for the DEMETER project. The most significant differences between model versions are as follows: ECHAM5 was run with a T42 horizontal resolution and 19 vertical levels. The MPI-OM horizontal grid was similar, except that the meridional resolution in the DEMETER model was enhanced to 0.5° between 10°S and 10°N. In addition, MPI-OM was run with 23-vertical levels. In terms of physics, ECHAM5 was run with the new cloud scheme developed by Adrian Tompkins. The old cloud scheme was used by MPI for their IPCC simulations and is used here. The ocean-atmosphere coupling was also modified to account for surface currents in the calculation of wind stress.

Improved Model Climate

The simulated climate of the ENSEMBLES version of the MPI model is described in detail by Johann et al., 2006, who also describe the impact of accounting for surface currents in the calculation of wind stress. Here we will focus on describing the most important improvements in the simulated climate with regard to forecasting the El Niño/Southern Oscillation (ENSO).

The mean state of the model, particularly over the Tropical Pacific, is quite realistic and compares favourably with the other coupled GCM. This is illustrated by the bias between simulated and observed mean sea surface temperature (SST) shown in figure 1a. In the tropical Pacific, the simulated equatorial cold-tongue SST is only one degree colder than observed. In the DEMETER model the equatorial cold tongue was
four degrees too cold (fig. 1b). Surface winds and precipitation, which are closely related to SST over the Tropical Pacific, are also significantly better simulated by the ENSEMBLES version of the model (not shown).

Figure 1: The simulated SST bias, with respect to the Reynolds OI observations, for (a) ENSEMBLES and (b) DEMETER versions of the MPI model. The bias in (a) and (b) are calculated from 350 and 500 year long simulations, respectively.

As well as improvements in the mean state, the simulation of tropical Pacific climate variability by the ENSEMBLES version is significantly better than that of the DEMETER model. The model now simulates a clear annual cycle in the eastern Pacific with strength, westward propagation, and phase similar to observations (Fig. 2). The DEMETER model simulated a semi-annual cycle in the eastern Pacific (Fig. 2). The ENSEMBLES model simulation has a dominant ENSO frequency close to 4 years, matching observations well. East-west propagation characteristics and the spatial pattern of simulated SST compare well to observations. The DEMETER model, despite the strong biases, also simulated ENSO with a realistic period, but the spatial structure and eastward propagating characteristics of SST anomalies were not well represented. The most significant difference, however, is seen in the strength of simulated interannual variability (Fig. 3). In the ENSEMBLES model, Tropical Pacific interannual variability is around 30% too strong (Fig. 3b). However, in the case of the DEMETER model, the simulated variability is around 170% too strong, at the time of the hindcast initiation (Fig. 3d).
Figure 2: Annual cycle of SST along the equator from (a) Reynolds OI observations (1982-2004), (b) ENSEMBLES and (c) DEMETER versions of the MPI model. The annual cycle in (b) and (c) are calculated from 225 and 500 year long simulations, respectively. Annual mean has been removed.

Figure 3: Standard deviations of SST anomalies (°C) for (a) Reynolds OI observations (1982-2001), (b) ENSEMBLES, (c) DEMETER, and (d) flux corrected DEMETER versions of the MPI model. The standard deviation in (b), (c), and (d) are calculated from 225, 500, and 40 year long simulations, respectively. The flux correct version has a mean state close to the observed and the state from which the DEMETER hindcasts were started. Note the different scale in (d).
Hindcast Initialisation

The DEMETER and ENSEMBLES hindcasts described here were initialized using a coupled initialization technique. The method involves running the coupled model with strong SST nudging (0.25Days$^{-1}$) to observations between 30°S and 30°N. In ENSEMBLES, three initialization runs were performed covering the period (1950-2004). Initial conditions for these three runs were taken from three 20th-century IPCC runs with all major forcing included. These runs were also performed for ENSEMBLES by the Max-Planck-Institute for Meteorology. The initial conditions for all 9-members of the hindcasts were obtained from different initial condition permutations from these three runs. This set up differs from that of DEMETER in two ways. First, only one coupled initialization run was performed, and second, ensemble member initial conditions were obtained from lagged atmospheric states.

The basis for this initialisation method is the strong coupling between ocean and atmosphere in the tropics. In particular, the SST, which is nudged into the model, forces atmospheric wind anomalies, which in turn force heat content variations. To assess the quality of the initial ocean initial conditions, simulated and observed (TAO/TRITON) equatorial 20-degree isotherm depth (Z20) anomalies were compared. The correlation between observed and simulated Z20 anomalies for both the ENSEMBLES and DEMETER initialisation runs is high (fig. 4a), with values exceeding 0.7 along most of the equator. The DEMETER model is consistently better than the ensemble mean and all the individual ensemble members from ENSEMBLE initialisation runs. A similar picture is seen for the RMS error (fig. 4b). Similar results are obtained when verifying against TOPEX/Poseidon sea level observations. Thus, in contrast to the improvements seen in the model’s climate simulation, equatorial Pacific heat content variations were better in the DEMETER model than in the ENSEMBLES model. The reasons for this are not clear, but are probably the result of enhanced meridional grid spacing in the DEMETER model.

![Figure 4: (a) correlation between 20-degree isotherm depth anomalies from coupled initialization runs and TOGA/TAO observations. Shown are results for the ensemble mean (solid red) of three ensemble member (red-dashed) coupled initialization runs with the ENSEMBLES version of the MPI model, and the single coupled run used in DEMETER (green). (b) as for (a) except for root mean square error. Period considered is 1986-2001.](image-url)
Improved hindcast skill

A set of nine-member hindcasts were performed with the ENSEMBLES model for the period 1960 till 2005. Seven-month long hindcasts were made for February, May, and August start dates, and fourteen-month long hindcasts for November start dates. A similar set of hindcasts was performed with the DEMETER version of the model. The only differences were that the hindcasts were only six-months long, covered the shorter period of 1967-2001, and did had fixed radiative forcing. The skill comparisons are made here for the period 1967-2001.

The model forecast skill for Niño3 averaged SST anomalies is good, with a correlation of 0.7, and a RMS error of 0.75°C at six-months lead (fig. 5). In contrast the correlation and RMS error at six months lead for the DEMETER model are 0.5 and 1.2°C, respectively (Fig. 5). This is significantly poorer than that of the ENSEMBLES model. The spatial correlation (fig. 6) and RMS error (fig. 7) patterns between observed and hindcast SST anomalies at six-month lead are also better for the ENSEMBLES model. For the latter, correlation values exceed 0.7 over large parts of the tropical Pacific and Indian oceans (fig. 6a). For the DEMETER model, these regions are much smaller in extent (fig. 6b).

Figure 5: (a) Anomaly correlation as a function of lead month for Niño3 averaged SST anomalies for the ENSEMBLES (red) and DEMETER (green) hindcasts and for persistence (blue). For the models, solid lines represent the ensemble mean, and dashed lines the individual ensemble members. (b) As for (a) except for RMS error. Skill measures are calculated for the period 1967 till 2001 for all four start dates.
Discussions and conclusions

Various reasons may exist for the improved hindcast skill of the latest version of the MPI model over the previous version. Two obvious candidates are improvements in model physics and better initial conditions. As described above, the simulation of tropical climate variability is significantly improved, which suggests that the important physics are better captured. In the case of ocean initial conditions, the ENSEMBLES initialisation is clearly not better than that of the DEMETER model. Thus, we may conclude that the improved hindcast skill derives mostly from improved model physics. Although it is not a surprising finding, it is a nice demonstration of the impact of model physics on forecasts skill and a publication based on these results is in preparation.