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1. Objectives

The primary goal of the project entitled “Incorporation of the HYbrid Coordinate Ocean Model (HYCOM) into the Community Climate System Model (CCSM): Evaluation and Climate Applications” was to systematically investigate the performance of the HYbrid Coordinate Ocean Model (HYCOM) as an alternative oceanic component of the NCAR’s Community Climate System Model (CCSM).

2. Progress to Date

2.1. Diagnostics of Long-term Fully Coupled Integrations with coupled CCSM3/HYCOM

As previously reported, we have configured two versions of the fully coupled CCSM3/HYCOM: one with a medium resolution (T42) Community Atmospheric Model (CAM) and the other with higher resolution (T85). We have performed a comprehensive analysis of the 400-year fully coupled CCSM3/HYCOM simulations and compared the results with those from CCSM3/POP and with climatological observations, and also we have performed tuning of critical model parameters, including Smagorinsky viscosity, isopycnal diffusivity, and background vertical diffusivity. The analysis shows that most oceanic features are well represented in the CCSM3/HYCOM.

The coupled CCSM3/HYCOM (T42) has been integrated for 400 years, and the results have been archived and transferred to the High Performance Computer in the Florida State University. In the last year, we have made comprehensive diagnostics of the long-term simulations by the comparison with the original CCSM3/POP simulation and with the observations. We have reported the main results during the annual DOE project PI meeting held in Washington DC. Two papers have been submitted to *Climate Dynamics* and are under peer review process (Lu et al. 2012; Michael et al. 2012).

To gain some understanding of the model biases, the mean climate and modes of climate variability of the two models are compared with observations. The examination includes the Northern and Southern Annular Modes (NAM and SAM), the Pacific-North-American (PNA) pattern, the Atlantic Multidecadal Oscillation (AMO), and the main Southern Ocean SST mode. We also compared the performance of ENSO simulation in the coupled models. Here we summarize the main findings from the comparison of long-term CCSM3/HYCOM and CCSM3/POP simulations.

(1) The simulation of Northern Annular Modes (NAM)

The NAM modes in the two models show a systematic shift of atmospheric jets, precipitation (Fig.1), and eddy activities (Fig.2) to the east of the observations, and the simulated centers of the NAM over the North Pacific are stronger than in the observations. This systematic eastward shift of the NAM can be related to the mean SST biases in the North Atlantic through interaction between the mean flow and the synoptic eddies.

Figure 2. The linear regressions of EKE at lowest CAM model-level on the NAM in CCSM3/HYCOM simulation (a) and NCEP/NCAR reanalysis data (b), normalized by the standard deviation of the NAM mode. The data for CCSM3/POP simulation are not available.

(2) The simulation of SST over the Southern Ocean

Over the Southern Ocean, the SSTs show warm biases in the CCSM3/HYCOM and cold biases in CCSM3/POP. The comparison of the dominant mode of the Southern Ocean SST (Fig.3) and its relationship with ENSO shows that the bias of the Southern Ocean SST variability in both the simulations partly originate from tropical bias, in addition to the misrepresentation of local physical processes.

Figure 3. The first EOF of the April-to-September-averaged SST over the Southern Ocean (40°S-90°S) for 200-year coupled simulations with present-day forcing (a). The linear regressions of surface wind stress (b), precipitation (c), and SLP (d) upon the SST mode. The regressions are normalized by the standard deviation of the SST mode. Left Panel: CCSM3/HYCOM; Right Panel: CCSM3/POP.

(3) The simulation of the PNA pattern

In contrast to the patterns in CCSM3/POP and the observations, the PNA pattern in CCSM3/HYCOM has no correlation with El Niño-Southern Oscillation (ENSO) in CCSM3/HYCOM, suggesting the PNA pattern can be a mode of internal variability in the extratropics, rather than being forced by ENSO.

Figure 4. The PNA pattern - the second EOF of the October-to-March-averaged sea level pressure (SLP) over 20°N-90°N for 200-year coupled simulations with present-day forcing (a). The linear regressions of surface wind stress (b), precipitation (c), and surface temperature (d) upon the PNA. The regressions are normalized by the standard deviation of the PNA mode. Left Panel: CCSM3/HYCOM; Right Panel: CCSM3/POP.

(4) The simulation of the ENSO

Fig. 5 shows the Niño 3 SST spectra for ERSST, CCSM3/HYCOM, and CCSM/POP. The Niño3 SST spectrum in ERSST contains a broad peak spanning from 2 to 7 years. A much weaker, but nonetheless equally broad peak is seen in CCSM3/HYCOM centered around 4 years. CCSM/POP has a stronger, narrower peak compared to CCSM3/HYCOM but centered around 2 years. This biennial oscillation was a prominent problem with CCSM3/POP, which has been significantly ameliorated in more recent versions of the model mainly through the improvement in convective parameterization (Neale et al. 2008). The suppression of the biennial oscillation in CCSM3/HYCOM suggests that the erroneous biennial peak of ENSO variability may be related to the representation of ocean dynamical processes in the coupled model. However, the variance in CCSM3/HYCOM is much weaker than either CCSM3/POP or ERSST. The overall low Niño3 SST variance in CCSM3/HYCOM is most likely a result of the mean bias of the weak zonal tilt of the equatorial Pacific thermocline depth (Fig. 6). As a result a relatively smaller warm water volume is available to be recharged or discharged, and give rise to weaker ENSO in CCSM3/HYCOM.

Figure 5. Sample Spectra of Niño 3 SST generated using the Maximum Entropy Method for ERSST (blue), CCSM3/HYCOM (red), and CCSM/POP (green).

Figure 6. Average Equatorial Pacific thermocline depth for GODAS (blue), CCSM3/HYCOM (red), and CCSM/POP (green).

We also compared the performance of the Southern Annular Mode (SAM), the Atlantic Multidecadal Oscillation (AMO) in the coupled CCSM3/HYCOM with that in CCSM3/POP and in the observations, and the results are reported in Lu et al. 2012, submitted to *Climate Dynamics*.

Given the same configurations of atmospheric, ice, and land-surface models, the differences mentioned above highlight the importance of ocean model configuration in coupled climate simulations. The role of ocean model configuration in model simulations is non-local and far-reaching through the effects of model configuration on the coupled modes of climate variability. However, we still lack effective diagnostic tools to reveal the connection between the physical processes and these modes in climate models. This hinders us from fully understanding what causes the difference in model simulations and what causes the model biases. However, it is important to understand the effect of numerical choices in vertical coordinates in the performance of earth system modeling. We are in the process of coupling HYCOM with the latest versions of CCSM (CCSM4) and CESM as well as developing new methods to better understand and reduce model biases.

2.3. Other Related Research Activities

In addition to the development of CCSM3/HYCOM, we have ported the newest version of CCSM4/CESM1 to the local HPC in Florida State University for coupling of HYCOM with CCSM4/CESM1.

Publications

Lu, J., E. P. Chassignet, J. Yin, V. Misra, J-P. Michael, 2012: Comparison of HYCOM2 and POP Models in the CCSM3.0 Framework. Part I: Understanding Model Biases from Modes of Climate Variability. *Climate Dynamics* (submitted).

J-P. Michael, V. Misra, E. P. Chassignet, Lu, J., 2012: Comparison of HYCOM2 and POP Models in the CCSM3.0 Framework. Part II: ENSO Fidelity. *Climate Dynamics* (submitted).