REGIONAL CLIMATE MODELING IN THE CALIFORNIA CURRENT SYSTEM

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BACKGROUND

Though global climate models can represent many identifiable features of the climate system, they also suffer from significant localized biases. Climate model biases are not uniform over the globe. For example, in the ocean, modeled sea surface temperature (SST) errors are often largest along the continental margins. Many coupled climate models generate very large SST biases in the coastal upwelling regions of the California Current system (CCS), the Humboldt Current System (HCS), and the Benguela Current System (BCS), where simulated mean SSTs are much warmer than observed. The NCAR-CCSM3 (spectral atmosphere) used in IPCC-AR4 was no exception, with biases in excess of 3˚C in all three regions. Furthermore, these SST biases have significant remote effects on surface and subsurface temperature and salinity, and on precipitation and hence atmospheric heating and circulation (Collins et al. 2006). Large and Danabasoglu (2006) showed, in particular, with observed SSTs imposed along the BCS coast in an otherwise freely-evolving CCSM3 simulation there are significant improvements in precipitation in the western Indian Ocean, over the African continent, and across the Equatorial Atlantic. Imposed SSTs along the HCS coast reduce precipitation in the so-called double Intertropical Convergence Zone (ITCZ) region of the south tropical Pacific.

These errors often coincide with regions of importance to oceanic ecosystems and nearby human populations. In the Intergovernmental Panel on Climate Change Fourth (IPCC-AR4) Working Group 1 Assessment Report, where the reliability of the models used to make projections of future climate change is assessed, Randall et al. (2007) discuss the many improvements and the strengths of the current generation of coupled models of the physical climate system, but they also highlight a number of remaining significant model errors. Furthermore, they state, "The ultimate source of most such errors is that many important small-scale processes cannot be represented explicitly in models, and so must be included in approximate form as they interact with larger-scale features." Some of the reasons given for the deficiencies are limited computer power, data availability, and scientific understanding. Conversely, regional models have shown significant skill in modeling coastal processes (e.g., Curchitser et al. 2005; Powell et al. 2007; Combes et al. 2009; Veneziani et al. 2009a,b). This creates the opportunity to develop multi-scale numerical solution schemes that adapt the resolution in specific areas of interest, such as the California Current system.

Coastal winds in the latest CCSM4 with a 2˚ resolution (finite volume) atmosphere produce even larger SST biases than were apparent in CCSM3, despite many improvements to the physical model components. Improving the coastal winds by increasing the atmospheric resolution to 1˚ however, significantly reduces the coastal SST biases. The implication is that the further reductions in the SSTs required to eliminate the coastal biases under present day conditions will likely also need to come from improvements to the ocean physics and the upwelling of cold water in particular. These improvements must be realized before the regional biogeochemistry and ecosystem models can be expected to behave accurately because of the sensitivity to temperature and the critical importance of upwelled nutrients for biological processes.

In order to address the above issues we developed a new multi-scale ocean as part of the U.S. National Center for Atmospheric Research Community Earth System Model (NCAR-CESM). The new composite ocean consists of the global Parallel Ocean Program (POP) and the Regional Ocean Modeling System (ROMS). The new composite ocean is connected to the rest of the CESM climate model through a modified flux coupler.

RESULTS FROM THE MULTI-SCALE COUPLED MODEL

In order to test and demonstrate the capabilities of the multi-scale climate model, we have been carrying out a series of simulations where the northeast Pacific upwelling region is solved using a high-resolution (7 km) ocean within a global (1˚) model and a 1˚ atmosphere. Sea ice is solved on the ocean grid and the land surface model on the atmospheric grid. The CESM is initialized from a spun-up climatology and time-stepped

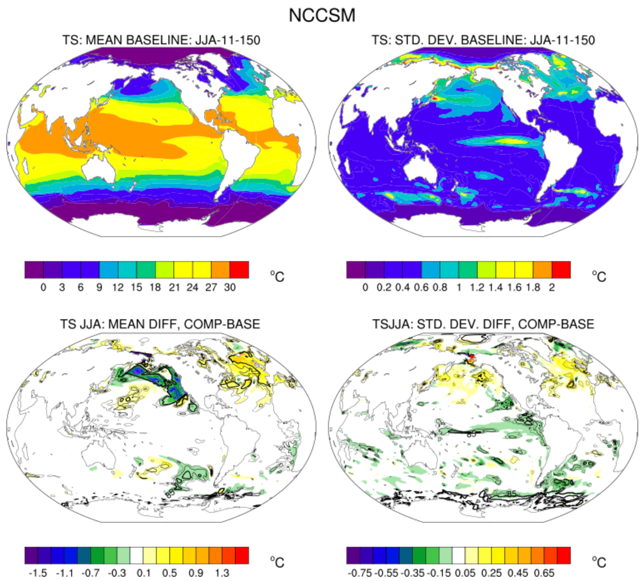

Figure 1. Mean and standard deviation for the summer months of both the control and composite simulations. Thick black lines indicate 95% confidence level using the T- and F-test for the mean and deviation, respectively. Note both the local and remote effects caused by the perturbation that results from resolving the upwelling signal in the northeast Pacific region.

for 150 years. This simulation is then compared to a control run without the high-resolution ocean. The new multi-scale ocean is able to resolve the upwelling that is mostly missing from the global simulations, and this has a significant effect on the regional wind patterns.

Figure 1 shows the surface sea temperature and standard deviation for summer months (June–August) of the control simulation and the corresponding anomalies with the composite model for the last 140 years of simulation. The thick black lines outline regions of 95% confidence based on T- and F-tests for the mean and standard deviations, respectively. The temperature anomaly plot shows the local cooling effect that results from resolving the upwelling in the northeast Pacific and also remote effects in the Atlantic ocean. Significant, and robust, effects are also seen in other variables such as tropical precipitation and sea level pressure.

SUMMARY

A new multi-scale capability was developed by merging a global ocean and a regional ocean model within a global climate model. The goal was to address some of the biases exhibited by low-resolution global models in regions with implications for marine ecosystems. Long integrations show that this configuration is able to address some of these regional biases. Furthermore, by preserving the feedbacks between the regional and global climate models we are able to study upscaling effects that arise from the regionally introduced perturbations. In the case presented here we see effect as far afield as the North Atlantic Ocean. Further studies are proceeding by studying the effects of resolving other major upwelling regions as well a new study in a western boundary current region where global models also show sea surface temperature biases. Future plans include adding a biogeochemistry model to this configuration in order to study the role of upwelling regions in the global CO_2 cycles.

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