2.2 DEVELOPMENT OF A REGIONAL COUPLED OCEAN-ATMOSPHERE MODEL

Hyodae Seo*, Arthur J. Miller, John O. Roads, and Masao Kanamitsu
Scripps Institution of Oceanography

1. Introduction

We are developing a regional coupled ocean-atmosphere model over the eastern North Pacific Ocean and Southern California coastal region in order to better account for small scale air-sea coupling processes. The atmospheric part of the coupled model is the Experimental Climate Prediction Center (ECPC) at Scripps Institution of Oceanography (SIO) Regional Spectral Model (RSM) and the oceanic component is the eddy-resolving Regional Ocean Modeling System (ROMS). Di Lorenzo (2003) used these RSM winds at 25 km resolution and monthly time-scale to force the ROMS to show successfully that the ocean model captured not only the statistics of observed circulation of the Southern California Current System but also the timing and spatial evolution of annually recurrent westward propagating depth anomalies during active upwelling season. The goal here is to establish an operational regional coupled air-sea modeling system that could be embedded within a coarser resolution, or global coupled atmospheric-oceanic forecasting system.

In this preliminary study, wind and ocean anomalies are simulated from April to December of 1999, a period of moderate equatorial La Nina conditions, using uncoupled and fully coupled (3-hourly) RSM/ROMS runs, and also compared with 20-year averaged National Centers for Environmental Prediction (NCEP) Pacific Ocean Analysis. Coupled model components are able to capture interesting air-sea interaction processes with small spatial scales. Targeted simulations are now in progress to understand the capability of this coupled model in simulating realistic atmospheric and oceanic response and the consequences of their interactions.

2. Coupled Model Description

(1) Atmospheric Model

The atmospheric component of the coupled model is ECPC's RSM. It is nested within a low-resolution Global Spectral Model (GSM), whose physics and dynamics are consistent with NCEP/NCAR Reanalysis model. The nesting method is one-way, and non-interactive, so that the regional response of RSM to the large-scale base field forcing provided by GSM is predicted. Since this nesting strategy is applied over a whole regional domain, not only along the lateral boundaries, and dynamics and physics are treated as perturbations only, it is referred as perturbation method. Great details are well documented in Juang and Kanamitsu (1994) and major RSM updates in Juang et al (1997).

(2) Regional Ocean Modeling System (ROMS)

The oceanic part of the coupled model is the Regional Ocean Modeling System (ROMS), which is an evolutionary descendent from S-Coordinates Rutgers University Model (SCRUM) (Song and Haidvogel, 1994). ROMS solves the incompressible and hydrostatic primitive equation with a free surface on a horizontal curvilinear coordinates, and utilizes stretched sigma coordinates in order to enhance the vertical resolution near the sea surface and bathymetry. A radiation method is used along the open boundaries in order to allow for stable, long-term integrations, together with flow-adaptive nudging term for relaxation toward prescribed lateral boundary conditions. That is, the nudging is stronger (timescale of 1 day) if the flow is inward and weaker (timescale of 1 year) for the outflow (Marchesiello et al, 2001). For more details, readers refer to Shchepetkin and McWilliams (2003).

(3) Coupling Process

Since we are given state-of-art atmosphere and ocean models, the most efforts for coupling are focused on designing flux coupler between two models and building an optimal coupling strategy. Currently we are able to run the coupled model in a sequential mode only, that is, RSM is run for a prescribed period of time, and provides time-averaged atmospheric forcing such as momentum flux, surface net heat flux, and freshwater flux to ROMS. In turn, ROMS is run for the commensurate time and provides the sea surface temperature (SST) of higher resolution back to RSM. This flux exchange is performed either every 3 hour, daily, or monthly depending on the purposes of experiments. In this preliminary experiment, we use 3 hourly coupling for 1-year test simulation. Integration is done using the SIO COMPAS Linux cluster.

3. Experiment Setup

(1) Model Domain

Figure 1 shows model domain, coastline, bathymetry, and topography. Model domain extends about 1200 km along the US West Coast from northern Baja to north of San Francisco Bay. Over the ocean domain, bottom topography is obtained by bi-linear interpolation from ETOPO5 analysis, and smoothed with Shapiro filter to reduce pressure-gradient error near steep topography. Over land grids, topography includes Sierra-Nevada Mountains, and much smaller-scale local orography, which are dynamically/physically important factors in simulating precipitations and local wind patterns in this region. Horizontal resolutions are 12km and 20km for ROMS and RSM, respectively.

(2) Experiments

Fully coupled and uncoupled experiments are designed with different initial conditions and boundary conditions. Experiment details for RSM and ROMS are summarized in Table 1 and Table 2, respectively. Coupled run is initialized with the solution from uncoupled ROMS, which is though to be already spun up, using NCEP ocean analysis forcing, in order to help reduce initial spin-up problem. It is then integrated for 1 year of 1999, and data only from

* Corresponding author address: Hyodae Seo, Scripps Institution of Oceanography, La Jolla, CA 92093-0224; email: hyseo@ucsd.edu

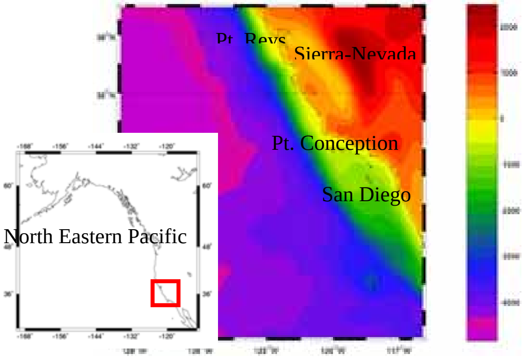

Figure 1. RSM and ROMS model domain and topography (m). Ocean topography is obtained by smoothing with Shapiro filter to keep the topographic slope below 0.2. Red rectangle shows this domain within a larger domain. Major geographycal locations are denoted in the map.

Apr 1 to Dec 31 are studied, allowing the first 3 months for spin-up. However, since we still believe the solutions presented here are degenerated due to the fact that 3-month is not long enough to be free from spin-up problem, we do not present here any verification of data against observations.

4. Analysis

Figure 2 shows time-averaged windstress curl from each experiment. Coarse-resolution analysis shows broader and smoother windstress curl pattern, while regional downscaled curls are more concentrated along the coastlines. High-resolution RSM windstress curls (Figure 2b,c) show spatial (and also temporal, not shown) patterns consistent with other observational and numerical studies in this region (e.g. Winant and Dorman, 1997, Koracin et al., 2004, Di Lorenzo, 2003); a strong positive windstress curl associated with coastlines and topography near the shore and weak or negative windstress curl far offshore. The simulated period from April to December 1999 is characterized by anomalously weak winds north of Point Conception and offshore, weak positive windstress anomaly in the Southern California Bight (Schwing et al, 2000), with resulting strong positive windstress curl anomaly. These wind anomalies favour enhanced upwelling during targeted period. It should be noted that relatively high windstress curl (Figure 2c) over the region of strong SST gradients (Figure 4c) offshore in the coupled RSM/ROMS experiment implies possible interaction of lower level wind field and SST field (Auad 2003, Chelton et al., 2004) at smaller scale, which does not occur in uncoupled experiments.

Net surface heat flux going into the ocean is plotted in Figure 3. It is calculated from sum of shortwave, longwave, latent, and sensible heat flux. Net heat flux is generally lower offshore where ocean is relatively warmer, and higher close to the shore where ocean is cooler due to upwelled water. Note that net surface heat flux (Figure 3c) also mimics the spatial pattern of SST (Figure 4c) in some areas, indicating the atmospheric boundary layer evolves in association with the oceanic state, thus important interaction between upper ocean thermodynamics and lower atmospheric boundary layer physics. There is also a marked difference of heat flux pattern between uncoupled (Figure 3b) and coupled (Figure 3c) runs in terms of magnitude and distribution.

It is also interesting to note that SST maps between coupled run (Figure 4c) and uncoupled run (Figure 4b) are quite different. Noting that difference between uROMS and cRSM are present only in atmospheric forcing, and since windstress and its curl are not very different except offshore and around Pt. Reyes, discrepancy of heatflux distribution and exchange of forcing across air-sea interface possibly produce discrepancy of SST.

In addition, 26.5 isopycnal depth from coupled run (Figure 5c) shows less meanders, more spatially coherent structure of California Current System (CCS) than uncoupled runs (cf. Di Lorenzo, 2003, Marchesiello et al., 2003). This implies that there is also a possible influence of air-sea exchange of forcing on dynamic structure of the upper ocean. Also note that isopycnal depth is shallower especially north of Pt. Conception in uncoupled ROMS (Figure 5b) than in coupled ROMS (Figure 5c). This suggests that upwelling should have been stronger in uncoupled case. Since SST distribution (Figure 4b) indicates that upwelling is not as strong as coupled runs (Figure 4c), or ncepROMS (Figure 4a), it is possibly the greater heatflux (Figure 3b) going into the ocean that is responsible for warmer SST (Figure 4b) by increasing upper ocean stratification, although we still do not have a clear clue as to why heatflux in uncoupled run (Figure3b) is greater.

	Description	IC	Lower BC	Lateral BC
ncep	NCEP Pacific Ocean Analysis*	-	-	-
uRSM	Uncoupled	Reanalysis 2	Reanalysis 2	Reanalysis 2
cRSM	Coupled	Reanalysis 2	3-hourly ROMS SST	Reanalysis 2

Table 1. Atmospheric Model Experiment-Setup. (*)NCEP Pacific Ocean Analysis data provided by the NOAA-CIRES Climate Diagnostics

	Atmospheric Forcing	IC	Lateral BC
ncepROMS	ncep	Levitus Climatology	Levitus Climatology
uROMS	uRSM	NcepROMS	Levitus Climatology
cROMS	cRSM	NcepROMS	Levitus Climatology

Table 2. Ocean Model Experiment-Setup

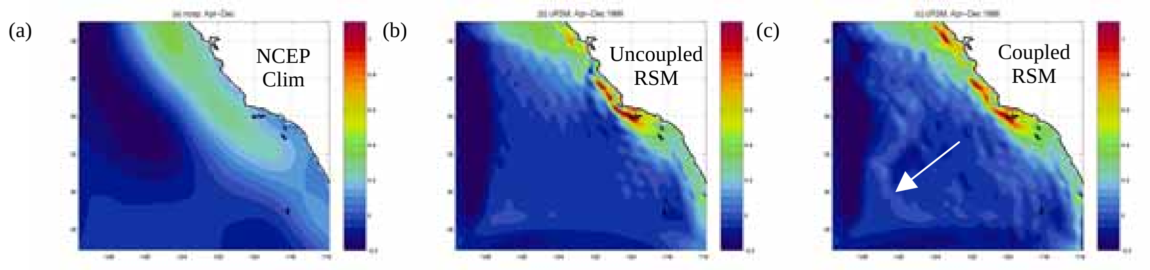

Figure 2. **Windstress Curl (10^{-6} N/m^3)** from April to December of 1999, (a) ncep, (b) uRSM, and (c) cRSM. Coarse resolution analysis (a) shows broader and smoother windstress curl pattern, while regional downscaled windstress curls (b and c) are more concentrated along the coastlines. Note that coupled RSM curl is intimately linked to strong SST gradients (Figure 4c).

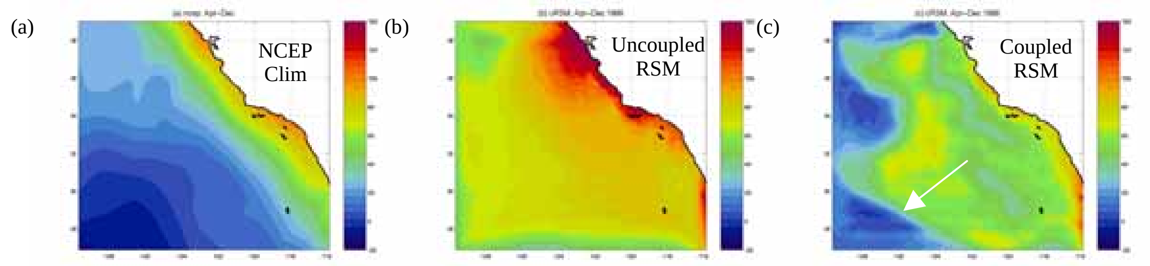

Figure 3. **Surface Net Heat Flux (W/m^2)** from April to December of 1999, (a) ncep, (b) uRSM, and (c) cRSM. Net heatflux is calculated from sum of shortwave, longwave, latent, and sensible heat flux. General heatflux pattern is low offshore where ocean is warm, and high close to shore where ocean is cool due to upwelled water. Coupled run heatflux(c) shows more consistent pattern with SST distribution (Figure 4c), and reflects more regional details of the ocean surface.

5. Conclusions and Outlook

Despite of the nature of our experiments that keep us from verifying our data against observations available in this region, we were at least able to isolate the evidence of possible interactions between lower atmosphere and upper-ocean. Fully (3-hourly) coupled simulation reveals that lower atmospheric boundary layer physics are intimately related to upper ocean thermodynamics; the most intense gradients of windstress curl and net heatflux are located over the region of the strongest SST fronts. We also found that lower layer meteorology closely interact with upper ocean dynamics that is represented by 26.5 isopycnal-depth.

Since we have only one realization and 1-year simulation, more rigorous and quantitative argument and analysis cannot be made. Certainly, we are planning to make long-term, ensemble simulations at various coupling frequency to investigate the long-term co-variability of the ocean current such as CCS with the atmosphere and its sensitivity to forcing at different time-scale, and to assess the model's

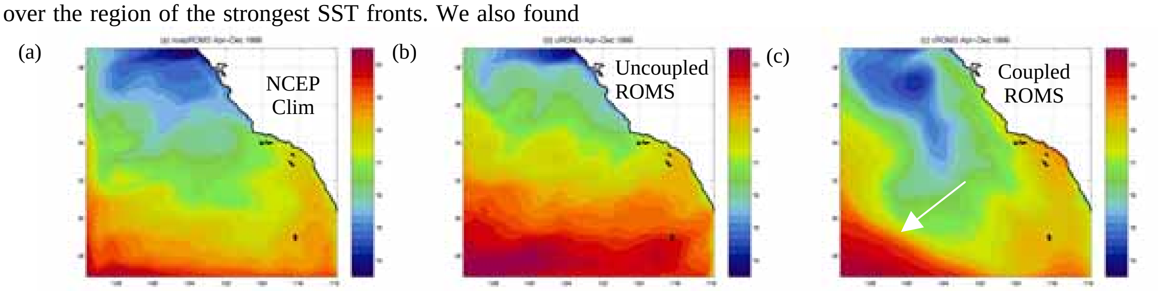

Figure 4. **Sea Surface Temperature (C)** from April to December of 1999, (a) ncepROMS, (b) uROMS, and (c) cROMS. SST distribution from coupled run(c) spatially corresponds relatively well to windstress curl and surface heatflux, suggesting the interaction between upper ocean thermodynamics and lower atmospheric boundary layer physics

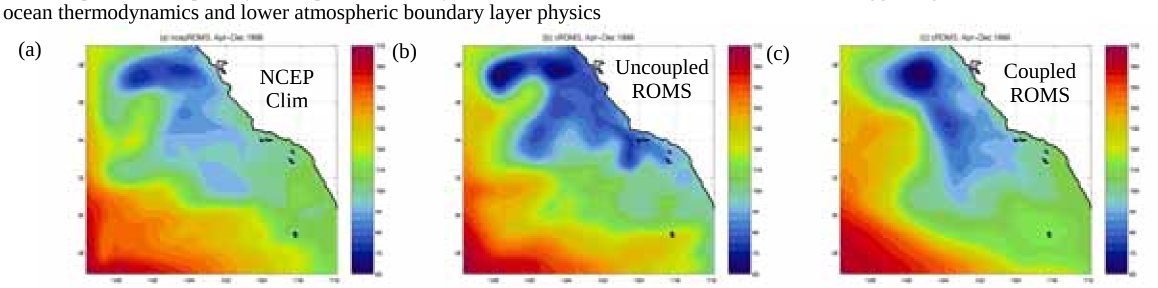

Figure 5. **26.5 Isopycnal Depth (m)** from April to December of 1999, (a) ncepROMS, (b) uROMS, and (c) cROMS. A current structure from coupled ROMS run(c) shows less meanders and smoother California Current System (CCS). This is an evidence of possible influence of air-sea exchange of forcing on dynamic structure of the ocean.

capability of producing skillful hindcast. This long-term model outputs also could be used as initial and boundary conditions for separate coupled simulations. In addition, we plan to implement bulk parameterizations to calculate the atmospheric forcings in order to account better for sea surface and lower meteorological state. We believe bulk parameterization can lead to more stable integration.

References

Auad, G., 2003: Interdecadal dynamics of the North Pacific Ocean. *J. Phys. Oceanogr*., **33**, 2483-2503

Chelton, D. B., Schlax, M. G., Freilich, M. H., and Milliff, R. F., 2004: Satellite measurements reveal persistent small-scale features in ocean winds. *Science*, **303**

Di Lorenzo, E., 2003: Seasonal dynamics of the surface circulation in the Southern California Current System, *Deep-Sea Res. II*, **50**, 2371-2388

Juang, H.-M. H., and M. Kanamitsu, 1994: The NMC nested regional spectral model, *Mon. Weather Rev*., **122**, 3-26

Juang, H.-M. H., S. –Y. Hong, and M. Kanamitsu, 1997: The NCEP Regional Spectral Model: An Update, *Bull. Am. Meteorol. Soc*., **78**, No 10.

Koracin, D., Dorman, C. E., and Dever, E. P., 2004: Coastal perturbations of marine-layer winds, winds stress, and wind stress curl along California and Baja California in June 1999. *J. Phys. Oceanogr*., **34**, 1152-1173

Marchesiello, P. Mc Williams, J. C., and Shchepetkin, A., 2001: Open boundary conditions for long-term integration of regional oceanic models. *Ocean Modelling*, **3**, 1-20

Marchesiello, P., McWilliams, J. C., and Shchepetkin, A., 2003: Equilibrium structure and dynamics of the California Current System. *J. Phys. Oceanogr*., **33(4),** 753-783

Schwing, F. B., Moore, C. S., Railston, S., Sakuma., and K. M., 2000: Coastal upwelling in California Current, 1999. *CalCOFI Report*, **41**

Shchepetkin, A., and McWilliams, J. C., 2003: The regional ocean modeling system: a split-explicit, free-surface, topography-following coordinate ocean model. *J. Geophys. Res*., submitted for publication

Song, Y. T., and D. B. Haidvogel, 1994: A semi-implicit ocean circulation model using a generalized topography following coordinate system. *J. Comput. Phys*., **115**, 228-248

Winant, C. D., Dorman, C. E., 1997: Seasonal patterns of surface wind stress and heat flux over the Southern California Bight. *J. Geophys. Res*. Ocean, **102(C3),** 5641-5653