Multiscale Study of Currents Affected by Topography

Bruce D. Cornuelle
Scripps Institution of Oceanography
University of California San Diego
Mail Code 0230
La Jolla, CA 92093-0230
Phone: (858) 534-4021   Fax: (858) 534-9820   Email: bcornuelle@ucsd.edu

LONG-TERM GOALS

This work seeks to understand the effects of topography on the ocean general and regional circulation with a focus on the wide range of scales of interactions. The small-scale details of the topography and the waves, eddies, drag, and turbulence it generates (at spatial scales ranging from meters to mesoscale) interact in the boundary layers to influence the ambient larger-scale flow. We have studied these issues through ocean model simulations, adjoint sensitivity experiments, and state estimation using ocean observations in the region surrounding an island in the westward-flowing limb of the subtropical gyre.

OBJECTIVES

The objectives of this program include addressing number of questions on ocean circulation that arise near islands and abrupt topography. Questions to study include:

- What is the steady-state flow around the feature, including isopycnal depths, currents, and water mass characteristics? How do these vary with changes in the surrounding large-scale flow and atmospheric forcing?

- What is the response of the local flow to time-dependent large-scale flow? i.e., how does the feature scatter incoming barotropic and baroclinic Rossby waves (as well as near-inertial waves and tides), into outgoing waves, mean flows, and topographically-trapped and damped waves?

- How much can be learned about the regional circulation or the larger scale currents from local observations? Can they be used for linear or nonlinear inverse estimates? i.e., can the regional or gyre circulation be monitored from pressure gauges, temperature sensors, current meters, or other measurements near the feature?

- The influence of the boundaries on the flow in the nested inner model can also be turned around to study how the feature influences the larger-scale boundary flow. Example questions are: what form drag is exerted on the larger scale flow? How far eastward, or "up-current" does the influence of the feature extend? How turbulent are the wakes? Are eddies shed? If so, do shed eddies create counter-currents in the wake of the feature?

APPROACH

We are exploring and answering these questions through numerical model-based data analysis, including state estimation in nested domains. We use assimilated global HYCOM/NCODA to supply ocean model initialization and boundary conditions for the MIT general circulation model (MITgcm) in nested domains starting from basin scale, connected to high-resolution (sub km) inner domains modeled with Delft3D or ROMS within about a degree of the island which will be configured and run by other investigators. Our results will be used in collaboration with other investigators to plan the experiments and to help to understand the observations. We will use the ocean models to provide a dynamically-consistent re-analysis of the observations in the region, both from the experiment and from other sources (Argo, Altimetry, SST, TAO, etc.).

WORK COMPLETED

We have experimented with assimilation window lengths and the viscosities of the forward and adjoint model simulations to see which combinations give the best hindcast fits and which give the best forecasts. Some selected examples are shown in Figure 1, which shows the root-mean-square difference (*RMS*) between the mapped AVISO sea surface height (SSH) and various model-based estimates, averaged over the region of interest $122^0 - 170^0$ E, $5^0 - 20^0$ N. For this particular example, a one-month assimilation window has similar hindcast skill as that of a two-month assimilation window, with only very small decrease in the *RMS* difference in March and an increase in difference in April. This result was not expected because the shorter window was thought to be easier to fit than the longer window. This may be due to particular aspects of this example, which could be checked through additional experiments. The forecasts for May 2010 from the one- and two-month state estimates (Figure 2) show that the shorter estimate is better during the first two weeks of the forecast period, and the longer estimate is better during the latter two weeks. This is expected, since the longer-term state estimate is constrained with more observations and should provide a better overall ocean state, but possibly with larger misfits at any given time, so the forecast starts out worse and then improves over time. On the other hand, the MITgcm forecast initialized from pure HYCOM/NCODA shows that HYCOM/NCODA has the best ocean state for SSH prediction for this region during this time for the chosen viscosity and diffusivity parameters. Comparison to other observations, such as gliders, will be helpful to assess the model skill more broadly. The viscosity in both the state estimation and the forecast simulations has a significant effect on the model-data differences. Lowering the viscosity of the adjoint to be as low as possible while still allowing backward integration for one or two months with usable gradients showed an improvement in hindcast and forecast skill (Figure 3). For the forecast runs, higher viscosities produced better long-term prediction errors at the expense of larger short-term errors (not shown).

We have provided statistics of current variability to the observers to aid in planning cruises and siting measurements, including up-to-date state estimates of the region to examine current conditions.

RESULTS

We have traced the pathways of control of the regional ocean circulation for a variety of regions through the waveguides created by beta, currents, and topography. We have also optimized the state estimation of the region through sensitivity experiments with assimilation window length and viscosity.

IMPACT/APPLICATIONS

We can provide a skillful hindcast and reanalysis for experiment planning and to synthesize observations together.

RELATED PROJECTS

FLEAT DRI

OKMC DRI

NOPP program on modeling with abrupt topography

REFERENCES

PUBLICATIONS

Edwards, CA, Moore AM, Hoteit I, Cornuelle BD. 2015. Regional ocean data assimilation. Annual Review of Marine Science, Vol 7. 7:21-42.   10.1146/annurev-marine-010814-015821
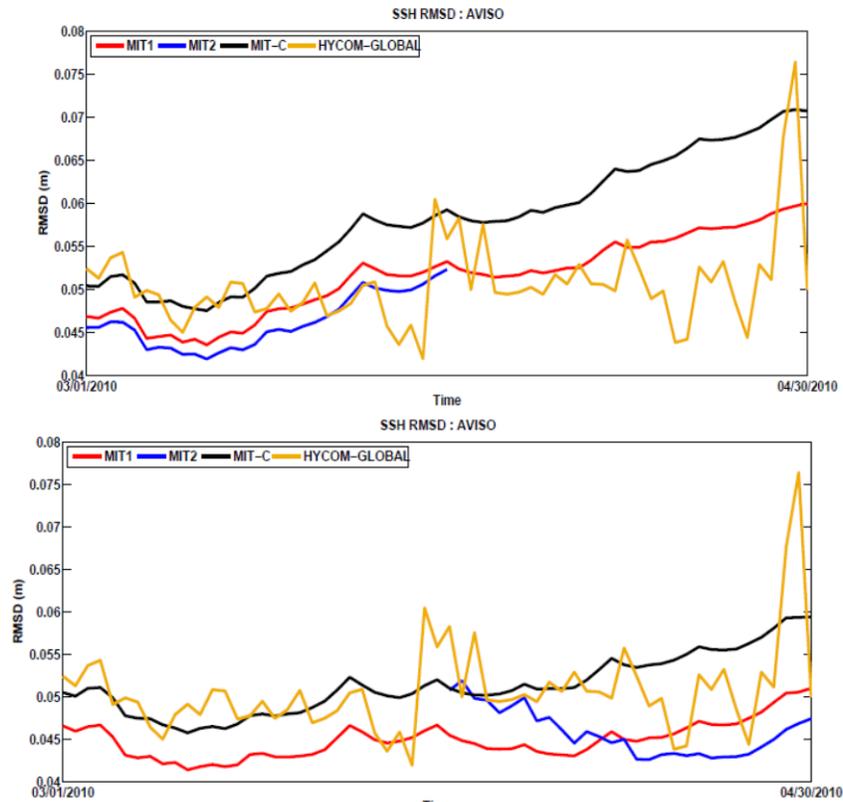
Figure 1 a,b: Comparison of AVISO mapped SSH for the region with a set of state estimates. The horizontal axis is time for March 1 2010 through April 30 2010. The vertical axis is the root-mean-square (RMS) difference between the state estimates and the mapped AVISO SSH averaged over the region $122^0 – 170^0$ E, $5^0 – 20^0$ N. Differences for one-month state estimates for March 2010 (blue line in top figure) and April 2010 (blue line in bottom figure) are compared to a two-month state estimate (red line, same in both figures). The RMS difference between AVISO and the HYCOM/NCODA global analysis is the gold line in both figures, while the black line is the RMS difference with a run initialized by HYCOM/NCODA and with HYCOM/NCODA boundary conditions, but without assimilation, which is the reference skill that we are trying to improve on. The two sets of state estimates (top and bottom panel) are simulated with different combination of forward and adjoint model viscosities.
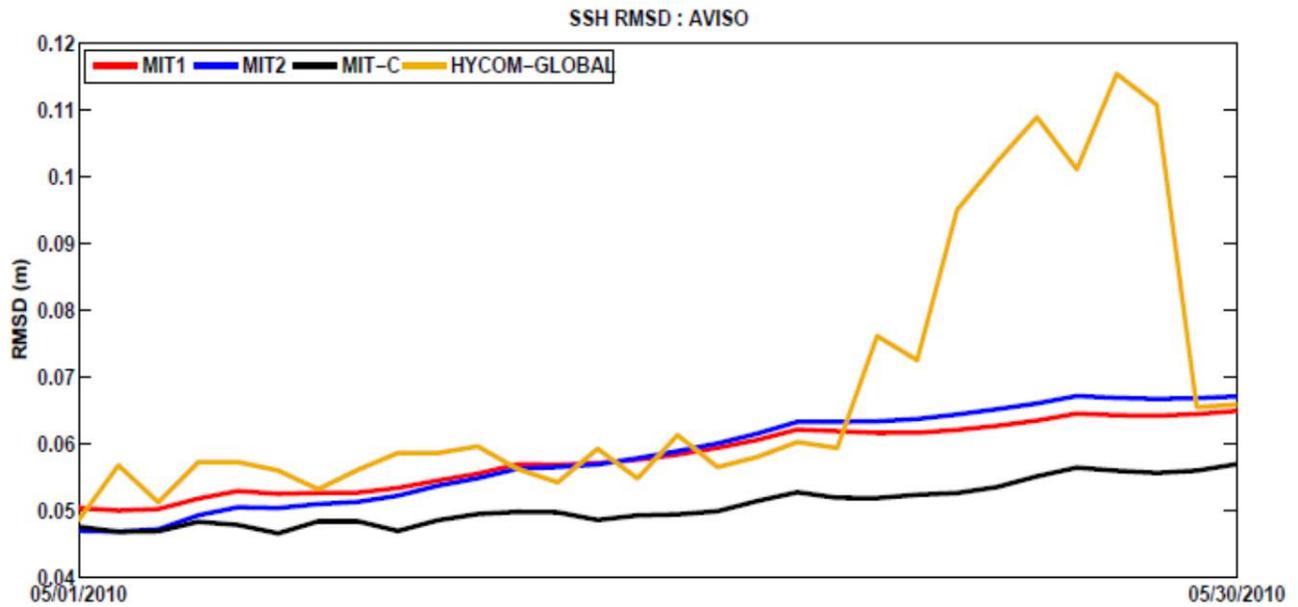
Figure 2: Same as Figure 1, but for RMS differences for forecasts (from Figure 1 bottom panel state estimates) from a one-month state estimate for April 2010 (blue line) and a two-month estimate for March through April 2010 (red line). The black line is now a MITgcm forecast initialized from the HYCOM/NCODA state on April 30, and the gold line is for the daily HYCOM/NCODA global analysis as in Figure 1. Note that the state estimate outperforms HYCOM/NCODA analysis in this case, but the forecast from the HYCOM/NCODA initial state has the least difference
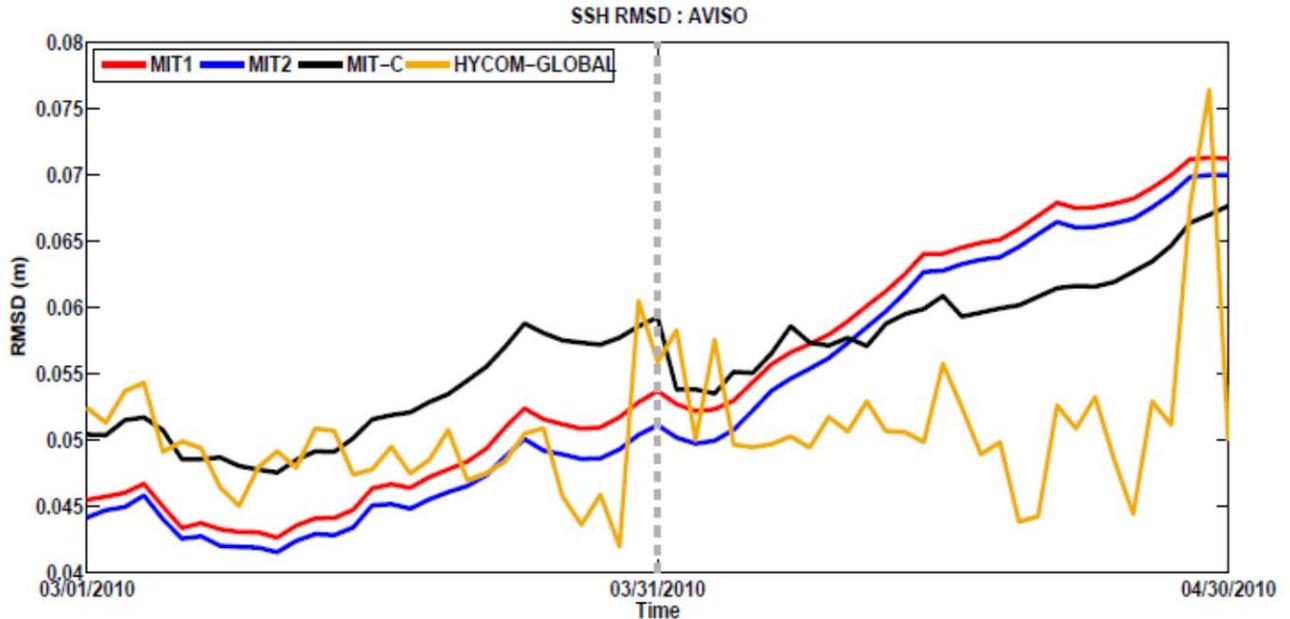

Figure 3: Same as Figure 1, but for RMS differences for hindcasts and forecasts (to the left and right of the vertical dashed grey line, respectively) from a one-month state estimate for March 2010 at viscosities of 5000 m^2/s (red line) and 500 m^2/s (blue line) as well as HYCOM/NCODA analysis and control hindcast/forecasts (gold and black lines, respectively). Forward simulations used viscosities of 100 m^2/s in all cases.