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Data Assimilation and Diagnostics of Inner Shelf Dynamics

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LONG-TERM GOALS

Our long-term goal is to develop a nested implementation of Regional Ocean Modeling System (ROMS), including a surface wave model, that simulates the processes that control stratification and currents in a theoretical inner shelf region, including the capability for 4Dvar data assimilation and Generalized Stability Analysis tools to diagnose simulated and observed ocean variability on the inner shelf. The region of interest currently corresponds to the Point Sal beach off the coast of Point Conception, which was the site of the Inner Shelf DRI Pilot Study in June-July 2015.

Our goal is to identify the dominant balances controlling the components of flow associated with *surface-forced & wave-forced response* (winds, heat fluxes, surface waves, etc.), *boundary-forced response* (tides, coastal currents, deep ocean currents, surf zone flows etc.) and *intrinsic variability* (instabilities, internal wave propagation, etc.) of the flows of the inner shelf in high-resolution (~100m-1km lateral resolution) ROMS simulations of observed fields in the Inner Shelf DRI field campaigns (as well as in any previous observational programs in the same region).

OBJECTIVES

The objectives and immediate scientific goals of the proposed research are:

1. *Develop and test a nested Inner-Shelf ROMS, including outer-shelf and surf zone regions for process studies in anticipation of deploying instrumentation as part of the Inner Shelf DRI.*
2. *Develop and test Generalized Stability Analysis applications of the model for understanding sensitivities of the flows in the Inner Shelf to perturbations associated with local internal instabilities and coupling with the variations occurring in the surf zone, outer-shelf and surface forcing.*

3. *Develop and test 4DVar ocean data assimilation applications of this model for fitting oceanic variables observed in the planned Inner Shelf DRI field campaign.*

APPROACH

We are working as a team to develop the nested ROMS in the Inner Shelf domain to study the dynamics controlling Inner Shelf variations and its sensitivities as members of the ONR Inner Shelf DRI. This is a fundamentally collaborative proposal that involves close collaboration with Dr. Arthur J. Miller of Scripps Institution of Oceanography, UCSD. The results presented here include collaborative work involving Di Lorenzo, Haas and Miller, along with Georgia Tech Ph.D. student Ms. Donghua Cai (model analysis, development and execution) and SIO post-docs Dr. Ata Suanda (model analysis and data comparison) and Dr. Nirnimesh Kumar (model development and execution), because we have discussed, instigated and synthesized each others' research activities and results by keeping in close contact via email, video conferernces and by meeting at Georgia Tech and conferences during the past year since the funding commenced.

The primary questions we are addressing include:

1) What processes are most important in controlling along-shelf variability in stratification and currents (including boundary and surface forcing (wave, wind and diurnal surface heating), bottom roughness etc.)?

2) What sources of the inner shelf variability arise from conditions within the inner shelf directly?

3) What sources of variability are transmitted through the boundaries of the margins of the inner shelf with either the surf zone (e.g. via rip currents) or the mid-shelf region (e.g. incoming wave fields, currents, eddies, etc.)?

4) What are the predictability of circulation structures in the inner shelf and their dependence on initial vs. boundary conditions?

5) What is the potential role of sub-mesoscale structures in the inner shelf circulation?

After building the model domain, we primarily focus on forward modeling, spinning up the flows in the domain and testing for stability of the integration schemes. After the model flows are shown to exhibit realistic behavior in terms of eddy structures on the shelf, rip currents across the surf zone, longshore flows, etc., we test sensitivities of the inner shelf circulation and stratification to various forcing functions associated with the June-July seasonal time frame. This includes: Wind direction changes, boundary current inflows and outflows, internal wave generation at the shelf break, and incoming swell from the SW. We also plan to address diurnal heating versus steady heating by solar radiation and diurnal sea breeze effects.

Our analysis of these forward runs is aimed at characterizing the vertical structure of the temperature and currents on the inner shelf in terms of it mean state and intermittency, especially as it may affect density and acoustic propagation.

After the forward-run analysis is completed, we plan to develop the procedure for using the ROMS Generalized Stability Tools in this domain. Metrics will be defined to quantify sensitivities to changes in the forcing functions. For example, a rip current intensity index will be developed along with a cross-shelf transport index at the inner-shelf-surf zone boundary. After choosing time intervals appropriate for following the model trajectory with the tangent linear and adjoint models

over quasi-linear periods (this may be hours, days or weeks, depending on the process involved), we will directly compute the gradients associated with change in wind stress, boundary current forcing, surface wave stress, etc. See Moore et al. (2009) for how this procedure is invoked.

WORK COMPLETED

During the past year, we have contributed to the following subset of accomplishments of the multi-institutional team:

- **a.** Developed a theoretical inner-shelf dynamical and thermodynamical framework that includes all the processes that are expected to be important (led by Miller, SIO, with Di Lorenzo and Haas, GaTech)
- **b.** Constructed a 4-tiered nested model of ROMS for the Point Sal region (led by Di Lorenzo and Haas, GaTech, with Miller, SIO)
- **c.** Tested sensitivity to surface forcing by winds and heat fluxes (led by Haas and Di Lorenzo, GaTech, with Miller, SIO)
- **d.** Executed a hindcast for summer 2000 and compared the results with the limited obverstaion at that time (led by Haas and Di Lorenzo, GaTech, with Miller, SIO)
- **e.** Communicated the results to Inner Shelf DRI observational oceanographers who placed their instrumentation in the key regions that the model results suggested were most interesting (led by Di Lorenzo and Haas, GaTech, with Miller, SIO)
- **f.** Commenced hindcast for summer 2015 to directly compared the results with observations collected during the Inner Shelf DRI Pilot Study (led by Haas and Di Lorenzo, GaTech, with Miller, SIO)

RESULTS

The following summarizes our most interesting and important results during the previous year of collaborative research under this research project.

The Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) modeling system is being used to perform the simulation in this study (Warner et al., 2010). The COAWST modeling system couples ocean circulation model ROMS, wave model SWAN, atmospheric model WRF and sediment transport model, and simulate exchange between all model components. In this study, only ROMS-SWAN coupling is switched on to simulate the processes that control the interactions between outer shelf, inner shelf and the surf zone.

The model system is configured with four nested grids with resolutions ranging from approximately 600m, which is embedded in a 1km ROMS grid, to the outer shelf (~200m) to the inner shelf (~66m) and finally to the surf zone (~22m). The domain is oriented north-south for all grids with open boundaries to the west, and north and south (see Figure 1 below). Forty-two vertical terrain following layers in ROMS sufficiently resolve for the vertical structures of the currents and stratification (reduced to 15 layers in the 22m grid to maintain stability). Bathymetric data for the model was extracted from NOAA's National Geophysical Data Center (http://maps.ngdc.noaa.gov/viewers/wcs-client/) with approximately 1-arc-second resolution.

A 15-year forward model simulation with approximately 3km resolution (Figure 2) has been provided by Prof Chris Edwards' research group from University of California, Santa Cruz. This hindcast model information is incorporated as the initial and boundary conditions for the 1km grid. The solution of the 1km grid provides boundary conditions for the inner 600m grid. Additionally, barotropic tidal elevation and velocities are extracted from ADCIRC tidal database and interpolated to the lateral boundary of the 600km grid as boundary forcing. Since the COAMPS wind field is used by UCSC to force their model, we also use this surface momentum and heat flux forcing for our grids, interpolated from the UCSC model grid.

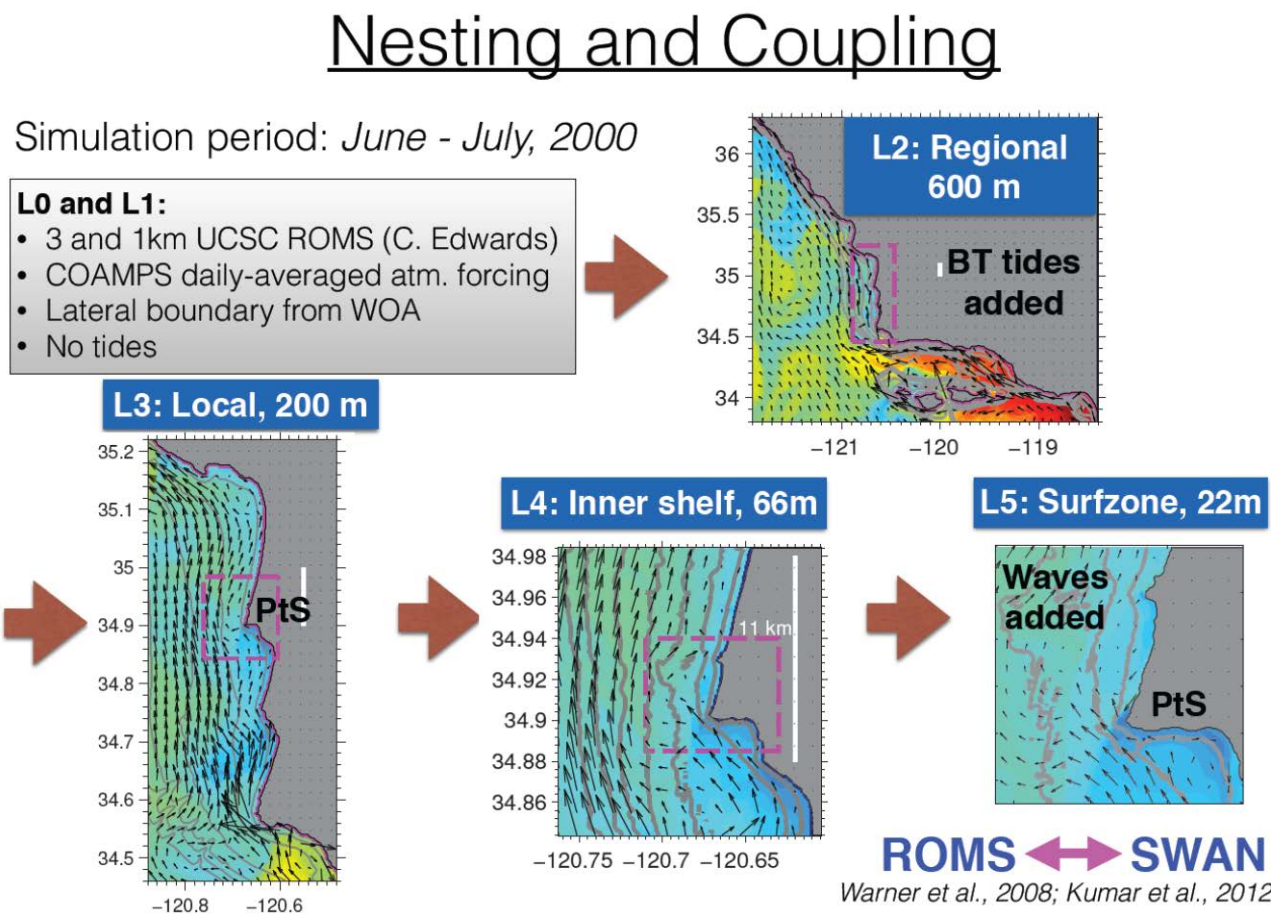

Figure 1: Nesting and coupling strategy showing the 4 nested model grids with resolutions.

We focused on summer 2000, when there was at least some *in situ* data to compare with the model. Figure 2 shows a comparison of currents and temperature from a mooring located off Point Sal. The model produces remarkably good representation of the flow, both from tides and large-scale currents. Note that mesoscale eddies can occur intrinsically in the model and observations (with no phase information) so perfect agreement is not expected. Also, a preponderance of internal tides signals are evident in both the model and observations. They are associated mainly with local generation by the smalls-scale topographic feature over the shelf. Suanda et al. (2015) are currently engaged in analyzing many aspects of these temperature and velocity fields to diagnosing controlling influences, e.g. the impact of resolution and surface wave processes on the circulation (Figure 3).

In summary, we found that both local and remote forcing contribute to Inner Shelf dynamical processes. Multiple nests and wave-circulation coupling are needed to properly simulate realistic

inner-shelf variability, and topographic variations reduce along-shelf homogeniety. We are currently analyzing the simulated results from summer 2015 when Pilot Study data is available.

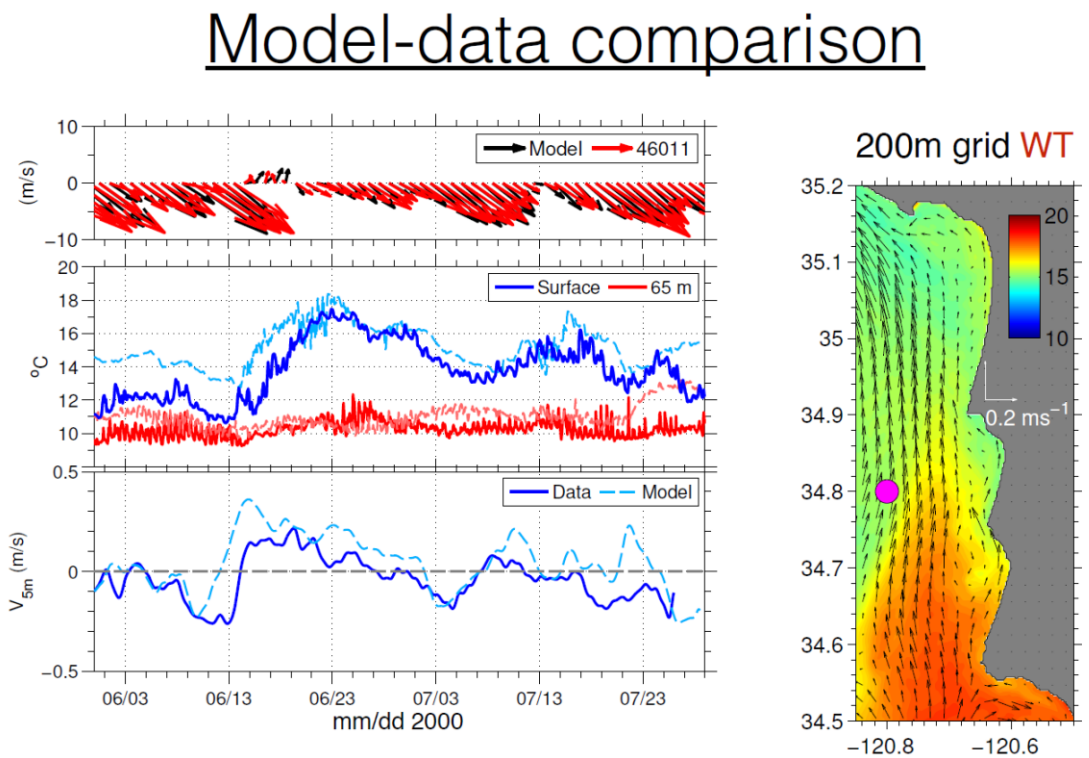

Figure 2: Comparison of the nested ROMS model output from June-July 2000 with available observations off Point Sal from Winant et al. (2003) and Washburn et al. (2011). Top of left panel shows COAMPS model winds used to force ROMS and NDBC buoy 46011 daily-averaged wind vectors. Middle left panel shows ROMS output (L3 grid simulation at 200m) compared to SBCSMB mooring in 100m water depth, with temperature at the surface (blue) and at 65m depth (red); model results are the dashed lines with lighter colors. Lower left panel shows subtidal (> 33 hour) north-south velocity at 5m below the surface. Right panel shows location of mooring in a snapshot of the simulated flow during that time period.

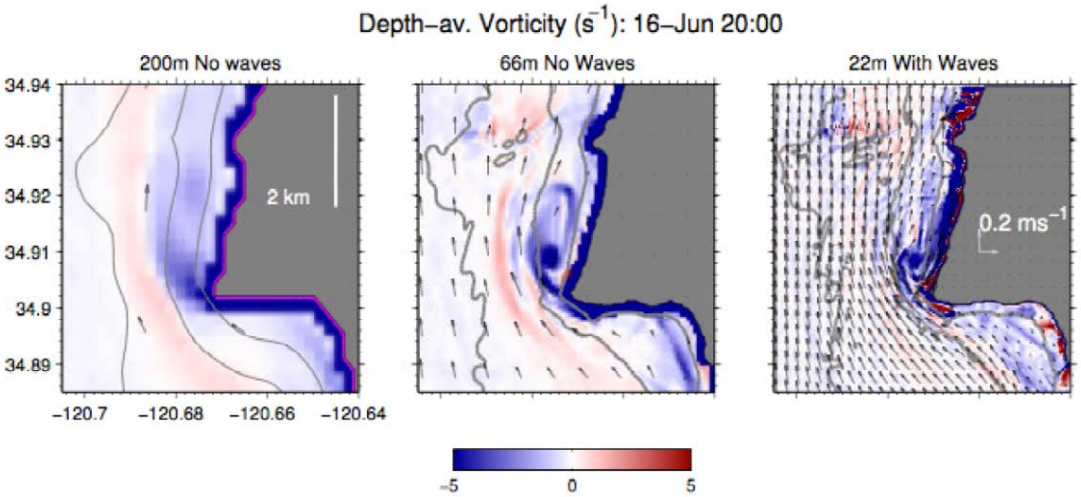

Figure 3. Hourly snapshots of depth-averaged vorticity (x10^{-4} s^{-1}) from three simulations on three different grids. Black arrows are depth-averaged velocity plotted every 10th grid point in each simulation. Left: No waves at 200m resolution. Middle: No waves but at higher (66m) resolution. Right Including surface wave forcing at 22m simulation, from the coupled ROMS-SWAN solution.

IMPACT/APPLICATIONS

We currently have an active collaboration with coastal oceanographer Dr. Falk Feddersen, who is a part of the Inner Shelf DRI, as well as with several of the other observationalists involved in the DRI. We teleconferenced with them many times (quasi-weekly) to assess the results of the modeling study in the context of where to deploy instrumentation on Point Sal. We also have a very active collaboration with UC, Santa Cruz, ROMS modeler Prof. Chris Edwards who provided large-scale ROMS simulations during the relevant time periods. We are also initiating new collaborations with UCSC ROMS scientist Prof. Andy Moore and his student Mr. Will Crawford on developing and applying GSA and data assimilation strategies for these simulations.

The results will be useful in determining what processes need to be observed and what resolution of instrumentation need to be placed in the field during the intensive Inner Shelf DRI field campaign.

RELATED PROJECTS

There are no related projects in which we are involved.

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PUBLICATIONS

Suanda, A., N. Kumar, A. J. Miller, E. Di Lorenzo, K. Haas, D. Cai, C. Edwards, and F. Feddersen, 2015: Modeling multi-scale exchange processes on a realistic inner shelf. In preparation.