Collaborative Proposal: Oceanic Energy Cascade from Global to Regional Predictive Models

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LONG-TERM GOALS

Understanding the evolution and fate of energy and momentum injected into the ocean is crucial to developing our knowledge of ocean predictability and dynamics. Steep ridges, islands, and atolls in the ocean scatter waves and convert energy and momentum at a variety of scales, from long Rossby waves through mesoscale, sub-mesoscale, and internal waves. This energy injected at the steep ridges has significant implications for global and regional ocean prediction. Models with insufficient resolution, or which lack the physics of the energy cascade will miss the topographic effects and suffer a drop in its predictive skill. These localized effects may play an important role in the basin-wide circulation that is currently predicted by the Navy's global HYCOM/NCODA system.

OBJECTIVES

The ONR-funded FLow Encountering Abrupt Topography (FLEAT) project aims to understand how the ocean structure and evolution is altered by steep ridges and islands at the full range of length scales in the western tropical Pacific region encompassing Palau and Guam. In cooperation with this project, we will use models to examine how the cascade of momentum, energy, and enstrophy due to topography impact global and regional predictive skill in the FLEAT region, with a focus on the Navy HYCOM model. We will use a state-of-the-art numerical model and advanced state estimation techniques to reproduce the flows in the FLEAT region by fitting the ocean circulation models to observations. Our goal is to examine the effects of local momentum and energy conversion at and near ridges, how the enstrophy affects local ridge processes, and how these processes affect lower wavenumbers away from the ridge in the open ocean.

APPROACH

In collaboration with FLEAT observationalists, NRL-Stennis HYCOM scientists, Brian Powell at the University of Hawaii, Pierre Lermusiaux at MIT, and other modelers, we will use 4D-Var data assimilation methods to produce accurate ocean state estimates for comparison to HYCOM. We will diagnose key processes such as form stress, energy conversion, and enstrophy conversion in state estimates for comparision with the same processes in HYCOM at the same locations and time. We will identify regions and mechanisms that exert strong influence on the outer model.

WORK COMPLETED

We use the MITgcm ocean model at a variety of resolutions nested in the 1/12 degree global HYCOM/NCODA system. We are making hindcasts of the ocean in the region of the FLEAT experiment using four-dimensional variational state estimation for an improved estimate of the regoinal processes.

We have constructed nested grids from 1/6 to 1/48 degree resolution and have carried out state estimates at the lower resolutions for the early part of the FLEAT experiment. We have been using only the standard global observing system data, including satellite SSH and SST, as well as Argo (T and S), CTD (T and S), and XBT (T) profiles, along with Spray glider (T and S) profiles. These state estimates can then be compared to the FLEAT observations as cross-validation before assimilating them. We are comparing our estimates with independent observations and refining our modeling and assimilation.

We have upgraded our 1/6 degree 4D-Var state estimation in the largest, basin-scale domain to use longer time windows (up to 4 months) with the expectation that it will provide better representation of the large-scale ocean state and provide extended analysis that are dynamically consistent. This is a strong test of model dynamics and model errors may degrade the fit to observations compared to what is possible with shorter-duration estimates, including sequential NCODA used in HYCOM.

We have used the ONR computing allocation to run a variety of regional models to compare results, although changes in the Navy HPC software stack have caused some delays. We are testing a state estimate on 1/12 degree grid that covers the same region as the 1/6 degree outer state estimate but uses the topography from D.S. Ko (Naval Research Laboratory Digital Bathymetry Data Base 2-minute resolution: NRL DBDB2, Figure 1) and will compare and contrast the two estimates. The 1/12 degree grid estimates will then be used for forward simulations at 1/24 and 1/48 degree resolution. The 1/6 degree state estimation has been extended through September 2016 to provide context for the observational efforts and to compare to the glider observations to understand the effects of resolution. We have adapted a technique to diagnose form stress in the model and are exploring the details highlighted by this aspect of the dynamics.

RESULTS

Dynamically-consistent state estimates have been extended to 4 months duration, which provides a measure of model error and the residence time of information in the domain. These state estimates cover 2015 through September 2016. They are the starting step in the nested approach, to be compared to 1/12 degree assimilation in ROMS and the MITgcm which is now underway. Atmospheric forcing and open boundaries play significant roles in the model control of the state estimate, since initial conditions cannot control time ranges longer than about a month in this strong, eddy-active study region. Figure 2 shows SSH root-mean-square difference (RMSD) with gridded AVISO from a 4 month hindcast for September-December 2015, during the time of parallel glider missions north of Palau on either side of the Guam-Palau Ridge (Figure 3). Figure 4 shows the comparison between the estimated and observed temperature from the glider tracks. The RMSD was decreased from 1 degree to 0.5 degree Celcius by the state estimate, which still managed to fit the SSH (Figure 2). Salinity RMSD also decreased from 0.09 to 0.06 psu in the fit (not shown). The resulting vertically-averaged 0-1000 m velocity time mean and standard deviation are shown in Figure 5, showing enhanced variability downstream, but this model is too coarse to accurately model the fine-scale local ridge processes. The fit to the glider observations near the Palau ridge may be limited by the model resolution, which will be explored by the higher-resolution state estimate.

Form stress was diagnosed in a hierarchy of model runs with increasing resolution for the same region around Palau. Form stress was seen to be strongly dependent on the model resolution. Figure 6 shows form stress integrated from the surface to 417 m depth for a 1/24 and a 1/12 degree forward model simulation for the Palau region.

IMPACT/APPLICATIONS

The benefits of this work will be improved Navy ocean hindcasts and forecasts in regions of abrupt topography and strong zonal current. These can be used for improved underwater navigation, SONAR systems performance estimates, and underwater communications. We will work with NRL to improve their HYCOM/NCODA representation of the region and perhaps their data assimilation methods.

RELATED PROJECTS

NRL HYCOM/NCODA global ocean analysis: we are working to improve their representation of the effects of topography.
Brian Powell, University of Hawaii, "Collaborative Proposal: Oceanic Energy Cascade from Global to Regional Predictive Models" We are working together to make complementary and comparable state estimates for use by the observationalists.
Pierre Lermusiaux, MIT: We will also compare and contrast state estimates with the MIT group.
FLEAT DRI: We will work with other modelers and observers to produce a good hindcast/synthesis of the observations for best diagnosis of the important processes.

FIGURES

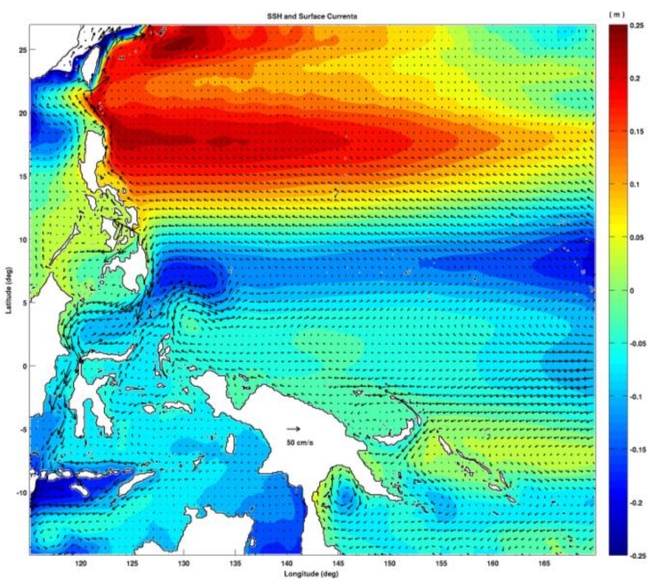

Figure 1: Model domain for the 1/6 degree and 1/12 degree basin-scale models. The figure shows time-mean SSH (color) in meters and time-mean current velocity (arrows) in cm/s for a 2009-2014, 1/12 degree basin-scale forward model simulation.

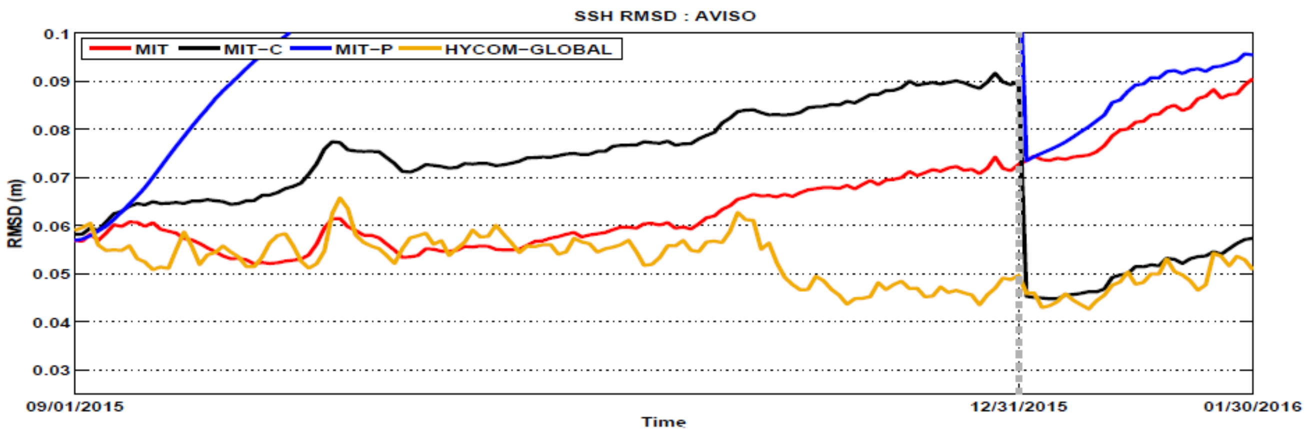

Figure 2: Daily root-mean-square difference (RMSD) in meters between model and AVISO SSH averaged over the assimilation domain (122E to -170E, 5N to 20N) for the 1/6 degree state estimate (red), HYCOM global analysis (gold), an MITgcm forecast initialized from HYCOM global analysis (black), and model persistence (blue) for the hindcast period (September - December, 2015) and forecast period (January, 2016). The hindcast and forecast periods are separated by the vertical gray dashed line.

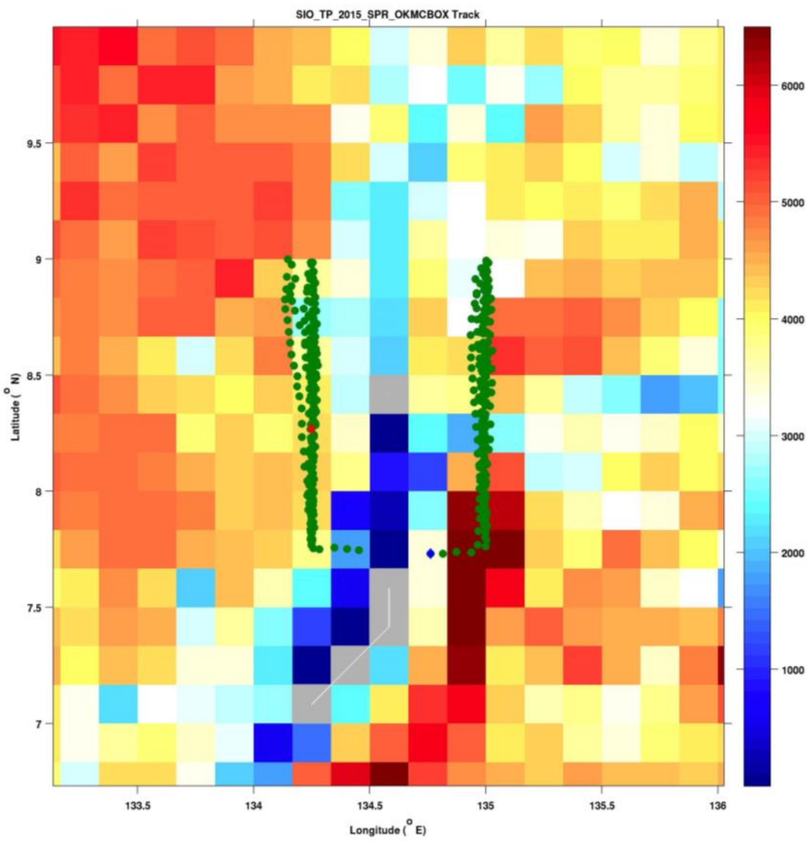

Figure 3: Glider trajectory for September -December, 2015 (green dots), superposed on the topography (color) in the 1/6 degree model.

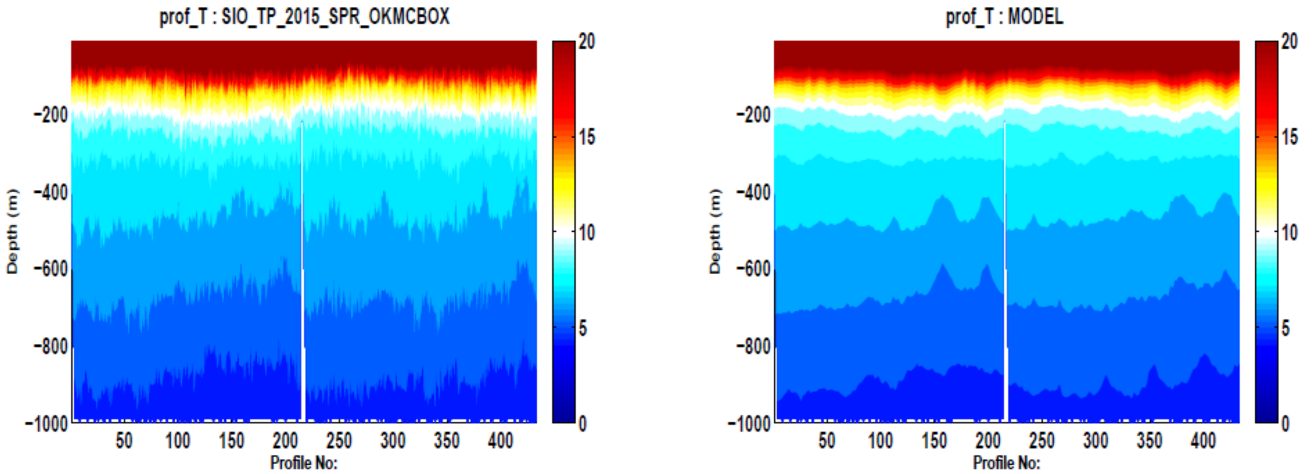

Figure 4: Glider comparison with model temperature for the 4 month state estimate. The left panel is the glider temperature along depth (m) vs glider profile number for both glider tracks, with profile numbers for the East glider track and then the West. The root-mean square difference (RMSD) between glider and model was reduced by the state estimate from 1 degree to 0.5 degree Celcius.

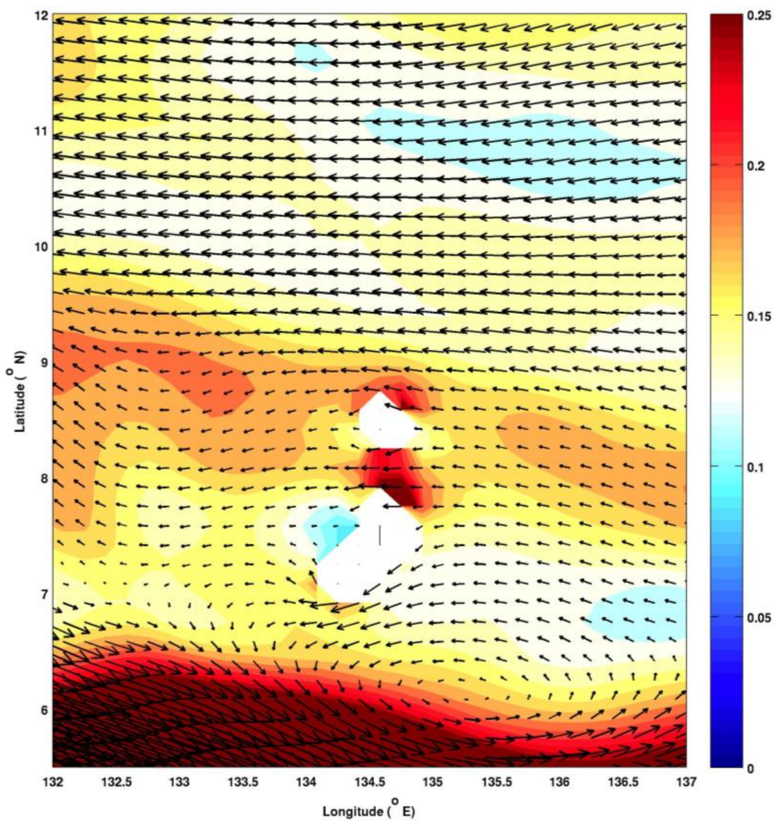

Figure 5: Mean (arrows) and standard deviation (color) of depth-averaged velocity (0 - 1000 m) in the Palau region from the 4 month state estimate. Spray glider data were assimilated in this estimate.

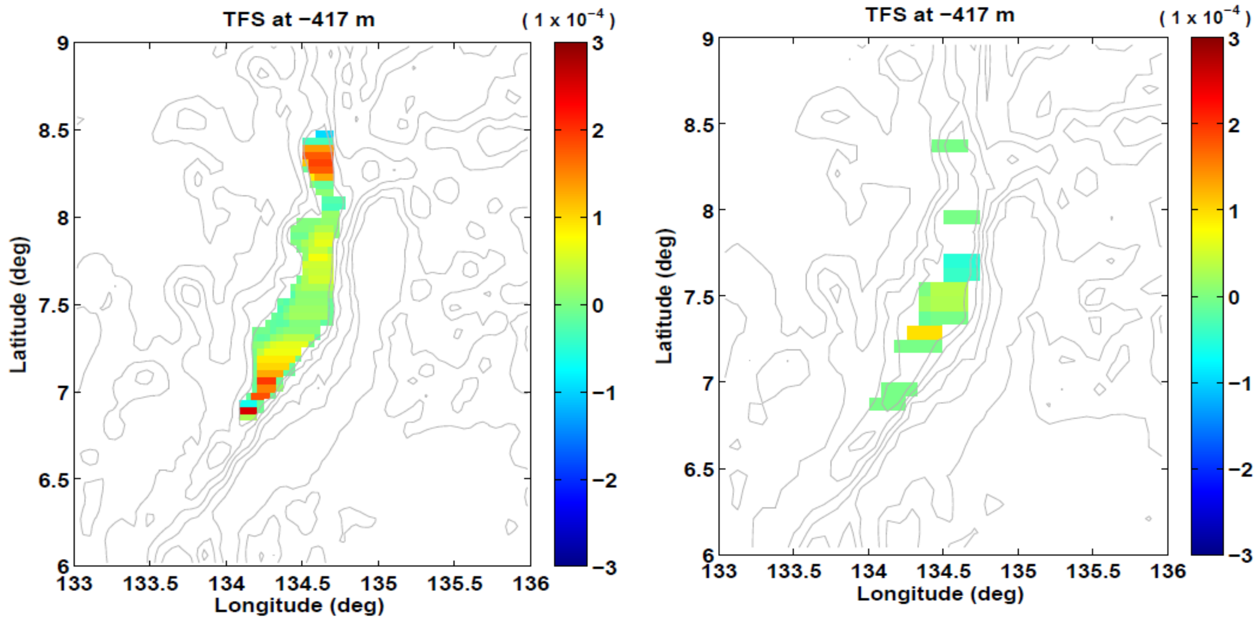

Figure 1: The depth integrated topographic form stress (TFS) (color) in the upper 500 m for the Palau region from 1/24 degree (left) and 1/12 degree (right) MITgcm forward simulations. The contours show the bottom topography, which is slightly different in the two cases. Both simulations span the period 2009 through 2014, use 1/12 degree HYCOM/NCODA global analysis for initial conditions and boundary conditions, and 6 hourly ERA-Interim atmospheric forcing. The lower-resolution run (right) uses NRL DBDB2 topography (courtesy of D.S.Ko).