Oceanic Energy Cascade to Global from Regional Predictive Models

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LONG-TERM GOALS

The long-term scientific goals of this research project are:

1. Examine how small-scale energy input (such as vorticity) may alter the predictability of global models
2. Examine the fl in the NECC and its sensitivity to these small-scale inputs
3. Using advanced state-estimation techniques identify the energy inputs and how they propagate out to large-scale models
4. Examine the sensitivity of the state-estimate to observations at the island-scale

OBJECTIVES

The primary objectives of this project are: (i) produce a suite of high-resolution state-estimates of the Western Pacific and region around Palau (including Yap) that include tides and are constrained by observations collected as part of the Flow Encountering Abrupt Topography (FLEAT) program; (ii) Use these state-estimates to examine how small-scale energy injected into the ocean cascades to lower wavenumbers; (iii) Examine how the excitation of the lower wavenumbers by the local processes affects the predictive skill of global models; (iv) Examine how well the local observations constrain estimates of the local processes that are missed by global models; and, (v) transition the results and methodology to NRL for further examination and possible inclusion into NRL operations.

APPROACH

We are using a unique multi-model approach that is well integrated into the FLEAT program to examine how the energy cascade is infl predictability in the Western Pacific. In particular, we are examining the meander and variability of the NECC to identify how and if local processes in the FLEAT region impact the NECC variability. Meanders of the NECC affect the predictability of global models across the entire Pacific basin, so small-scale variability in the Palau region that affects the NECC will impact global model predictions.

A pre-cursor to understanding energy transfer across scales is characterizing the variability in the circulation features and how they are forced. Sverdrup [1947] was the fi to solve for the steady state circulation, and there has been recent progress in understanding the large scale controls on its variability. The Sverdrup balance comprises a series of large-scale alternating zonal currents across the Pacific basin including the South Equatorial Current (SEC), the North Equatorial Counter Current (NECC), and the North Equatorial Current (NEC). The currents are bounded to the west by the Philippines and New Guinea, and the circulaiton features are closed by the northwards and southwards fl wing (respectively) geostrophically adjusted western boundary currents [Qu et al., 2012], the New Guinea Coastal Current (NGCC) and the Mindanao Current (MC). Just south of the Philippines, the southward fl wing MC and northward fl wing NGCC converge to feed the eastward fl wing NECC. There are also a pair of quasi-permanent large-scale counter-rotating eddies just to the east of Mindanao (Mindanao Eddy; ME) and Indonesia (Halmahera Eddy; HE). In a 1.5 layer reduced-gravity model, Arruda and Nof [2003] showed that these eddies are necessary features to close the non-linear momentum budget on a β-plane (Fig. 1).

We have completed a 2.5 year state-estimate at 1/12° of the region to serve as the baseline for our studies. The state-estimate was a combination of nearly 21.5 million observations with the ROMS model using 4D-Var. Of the observations used, roughly 85% of the data were from NAVO SST, 10% from along-track SSH satellites, and the remainder from: Aquarius SSS, Argo (T, S), Rudnick Gliders (T, S), TAO (T, S, u, and v). As shown in Figure 2, the normalized vorticity is most strong in the FLEAT region, and the islands and seamounts are a major source of vorticity injection into the ocean. As discussed, the convergence of the two mean fl ws force the NECC to the east, setting up quasi-permanent eddies (ME and HE). Advection of vorticity may alter the balance of these structures and lead to significant variability in the NECC. Furthermore, work from the state-estimate shows an input of baroclinic tidal energy in the region that could alter the stability of the shear front of the NECC as well as the frontal mixing of the HE and ME eddies.

To further understand the role of scale, we will be using a 1/48° model nested within the 1/12° that will provide greater fi y in the topography and allow more dynamical frequencies to propagate within the region. This model will serve as the comparison to the 1/12° to help understand which scales are necessary.

As part of the state-estimation procedure at a wide variety of scales into models of varying physics, we will examine how the control vectors account for "mismatches" in resolved energy between island-scale, medium-scale regional, and large-scale global models. The state-estimate will adjust the boundaries of the models, which provides valuable information into how the energy from the outer model (whether global or our 1/12°) must be converted for either outgoing or incoming energy fl Furthermore, the mechanisms allow us to examine how each observation contributes to our understanding of vorticity in the region.

A major goal of this proposal to provide useful techniques, ideas, and methodologies to the Navy that can be integrated into the operational context. While the work within this proposal is of basic research, results and experimental design will be shared with the NRL team throughout the period of this proposal.

WORK COMPLETED

Year 1:

- Produced a reanalysis state estimate with tides of one year at 1/12° for the October, 2015 cruise to assist with cruise planning

- Processed, quality controlled, and validated observations from satellites (SSH, SST, SSS), Argo, TAO, FLEAT (gliders, CTDs, acrobat, and moorings)
- Produced a research quality state estimate with tides using all available observations from Jan, 2014 to June, 2016 at 1/12° for the Western Pacific. These data are used to force a higher resolution nested model.
- Produced a forward simulation at 1/48° of the Palau/Yap region nested with the state-estimate above. These data are supplied to other groups for nesting there own models within.
- Generated methods to analyze the location and variations of the NECC intrusion latitude to examine the role of upstream variability in vorticity, drag, and other fi in the variability of the HLCC
- Provided data and atmospheric forcing fi to Harper Simmons' s group at UAF for their high-resolution simulations.

Tasks remaining to be completed by the end of the proposal include:
Remaining:

- Complete the state-estimate using all available FLEAT data of the 1/48° model nested with the 1/12° state estimate.
- Quantify the role of upstream vorticity in the meander of the NECC
- Work with Bruce Cornuelle group to compare ROMS and MITgcm simulations at varying scales and without tides to examine the meander and variability of NECC and its subsequent predictions
- Assess the sensitivity of the state-estimates to the observations used
- Determine how the observations constrain the fl w
- Provide context to the observational group' s data
- Work with the HYCOM team at NRL to compare nesting our simulations in their new 1/25° simulation with tides, and how their new model improves the predictability of the NECC.

From the results accomplished, we are working on a manuscript to detail the state-estimate solution. We are also working on a second manuscript investigating the meander of the NECC. Using the 1/48° model, we will compare to the 1/12° to examine increased vorticity and resulting variability in NECC meanders. In addition, using the state-vectors of the 1/48° simulation, we can understand what the coarser model is not resolving.

IMPACT/APPLICATIONS

This is an important multi-institute, multi-investigator team including MIT, NRL, SIO, UAF, and UH. In collaboration with Bruce Cornuelle, Maarten Buijsman, Hemantha Wijesekera, and others, the results from this collaborative proposal will be made available with the expectation that they will be incorporated into NRL operational systems that utilize a wide variety of oceanographic observations.

At UH, one female post-doctoral scholar is funded by this effort, and will be trained in assimilation, prediction, and ocean energy budgets.

TRANSITIONS

We will be working with Maarten Buijsman to evaluate the new HYCOM 1/25° model with tides and provide information about the small-scales that infl the NECC to help with NRL transitions and parameterizations. Using the adjoint model, we will identify the corrections that are often made to the HYCOM simulation from our work to provide information about biases, unresolved scales, etc. to the NRL group.

RELATED PROJECTS

This project is collaborating with a number of ONR sponsored investigators:

- Pierre Lermusiaux, MIT
- Hemantha Wijesekera, NRL
- Bruce Cornuelle, Scripps
- Dan Rudnick, Scripps
- Harper Simmons, UAF
- Mark Merrifield, UH

In addition, work from this project is being used as data and boundary conditions for other groups within FLEAT.

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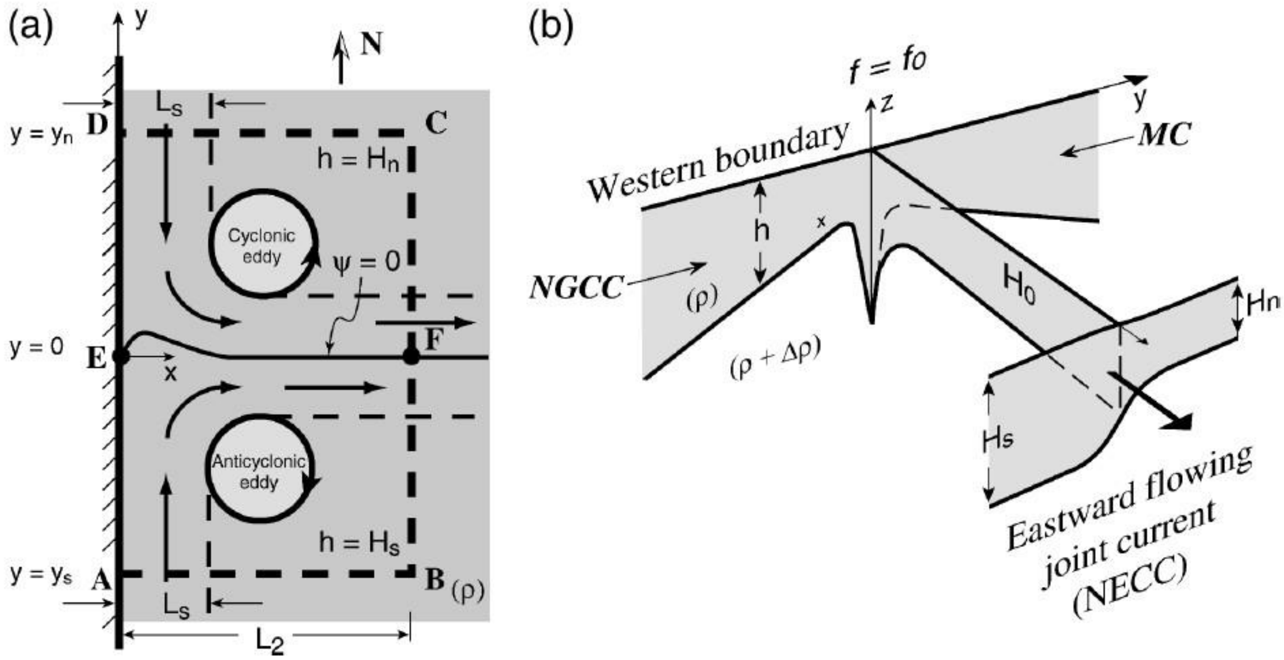

Figure 1: Figure 11 from Arruda and Nof [2003]. (a) Schematic showing pair of counter-rotating eddies that exist when two western boundary currents converge to form an eastward fl wing current. The cyclonic/anticyclonic pair of eddies are necessary features to close the momentum budget for two converging western boundary currents. (b) 3-D schematic showing upper layer seasonal thermocline, with indications of currents likely involved in eddy formation in the western tropical Pacific. The colliding western boundary currents are identified as the New Guinea Coastal Current (NGCC) and the Mindanao Current (MC). The eastward fl wing return current that forms where they meet is the North Equatorial Counter Current (NECC).

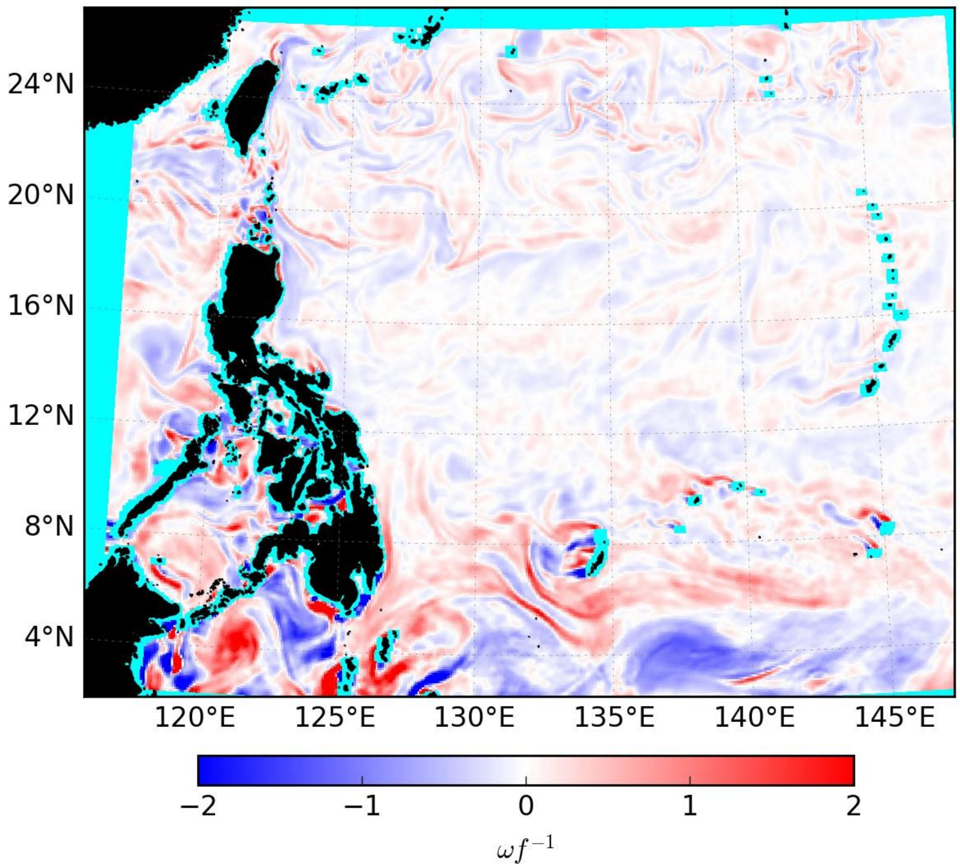

Figure 2: Snapshot of normalized vorticity from the 1/12° state-estimate shows that the study region dominates the vorticity signal in the ocean. In the lee of the islands and seamounts, significant vorticity is injected into the ocean. Understanding how this energy is infl the variability of the larger-scale NECC, etc. is the goal of the project.