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Principal Investigator: Di Lorenzo, Emanuele .
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Organization: GA Tech Res Corp - GIT
Submitted By:
Di Lorenzo, Emanuele - Principal Investigator
Title:
US-GLOBEC NEP Phase IIIb-CGOA: Synthesis of biophysical observations at multiple trophic levels using spatially nested, data-assimilating models of the Coastal Gulf of Alaska

Project Participants

Senior Personnel

Name: Di Lorenzo, Emanuele
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Combes, Vincent
Worked for more than 160 Hours: Yes
Contribution to Project:
Vincent Combes is conducting his Ph.D. dissertation on the dynamics of the Gulf of Alaska (GOA) circulation. As part of his thesis he has been conducting ensemle ocean simulations of the GOA, which are currently beeing used to setup the adjoint sensitivities and data assimilation experiments.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

University of Washington

University of California-Berkeley

University of California-Santa Cruz

Other Collaborators or Contacts

no

Activities and Findings

Research and Education Activities:

see attached PDF

Findings:

see attached PDF

Training and Development:

see attached PDF

Outreach Activities:

see attached PDF

Journal Publications

Di Lorenzo, E., A. M. Moore, H. G. Arango, B. D. Cornuelle, A. J. Miller, B. Powell, B. S. Chua, and A. F. Bennett, "Weak and strong constraint data assimilation in the inverse Regional Ocean Modeling System (ROMS): Development and application for a baroclinic coastal upwelling system", Ocean Modeling, p. 160-187, vol. 16, (2007). Published,

Haidvogel, D. B., H. Arango, W. P. Budgell, B. D. Cornuelle, E. Curchitser, E. Di Lorenzo, K. Fennel, W. R. Geyer, A. J. Hermann, L. Lanerolle, J. Levin, J. C. McWilliams, A. J. Miller, A. M. Moore, T. M. Powell, A. F. Shchepetkin, C. R. Sherwood, R. P. S, "Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the Regional Ocean Modeling System", Journal of Computational Physics, p. 3595-3624, vol. 227, (2008). Published,

Combes, V., E. Di Lorenzo and E. Curchister, "Interannual and Decadal Variations in Cross- Shelf Transport in the Gulf of Alaska", Journal of Physical Oceanography, p. 1050-1059, vol. 39, (2009). Published,

Chhak, K., E. Di Lorenzo, N. Schneider and P. Cummins, "Forcing of Low-Frequency Ocean Variability in the Northeast Pacific", Journal of Climate, p. 1255-1276, vol. 22, (2009). Published,

Capotondi, A., V. Combes, M. A. Alexander, E. Di Lorenzo, and A. J. Miller, "Low-frequency variability in the Gulf of Alaska from coarse and eddy-permitting ocean models", Journal of Geophysical Research-Oceans, p. , vol. 114, (2009). Published,

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Fiechter, J., A. M. Moore, C. A. Edwards, K. W. Bruland, E. Di Lorenzo, C. V. W. Lewis, and T. M. Powell, "A simple approach to model iron limitation on primary production in the coastal Gulf of Alaska", Deep-Sea Research II, p. 2503-2519, vol. 56, (2008). Published,

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Moore, A. M., H. G. Arango, E. Di Lorenzo, A. J. Miller, and B. D. Cornuelle, "An Adjoint Sensitivity Analysis of the Southern California Current Circulation and Ecosystem", Journal of Physical Oceanography, p. 702-720, vol. 39, (2009). Published,

Muccino, J. C., H. G. Arango, A. F. Bennett, B. S. Chua, B. D. Cornuelle, E. Di Lorenzo, G. D. Egbert, D. Haidvogel, J. C. Levin, H. Luo, A. J. Miller, A. A. Moore, and E. D. Zaron, "The Inverse Ocean Modeling system. Part II: Applications", Journal of Atmospheric and Oceanic Technology, p. 1623-1637, vol. 25, (2008). Published,

Combes, V. and E. Di Lorenzo, "Intrinsic and forced interannual variability of the Gulf of Alaska mesoscale circulation", Progress in Oceanography, p. , vol. , (2007). Published, 10.1016/j.pocean.2007.08.011

Books or Other One-time Publications

Web/Internet Site

URL(s):
http://www.o3d.org/globec/
Description:
GLOBEC Northeast Pacific: ROMS Ocean Modeling Support Page
provides access to the modeling data and tools to setup regional high-resolution integrations in the Northeast Pacific using physical-biological configurations.

Other Specific Products

Contributions

Contributions within Discipline:
see attached PDF

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:
see attached PDF
Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Any Book
Any Product
Contributions: To Any Other Disciplines
Contributions: To Any Human Resource Development
Contributions: To Any Beyond Science and Engineering
Any Conference

NSF Final Report

Period 04/2006 to 03/2010

US-GLOBEC NEP Phase IIIb-CGOA: Synthesis of biophysical observations at multiple trophic levels using spatially nested, data-assimilating models of the Coastal Gulf of Alaska

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TABLE OF CONTENT

RESEARCH ACTIVITIES & FINDINGS

The central focus of this project is a spatially nested set of models of the Northeast Pacific (NEP) and the Coastal Gulf of Alaska (CGOA), used to study physical and biological dynamics of the CGOA. These models are intended to synthesize field and modeling work conducted under related GLOBEC projects. Specific project activities conducted at Georgia Tech and in collaboration with UCSC and NOAA PMEL include: (**A**) generating model hindcasts of ocean circulation and ecosystem variability (1950-2008), (**B**) diagnosing ocean and ecosystems dynamics over the period 1950-2008 and (**C**) developing adjoint based data assimilation and sensitivity analysis tools for the Gulf of Alaska. Below is an extended summary of the activities listed above.

A. MODELING OCEAN CIRCULATION AND ECOSYSTEMS OVER THE PERIOD 1950-2008

A.1 Physical Model

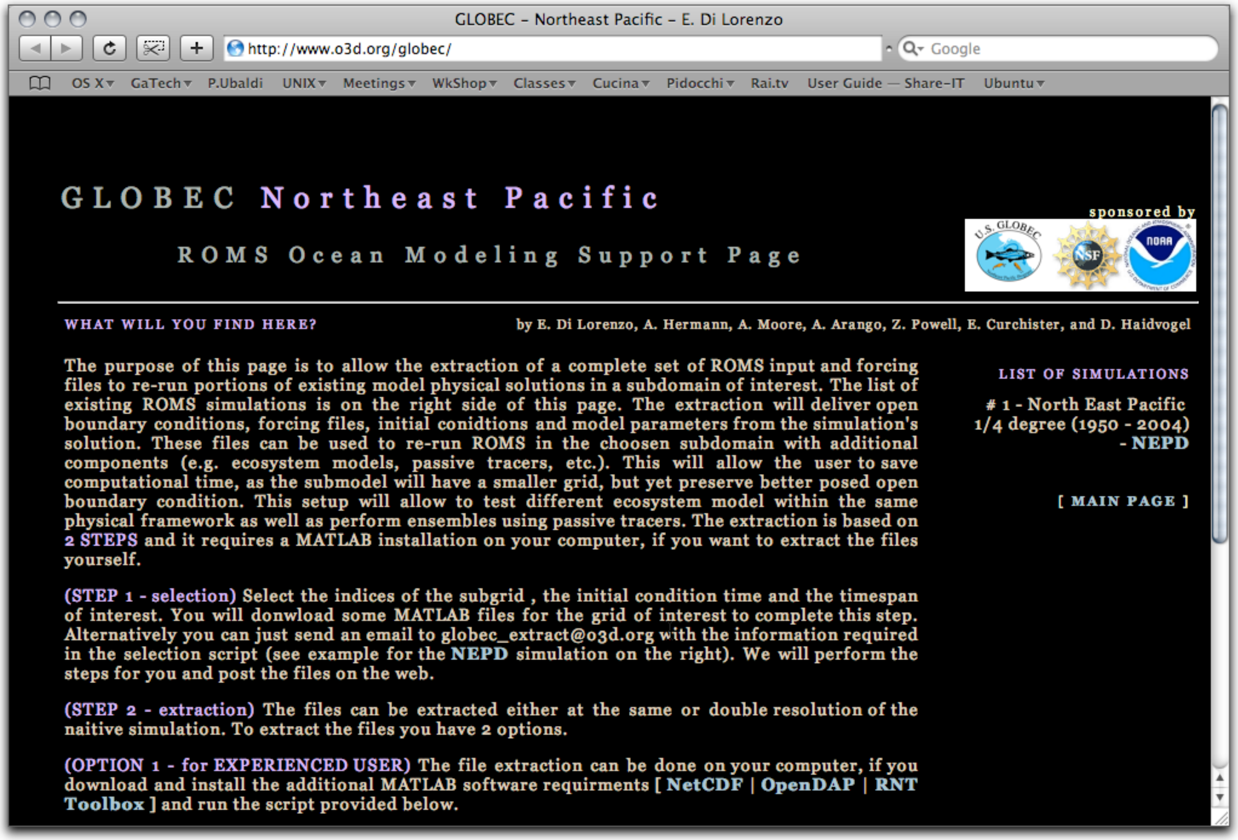
We have conducted several integrations with the Regional Ocean Modeling System (ROMS) to hindcast the ocean circulation and ecosystem variability of the Gulf of Alaska. The ROMS model was used in a nested configuration over the northeast Pacific region 180°W-110°W; 25°N-62°N. The model computational grids have varying degree of resolution from 20km to 10km with 30 vertical terrain-following layers. The surface wind stresses and heat fluxes used to force the model are from the US National Center for Environmental Prediction (NCEP) for the period 1950-2008. At the surface we use a corrected monthly climatology of heat and freshwater flux for temperature and salinity to avoid long-term drifts associated with errors in the NCEP surface fluxes. This corrected flux climatology is estimated by saving the net surface fluxes of a 100 year spin-up run where the surface temperature and salinity are relaxed to their observed climatologies with a timescale ≈ 1 month. To account for the temporal variability in the heat flux for the hindcast integration 1950-2008, we add on the corrected monthly climatology a time-dependent relaxation to SST reanalysis from NOAA with a timescale ≈ 1 month. For the salinity surface boundary condition we only use the corrected monthly flux climatology with no surface relaxation and thereby assume that the dominant changes in salinity on periodicities larger than the seasonal cycle are only controlled by ocean advection.

A.2 Ecosystem Model

The ecosystem sub-model includes nutrient-phytoplankton-zooplankton-detritus (NPZD) and an iron limitation component developed for this project [*Fietcher et al., 2009*]. The initial conditions along with a monthly climatological open boundary conditions for the nutrient component are extracted from the nitrate (NO3) field of the World Ocean Atlas available at http://www.nodc.noaa.gov. The other ecosystem components are set to constants both in the initial and open boundary conditions (Phytoplankton=0.08; Zooplankton=0.06; Detritus=0.04; units are μmol NO3 m-3) and evolve to equilibrium concentrations in the first 25 years (1950-1975) of the hindcast run.

A.3 Web Data Access and Modeling Tools

All the modeling data has been made available on the Georgia Tech OpenDAP Data Server (http://data.eas.gatech.edu). Georgia Tech also developed a "service" website (http://ocean.eas.gatech.edu/globec) to allow the generation of nested configuration files (grid, initial, open boundary and forcing conditions) that use existing ROMS solutions for the northeast Pacific Ocean described above. The purpose of this page is to allow the extraction of a complete set of ROMS input and forcing files to re-run portions of existing model physical solutions in a subdomain of interest. The extraction will deliver open boundary conditions, forcing files, initial conditions and model parameters from the simulation's solution. These files can be used to re-run ROMS in the chosen subdomain with additional components (e.g. ecosystem models, passive tracers, etc.). This allows the users to save computational time, as the submodel will have a smaller grid, but yet preserve better posed open boundary condition. This webpage will allow testing different ecosystem model within the same physical framework as well as performing ensembles using passive tracers.



GLOBEC Northeast Pacific

ROMS Ocean Modeling Support Page

WHAT WILL YOU FIND HERE?

by E. Di Lorenzo, A. Hermann, A. Moore, A. Arango, Z. Powell, E. Curchister, and D. Haidvogel

The purpose of this page is to allow the extraction of a complete set of ROMS input and forcing files to re-run portions of existing model physical solutions in a subdomain of interest. The list of existing ROMS simulations is on the right side of this page. The extraction will deliver open boundary conditions, forcing files, initial conidtions and model parameters from the simulation's solution. These files can be used to re-run ROMS in the choosen subdomain with additional components (e.g. ecosystem models, passive tracers, etc.). This will allow the user to save computational time, as the submodel will have a smaller grid, but yet preserve better posed open boundary condition. This setup will allow to test different ecosystem model within the same physical framework as well as perform ensembles using passive tracers. The extraction is based on 2 STEPS and it requires a MATLAB installation on your computer, if you want to extract the files yourself.

(STEP 1 - selection) Select the indices of the subgrid , the initial condition time and the timespan of interest. You will donwload some MATLAB files for the grid of interest to complete this step. Alternatively you can just send an email to globec_extract@o3d.org with the information required in the selection script (see example for the **NEPD** simulation on the right). We will perform the steps for you and post the files on the web.

(STEP 2 - extraction) The files can be extracted either at the same or double resolution of the naitive simulation. To extract the files you have 2 options.

(OPTION 1 - for EXPERIENCED USER) The file extraction can be done on your computer, if you download and install the additional MATLAB software requirments [**NetCDF** | **OpenDAP** | **RNT Toolbox**] and run the script provided below.

LIST OF SIMULATIONS

1 - North East Pacific 1/4 degree (1950 - 2004) - **NEPD**

[MAIN PAGE]

B. OCEAN AND ECOSYSTEMS DYNAMICS IN THE GULF OF ALASKA OVER THE PERIOD 1950-2008

The modeling output described in the previous section has been used to diagnose several aspects of the Gulf of Alaska ocean and ecosystem dynamics. Below is a summary and report of the major findings and publications.

B.1 Nutrient and Salinity Decadal Variations [Di Lorenzo et al., 2009]

In this study the long-term timeseries of upper ocean salinity and nutrients collected in the Alaskan Gyre along Line P are examined. We show that their decadal variations that are in phase with variations recorded in the Southern California Current System by the California Cooperative Oceanic Fisheries Investigation (CalCOFI). We present evidence that these variations are linked to the North Pacific Gyre Oscillation (NPGO) -- a climate mode of variability that tracks changes in strength of the central and eastern branches of the North Pacific gyres and of the Kuroshio-Oyashio Extension (KOE). The NPGO emerges as the leading mode of low-frequency variability for salinity and nutrients. We reconstruct the spatial expressions of the salinity and nutrient modes over the northeast Pacific using the ROMS hindcasts. These modes exhibit a large-scale coherent pattern that adequately predicts the in-phase relationship between the Alaskan Gyre and California Current timeseries (see example from figure 3 of *Di Lorenzo et al., 2009* below).

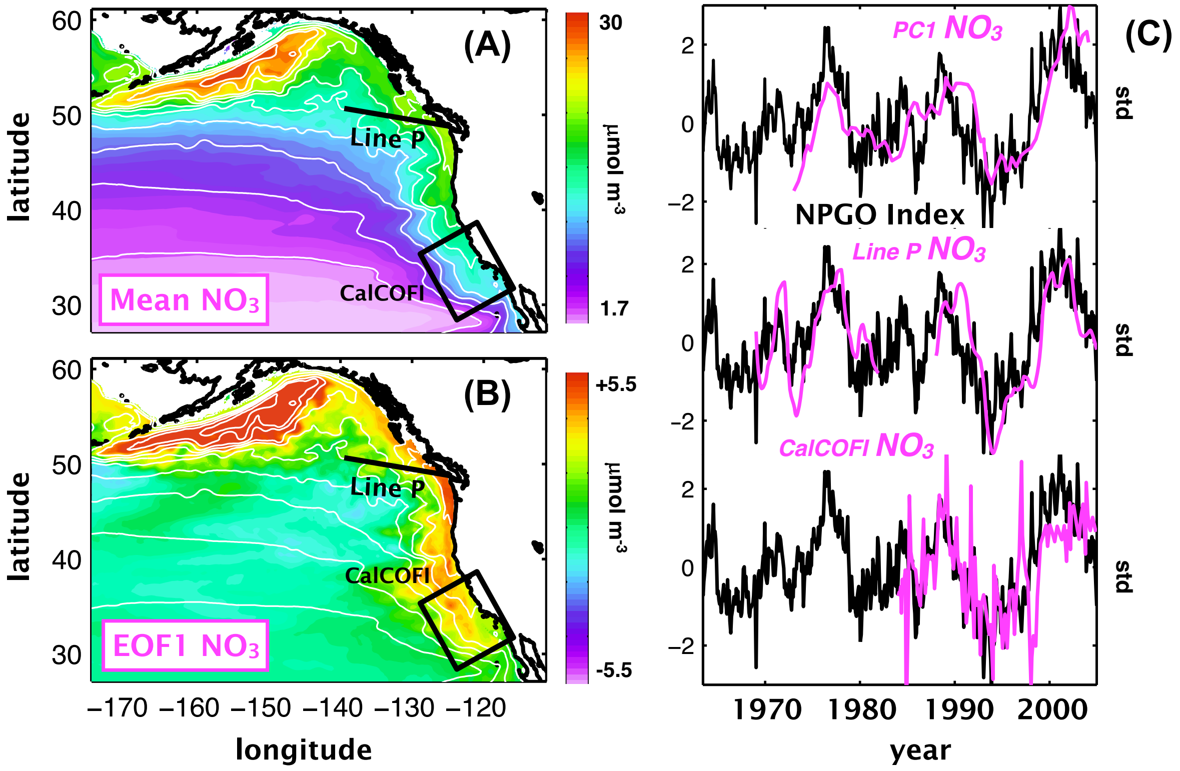


Figure 3. Temporal and spatial variability of subsurface nitrate (NO_3). (A) Mean subsurface (150m) NO_3 from ROMS ocean model over the period 1975-2004. (**B**) First mode of variability for model subsurface (150m) NO_3 anomaly inferred from EOF1. White contours mark the mean NO_3 distributions in both panels A and B. (**C**) Timeseries of NPGO index (black) compared to PC1 of NO_3 (R=0.65, 99%), observed mix layer NO_3 at Line-P [*Peña and Varela, 2007*] (R=0.68, 99%), and observed NO_3 from CalCOFI program (R=0.51, 95%). All timeseries are normalized by their standard deviations, units are in standard deviations (std).

The fact that large-amplitude, low-frequency fluctuations in salinity and nutrients are spatially phase-locked and correlated with a measurable climate index (the NPGO) open new avenues for exploring and predicting the effects of long-term climate change on marine ecosystem dynamics.

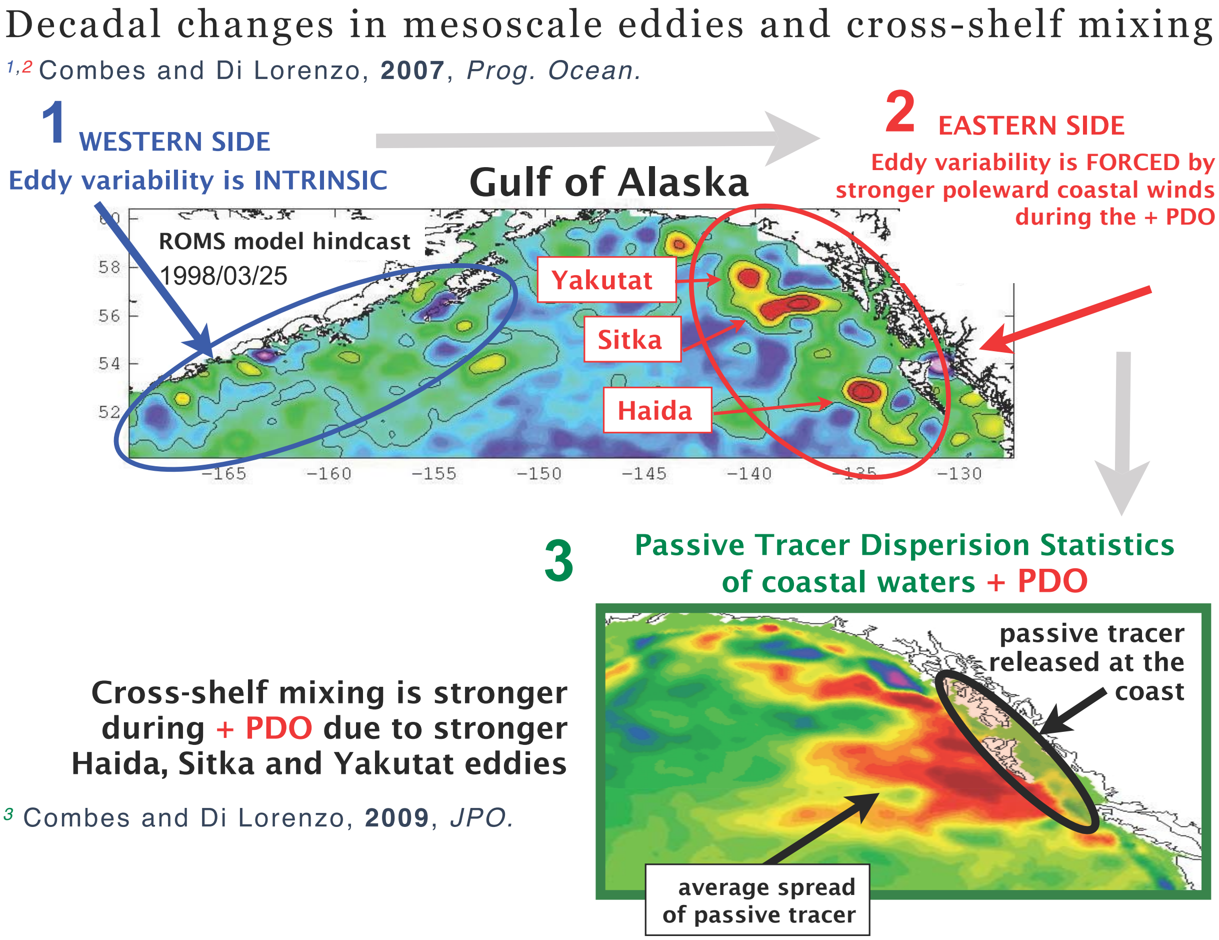
B.2 Forcing dynamics of temperature and salinity low-frequency variations [Chhak et al., 2009]

In this study we examine and compare the forcing mechanisms, and underlying ocean dynamics, of the two dominant modes of ocean variability in the Northeast Pacific (NEP). The first mode is identified with the Pacific Decadal Oscillation (PDO) and accounts for the most variance in model sea surface temperatures (SST) and sea surface heights (SSH). It is characterized by a monopole structure with a strong coherent signature along the coast. The second mode of variability is termed the North Pacific Gyre Oscillation (NPGO). This mode accounts for the most variance in sea surface salinities (SSS) in the model and in long-term observations. While the NPGO is related to the second EOF of North Pacific SST anomalies (the Victoria mode), it is defined here in terms of SSH anomalies. The NPGO is characterized by a pronounced dipole structure corresponding to variations in the strengths of the eastern and central branches of the subpolar and subtropical gyres in the North Pacific. We find that the PDO and NPGO modes are each tied to a specific atmospheric forcing pattern. The PDO is related to the overlying Aleutian Low, while the NPGO is forced by the North Pacific Oscillation. The aforementioned climate modes captured in our model hindcast are reflected in satellite altimeter data.

A budget reconstruction is used to study how the atmospheric forcing drives the SST and SSH anomalies. Results show that the basinwide SST and SSS anomaly patterns associated with each mode are shaped primarily by anomalous horizontal advection of mean surface temperature and salinity gradients (and) via anomalous surface Ekman currents. This suggests a direct link of these modes with atmospheric forcing and the mean ocean circulation. Smaller-scale patterns in various locations along the coast and in the Gulf of Alaska are, however, not resolved with the budget reconstructions. Vertical profiles of the PDO and NPGO indicate that the modes are strongest mainly in the upper ocean down to 250 m. The shallowness of the modes in addition to the depth of the mean mixed layer and winter time temperature profile inversions are factors that may contribute to the sensitivity of the budget analysis in the regions that have less skill in the reconstruction.

B.3 Dynamics of cross-shore mixing in the Gulf of Alaska [Combes et al., 2007; 2009]

In this study we use the higher resolution ROMS output to diagnose the dynamics of cross-shore mixing. Specifically, we investigate the role of mesoscale eddies associated with the deterministic and intrinsic components of the circulation isolated in previous years [*Combes et al., 2007*] (see figure below). The statistics of coastal water transport into the Gulf of Alaska are computed using a model passive tracer, which is continuously released at the coast. The passive tracer can thus be considered a proxy for coastal biogeochemical quantities such as silicate, nitrate, iron, or oxygen, which are critical for explaining the GOA ecosystem dynamics. On average along the Alaska Current, it has been shown that at the surface while the advection of tracers by the average flow is directed toward the coast consistent with the dominant downwelling regime of the GOA, it is the mean eddy fluxes that contribute to offshore advection into the gyre interior. South of the Alaskan Peninsula, both the advection of tracers by the average flow and the mean eddy fluxes contribute to the mean offshore advection. On interannual and longer time scales, the offshore transport of the passive tracer in the Alaskan Stream does not correlate with large-scale atmospheric forcing, nor with local winds. In contrast in the Alaska Current region, stronger offshore transport of the passive tracer coincides with periods of stronger downwelling (in particular during positive phases of the PDO), which trigger the development of stronger eddies.



B.4 Low-Frequency Variability in the Gulf of Alaska from coarse and eddy-permitting ocean models [Capotondi et al., 2009]

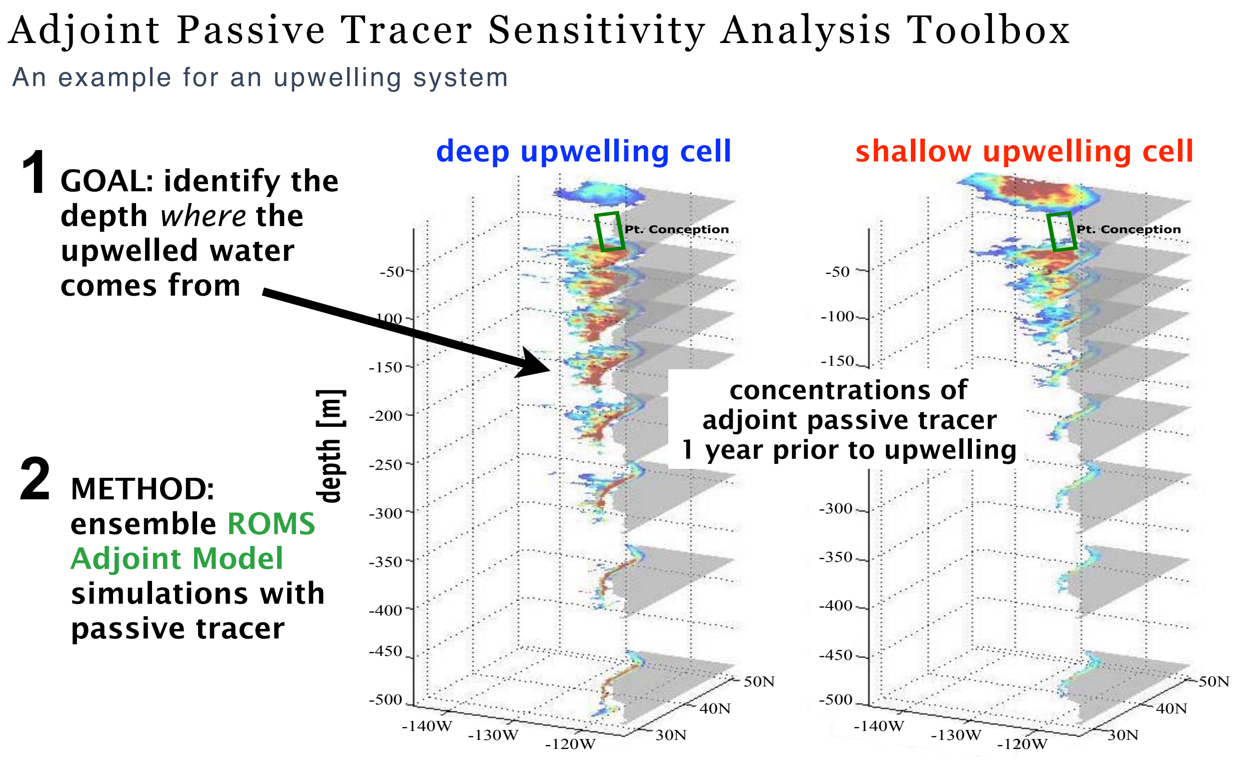
The ROMS model hindcast were also used to further diagnose the low-frequency dynamics of the Gulf of Alaska by comparing with the output of coarse ocean model hindcasts. We is found that the adjustment of the ROMS ocean model in the presence of mesoscale eddies is similar to that obtained with coarse-resolution models. Local Ekman pumping plays a key role in forcing pycnocline depth variability and, to a lesser degree, sea surface height (SSH) variability in the center of the Alaska gyre and in some areas of the eastern and northern GOA. Westward Rossby wave propagation is evident in the SSH field along some latitudes but is less noticeable in the pycnocline depth field. Differences between SSH and pycnocline depth are also found when considering their relationship with the local forcing and leading modes of climate variability in the northeast Pacific. In the central GOA pycnocline depth variations are more clearly related to changes in the local Ekman pumping than SSH. While SSH is marginally correlated with both Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) indices, the pycnocline depth evolution is primarily related to NPGO variability. The intensity of the mesoscale eddy field increases with increasing circulation strength. The eddy field is generally more energetic after the 1976 – 1977 climate regime shift, when the gyre circulation intensified. In the western basin, where eddies primarily originate from intrinsic instabilities of the flow, variations in eddy kinetic energy are statistically significant correlated with the PDO index, indicating that eddy statistics may be inferred, to some degree, from the characteristics of the large-scale flow.

C. DEVELOPMENT OF ADJOINT BASED DATA ASSIMILATION AND SENSITIVITY ANALYSIS TOOLS

Another important aspect of this project was the development and application of an adjoint based data assimilation and sensitivity analysis platform for the ROMS in the Gulf of Alaska. This activity is led by PI A. Moore at UCSC. Georgia Tech has contributed to the following activities:

C.1 An Adjoint Sensitivity Analysis of the Southern California Current Circulation and Ecosystem [Moore et al., 2009]

In this study the newly developed adjoint sensitivity analysis tools is tested to study the dynamics of the Southern California Current System (SCCS). Although this applications is not directly related to the Gulf of Alaska it has provided the basic roadmap to implement such an analysis in the Gulf. Adjoint methods of sensitivity analysis were applied to the California Current using the Regional Ocean Modeling Systems (ROMS) with medium resolution, aimed at diagnosing the circulation sensitivity to variations in surface forcing. The sensitivities of coastal variations in SST, eddy kinetic energy, and baroclinic instability of complex time evolving flows were quan- tified. Each aspect of the circulation exhibits significant interannual and seasonal variations in sensitivity controlled by mesoscale circulation features. Central California SST is equally sensitive to wind stress and surface heat flux, and less so to wind stress curl, displaying greatest sensitivity when upwelling favorable winds are relaxing, and least sensitivity during the peak of upwelling. SST sensitivity is typically 2-4 times larger during Summer than during Spring, although larger variations occur during some years. The sensitivity of central coast eddy kinetic energy to surface forcing is on average constant throughout the year. Perturbations in the wind that align with mesoscale eddies to enhance the strength of the circulation by local Ekman pumping yield the greatest sensitivities. The sensitivity of the potential for baroclinic instability is greatest when nearshore hor- izontal temperature gradients are largest, and is associated with variations in wind stress concentrated along the core of the California Current. The sensitivity varies by a factor ~ 1.5 throughout the year. A new and important aspect of this work is identification of the complex flow dependence and seasonal dependence of the sensitivity of the ROMS CCS circulation to variations in surface forcing that was hitherto not previously appreciated.



Adjoint Passive Tracer Sensitivity Analysis Toolbox

An example for an upwelling system

1 GOAL: identify the depth *where* the upwelled water comes from

2 METHOD: ensemble ROMS Adjoint Model simulations with passive tracer

deep upwelling cell

shallow upwelling cell

concentrations of adjoint passive tracer 1 year prior to upwelling

C.2 Adjoint Passive Tracer Analysis and Tutorial [Di Lorenzo et al. in prep]

As part of this grant Georgia Tech is led the development of a toolbox and tutorial to use adjoint passive tracer to perform backward integration of water dispersion. These integrations are useful to explore the dynamics of inverse advection. The figure above provides an example of calculation for an upwelling system. These calculations show where the upwelled water masses have originated 9 months earlier. The example of the left shows the case when the upwelling winds are stronger and the upwelling cell is deeper with more water coming from below the surface mix layer. The example on the right is for a case when the upwelling winds are weak, and an important fraction of the water masses found in the upwelling system is entrained horizontally in the surface layer.

EDUCATION AND OUTREACH

This project has provided funding for graduate student Vincent Combes who has completed his Ph.D. in 2010 on several aspects of the Gulf of Alaska ocean dynamics. We also have developed web portals that allow real time access to all the modeling products (http://data.eas.gatech.edu) as well as modeling toolboxes (http://ocean.eas.gatech.edu/globec)(see report section A for more details).

Results from this research have also been posted on the website for the North Pacific Gyre Oscillation (http://www.o3d.org/npgo) as short 15 minutes videos that describe various aspects of the Gulf of Alaska Dynamics and relationship with NPGO (http://www.o3d.org/npgo/videos-images.html).

Publications

1. Capotondi, A., V. Combes, M. A. Alexander, E. Di Lorenzo, and A. J. Miller, 2009: Low-frequency variability in the Gulf of Alaska from coarse and eddy-permitting ocean models. *Journal of Geophysical Research-Oceans*, **114**.
2. Chhak, K. C., E. Di Lorenzo, N. Schneider, and P. F. Cummins, 2009: Forcing of Low-Frequency Ocean Variability in the Northeast Pacific. *Journal of Climate*, **22,** 1255-1276.
3. Combes, V. and E. Di Lorenzo, 2007: Intrinsic and forced interannual variability of the Gulf of Alaska mesoscale circulation. Progress in Oceanography, 266-286, doi:10.1016/j.pocean.2007.08.011.
4. Combes, V., E. Di Lorenzo, and E. Curchitser, 2009: Interannual and Decadal Variations in Cross-Shelf Transport in the Gulf of Alaska. *Journal of Physical Oceanography*, **39,** 1050-1059.
5. Di Lorenzo, E., J. Fiechter, N. Schneider, A. Bracco, P. J. S. Franks, S. J. Bograd, A. M. Moore, A. C. Thomson, W. R. Crawford, A. Peña, and A. J. Hermann, 2009: Nutrient and Salinity Decadal Variations in the central and eastern North Pacific. *Geophysical Research Letters*, doi:10.1029/2009GL038261.
6. Di Lorenzo, E., A. M. Moore, H. G. Arango, B. D. Cornuelle, A. J. Miller, B. Powell, B. S. Chua, and A. F. Bennett, 2007: Weak and strong constraint data assimilation in the inverse Regional Ocean Modeling System (ROMS): Development and application for a baroclinic coastal upwelling system. *Ocean Modelling*, **16,** 160-187.
7. Fiechter, J., A. M. Moore, C. A. Edwards, K. W. Bruland, E. Di Lorenzo, C. V. W. Lewis, and T. M. Powell, 2009: A simple approach to model iron limitation on primary production in the coastal Gulf of Alaska. *Deep-Sea Research II*, (56) 2503-2519.
8. Foreman, M. G. G., W. Callendar, A. MacFadyen, B. M. Hickey, R. E. Thomson, and E. Di Lorenzo, 2008: Modeling the generation of the Juan de Fuca Eddy. *Journal of Geophysical Research-Oceans*, **113**.
9. Haidvogel, D. B., H. Arango, W. P. Budgell, B. D. Cornuelle, E. Curchitser, E. Di Lorenzo, K. Fennel, W. R. Geyer, A. J. Hermann, L. Lanerolle, J. Levin, J. C. McWilliams, A. J. Miller, A. M. Moore, T. M. Powell, A. F. Shchepetkin, C. R. Sherwood, R. P. Signell, J. C. Warner, and J. Wilkin, 2008: Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the Regional Ocean Modeling System. *Journal of Computational Physics*, **227,** 3595-3624.
10. Moore, A. M., H. G. Arango, E. Di Lorenzo, A. J. Miller, and B. D. Cornuelle, 2009: An Adjoint Sensitivity Analysis of the Southern California Current Circulation and Ecosystem. *Journal of Physical Oceanography*, **39,** 702-720.
11. Muccino, J. C., H. G. Arango, A. F. Bennett, B. S. Chua, B. D. Cornuelle, E. Di Lorenzo, G. D. Egbert, D. Haidvogel, J. C. Levin, H. Luo, A. J. Miller, A. A. Moore, and E. D. Zaron, 2008: The Inverse Ocean Modeling system. Part II: Applications. *Journal of Atmospheric and Oceanic Technology*, **25,** 1623-1637.