2005 ROMS/TOMS User Workshop: Adjoint Modeling and Applications

Scripps Institution of Oceanography
Martin Johnson House, La Jolla,CA
October 24-26, 2005

Organized by: H. G. Arango, A. J. Miller, B. D. Cornuelle, A. M. Moore, and E. Di Lorenzo

How to get to the Sea Lodge Hotel, La Jolla

From San Diego International Airport, follow the signs to Interstate 5 North, Exit west on La Jolla Parkway. Follow to third traffic light and turn right on La Jolla Shores Drive. Turn left on Avenida De La Playa and right on Camino Del Oro. The hotel is on the left. Underground parking is available for hotel guests.

How to get to the Martin Johnson House (T-29)

From the Sea Lodge Hotel walk or drive north on Camino Del Oro, bear left on El Paseo Grande, Follow to the end to the traffic light for La Jolla Shores Drive. Turn left and continue on La Jolla Shores Drive until you find the entrance to Scripps Institution on your left. Turn left on to Naga Way and go straight to Biological Grade until you reach the Martin Johnson House. See attached maps.

Parking

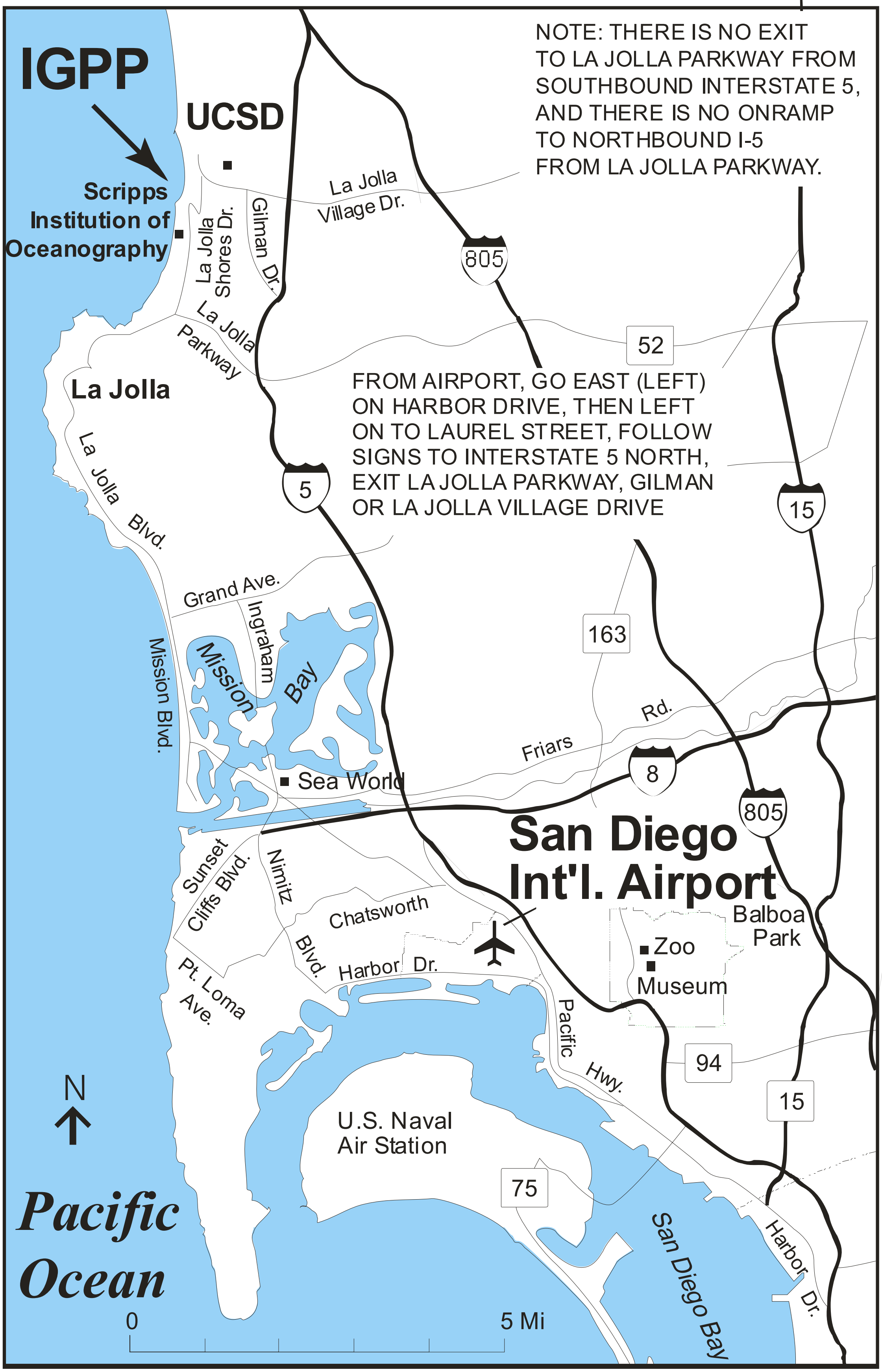
Very few spots will be available for parking, so car pooling or walking is recommended. Spots across the street at Nierenberg Hall are often available when the lots around T-29 fill up.

Near-by restaurants (to the Sea Lodge)

Barbarella (Italian)
Piatti's (Italian)
Osteria Romantica (Italian)
Cheese Shop (sandwiches)
Squires Cafe (sandwiches)
a couple pizza places, a chinese place.

Near-by lunch places (to the Martin Johnson House)

Next to the SIO library is "Cups Cafe" which serves espresso, some pastries, and a few sandwiches and salads. South of the pier, next to the new and old Scripps building is the SIO Snakropolis snack bar, which has lots of choices for lunch. North of Scripps (a 5 min drive) is the hang glider port (where they make burgers and you can watch the people land and take off).



IGPP
UCSD
Scripps Institution of Oceanography
NOTE: THERE IS NO EXIT TO LA JOLLA PARKWAY FROM SOUTHBOUND INTERSTATE 5, AND THERE IS NO ONRAMP TO NORTHBOUND I-5 FROM LA JOLLA PARKWAY.
La Jolla Village Dr.
La Jolla Shores Dr.
Gilman Dr.
805
52
La Jolla Parkway
La Jolla
FROM AIRPORT, GO EAST (LEFT) ON HARBOR DRIVE, THEN LEFT ON TO LAUREL STREET, FOLLOW SIGNS TO INTERSTATE 5 NORTH, EXIT LA JOLLA PARKWAY, GILMAN OR LA JOLLA VILLAGE DRIVE
5
15
La Jolla Blvd.
Grand Ave.
Ingraham
163
Mission Bay
Mission Blvd.
Friars Rd.
8
Sea World
805
San Diego Int'l. Airport
Sunset Cliffs Blvd.
Nimitz Blvd.
Chatsworth
Balboa Park
Zoo
Museum
Harbor Dr.
Pt. Loma Ave.
Pacific Hwy.
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U.S. Naval Air Station
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Pacific Ocean
San Diego Bay
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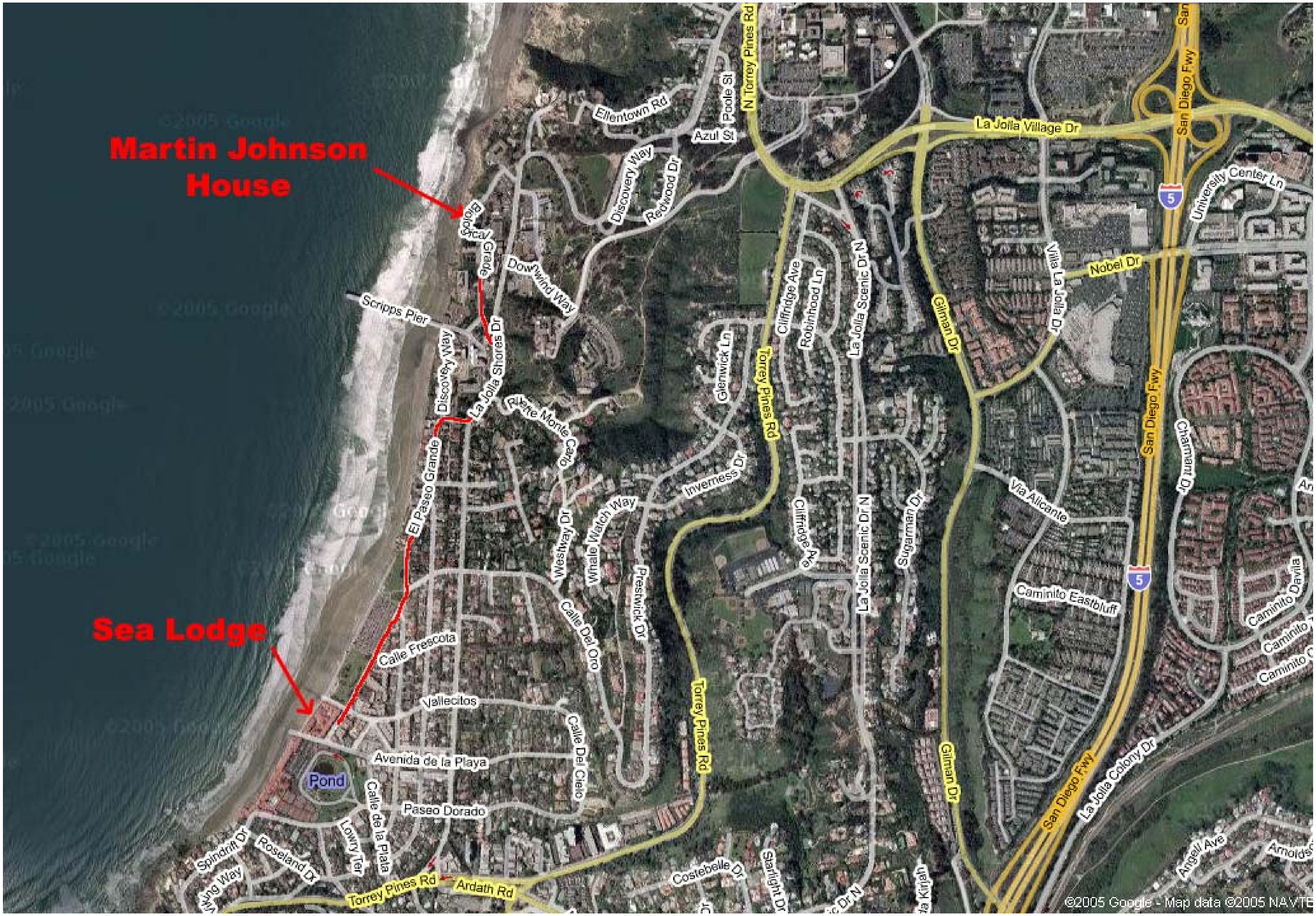

Martin Johnson House
Sea Lodge
Scripps Pier
El Paseo Grande
Discovery Way
La Jolla Shores Dr
Downwind Way
Ellentown Rd
Azul St
Poole St
N Torrey Pines Rd
Redwood Dr
La Jolla Village Dr
San Diego Fwy
University Center Ln
Nobel Dr
Villa La Jolla Dr
Gilman Dr
La Jolla Scenic Dr N
Robinhood Ln
Cliffridge Ave
Glenwick Ln
Torrey Pines Rd
Inverness Dr
Whale Watch Way
Westway Dr
Prestwick Dr
Calle Del Oro
Calle Frescota
Vallecitos
Avenida de la Playa
Calle Del Cielo
Pond
Paseo Dorado
Calle de la Plata
Lowry Ter
Roseland Dr
Spindrift Dr
Ardath Rd
Costebelle Dr
Starlight Dr
Sugarman Dr
Via Alicante
Caminito Eastbluff
Charmant Dr
Caminito Davila
La Jolla Colony Dr
Angell Ave
5
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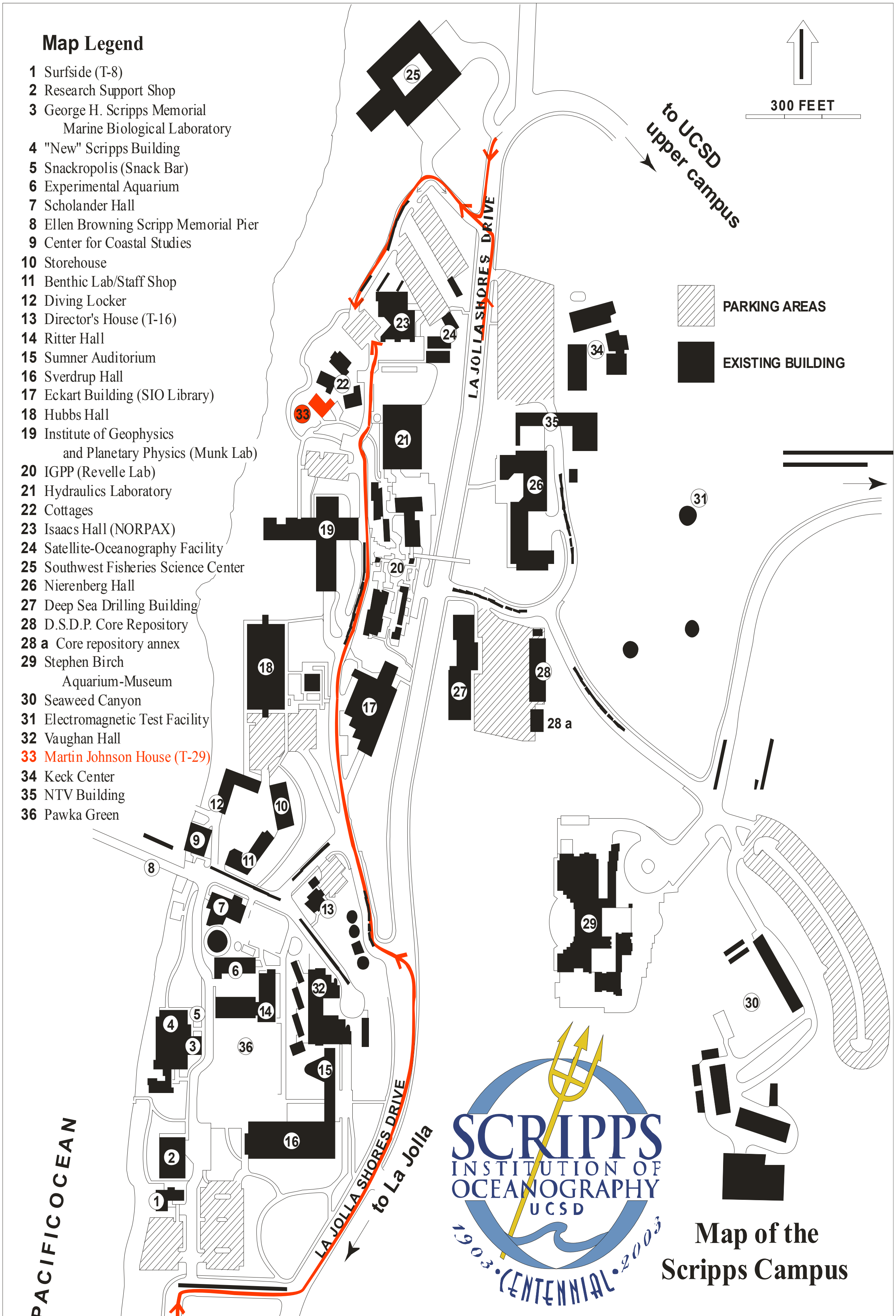

From the Sea Lodge

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PROGRAM

---------- Monday AM, October 24, 2005 ----------

08:15-08:55 Registration and Light Continental Breakfast

08:55-09:00 Arthur J. Miller: Welcome, logistics

ROMS/TOMS Nonlinear Model Algorithms and Applications

Chairperson: Arthur J. Miller

09:00-09:30 (30 min) John C. Warner, USGS
Incorporating Nearshore Process into ROMS

09:30-10:00 (30 min) Yuliya Kanarska, UCLA
Non-hydrostatic Algorithm and Dynamics in ROMS

10:00-10:20 (20 min) Kate Hedstrom, ARCS
Sea-ice Model in ROMS

10:20-10:40 (20 min) Enrique Curchitser, LDEO, Columbia U.
Coupled Sea-Ice/Ocean Numerical Simulation of the Bearing Sea for the Period 1996-2003

10:40-11:00 Break

Chairperson: James C. McWilliams

11:00-11:30 (30 min) Xavier Capet, UCLA
Submesoscale Secondary Instabilities and their Significance for Upper Ocean Dynamics

11:30-11:50 (20 min) Hyodae Seo, SIO
Regional Ocean-Atmosphere Feedback in Eastern Pacific

11:50-12:10 (20 min) Yusuke Uchiyama, UCLA
Infragravity Waves Forced by Surface Wind Waves in the Central North Pacific Ocean

12:10-12:30 (20 min) Guillermo Auad, SIO
A Quasi-Global ROMS: Preliminary Results of a Climate Run

12:30-14:30 Lunch

---------- Monday PM, October 24, 2004 ----------

Chairperson: John Wilkin

14:30-15:00 (30 min) Alexander Shchepetkin, UCLA
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15:00-15:30 (30 min) Katja Fennel, IMCS, Rutgers University
A Biogeochemical Model for the Northwestern Atlantic Continental Shelf

15:30-15:50 (20 min) Natalie Perlin, OSU
Coastal Upwelling Studies Using a Coupled Ocean-Atmosphere Model

15:50-16:10 (20 min) Ruoying He, WHOI
Applying Basin-scale Hindcast in Providing Open Ocean Boundary Conditions for Nested High-resolution ROMS Coastal Circulation Model

16:10-16:40 Break

Chairperson: John C. Warner

16:40-17:00 (20 min) Albert J. Hermann, JISAO, U. of Washington
The Estuarine Parameterization Problem: Sensitivity of ROMS to the Specifics of Line Source Buoyancy Input in the Costal Gulf of Alaska

17:00-17:20 (20 min) John Wilkin, IMCS, Rutgers University
Modeling the Hudson River Plume

16:40-17:00 (20 min) Robert Hetland, Texas A&M University
Water Mass Modification in Near-field River Plumes

17:30-18:00 Poster Setup

18:00 Reception

PROGRAM

---------- Tuesday AM, October 25, 2005 ----------

08:30-09:00 Light Continental Breakfast

ROMS/TOMS Adjoint Model Algorithms and Applications

Chairperson: Emanuele Di Lorenzo

09:00-09:40 (40 min) Andrew M. Moore, PAOS, U. of Colorado
Physical and Mathematical Interpretations of an Adjoint Model with Application to ROMS

09:40-09:50 (10 min) Hernan G. Arango, IMCS, Rutgers U.
Generalized Stability Theory Drivers

09:50-10:30 (40 min) Bruce D. Cornuelle, SIO
Least-Squares Fitting a Numerical Model to Observations

10:30-10:50 Break

Chairperson: Andrew M. Moore

10:50-11:30 (40 min) Emanule DI Lorenzo, Georgia Tech
The Inverse Regional Ocean Modeling System: Development and Application to Data Assimilation of Coastal Mesoscale Eddies

11:30-11:40 (10 min) Hernan G. Arango, IMCS, Rutgers U.
4D Variational Data Assimilation Drivers

11:40-12:10 (30 min) Alexander Kurapov, OSU
Variational Data Assimilation in Oceanic Problems with Instabilities

12:35-15:30 Lunch

---------- Tuesday PM, October 25, 2004 ----------

Chairperson: Bruce D. Cornuelle

14:00-14:30 (30 min) Zhijin Li, JPL
Real-time Implemetation of a Three-dimensional Variational Data Assimilation for ROMS

14:30-15:00 (30 min) Hernan G. Arango, IMCS, Rutgers U.
How Does One Build an Adjoint for ROMS/TOMS?

15:00-15:30 (30 min) Julia Levin, IMCS, Rutgers University
An Alternative Approach to Building Adjoints

15:30-15:50 Break

Chairperson: Hernan G. Arango

15:50-16:20 (30 min) Andrew M. Moore, PAOS, U. of Colorado
An Adjoint Sesitivity Analysis of the Southern California Circulation and Ecosystem

16:20-16:40 (20 min) Weifeng Zhang, IMCS, Rutgers University
Sensitivity Analysis of SST along the New Jersey Coast with Adjoint ROMS

16:40-17:10 (30 min) Scott Durski, OSU
Scale Evolution in Coastal Upwelling Frontal Instabilities

PROGRAM

-------- Wednesday AM, October 26, 2004 --------

08:30-09:00	Light Continental Breakfast

ROMS/TOMS General Discussion

Chairperson: Alexander Shchepetkin

09:00-09:20 (20 min)	Changming Dong, UCLA **Numerical Study of Shallow-Water Island Wake**
09:20-09:40 (20 min)	Xiochun Wang, JPL **Tidal Simulation Using ROMS**
09:40-10:00 (20 min)	David Robertson, IMCS, Rutgers University **ROMS/TOMS Web Site**
10:00-10:30	Break
10:30-11:30 (90 min)	Moderator: Hernan G. Arango **General Discussion I**
11:00-12:30 (90 min)	Moderator: Rich Signell **General Discussion II**
12:30-14:30	Lunch

Social Events

Host: Arthur J. Miller

14:30-17:30	Informal Discussions Group Pictures Wine Testing Contest

Poster Instructions:

The posters should be set up on Monday after we adjourn and taken back down after the reception. We do not have access to the poster area before we adjourn or after the reception so please make sure you remember your poster.

POSTERS

1. Ådlandsvik, Bjørn, Havforskningsunstituttet, Norway
Downscaling Future Climate Scenarios for the North Sea

2. Choi, Byoung-Ju, Oregon State University, USA
Wind Effect on Hudson River Plume

3. Colas, Francois, IGPP, UCLA, USA
Interannual Variability Along the Peruvian Cost Using a High Resolution (1/9) ROMS Configuration

4. Cox, Deborah, U. of New South Wales, Australia
Three Dimensional Aspects of Shallow-Water Island Wakes

5. Cure, Marcel, Kieran Lyons, Marine Institute, Ireland
Modeling on the Irish continental shelf - An Example of Downscaling Using ROMS

6. Foreman, Mike, IOS, Sidney, Vancouver, Canada
A Circulation Model for the Broughton Archipelago

7. Kim, Chang S., Korea Ocean R&D Institute, Korea
Meandering, Patch and Lens Structures of Changjiang Diluted Water in Yellow Sea in Summer 2003

8. Kim, Hey-Jin, Scripps, USA
Stratification Changes and Upwelling Efficiency in Southern California Current

9. Martin, Wayne , University Of Washington, USA
LISA, the Lopez Island Study Area

10. Sheinbaum, Julio, CICESE, Mexico
Dynamical Systems Analysis of IAS-ROMS Near-surface Velocity Field

11. Signell, Rich, USGS, Woods Hole, MA, USA
The Tidal Headland Test Case: ROMS & Delft3D

12. Wu, Chau-Ron, National Taiwan Normal University
Temporal and Spatial Variations of Kuroshio East of Taiwan

13. Zuo, Yue, Xingfu Wu, and Valerie Taylor, Texas A&M
Performance Analysis and Optimization of the Regional Ocean Model System (ROMS)

Talk Abstracts

How Does One Build and Adjoint for ROMS/TOMS?

Hernan G. Arango
IMCS, Rutgers University, New Brunswick, NJ, USA

An overview of the current ROMS/TOMS framework will be presented with particular emphasis to its associated tangent linear (TLM), representer (RPM), and adjoint models (ADM). These new models are used, in conjunction with the nonlinear model (NLM), for stability and sensitivity analysis, variational data assimilation, and ensemble prediction. The complexity of the ROMS/TOMS has increased tremendously and any future change to the basic algorithm has to be propagated to four different but related models. Therefore, it is important to know how all these new models are build. The building of these algorithms is shown in a simple example with animations. Several technical issues regarding the efficiency, parallelization, and testing will be addressed.

Generalized Stability Theory Drivers

Hernan G. Arango
IMCS, Rutgers University, New Brunswick, NJ, USA

The Generalized stability Theory drivers can be used to study the dynamics, sensitivity and stability of the ocean circulation to naturally occurring perturbation, errors or uncertainties in a forecast system. The propagators for optimal perturbations (singular vectors), finite time eigenmodes, adjoint finite time eigenmodes, and forcing singular vectors will be discussed in terms of the practical steps need to run these algorithms.

4D Variational Data Assimilation Drivers

Hernan G. Arango
IMCS, Rutgers University, New Brunswick, NJ, USA

The drivers for data assimilation includes both strong and weak constraint four-dimensional variational assimilation (4DVAR) algorithms. The strong constraint algorithms (conventional and incremental methods) assume that errors exits only in the observational data while the weak constraint algorithms (indirect representer method) includes both observational and model errors. These drivers will be discussed in terms of the practical steps needed to run these algorithms.

A Quasi-Global ROMS: Preliminary Results of a Climate Run

Guillermo Auad and **Art Miller**
Scripps Institution of Oceanography, USA

A quasi global (80S-80N) ROMS grid has been developed with a horizontal resolution of 0.8 degrees zonally and 0.3 to 0.5 degrees meridionally. Twenty levels are included in the vertical, while the climatological forcing was estimated from 40 years of NCEP wind stresses and surface heat fluxes. The first results show a reasonable representation of most world ocean currents and temperatures at the surface (*e.g.*, Gulf Stream, Kuroshio Extension, Loop Current, Malvinas-Brazil Confluence, East Greenland current, ACC, Benguela-Agulhas System, etc) and of currents and temperatures at depth (*e.g.*, Equatorial Counter-Current). The simulation also reproduces the main features of tropical-instability waves and the geographical location and properties of the North Pacific Intermediate Water, a water-mass which depth ranges between 300m and 1000m.

Submesocale Secondary Instabilities and their Significance for the Upper Ocean Dynamics

Xavier Capet and **James C. McWilliams**
I.G.P.P. UCLA, USA

The existence of a sub-mesoscale instability of mesoscale eddies as a necessary route to dissipation for the oceanic general circulation has been anticipated by theory and several instances have been demonstrated in highly idealized settings, but their role in more realistic oceanic situations is far from clear. We are investigating this phenomenon in an eastern boundary upwelling system configuration. Solutions for an identical 720km x 720km domain are computed at 12, 6, 3, 1.5, and 0.75 km horizontal grid resolutions for 1 year during a statistical equilibrium phase. The resulting upper-ocean kinetic energy spectra exhibit a shallowing when going from 12 to 1.5 km resolution, which is the signature of an increasingly efficient forward cascade of energy to dissipation; accompanying flow visualization implicates an increasing degree of sub-mesoscale instability. There seems to be a spectrum saturation beyond 1.5 km, suggesting convergence of the sub-mesoscale simulation. As for their upscale implications, the sub-mesoscale processes are associated with an important vertical heat redistribution in the mixed layer, significantly contributing to restratification there. We observe a much weaker submesocale activity in the ocean interior but implications for the large scale dynamics are not ruled out.

Least Squares Fitting a Numerical Model to Observations

Bruce Cornuelle
Scripps Institution of Oceanography, USA

Variational data assimilation is a complicated form of least-squares fitting, but the basic structure remains the same. I will review the theory behind these methods from basic regression through the adjoint method (and Kalman filtering).

Coupled Sea-Ice/Ocean Numerical Simulations of the Bering Sea for the Period 1996-2003

Enrique Curchitser
LDEO, Columbia University, USA,

Albert Hermann
Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, USA,

Kate Hedstrom
ARCS/University of Alaska, USA, and

Paul Budgell
Institute of Marine Research and Bjerknes Centre for Climate Research, Bergen, Norway

A coupled, regional sea-ice/ocean model has been developed to examine the interannual variability of circulation, sea ice extent, thickness and concentration within the Bering Sea for the period 1996-2003. In particular we examine the variability induced by the 1997/1998 El Nino, and the post-1999 cool phase in the Northeast Pacific. Our coupled model is based on the Regional Ocean Modeling System (ROMS), implemented at 10 km resolution for a Northeast Pacific domain which includes the Gulf of Alaska and the Bering Sea. The regional model is embedded in a lower resolution basin-scale model, which is used to generate the large-scale signals and provides both boundary and initial conditions for the Bering Sea via one-way nesting. Ice dynamics are based on the efficient elastic-viscous-plastic rheology of Hunke and Dukowicz (1997); ice thermodynamics are based upon Mellor and Kantha (1989) and include a three level ice layer, a snow layer, and a molecular sub-layer at the ice/ocean interface. Atmospheric forcing is derived from NCEP Reanalysis fluxes, corrected for model sea surface temperature and sea ice concentration. Regional model results are compared with satellite derived products based upon Pathfinder SSM/I and sea surface temperature. We further compare interannual patterns of the Bering with those of the Barents/Norwegian Seas, derived from ongoing, ROMS-based, sea-ice/ocean modeling of that region.

The Inverse Regional Ocean Modeling System (IROMS): Development and Application to Data Assimilation of Coastal Mesoscale Eddies.

Emanuele Di Lorenzo
Georgia Institute of Technology, USA

We describe the development and application of the Inverse Regional Ocean Modeling System (IROMS), a 4D-variational data assimilation system for high-resolution basin-wide and coastal oceanic flows. IROMS makes use of the recently developed perturbation tangent linear (TLM), representer tangent linear (RPM) and adjoint (ADM) models of the Regional Ocean Modeling System (ROMS) to implement a representer-based generalized inverse modeling system. This modeling framework is modular. The TLM, RPM and ADM models are used as stand-alone sub-models within the Inverse Ocean Modeling (IOM) system described in Chua and Bennett (2001). The system allows the assimilation of a wide range of observation types and uses an iterative algorithm to solve nonlinear assimilation problems. The assimilation is performed either under the perfect model assumption (strong constraint) or by also allowing errors in the model dynamics (weak constraints). For the weak constraint case the TLM and RPM models are modified to include additional forcing terms on the right hand side of the model equations. These terms are needed to account for errors in the model dynamics. Posterior error statistics, term balances and array assessment are computed using separate diagnostic tools provided by the IOM.

After testing IROMS in an idealized 3D double gyre circulation we present a realistic application for the Southern California Bight (SCB), a region characterized by strong mesoscale eddy variability. The SCB model domain geometry is derived using real coastlines and a smooth version of satellite bottom topography. We assimilate synthetic data for sea surface height, upper ocean (0-500m) temperatures, salinities and currents over a period of 3 days. The spatial distribution of the synthetic observations follows the California Cooperative Oceanographic Fisheries Investigations (CalCOFI) sampling grid. The model first guess, prior to assimilation, is initialized using climatological conditions. The assimilation solution for the strong constraint experiment successfully reduces the initial model-observation misfit by 75% and improves the model fields also at locations where observations are not assimilated. In the weak constraint experiment the model-observation misfit is reduced by 89%. To verify the quality of the assimilation solution we integrate the model beyond the assimilation window for additional 3 days and measure the predictive skill against independent observations. Both the strong and weak constraint case show forecast skill greater than persistence and climatology.

Numerical Study of Shallow-Water Island Wake

Changming Dong and **James McWilliams**
IGPP, University of California at Los Angeles, USA

In terms of the vorticity generation mechanisms, there are two types of island wakes: deep-water and shallow-water. In the former one, the lateral friction boundary is the source of the vorticity and for the latter, the bottom friction is the primary source of the vorticity. We extend our previous study on the stratified and rotating deep water wake to the shallow-water one. With the existence of the shelf slope, internal Froude number is the controlling non-dimensional parameter determining if the current flows over or around the island shelf, which leads to different effective island diameters. In the basic experiment, the vorticity generation in the shallow water wake is analyzed. A series of numerical experiments are performed to test the sensitivity of shallow-water island wake to non-dimensional parameters, such as Ekman number, Burger number and Rossby number. The studies are applied to the real island wakes in the Southern California Bight.

Scale Evolution in Coastal Upwelling Frontal Instabilities

Scott Durski
Oregon State University, USA

Nonlinear model studies of instability evolution on a time-evolving coastal upwelling front indicate that disturbances develop on short horizontal scales but rapidly evolve to longer wavelengths. Several mechanism associated with the non-stationarity of the basic state on which the instabilities develop may promote the progression in scale. The upwelling evolution alters the flow structure either when advecting offshore under sustained winds or falling shoreward under wind relaxation. The finite amplitude amplification of the disturbances alter the alongshore mean flow state potentially promoting growth at new scales. Wave-wave interactions between finite amplitude instabilities may lead to growth at different scales as well. To examine these possibilities, tangent linear ROMS simulations about basic states that represent different approximations to the unstable upwelling evolution are performed. Under relaxing wind conditions it is found that a significant fraction of the scale change is associated with the alteration of the mean flow state by the finite amplitude instabilities. The scale change observed under sustained upwelling winds however results primarily from wave-wave interactions.

A Biogeochemical Model for the Northwestern Atlantic Continental Shelf

Katja Fennel and **John Wilkin**
IMCS, Rutgers Univerisity, USA

Biogeochemical processes in continental shelf systems such as shelf primary production or sediment denitrification are thought to contribute significantly to global primary production and denitrification. Shelf processes thus play an important role in the elemental cycling of nitrogen and carbon, yet shelf systems are generally not resolved in basin-wide and global biogeochemical models. We developed a high-resolution biogeochemical-physical ROMS for the northwestern Atlantic Ocean's continental shelves and adjacent deep ocean in order to estimate shelf fluxes of nitrogen and carbon. Our biological model is a relatively simple representation of nitrogen cycling in the water column and organic matter remineralization at the water-sediment interface that explicitly accounts for sediment denitrification. Carbon and oxygen dynamics are explicitly included and are driven by the photosynthetic production and remineralization of organic matter and by air-sea exchange of CO2 and O2. Model/data comparisons using climatological nutrient, chlorophyll, primary production and denitrification data, statistical measures of pattern variability, and a nitrogen budget for the Middle Atlantic Bight will be presented. Our results emphasize the importance of representing shelf processes in biogeochemical models.

Applying Basin-Scale Hindcast in Providing Open Boundary Conditions for Nested High-resolution ROMS Coastal Circulation Modeling

Ruoying He
Woods Hole Oceanographic Institution, USA

The offshore ocean can exert a significant influence in many coastal regions due to a wide range of processes such as basin-scale seasonal and inter-annual variability, boundary current meanders, and meso-scale and submeso-scale eddies. To effectively represent the impact of this offshore variability on a coastal ocean setting, the coastal model must be driven by open boundary conditions (OBCs) that can represent the state of the open ocean and its variability. The Hybrid Coordinate Ocean Model (HYCOM) Global Ocean Data Assimilation Experiment (GODAE) hindcast was used for this purpose to provide boundary conditions to a nested Regional Ocean Modeling System (ROMS).

The nested (1st-level nesting) ROMS provided circulation hindcast for the coastal area encompassing the Gulf of Maine (GOM) and the Middle Atlantic Bight (MAB). Inside this regional ROMS, additional two smaller-scale ROMS models were embedded (2nd-level nesting) to provide high-resolution model realizations of circulation in the Gulf of Maine and the Mid-Atlantic Bight shelf-break region, respectively. Our objective is through such multi-nesting approach, to bring deep-ocean influence to the coastal region in a dynamically consistent, and quantitatively accurate manner, thereby facilitating the realism and fidelity of high-resolution coastal circulation modeling. We report here some preliminary results of such effort.

The Sea-ice Model in ROMS

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Paul Budgell
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Enrique Curchitser
LDEO, Columbia University, USA

ROMS now includes an optional sea-ice component. This model will be described in terms of the algorithms used and the parameters to set when using it. It is a combination of other models, with the elastic-viscous-plastic (EVP) dynamics from Hunke and Dukowicz (1997) and the thermodynamics from Mellor and Kantha (1989). Currently, the thermodynamics include just one ice category with a thickness, concentration, and internal temperature, but we'd like to expand it to include more categories and more vertical temperature levels, much like the modern CICE model. Meanwhile, the largest errors come about due to uncertainties in the atmospheric fluxes - the atmospheric bulk flux formulation is also subject to change.

The Estuarine Parameterization Problem: Sensitivity of ROMS to the Specifics of Line Source Buoyancy Input in the Coastal Gulf of Alaska

Albert J. Hermann and **Elizabeth L. Dobbins**
Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, USA

For several years we have been using ROMS to simulate the buoyancy- and wind-driven Alaskan Coastal Current (ACC) in the Coastal Gulf of Alaska (CGOA), and its effect on biological productivity on the shelf. The buoyancy that drives the ACC is provided by innumerable streams and rivers which feed into deep, narrow fjords that, in many cases, are not resolved by the scale of our grid. We treat these inputs as a "line source" of buoyancy, and attempt to parameterize the unresolved processes within the fjord/estuaries by adjusting the vertical profile and salinity of the input freshwater. This has been complicated by a lack of knowledge regarding the physics which govern the buoyant plume of a line source (with the exception of Williams, 2003) relative to river point sources, and by the paucity of data collected within the fjords and the ACC. Recent data collected in the CGOA allow us to use transport within the ACC, and stratification across the shelf near Seward, AK, to validate the results of several buoyancy input schemes. The various possibilities for coastal freshwater input include the following, where Q represents the flux of freshwater into the system. Note that in each case we do not attempt to resolve the tidal flux across the model coast into the unresolved estuaries, but instead look to approximate the subtidal result.

1) Input of zero salinity water at rate Q to the surface level of the model. In this case, the estuarine conditions are essentially pushed onto the shelf, aliasing the stability of the water column there, to the detriment of the biological calculations;

2) Similar to scheme 1, but the outflow Q is distributed vertically, to approximate vertical mixing within the unresolved fjords/estuaries;

3) Input of brackish water at a rate greater than Q in the surface level. This represents continuous estuarine mixing of fresh and ocean waters (estuarine amplification) landward of the model's coastline, but ignores the corresponding inflow of ocean water at depth;

4) Input of brackish water at rate Q in the topmost layer. This represents "perfect" estuarine mixing of fresh and ocean waters generated by each flood tide, followed by discharge of the resulting brackish product on the ebb.

At present, scheme 4 appears to give the most satisfactory result, and the closest match to observations. We discuss the merits and deficiencies of each approach, and other possible schemes for the parameterization of estuaries in the CGOA.

Water Mass Modification in Near-field River Plumes

Robert Hetland
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This paper describes numerical solutions to a simple layer model of a near-field river plume. The near-field is defined as the region where buoyant outflow from an estuary is supercritical. The layer model is intended to reproduce the scales of the near-field plume, in particular the density anomaly of the water leaving the near field, by balancing the competing processes of entrainment and plume spreading. The structure of the solutions is qualitatively similar to observations and three-dimensional simulations of near-field plumes, and agrees reasonably well with three-dimensional simulations of near-field plumes. The properties of water exiting the near-field plume depend functionally on the normalized entrainment velocity, **Wn = We * 2 * Wo / Qo**, where **We** is either a representative or minimum background entrainment velocity, **Wo** is the width of the estuary mouth, and **Qo** is the volume flux of water leaving the estuary. Water leaving this region will determine to a large extent the water properties of the larger scale river plume structure over the continental shelf. Thus, this simple model may be useful in estimating the characteristic density of buoyant water in larger scale analytic models of buoyancy-driven flow on the continental shelf, or in estimating unresolved mixing near buoyancy sources in numerical models of coastal ocean flow.

Non-hydrostatic Algorithm and Dynamics in ROMS

Yuliya Kanarska, **Alexander Shchepetkin** and **James C. McWilliams**
I.G.P.P. UCLA, USA

A non-hydrostatic extension for ROMS model is proposed. It includes decomposition technique on hydrostatic and non-hydrostatic components for pressure and velocity fields. The resulting equations are solved with a pressure correction scheme which includes explicit treatment of free surface and mode splitting technique. Special attention is given to the effective solution of resulting elliptic problem in terrain-following coordinates.

The algorithm is tested on several examples for barotropic and baroclinic flows where non-hydrostatic effects are important. The model is applied to the South China Sea region to explore internal wave generation, modal transformation processes in vicinity of the Luzon Strait sill. The impact of changes in stratification, differential steepening due to depth and 3D effects on these processes are studied.

Variational Data Assimilation in Oceanic Problems with Instabilities

Alexander Kurapov
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Emerging tangent linear (TL) and adjoint (AD) ROMS codes utilized with the variational representer-based generalized inverse method (GIM, ref.: Chua and Bennett, Ocean Modelling, 2001) will provide powerful tools for rigorous assimilation of massive data sets into the nonlinear oceanic model, allowing to correct model inputs (including forcing, initial, and boundary conditions). Using GIM, a quadratic functional penalizing model and data errors over a finite time interval is defined. Nonlinear Euler-Lagrange equations, providing necessary conditions for the minimum of the penalty functional, are solved iteratively via a series of linearized optimization problems.

In many coastal applications, energetic alongshore flows are prone to instabilities. While their growth can be constrained by nonlinear advection in the nonlinear model, it is not similarly constrained in the companion tangent linear model, potentially posing a threat to the stability of GIM. This issue is fundamental in coastal ocean data assimilation and is relevant both for shallow-water and three-dimensional stratified flows. To address it, TL and AD codes for a shallow-water equation model have been built using algorithmic features of the two-dimensional part of ROMS and recipes for TL-AD code development shared with us by ROMS Adjoint Group. Using these codes, GIM is applied with synthetic measurements in a study of forced-dissipative flows over variable beach bathymetry, driven by radiation stresses from shoaling waves. In cases of relatively small dissipation, in which the model exhibits instabilities (including a regular equilibrated wave pattern or "turbulent" behavior), the utility of GIM and requirements for adequate data coverage are determined.

An Alternative Approach to Building Adjoints

Julia Levin
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ROMS nonlinear model in continuously evolving and improving. Changes to the core algorithm need to be propagated to the tangent linear, representer and adjoint models. The adjoint model is built by "symbolic" manipulation of the forward, nonlinear code. The algorithm is based on applying a set of "inversion" rules for every single operator in the code. An alternative approach consists of analytically deriving the discrete adjoint equations and then coding them up. In certain circumstances, it is easier to obtain an adjoint code using this alternative approach. Moreover, it gives a clear definition of the adjoint variables and their physical meaning.

We describe the approach in a simple setting, first in a continuous, and then in a discrete form.

Real-time Implementation of a Three-dimensional Variational Data Assimilation for ROMS

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Jet Propulsion Laboratory, USA,

James C. McWilliams and **Kayo Ide**
I.G.P.P. UCLA

A three-dimensional variational data assimilation (3DVAR) scheme, which is associated with the nested Regional Ocean Modeling System (ROMS) and called ROMS-DAS, has been implemented in the U. S West coast. ROMS-DAS emphasizes the capability for predicting meso- to small-scale variations with temporal scales from hours to days in coastal oceans. To cope with particular difficulties that result from complex coastline and bottom topography, complex dynamics, and sparse observations, ROMS-DAS is incorporated with novel strategies. These strategies include the implementation of three-dimensional anisotropic and inhomogeneous error correlations, application of particular weak dynamic constraints, and implementation of efficient and reliable minimization methods. These strategies will be presented. The performance of real-time implementation of ROMS-DAS with simultaneously assimilating sea surface temperatures and heights from multiple satellites, ship reports, various temperature/salinity vertical profiles will be described. The issues on the assimilation of velocity observations from ADCP and HF radars will be discussed.

Physical and Mathematical Interpretations of an Adjoint Model with Application to ROMS

Andrew M. Moore
University of Colorado, USA

The mathematical properties of adjoint operators will be introduced and discussed and, where possible, physical interpretations or examples will be given. These ideas will then be expanded and discussed in the context of the ROMS generalized stability analysis and adjoint sensitivity analysis tool kits.

An Adjoint Sensitivity Analysis of the Southern California Current Circulation and Ecosystem

Andrew M. Moore
University of Colorado, USA

The ROMS adjoint sensitivity analysis tool kit has been used to explore the sensitivity of various aspects of the physical and biological circulations in the southern portion of the California Current system to variations is various fundamental attributes of the system. The use of the adjoint of ROMS in this way is an extremely efficient method of sensitivity analysis, and the results of various experiments will be presented and discussed.

Coastal Upwelling Studies Using a Coupled Ocean-Atmosphere Model

Natalie Perlin, **Eric Skyllingstad**, **Roger Samelson**, and **Phil Barbour**
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A fully coupled ocean-atmosphere modeling system is applied to study summertime wind-driven coastal upwelling off Oregon. Two-way model interaction during the simulation supplies the ocean model with atmospheric wind stress and heat fluxes, including solar radiation; the atmosphere receives sea surface temperatures as a feedback from the ocean. Current idealized studies with 1km horizontal resolution in both models are set essentially as two-dimensional cases, being periodic in north-south direction, with eastern coastal wall and linear shelf slope.

Model results suggest that coastal upwelling develops faster when surface wind and heat forcing from atmospheric model is used. In the atmosphere, internal boundary layer develops over the cold inshore waters during the coupled simulation.

Plans for future work involve extension of the ocean domain further offshore to include shelf break, inclusion of coastal topography, and ultimately, alongshore variations in coastal bathymetric and topographic features. Previous observational and modeling studies demonstrate that irregular coastline could notably affect wind forcing of the coastal ocean.

ROMS/TOMS Web Site

David Robertson and **Hernan Arango**
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We will discuss the current status and capabilities of ROMS/TOMS web sites. As the model evolves and increases in size, the documentation has become our priority. We have designed a dynamic web-based interface to update the model documentation. This interface will be shown. We want to encourage the user community to participate actively in developing, updating, and improving the model documentation.

Regional Ocean-Atmosphere Feedback in Eastern Pacific

Hyodae Seo, **Art Miller**, and **John Roads**
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Using a high-resolution ocean-atmosphere coupled model, recent observational evidence for air-sea interactions in the eastern Pacific is reproduced. Model data are subsequently analyzed to examine various hypotheses for the regional-scale coupling processes.

As a specific focus, undulations of SST by Tropical Instability Waves (TIWs) and vertical shear adjustment of the atmospheric boundary layer (BL) in eastern tropical Pacific are studied. It is shown that undulating SST fronts force an unambiguous response in the atmospheric BL throughout its whole height. Furthermore, it is seen that there are significant changes of wind curl and divergence fields around the SST fronts implying that perturbed surface wind-derivative fields may lead to an additional feedback to the ocean. In addition to this dynamic feedback, there seems to be significant thermodynamic feedback due to changes in air-sea temperature difference and winds across the SST front. Similar coupling patterns are also seen in the midlatitude ocean near the California coast on much smaller spatial and temporal scales. This implies that this regional-scale coupling is ubiquitous over the world ocean wherever strong SST fronts are associated with mesoscale oceanic meanders, eddies, and filaments.

If-less KPP

Alexander Shchepetkin
I.G.P.P. UCLA

Over the years vertical mixing schemes have been shown to be a major factor which controls success or failure of realistic ocean modeling. The problem is especially challenging because of multiple mixing regimes occurring in oceanic conditions, which makes a model focusing of a particular physical scenario to be unsuccessful, while multi-process schemes involve conceptually complex (and often not well defined) rules of transition between different regimes. The practical constraints impose the requirement that the model must be able to work at relatively coarse resolution, which puts preference to relatively a low-order closure, emphasis on careful design of numerical discretizations to escape the problem of resolution dependency of behavior of the model. This talk presents an integral version of KPP, which is built around a boundary layer algorithm capable of smooth transition between regimes of shear layer instability, Ekman layer and convective boundary layer, and which matches the correct projections in these pure limits. Also discussed are numerical techniques to count "resolution drift", which prevents successful parameter tuning, practical verification using results from ROMS Pacific model.

Infragravity Waves Forced by Surface Wind Waves in the Central North Pacific Ocean

Yusuke Uchiyama and **James C. McWilliams**
IGPP, UCLA, USA

Recent studies have suggested that infragravity long-waves forced by surface wind waves could generate significant pressure fluctuations on the seafloor for the frequency band 3-15 mHz (periods of about 70-330 s), and thus excite micro-seismic oscillations in the infragravity frequency band at almost every seismically quiet site in the world [Webb, 1998; Tanimoto, 2005]. The central North Pacific Ocean (98 deg. E - 112 deg. W, 67 deg. N - 47 deg. S) is one of the most active regions where this mechanism is believed to be predominant particularly in stormy winter [Rhie and Romanowicz, 2004]. A barotropic version of ROMS for theoretically derived infragravity wave generation terms [McWilliams et al., 2004] has been developed, and realistic simulations are being made of the forced infragravity waves due to the primary wind-wave field and seafloor pressure response in the Pacific for prediction of the seismic detection of the Earth's "hum". The experiments require wavenumber spectral data to evaluate the wave-averaged forcing terms. We have exploited reanalyzed spectral data provided by ECMWF and UCAR on a 1.5 degree geographical grid.

Tidal Simulation Using ROMS

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Changming Dong and **James McWilliams**
I.G.P.P. UCLA, USA

A three dimensional general circulation model (ROMS) is used to simulate tides along the central western coast of US. The model is three-level nested with the finest resolution of 1.6 km in the Monterey Bay region. The motivation of the study is to test the capability of ROMS in simulating tides and to develop an operational forecasting system for the region. Forced by tidal signal along the open boundaries in west, north and south directions, ROMS can simulate tidal signal reasonably well in the region. The total error of the amplitudes of eight major constituents, measured by root of summed squares, is less than 6 cm which is about 10% of the amplitude of the most energetic M2 constituent. For these major tide constituents, the phase error is less than half hour. A comparison of hourly sea level for August of 2003 shows a RMS error of 8 cm, with slightly less error in the finest model domain. Comparing with barotropic tide models, the tide simulation from a general circulation model is not sensitive to model parameters such as drag coefficient. The addition of tide signal in the ROMS model is a significant step toward an operational forecasting system of the Monterey Bay region.

Incorporating Nearshore Processes into ROMS

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Hernan G. Arango
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Prediction of nearshore processes is important for coastal circulation, water quality concerns, shoreline change, and recreational safety. Nearshore processes are driven primarily by wind-generated waves that propagate shoreward. As water depths decrease the orbital motions of the waves impinge on the seafloor and modify the wave dynamics. The waves also drive a shoreward flux of momentum that is balanced by an opposing pressure gradient, and a shoreward mass flux that is compensated by an offshore undertow transport, all resulting in a modification of the vertical structure of the currents.

We are incorporating nearshore processes into ROMS. First we have included capabilities for wetting and drying which is essential for many shallow water estuarine processes and shoreline evolution. Second we have incorporated nearshore radiation stress terms into the momentum equations. We have based these algorithms on the Mellor (2003; 2004) formulation that provides a vertical distribution of the radiation stress terms. Comparison to other formulations such as the vortex-force representation (McWilliams *et al.*, 2004; Lane *et al.*, submitted) will be discussed. Finally we have coupled ROMS to the nearshore wave model SWAN using the Model Coupling Toolkit (http://www-unix.mcs.anl.gov/mct/; Larson, *et al.*, 2004; Jacob *et al.*, 2005). The toolkit provides a means to construct parallel coupled models from individual models. We will describe the methodology to incorporate all of these algorithms into ROMS and demonstrate the performance with several simple test cases.

Modeling the Hudson River Plume

John Wilkin and **Gregg Foti**
IMCS, Rutgers University, New Brunswick, NJ

Byoung-Ju Choi
COAS, Oregon State University, Corvallis, OR, USA

The dispersal of the spring maximum discharge (freshet) of the Hudson River into the New York Bight and inner New Jersey shelf region is the focus of an integrated physical, biological and geochemical study employing a variety of observational systems (moorings, CODAR, autonomous gliders, ships, satellites) and forecast and hindcast modeling with ROMS.

A ROMS ocean prediction system using atmospheric forcing from the NCEP/NAM forecast and observed river flows was used to predict the dispersal of the spring freshet during the May 2005 intensive observing period. The trajectory of dye released in two Lagrangian tracer experiments was also forecast.

The dispersal of the freshwater anomaly associated with the plume was seen to be highly responsive to local winds on short time scales. Relatively little low salinity water immediately traveled southward along the New Jersey coast in a coastally trapped buoyancy driven current. A coastal current formed only with the assistance of favorable winds. The presence of the Hudson Shelf Valley exerts significant control on the overlying surface trapped plume, such that low salinity anomalies initially directed east along the Long Island, New York, coast were obstructed from joining any down-coast flow.

Sensitivity Analysis of SST Along the New Jersey Coast with ROMS Adjoint

Weifeng Zhang
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As a prelude to data assimilation work in the New York Bight and New Jersey coast area, the ROMS Adjoint Sensitivity model is used to examine transport pathways and ocean dynamics in this region.

The along-shelf flow on the New Jersey coast is affected by local winds and buoyancy forcing associated with the Hudson River plume. Circulation in this region is being monitored intensively by the New Jersey Shelf Observing System, and modeled with ROMS. We are using the ROMS Adjoint model to re-examine our understanding of circulation in this area based on forward simulations and observations, and also to improve the simulation by combining numerical model and measurement data together.

Here we test the newly available ROMS Adjoint model. The adjoint sensitivity of the sea surface temperature in a near coast region against different state variables, such temperature itself, salinity, wind stress, and surface net heat flux is examined. Different idealized wind forcing cases are considered. The adjoint results concur with expected qualitative features of the dynamics in this area, but add spatial and temporal detail, and quantitative information on the relative magnitude of SST anomaly dependence on different state variables and forcing terms.

Poster Abstracts

Downscaling Future Climate Scenarios for the North Sea

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The ROMS ocean model is used in the North Sea to dynamically downscale climate scenarios from the global coupled ocean-atmosphere model Bergen Climate Model (BCM). The objective is to produce input to marine climate impact studies.

As a validation, a hindcast run for 6 years has been performed with atmospheric forcing from NCAR/NCEP and climatology at the lateral boundaries. The Flow Relaxation Scheme (FRS) is used as the lateral boundary scheme, while a flux-based parameterization is used for the atmosphere. The model output is compared with hydrographic sections and time series from costal stations. The results show that the model is able to reproduce much of the annual and interannual climate variability, even with relatively coarse input.

For the actual downscaling, both atmospheric and lateral boundary forcing are taken from the BCM model. This one-way nesting approach works, in that the region model provides increased regional details while staying consistent with the global model. In particular, the Norwegian Coastal Current, which is absent in the global model, is created within the regional domain.

Wind Effect on Hudson River Plume

Byoung-Ju Choi
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John Wilkin and **Dale B. Haidvogel**
IMCS, Rutgers University, New Brunswick, NJ, USA

The Hudson River plume transports freshwater, nutrients, contaminants, sediments and momentum into the New York Bight. In this study we try to answer two questions: (1) where does the freshwater from the Hudson River travel? (2) which forces are dominant in the momentum balance?

ROMS is utilized to investigate the Hudson River plume response to wind forcing. The model is setup with realistic coastlines and bottom topography. Tidal forcing is also included.

In a constant low discharge case, northward and eastward winds move freshwater out of Raritan Bay and away from the New Jersey coast while southward and westward winds accumulate freshwater in those locations.

During a two week of high discharge event in spring, the simulated river plume forms a growing freshwater bulge without wind forcing. However, with northward wind forcing the freshwater is directed to the east, while with southward wind forcing freshwater drains to the south. Eastward and westward winds arrest the plume near the mouth of Raritan Bay.

Interannual Variability Along the Peruvian Cost Using a High Resolution (1/9) ROMS Configuration

Francois Colas
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A modeling study of the Peru coastal and regional circulation has been performed in order to reproduce main patterns of the mean circulation and their seasonal variability. A climatological solution of a 1/9 degree Peru ROMS configuration, forced by a general circulation model at its open boundaries, has been previously validated and shows good agreement with available data (Penven *et al.* 2005).

In order to assess interannual variability over the 90's we provide the same configuration with boundary conditions from a interannual lower resolution (1/2 degree) model encompassing the Pacific basin. We use a mixture of ERS/Quikscat and NCEP datasets as atmospheric forcing fields.

The solution captures the main interannual SSH anomalies, especially the 97/98 El Nino with its two major peaks. ENSO implications for the near-shore current system are discussed in particular with the help of Lagrangian diagnostics. It is also shown that this regional solution is very sensitive to the information provided at the open boundaries (*i.e.* sensitive to the solution over the Pacific basin at lower resolution).

Three Dimensional Aspects of Shallow-Water Island Wakes

Deborah R. Cox and **Jason H. Middleton**
University of New South Wales, Australia

Field observations and satellite imagery have shown that island wakes have important implications for mixing, sediment transport and the distribution of biological species. While laboratory experiments and numerical modeling of the flow around hills and structures such as buildings and piers have shown that the wakes produced are complex and strongly three dimensional, there has been limited investigation of the three dimensional structure of island wakes. This paper will present some preliminary results of three dimensional numerical simulations (using ROMS) of the wakes for different island shapes and incident flow profiles.

Operational Forecasting in the IBIROOS Region

Marcel Cure, **Kieran Lyons** and **Glenn Nolan**
The Marine Institute, Ireland

European seas are being divided into Ocean Observation Systems operational systems such as MEDGOOS (Mediterranean) NOOS (North Sea), BOOS (Black Sea) and our new regional alliance IBIROOS, which is the Iberian-Biscay-Irish regional OOS. The IBIROOS system is characterized by strong tidal forcing and open ocean deep water boundaries, with exchange of nutrients, momentum, heat and salt between continental shelves and the deep ocean. The configuration of the North Atlantic Current system and the position of eddies cannot be ignored even though our main interest focuses on applications in bays and estuaries which are environmentally sensitive and yet are important in terms of shellfish and fin fish aquaculture.

In this poster we will show how we have recently implemented ROMS for the Irish shelf coastal areas, downscaled from a GCM, MERCATOR. Nested within our Irish Shelf model are further fine scale ROMS domains. We will show some early results and discuss plans we have to implement a coupled ecosystem model and fine scale meteorological models and to utilize some of the new features within ROMS such as the tangent linear and adjoint methods to improve the accuracy of hindcasts and predictions, as we move towards operational forecasting with our partners within IBIROOS.

A Circulation Model for the Broughton Archipelago

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The Broughton Archipelago is a complex network of islands, channels, and fiords lying off the mainland of British Columbia, approximately 300km northwest of Vancouver. In addition to river and glacial runoff that enters from the nearby mountainous terrain, circulation within the archipelago is also forced by winds and strong tidal and estuarine flows in both Johnstone and Queen Charlotte Straits, the primary conduits into the archipelago. The region is a primary location for salmon farms in British Columbia and has recently become the focus of confrontations between environmentalists, commercial fisherman, and agencies regulating the fish farm industry. Although circulation plays an important role in oxygen renewal and the transport of farm waste, sea lice, and viruses, there have been very few observations taken in the archipelago. In an effort to better to understand the circulation patterns, ROMS has been applied with a resolution of 250 meters. Preliminary results will be shown.

Meandering, Patch and Lens Structures of Changjiang Diluted Water in Yellow Sea in Summer 2003

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The dynamic behavior of Changjiang Diluted Water was simulated numerically by using the ROMS 2.2 in the MPI mode on Onyx350 16-cpu machine. The 4x4 tiling parallel computing was a very powerful mode for computation, especially for reproduction of the behavior of low-saline water patch originated from Changjiang Diluted Water. The patch and sometimes so-called 'lens' of low-saline water body have been generally observed in the field survey in summer.

The goal of this study is to elucidate the generation, pathway and forms of the CDW dispersion in meandering, patch and lens structures in summer 2003 as reported in many field observations. To simulate the fate of the CDW dispersion, the terrain-following ROMS model has been applied. The scale of patches ranges from 50km to 150 km in horizon and 10m to 20m in vertical thickness. During summer of 2003 the life span has been estimated as approximately 20 days from generation of meandering to fading out from lens pattern. The moving speed of patch core has been estimated as approximately 40 cm/s along the major axis of meandering path with life span of 10 to 20 days dependent upon the local winds and tidal action.

Through the numerical drifter experiment and vorticity field, the local winds and tidal action are very important agency controlling the meandering, patch and lens structures of the CDW low saline water body in summer.

Stratification Changes and Upwelling Efficiency in Southern California Current

Hey-Jin Kim, **Art Miller**, **Doug Neilson**, and **John McGowan**
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California current System (CCS) is highly variable and very productive. Many physical processes interact with various temporal and spatial scales, and they interact with the marine ecosystem. Long-term changes of the biological response to physical climate forcing are one of the main issues of interest, because the nonlinear ecosystem may not be linearly related to the persistent environmental disturbances (Hsieh *et al.*, 2005). Roemmich and McGowan (1995) showed very unique observations of long-term physical-biological interaction in Southern California current and suggested that surface warming forced increased stratification, which capped the cold nutrient-rich upwelling cell, and consequently resulted in 70% decrease in macrozooplankton biomass in the Southern California current. However, the linkage between stratification changes and zooplankton biomass is still not well understood. This study analyzes patterns of long-term stratification changes quantitatively in terms of mixed layer depth and thermocline depth with the in-situ dataset of 55 year CalCOFI (California Cooperative Oceanic Fisheries Investigations), and examines the upwelling efficiency and the primary production related to the stratification changes by ROMS.

LISA, the Lopez Island Study Area

Wayne Martin
University of Washington, USA

Lopez Island is part of the San Juan Archipelago, at the eastern end of the Strait of Juan de Fuca, between Washington State and British Colombia. LISA is an area on the east side of Lopez Island, approximately 10 x 6 km, with several bays, small islands and channels. The depth ranges from 1 to 50m and there is an energetic forcing through Lopez Pass where tidal currents exceed 1 m/s on a daily basis. Within LISA, there are distinct sites with repeatable conditions of interest including high turbulence, dissipation and mixing, non-hydrostatic flow, internal wave generation, flow separation, wetting and drying and significant tidal depth variations. Over the next several years, we intend to develop a comprehensive monitoring system for the physical oceanography at LISA using ADCPs, CTDs, tide gages and stereographic cameras. We will also implement one or more detailed numerical models, beginning with ROMS, and including data assimilation from the sensor suite. Our primary research interest is the understanding and modeling of stratified flow over topography. However, LISA will also be available for biological and other research that can benefit from a detailed knowledge of the physical environment.

Dynamical Systems Analysis of IAS-ROMS Near-surface Velocity Field

Fernando Andrade, **Julio Sheinbaum** and **Oscar Velasco-Fuentes**
Physical Oceanography, CICESE, Ensenada, Baja California, Mexico

Dynamical systems techniques are used to analyze the near-surface velocity (30 m depth) of the Intra-Americas (Caribbean and Gulf of Mexico) ROMS model and understand the transport and mixing of particles in the system. Finite Size Lyapunov Exponents (FSLE) and the double time slice method are used to identify stable and unstable manifolds (or repelling and attracting material lines) of the flow field which define directions of transport. Lobes arising from intersection of these manifolds at vortex edges indicate regions of exchange in and out of the vortices, whereas barriers to transport are identified by their tangency. A particular condition consisting of two interacting vortices near the Yucatan Channel is investigated in detail. Time-averaged FSLE maps and of the Okubo-Weiss invariant are used to identify areas of strong and weak mixing in the region.

The Tidal Headland Test Case: ROMS & Delft3D

Richard P. Signell, **John C. Warner**, **Christopher R. Sherwood**
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The development of sand banks driven by tidal flows around a headland is an excellent test case for coastal sediment transport models http://woodshole.er.usgs.gov/project-pages/sediment-transport/Test_Case_4.htm. It is simple to configure, but tests many complex related processes. Flow asymmetries induced by the headland in the oscillatory tide lead to net erosion and deposition over the tidal cycle. As sand banks formed on either side of the headland grow, they start to affect the flow dynamics. The equilibrium state is determined by the strength of the tidal flow, the depth of the water, the length scale of the headland, the sediment grain diameter, and the wave field. Running this test case to equilibrium requires morphological feedback, wetting and drying, wave-driven transport and thus is a good test for the new shallow and nearshore processes in ROMS. The ROMS results are compared and contrasted to Delft3D results, which has incorporated these processes for several years.

Temporal and Spatial Variations of Kuroshio East of Taiwan

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A fine grid resolution model with realistic bathymetry was constructed to study the spatial and temporal variations of Kuroshio east of Taiwan where observations are limited. The model covers an expanded domain that includes the entire East China Sea and South China Sea, as well as the region occupied by the Kuroshio. The fine-resolution model derives its open boundary conditions from a larger scale Northern Pacific Ocean model. Two numerical weather products from European Center for Medium-Range Weather Forecasts and National Centers for Environmental Prediction, and one satellite observation-based wind set (QSCAT) are used to force the ocean model. All model experiments are collaborated by both bottom-mounted Acoustic Doppler Current Profiler (ADCP) and shipboard ADCP observations. Further, model experiments suggested that the best simulation is achieved when the model is driven by the QSCAT wind forcing. Several important features are reproduced in the model simulation. An eddy-Kuroshio interaction is evident in the model simulation. Most eddies are concentrated in a zonal band near 22°N, and there is an interannual variation in the number of eddies. Eddies propagate westward along over 22 ~ 24°N to reach the Kuroshio east of Taiwan, where eddies were dissipated and in turn affected the Kuroshio in many ways. The simulation results also indicate that the seasonal variation of Kuroshio east of Taiwan is generally weak except for the shallow water regimes. The Kuroshio has double velocity cores southeast of Taiwan, but gradually combines into one as the Kuroshio flowed north. The Kuroshio is deflected by the I-Lan Ridge east of Taiwan and turns eastward northeast of Taiwan afterwards. At the shelf break, the Kuroshio splits, with one branch intruding onto the shelf. Further, a branch of the Kuroshio intrudes steadily into the South China Sea through the central Luzon Strait. The Kuroshio intrusion waters flow out of the South China Sea through the northern Luzon Strait and hugs the main stream Kuroshio finally.

Performance Analysis and Optimization of the Regional Ocean Model System (ROMS)

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In this poster, we focus on how to optimize the communication time of ROMS code so that it can be efficiently executed on a grid environment: Teragrid (www.teragrid.org). The basic strategy we exploit to improve the communication efficiency is to combine the multiple communications and to overlap the communication with the computation as much as possible. The communication kernel, MP_Exchange is rewritten, and several new communication modules are added. To demonstrate the advantages of making this change to the communication kernel, we focus on the "step2d" function, which dominates execution time of the ROMS code. Experiments are conducted on Teragrid resources at NCSA, UC and CALTECH site with different number of processors and problem sizes. ROMS is configured and built using the BENCHMARK configuration. The overall execution time of 2D engine is improved up to 50% depends on the network latency and the problem sizes.