Proceedings from the

Princeton Ocean Model (POM) Users Meeting

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Edited by Tal Ezer

Program in Atmospheric and Oceanic Sciences
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These proceedings are also available from the POM web page:
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POM Users Group Meeting Schedule

Monday, June 10

Morning Session (Presiding: Alan Blumberg)

Time			Abstract Pages
08:00-08:50	Registration		
08:50-09:00	Welcome/logistics	G. Mellor/ T. Ezer	
09:00-09:20	George Mellor A short history of the POM model		8
09:20-09:40	Alan Blumberg An estuarine and coastal ocean version of POM		9
09:40-10:00	Jerry Miller Inter-estuary exchange via the inner shelf		10
10:00-10:20	Alan Blumberg and Zhen-Gang (Jeff) Ji High resolution modeling of New York Bight, New York Harbor and Long Island Sound water system		11
10:20-10:40	Coffee break		
10:40-11:00	Emil Petruncio, L.K. Rosenfeld, and J.D. Paduan Observations and modelling of the baroclinic semidiurnal tide in a submarine canyon		12
11:00-11:20	Hua Wang A modelling study of the hydrodynamics in a small embayment and its adjacent shelf		13
11:20-11:40	Lars Asplin On insufficient vertical grid resolution in a 3D numerical coastal ocean model		14
11:40-12:00	Paul Jewell The geologic record: simulations of Pleistocene Lake Bonneville and the Cretacous North American seaway		16
12:00-13:30	Lunch Break		

Monday, June 10

Afternoon Session (Presiding: Jerry Miller)

18:00 Dinner at Prospect (Princeton University Main Campus)

Tuesday, June 11

Morning Session (Presiding: Chris Mooers)

Tuesday, June 11

Afternoon Session (Presiding: Tal Ezer)

Wednesday, June 12

Morning Session (Presiding: Leo Oey)

Afternoon Session (Presiding: George Mellor)

13:30-15:30 Open discussion

Possible Topics: open BC, sigma-coordinate & steep topography, initialization and grid generation, graphic packages, horizontal and vertical diffusion, future model developments.

ABSTRACTS

A Short History of the POM model

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In 1974, Alan Blumberg came to Princeton under the GFDL funded, Visiting Scientist Program. From his Chesapeake Bay modeling experience and my turbulent boundary layer experience, there emerged - painfully at first - a three-dimensional, numerical ocean model. Model architectural decisions were made, based on our perception of the needs of small scale model domains; the model would need to simulate surface and bottom boundary layers, the latter to create tidal mixing and bottom drag; it would have to handle tides in the first place and it would need to respond to surface fluxes, all in the presence of complex topography. Development of the model continued at Dynalysis of Princeton, at Princeton University and GFDL until it became clear that, given sufficient computer resources, the model was capable of solving a lot of problems. Through the years there has been polishing and extensions, but the basic architecture remains the same. Now, it may seem surprising to some, and not to others, that the attributes of the model, conceived with small scale ocean dynamics in mind, also apply to large scale ocean basins. The bottom boundary layer may be important! Tides may be important!

The talk will fill in some details of the model's history between 1974 and 1996. The discussion will include the topics of model error and bottom topography.

An Estuarine and Coastal Ocean Version of POM

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The three-dimensional ocean circulation model developed by George Mellor and me, commonly known as the "Princeton Ocean Model" or POM, has constantly evolved since its beginning days in 1975. POM has become well-known in the world of ocean modeling because confidence has been established that the predominant oceanographic physics are realistically reproduced by this model. Building upon that success, modifications have been introduced to the model which emphasize the physical processes operating in the shallower water portions of the world's ocean, namely the estuarine and coastal ocean environment. The skill of this estuarine and coastal ocean model, called ECOM, has been extensively assessed in over 30 published studies of estuarine and coastal ocean regions.

The technical changes introduced to POM to form ECOM include:

1. a semi-implicit method in which the barotropic pressure gradient in the momentum equations and the horizontal velocity divergence in the continuity equations are treated implicitly,
2. a capability for flooding and drying of tidal flat regions,
3. a choice of numerical advection schemes for controlling numerical dispersion,
4. a capability for the simulation of suspended sediment transport, both cohesive and non-cohesive, and
5. an option to use a z-level based coordinate system containing a vertical coordinate which is discretized using horizontally-constant grid spacing.

A series of examples will be provided to demonstrate the implementation and utility of these technical changes. The examples will be drawn from studies in Mamala Bay, Florida Bay, Onondaga Lake and the Yellow Sea.

Inter-Estuary Exchange via the Inner Shelf

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Monthly observations of salinity and temperature in lower Chesapeake Bay reflect the seasonal variations of river discharge and air-sea heat flux, respectively. The associated seasonally-modulated density-driven estuarine circulation causes higher salinity coastal waters to enter the Bay from the adjacent inner shelf. Likewise, the strength of the Delaware plume which approaches the mouth of Chesapeake Bay from the north is modulated by its annual cycle of river discharge. Quasi-quarterly hydrographic cruises have been conducted on the Virginia inner shelf to investigate the seasonal variation of the effects of the Delaware plume on flow at the mouth of Chesapeake Bay. Complementary numerical simulations have been performed. During late spring and early summer, the Chesapeake's estuarine circulation is strong, the Delaware plume extends southward and merges with the outflowing Chesapeake plume and Delaware waters enter Chesapeake Bay. During late summer and autumn when discharge is low, the Delaware plume does not have a significant impact at the entrance of the Chesapeake Bay but a narrow band of lower salinity water is still observed on the inner shelf north of the Bay mouth. A series of numerical process studies reveals that outflow from a large upstream estuary can significantly modify exchange through the mouth of a smaller estuary located down the coast.

A Three-Dimensional Hydrodynamic Model of New York Harbor and Western Long Island Sound

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Three-dimensional simulations of estuarine circulation in the New York Harbor complex and Western Long Island Sound have been conducted. The numerical model being used is ECOM-3D (Blumberg and Mellor, 1987). The model grid is curvilinear and orthogonal with resolution from one hundred meters up to a few kilometers. The modeling period is 12 months from October 1988 to September 1989. The following information are used to force the model: 1) meteorological data, including wind, precipitation, atmospheric pressure and solar radiation, 2) water elevation along the open boundaries, 3) temperature and salinity along the open boundaries, and 4) 18 rivers, 61 waste water treatment plants and 462 discharges from combined sewer overflow and surface runoff. The measured data for model calibration and validation include water surface elevation at 10 stations, currents at 6 stations and temperature and salinity at 26 stations.

Comparison between model results and data indicates that the model results match the data very well at all the stations for water surface elevation, current velocity, salinity and temperature. The model is capable of describing the entire spectrum of time scales for the compared quantities including the semi-diurnal tidal scale, diurnal scale, meteorological scale (a few days), spring and neap tidal scale (15 days), and monthly, seasonal and annual scales.

Numerical experiments illustrate that 1) reliable water elevation data along open boundaries are essential to the tidal simulation, 2) the incorporation of a surface heat flux calculation scheme improves temperature predictions significantly, and 3) accurate estimation of all relevant sources of discharges and their locations enhances the model's salinity prediction considerably. It is concluded that since the hydrodynamic model is capable of simulating estuarine circulations of New York Harbor complex and Western Long Island Sound water system very well, it will be a useful and important tool for water quality modeling and water resources management in this region.

Observations and Modelling of the Baroclinic Semidiurnal Tide in a Submarine Canyon

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A description of the baroclinic semidiurnal tide in Monterey Submarine Canyon is given based upon remote and in-situ measurements and numerical simulations using the Princeton Ocean Model (POM). Shipboard ADCP and CTD measurements obtained from cruises in April and October 1994 reveal a bottom-intensified internal tide which propagates energy upcanyon at nearly the same angle as the slope of the canyon floor. HF radar current data show the surface M2 current ellipses to be amplified at the head of the canyon and aligned with bathymetry.

POM simulations employing tidal sea level forcing with idealized bathymetry and density stratification typical of the Central California coast reveal internal tide generation at the continental shelf break. Seaward propagation of the internal tide occurs in an oceanic beam which is bounded by rays emanating from the shelf break and the sea surface above the shelf break. Shoreward propagation occurs in a shelf beam which reflects between the sea surface and shelf floor. The presence of a submarine canyon incising the continental shelf and slope is seen to alter the 2-dimensional character of the coastal tidal currents, as internal tide generation occurs at the foot and rims of the canyon. When the model canyon floor slopes at an angle that is near-critical for the M2 frequency, several features of the internal tide in Monterey Submarine Canyon are reproduced, including bottom-intensification, upcanyon energy propagation, and strong (O(10cm/s)) surface currents near the canyon head.

A Modelling Study of A Small Embayment in Response to Forcing on its Adjacent Shelf

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A three-dimensional hydrodynamic model is used to study dynamics of a small embayment in a summer stratification to various forcings namely 1) observed wind; 2) a coastally trapped waves on the shelf and 3) a steady southward coastal flow. The modeling study has shown that the sub-inertial oscillations observed in the bay are not forced by the local wind but the responses to the scattering of a coastal trapped wave (CTW) on the shelf. Wind driven currents can be reasonably predicted by the model during a strong wind event, although bottom currents are heavily damped. The model study has also shown an anti-clockwise residual circulation in the bay generated by the coastal flow on the shelf, however, a comparison with the observation shows that residual currents in the bay are mostly resulted from a non-linear flow system when forced by the CTW on the shelf.

On Insufficient Vertical Grid Resolution in a 3D Numerical Coastal Ocean Model

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In numerical models the discretizing of the model domain onto a grid will often be a compromise between desired resolution and available computer resources. This compromise can lead to an insufficient vertical grid resolution during a simulation. Especially in numerical models with a terrain following vertical sigma-coordinate, a situation with poorly resolved vertical dynamic layers can occur (without the operator being aware) in areas of the domain with greatest bottom depths. The present work investigates the consequences of not resolving an upper dynamic layer. For this study, a 3D sigma-coordinate numerical model is used, but it is likely that the results of the investigation apply to all numerical models with poor vertical resolution.

A numerical simulation of river runoff into two parallel channels is performed. The bottom is flat in the domain except for a deep trench across the left channel. Due to the vertical displacement of the sigma-coordinates, the upper brackish layer will not be resolved above this trench. Except for the positions of the vertical grid nodes the conditions in the two channels are similar. The results of the right channel (flat bottom) represents a physical realistic flow.

Because this simulation is of an idealized nature, it can easily be seen that the simulated flow in the channel of poor vertical resolution is erroneous. The most obvious difference between the two channels is the lack of an upper brackish layer in the left. Also this channel has a much deeper flow than in the right channel, and the velocities are greater. This leads to very large volume fluxes in the left channel. However, the net volume flux out of both channels is similar and close to the volume flux added by the rivers.

Although the erroneous results due to the insufficient vertical resolution are easily seen in the present simulation, there are similarities with the real flow indicating that it could be very hard to detect these errors in more complex simulations (with many mixing sources). Most of all this applies to the surface velocity field being qualitatively alike in the two channels. Thus, in inspection of the results of the surface layer only the erroneous results are difficult to detect.

The consequences of having insufficient vertical resolution are many. The present investigation shows a flow field being vertically spread and increased, and a vanishing upper density layer. In most applications (e.g. water quality models or biological models) these errors would be fatal. Finally, it is expected that difficulties will arise also in other numerical simulations not resolving vertical dynamic layers (as for instance when modelling surface Ekman layers).

The geologic record: simulations of Pleistocene Lake Bonneville and the Cretacous North American seaway

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Traditional interpretations of many geologic settings often lack rigorous physical analysis. Numerical modeling of the physics of these settings thus adds considerable insight into their origin. Recent research by the author has concentrated on applying the Princeton Ocean Model (POM) to selected marine and lacustrine settings in the geologic record. Potential pitfalls for these applications include lack of extensive data for model validation and poorly constrained model boundary conditions. Model validation must rely on a sedimentary record which is often poorly preserved or difficult to interpret. Model boundary conditions are frequently derived from atmospheric GCMs or Regional Climate Models or from heuristic calculations of atmospheric, aquatic, or oceanographic conditions which existed in the geologic past. The most appropriate settings for this research are ones where (1) the model can test a variety of boundary conditions against evidence in the geologic record, (2) interest or controversy between conflicting theories of a particular setting is high and (3) the geologic record is well-studied and documented. Two geologic settings which fit these criteria are the Cretaceous North American Seaway and Pleistocene Lake Bonneville in the Great Basin of western North America.

The Cretaceous North American Seaway existed across the central part of North America between 135 and 65 million years before the present. At its maximum extent, the seaway connected the Arctic Ocean with the Gulf of Mexico and was approximately 2000 km wide. Sediments deposited in the seaway are among the most extensively studied in the world. During its maximum transgressive stage deep water in the seaway was anoxic. It is uncertain whether this anoxia was a local phenomenon or related to global oceanic anoxia. Stable isotope geochemistry of carbonates from these sediments suggest that surface water salinity was diluted by approximately 20% freshwater resulting in a stably stratified water column. Paleontologists have hotly disputed this "brackish water lid" model because many species of foraminifera from this time period cannot tolerate low salinity water. Numerical experiments of the seaway have been conducted with the POM in order to test the two conflicting theories. Atmospheric GCM output was used for wind forcing and a variety of P - E scenarios were tested. Maximum vertical salinity differences within the seaway are approximately 3 ppt (10% freshwater dilution) when average P - E is ~1.5 m/yr and 6 ppt (20% freshwater dilution) when P - E is ~3.5 m/yr. Extreme P - E conditions were therefore necessary to produce the freshwater dilutions documented by the stable isotope geochemists. The numerical simulations and simple box model calculations suggest that the anoxic episodes in the seaway were the result of incursions of mid-depth, suboxic or anoxic water from the open ocean or restricted deep water circulation due to a sill at the seaway entrance and were not the result of a stratified water column.

Simulations of Pleistocene Lake Bonneville are only now being started. In this work differing boundary conditions (principally changes in solar heat flux and climatological wind intensity) will be examined in order to understand the origin of well-studied features of physical geology (e.g., spits, bars, and deltas) within the Bonneville Basin.

Modeling the Exchange Flow Through the Strait of Gibraltar

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The Mediterranean Sea communicates with the Atlantic Ocean via the narrow (15km) and shallow (<300m) Strait of Gibraltar. The two-layer flow underlies hydraulic control but is also influenced by temporally varying forces such as tides and moving atmospheric pressure fields. The curvilinear grid used by Zavatarelli and Mellor (1995) was modified and refined to allow for high resolution in the Strait (2-5km). This grid configuration makes it possible to simulate the processes within the strait accurately and to include parts of the Atlantic and the Mediterranean in the simulation.

I present process studies on the adjustment of the strait flow to the density gradient between the two basins. The model is initialized using datasets for topography, temperature and salinity that were released only recently. The model results agree with observations of the interface structure and the water mass transformation within the strait. An experiment with semi-diurnal tidal forcing highlights the importance of interface fluctuations for the transfer of Western Mediterranean Deep Water over the sill.

Three-Dimensional Modeling of Overflow Plumes

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Bottom water in the global ocean basins has but a few sources from marginal seas: the Norwegian-Greenland Sea, the Weddell Sea, and the Mediterranean Sea. Overflow dynamics from these sources is important to large scale circulation and climate variation because it is a primary source of bottom water. Early numerical models of dense bottom plumes on continental slopes were predominantly of the steady stream-tube type, excluding processes that we now find to be important. The one-dimensional stream-tube models are useful for examining the bulk changes in properties along the path of the overflow. Stream-tube models have difficulties with overflows on continental shelves and slopes with complex topography. To further our understanding of overflow dynamics, we conducted three-dimensional simulations of dense overflows from marginal seas onto continental slopes using a three-dimensional, primitive equation numerical ocean model. The numerical simulations reveal important instability and three-dimensional features of the overflow plumes that have not been included in previous simulations with either one-dimensional stream-tube or two-dimensional plume models. It is shown that the large primary plume breaks into a number of smaller sub-plumes on the offshore side of the plume due to instabilities which are manifested as growing topographic Rossby waves over the slope. The observed high temporal and spatial variabilities in the Denmark Strait Overflow could be caused by inherent dynamic instabilities of the overflow plumes, as revealed by the numerical simulations. The model simulations also show that a chain of surface cyclonic eddies form and travel almost parallel to the isobaths toward the right and downstream of the plumes' source. These eddies provide a surface signature of the sinking, breaking-away sub-plumes, as a result of vortex stretching in the upper part of the water column. Such surface features may have been observed in satellite IR imagery along the East Greenland continental shelfbreak.

We also examined the steering effects of three idealized topographic features in continental slopes: a canyon, a ridge and a seamount, and the effects of the ambient slope water stratification. In the presence of a canyon, a portion of the dense water descends into the canyon, forming bottom-trapped plumes that flow offshore along the axis of the canyon while hugging the right side (facing the ocean) of the canyon. The remainder of the plumes water is able to flow across the canyon and keeps descending on the slope while being deflected to the right-hand side. A canyon acts as a conduit for cross-slope transport of dense water and it enhances deep water production compared with the plume on the uniform slope. In the presence of a cross-slope ridge, part of the water is blocked by the ridge and the flow is confined along the left side of the ridge. The remainder of the plume water is able to flow over the ridge and continues to flow towards the right-hand-side. The presence of a ridge also significantly enhances the down-slope transport of dense water. A seamount does not affect the cross-isobath transport of dense water as much as does a canyon or a ridge. A seamount does influence the mixing, entrainment, and the path of the dense bottom plumes.

Open Ocean Convection Studies in the Eastern Mediterranean Sea

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The Levantine Intermediate Water (LIW) is the characteristic saline water mass of the Mediterranean sea that is formed in the Levantine basin during winter time mixing and convection to intermediate depths (200-400m). We study the formation mechanisms of LIW using a high resolution 3-D numerical model initialized and forced by realistic data. The Princeton Ocean Model is implemented in the Levantine basin with an eddy resolving horizontal resolution of 5.5 km (first internal Rossby radius of deformation: 10-14 km). The model is initialized by the MED-2 data set, while the 1980-1988 twice a day weather analysis from the NMC is used as atmospheric forcing. These data (air temperature-humidity and wind speed) together with the sea surface temperature provided by the model are used for interactive calculation of the heat fluxes and the evaporation through appropriate bulk formulas.

The climatological experiments (using "perpetual year" monthly means) clearly outline the Rhodes gyre area as the unique LIW formation site in the Levantine under such conditions. The formation event has a typical time scale of ~2 months (February - March) and a spatial extent of ~200km which is the size of the cyclonic gyre. The maximum depth of convection is ~300m in the center of the gyre with characteristic potential density of 29.05. The presence of the gyre, which is a permanent feature of the basin generated by the wind curl and bottom topography, is proved to be the main preconditioning factor that controls the LIW formation site. The annual mean formation rate is estimated to be 1.2 Sv.

Twin experiments with different horizontal resolutions reveal the significant role of small scale baroclinic eddies on the formation process. These eddies, generated in the periphery of the cyclonic gyre, control the horizontal and vertical extension of the convection area through lateral advection of buoyancy towards the center of the gyre. In our high resolution experiments where such eddies are resolved, the extent of the formation area is smaller and stability is restored much faster compared to the low resolution experiment where these features are not reproduced.

The interannual variability of LIW formation, was studied using the 12hours NMC atmospheric data from characteristic winters of the 1980-88 period. The significant variability of surface forcing from one winter to an other (more than 40%) leads to a wide range of LIW formation rates (0.6-1.3 Sv). The preferred location of convection is still the Rhodes cyclone, but under extreme conditions (eg. winter 1987) intermediate water is formed in the whole north Levantine with simultaneous deep convection (down to 1000m) in the center of the gyre. The short duration, extreme cooling events associated with passage of storms over the Levantine are found to be equally or even more important than the mean seasonal cooling cycle. They are particularly effective during the end of the cooling period when the stratification is already weak and convection to deeper layers is much easier.

Research and Model Development at Norwegian Meteorological Institute (DNMI)- an Overview.

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The model is used operationally to produce forecasts of sea level and surface current. Presently 3 different versions of the model are run twice a day each giving 48 hours forecasts. In one setup, used for storm surge warning, the model is run in barotropic mode covering the North Sea, eastern part of the Norwegian Sea and the Barents Sea. In the other two setups, the model is run in baroclinic mode. One of these cover the same area as the barotropic version. The other have a higher resolution nested into the large scale model and cover the coastal waters around the southern part of Norway. Forecasts of the surface currents are used for prediction of the drift and fate of oil spills. In addition the model is used in hindcast simulations of currents.

The main research and development of the model at DNMI have been: 1) to include sea ice models as an module in the code, 2) to include calculation of tracers concentrations to study exchange of different water masses in an area, 3) to study the sensitivity of the vertical structure to parameterization of the mixing processes.

Examples from the operational runs and the different research activities will be presented.

Sensitivity Tests for Vertical Mixing in POM. Implications for Further Development.

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In the setup of the Princeton Ocean Model at the Norwegian Meteorological Institute, simulation of the ocean circulation is terminated whenever one or both of the velocity components exceed 5 m/s anywhere. Occasionally, we have experienced such bursts in the surface layer in our model runs. A detailed analysis of one such case will be presented, where wind forcing is significant and vertical momentum mixing is locally extremely low. In order to investigate details further, results obtained using idealized domain and conditions will also be discussed. It will be demonstrated that the unphysically large velocities result from the implementation in POM of the equations for turbulence closure.

A preliminary attempt to remedy the present problem will be suggested, and a crude comparison with the original simulation results will be presented.

Experiments with the Norwegian Ecological Model System

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The NORWegian ECOlogical Model system is a coupled physical, chemical, biological model system applied on an extended NorthSea to study primary production and dispersion of particles (fish larvae, pollution). The physical module are based on the Princeton Ocean Model, while the chemical/biological module is made in cooperation between the University of Bergen and The Institute of Marine Research, Bergen.

The model system has been validated against the extensive SKAGEX dataset. In addition results from modeling of a flood in a Norwegian river, Glomma, and results from primary production and recruitment studies will be presented.

Observed and Modeled Atlantic Water Transport in the Svinoy Section

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Climate variations in the Nordic Countries and especially Norway are greatly influenced by the North Atlantic current, which character and transport varies through seasons and years. For a better understanding of the circulation the main aim of a new project at Department of Oceanography, University of Bergen is to quantify variations in volume transports in the Svinoy section, a confluence region of the Atlantic Current with pronounced bottom topography. In addition to use current observations, we also wanted to find out if a numerical model could be used as a supplement to current meter observations. As a preliminary study current observations from the Svinoy section in summer 1969 are re-examined and three-hourly volume transport are calculated. An experiment with the Blumberg-Mellor-model was carried out, using wind field, river outlet and climatological fields as the driving forces. The grid size was 20 * 20 km, covering all the Nordic Sea, the North Sea and the Barents Sea. The results are promising: comparison of the 43 day long time series of volume transports from observations and modeling give a mean observed volume transport of 3.3 Sv, and 3.1 Sv as mean modeled volume transport.

Our future plans are to compare a one year long time series (Apr. 1995 - Apr. 1996) of current meter observations with results from the Blumberg-Mellor-model.

Coastal Ocean Modeling Using POM at NPS.

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The talk will be on coastal ocean modeling efforts using POM and grid generation techniques at the Naval Postgraduate School.

Applications of POM to Basin-Scale Climate Problems

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The Princeton Ocean Model (POM) has been originally developed for modeling of bays estuaries and coastal regions. However, in recent years it has been applied also to basin-scale problems with considerable success. Some of the model's features are especially attractive for basin-scale climate simulations. For example, processes that are affected by bottom topography, such as flow over sills and deep boundary currents, are resolved quite well with sigma coordinates, even with the limited number of vertical layers that one can afford in large-scale ocean models. The curvilinear horizontal grid allows to have a relatively coarse resolution open ocean grid, while maintaining high resolution near the coast and in regions of sharp fronts.

A few examples from recent simulations of the Atlantic Ocean with different model domains and grids will be presented. In particular, a climate model of the entire Atlantic Ocean from the Antarctic Circumpolar Current region to the Greenland Sea is used to study the interannual and interdecadal variabilities of the ocean and its response to observed SST and wind stress anomalies.

Wind and Thermohaline Driven Circulation From an Arctic-North Atlantic Ocean Model

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A fully prognostic coupled ocean-ice model is used to study the seasonal variability in the Arctic-North-Atlantic system (from Bering Strait to 15^{o}S) using monthly surface fluxes of momentum, heat and fresh water as derived from the European Center for Medium Range Weather Forecasting (ECMWF) and from the National Meteorological Center (NMC) atmospheric analysis products. The formation of the Northern recirculation gyre and the Gulf Stream separation at Cape Hatteras are the robust features of the model. The Gulf Stream transport enhanced by the contribution from the Northern recirculation gyre is about 70 Sv. Our results show that the existence of the northern recirculation gyre is essential for the separation of the Gulf Stream. Furthermore, the Deep Western Boundary Current (DWBC) is a necessary component for the formation of the Northern recirculation gyre. The applied surface forcing in the Greenland and Barents Seas simulates the production of water masses that constitute DWBC. The water masses formed in the Barents Sea are modified further during their circulation around the periphery of the Arctic Ocean before exiting through Fram Strait.

Simulations of the Kuroshio

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Numerical simulation is performed using a high-resolution ocean general circulation model to investigate seasonal variations of the Kuroshio transport. The simulated velocity profiles of the Kuroshio agree surprisingly well for the first time with ADCP observations and dynamic calculations. The annual mean and seasonal variation of the model Kuroshio transport relative to 700 m across the PN-line near the Nansei (Ryukyu) Islands is almost the same with the estimates based on the long-term hydrographic observations The transport shows a weak maximum in summer and a weak minimum in winter. The Sverdrup balance perfectly fails to predict the variations as well as the transport of the Kuroshio south of Japan.

The above discrepancy between the Sverdrup theory and the model (observation, as well) is studied in detail by analyzing the torque balance. In winter the Kuroshio transport across the PN-line is much smaller than expected from the Sverdrup theory because the topographic control prevents the western boundary current from intruding west of the continental slope near the Nansei (Ryukyu) Islands. The current over the slope region changes its direction from winter to summer due to anticyclonic eddy activity related to the joint effect of baroclinicity and bottom topography (JEBAR). The deep northeastward current over the slope in winter is canceled in summer by the eddy activity so that the interaction between the continental slope and the current is much reduced. Since the same eddy activity intensifies the Kuroshio recirculation, the Kuroshio transport across the PN-line in the East China Sea is increased in summer.

Applications of POM in the Great Lakes

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The POM has been used for several different applications in the Great Lakes. First, in collaboration with Ohio State University, it has been used since 1993 in an operational coastal forecasting system for Lake Erie. Surface fluxes are derived from meteorological observations and NWS numerical weather prediction models. Nowcasts and 24 hour forecasts of the three dimensional thermal structure and circulation in Lake Erie are produced every 6 hours and results are made available on the Internet. Second, we are using POM to calculate the seasonal changes in currents and thermal structure in Lake Michigan in support of an EPA mass balance study for toxic chemicals in the lake. In this study, surface fluxes are calculated from observed meteorological data. Lake circulation and thermal structure are calculated with POM on a 5 km grid for two different two year time periods. Results from these calculations are used in particle dynamics and water quality models. Third, we have used POM in idealized studies of several hydrodynamical processes which are important in the Great Lakes, including internal Kelvin wave propagation and the influence of summer stratification on mean circulation. These studies also provide insight into the limitations of numerical models when they are used to simulate lake hydrodynamics.

Use of POM for Coupled Hurricane-Ocean Modeling

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A high-resolution coupled hurricane-ocean model has been developed to investigate the role of negative feedbacks in the hurricane-ocean system. The model consists of the 18-level triply-nested movable mesh GFDL hurricane prediction model and the 21-level Princeton Ocean Model. The newly developed model is currently being tested for air-sea interaction during the passage of hurricanes over the Gulf of Mexico.

For our experiments, we use only the data that are operationally available at the time of the storm passage. The data base for the initialization of the GFDL hurricane model is obtained from NCEP global analysis. The ocean model is initialized using Levitus temperature climatology and the SST data from the NCEP global analysis.

Two cases will be discussed: Hurricane Gilbert in September 1988 and Hurricane Opal in October 1995. The results of the experiments reveal some important effects the ocean might have on Gilbert and Opal during their passages across the Gulf of Mexico. We will demonstrate that the intensity forecasts with the coupled hurricane-ocean system is in much better agreement with the observed intensity, because the sea surface is cooled by storm-induced mixing in the upper ocean.

In case of Hurricane Gilbert, the model simulations are compared with observations obtained during a joint ONR/NOAA upper ocean response experiment. The results indicate very reliable reproduction of the essential features of the observed hurricane-induced currents and temperatures when the model is properly initialized and forced by realistic hurricane wind stress.

Coupling POM to the NRL Global Layer Model: Application to the West Coast

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A sigma-coordinate Pacific West Coast coastal model was established and driven by circulation features from a global layer model. Using a fairly simple one-way nudging scheme to specify the boundary conditions of the coastal model from the layer model simulations, the seasonal circulation off the U.S. Pacific west coast is successfully reproduced.

The coastal model is the Princeton Ocean Model (POM) applied to the West Coast with a 1/12 degree (~10 km) horizontal resolution and 30 sigma levels in the vertical. The sigma levels are unevenly spaced with small spacing near the surface and bottom to resolve the important Ekman flow near shore. The coastal model domain covers a large area spanning from the coast seaward to 135W, and from 30N to 49N. The model bathymetry was obtained from the Navy DBDB5 with mild smoothing and adjustment. The initial temperature and salinity were taken from the Levitus climatology. Since salinity has been shown to be important in the region, the coastal model included all seven major rivers which drain into the model's domain. An active river scheme was applied which prescribes, instead of salt flux, the depth-average velocity according to the monthly fresh water runoff.

The coastal model is driven by insertion of information via one-way coupling from the 1/4 degree global Navy Ocean Layer Model (NLOM). The latter is a reduced gravity hydrodynamic model with 5 active layers and a horizontal resolution of 1/4 degree spanning the globe. The lateral boundaries of the global are set at the 200 m isobath. At the coastal model open boundaries, a radiation boundary condition was applied to the normal component of velocity and the surface elevation. For the tangential velocity and the temperature/ salinity an advection boundary condition was applied. Information from the global model was nudged into the coastal model through a nudging layer. The layer ocean properties are exponentially weighted to decrease proceeding from the coastal model boundary to the interior. A layer of 20 grid points was used with each 5th grid point at an e-fold decrease. The weight at the open boundary (nudging coefficient) was chosen to be 0.02.

The only data used for the coupling was the layer model transport. The global model layer thickness and layer velocity were horizontally interpolated to the coastal model grid. The coastal model transports were then computed by integrating the layer velocity from the surface to the bottom of coastal model. On the northern shelf region beyond the 200 m isobath lateral boundaries of the global model, the Shapiro filter was used to extrapolate the information. The total transport across the coastal model open boundary of the computed may not exactly equal the global model transport, the coastal model area-average surface elevation was forced to that from the global model.

In the simulations, the Hellerman and Rosenstein climatological monthly wind stress as well as the synoptic FNOC NOGAPS model wind stress were used for the surface forcing. Seasonal temperature and salinity from Levitus were applied with a relaxation scheme instead of heat and salt fluxes at surface.

The fields predicted by the coastal model are reasonable and reflect the presence of a vigorously meandering California Current System with its associated eddies. Even with only climatological forcing, the model exhibits many of the known characteristics of oceanographic variability off the U.S. West Coast. This includes the annual migration of the California Current, the formation of the Davidson Current and the Southern California Countercurrent, the reversal of coastal current at the Washington-Oregon shelf, the annual cycle of coastal upwelling, and the presence of jets, cold filaments and eddies near the coast. The active river scheme also works very well. The model vividly presents the seasonal extension and retread of the river plums, especially around the Columbia River whose run-off is the largest.

The East Coast Ocean Forecast System: The Operational System, Evaluation and Enhancements

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The East Coast Ocean Forecast System (ECOFS) has been producing experimental daily 24-hour forecasts on an operational basis for almost three years at NOAA's National Center for Environmental Prediction. The POM is forced at the surface by forecast heat and momentum fluxes derived from the Eta atmospheric model, but the POM has not been reinitialized since beginning from a climatological mean state in August 1993. The evolving operational system will be described, including the forecast schedule, post-processing and output archival considerations. The results of an ongoing evaluation of forecast sea surface temperature (based on comparisons to NDBC buoy SSTs) and subtidal coastal water level (based on comparisons to coastal water level gauge data) will be presented. These comparisons reveal encouraging predictability of wind-driven set-up and set-down at the coast and the limits of SST predictability (especially offshore) without the benefit of data assimilation or reinitialization. Based on sensitivity studies, a number of enhancements that have been implemented will be described. Experimental efforts are presently underway to first implement assimilation of satellite-derived SST, which will be followed by operational experiments at assimilation of altimeter- based SSH fields.

On the Evaluation of the POM Model (Especially with Examples from the Gulf of Mexico)

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Results from the Princeton Ocean Model (POM) have been compared with observations, especially in an extensive series of regional studies sponsored by the Minerals Management Service (MMS) over the past two decades. Some examples from earlier studies are presented as a prelude to focusing on analyses for a recent DYNALYSIS Gulf of Mexico POM model. Comparisons include several statistics: means, variances, spectra, principal axis, EOFs, vertical profiles, and vertical transects. Temporal scales emphasized are the seasonal cycle, weather cycle, and near-inertial. The spatial subdomain emphasized is the shelfbreak zone, where issues of cross-shelf exchange are examined. Lessons learned include the importance of (1) selection of model domains and their open boundary conditions; (2) using synoptic atmospheric forcing with hourly temporal resolution in order to excite realistically energetic near-inertial motions, which are important to mixed layer and thermocline evolution; and (3) coordinating observing system and modeling system designs to facilitate model validation (skill assessment).

Baroclinic Instability in the Presence of Topography: A Comparison of Using MICOM, GFDL, POM, and QG Models

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Mesoscale motions associated with baroclinic instability are examined in an idealized channel using MICOM, GFDL, POM, and QG models. The effects of topography in comparison to the flat bottom channel are emphasized. The growth rates of baroclinic instability for different sloping rates are derived from the four models. The results indicate that all four models can produce reasonable growth rate for the flat bottom case. However, in the presence of bottom topography, MICOM and GFDL models produce reasonable growth rates, while the growth rate of POM is relatively small and QG approximation breaks down with the steep topography. The possible errors resulting from the numerical schemes and coordinate systems are discussed. Some future efforts are outlined to improve model prediction capability of mesoscale dynamics in the ocean.

Pressure Compensation and the Bottom Boundary Layer

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It is an observed characteristic of oceans that velocities and horizontal pressure gradients are larger near the ocean surface than they are in deeper water. This is conventionally labeled pressure compensation whereby baroclinic structure, comprised of sloping isopycnal surfaces, is adjusted so that surface pressure gradients are reduced in deeper water. In this paper, a two-dimensional flow in a channel is numerically modeled to demonstrate the baroclinic adjustment process and its relationship to the bottom boundary layer. A simple analytical model is also developed and defines the time scale of the adjustment process.

Modeling of open boundary conditions and coupling fine and coarse resolution models.

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The problem of open boundary conditions for limited-area coastal models is addressed. For accurate modeling of estuarine and coastal environments, it is important to assimilate available information from observations and from other model runs on open boundaries. The optimization approach based on combining the available data on the open boundary with the physics of the hydrodynamic model, represented by the energy flux on the open boundary is presented. The proposed boundary conditions allow the inclusion of the extraneous information in the specification of boundary conditions. This information can be estimated from available observations and/or from the coarse resolution model (coupling fine and coarse resolution models) and/or from some of the other specifications of boundary conditions, for example, the modified Orlanski condition. The results of testing and comparison of this approach with some other specifications of boundary conditions are presented.

A Software System for Analysis and Visualization Of Model Output Using Netcdf, Matlab And AVS

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A machine-independent, extensible software system has been developed to visualize and analyze the model output from Blumberg/Mellor circulation models (e.g POM and ECOM). The first component of this system is a FORTRAN subroutine which stores the 4D model output in a NetCDF file, a machine-independent binary format <http://www.unidata.ucar.edu/packages/netcdf/>. The second component is a collection of Matlab <http://www.mathworks.com/> routines that allow 1D or 2D extraction, analysis and visualization of the data. The third component is a collection of AVS <http://www.avs.com> modules that allow 3D extraction, manipulation and volume rendering of the data. The tools are more fully described and are available at <http://crusty.er.usgs.gov/omviz/>.

On TVD Flux Limiters for Forward in Time Upstream Biased Advection Schemes

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This talk describes a number of flux limiters for forward in time upstream biased advection schemes. The limiters are based on concepts from Total Variation Diminishing (TVD) schemes. The constant grid flux schemes described in the following are Crowley type upstream biased Eulerian advection schemes. The flux limiters prevent under and over shooting associated with numerical dispersion. Numerical dispersion errors are typical of the leap frog scheme and an alternative effectively monotone scheme suitable for the Princeton Ocean Model is described. The flux limited schemes are easy to implement, computationally efficient and non oscillatory. A number of 1, 2 and 3-D examples are presented. A multi-dimensional version which employs a modified time splitting approach is shown to be suitable for three dimensional primitive equation ocean modelling.

Application of the Mellor-Yamada Model in Mesoscale Meteorology

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The so-called Mellor-Yamada turbulence-closure model has been used widely in modeling oceanic and atmospheric turbulence. This paper reviews a three-dimensional atmospheric model, HOTMAC, and a three-dimensional transport and diffusion model, RAPTAD. HOTMAC forecasts three-dimensional distributions of wind speed, wind direction, temperature, moisture, and atmospheric turbulence. RAPTAD simulates transport and diffusion processes of airborne materials.

Recent improvements include the use of nested grids, four-dimensional data assimilation, and precipitation microphysics. Grid spacing can be reduced by a factor of 2, 3, or 4 with a nested grid. The outer grid provides boundary values to the inner grid and the inner grid updates the outer grid values at the common grid locations (two-way nesting).

We will present examples of simulations and demonstrate the graphical user interfaces which make the model operations simple and efficient.

A Mixed Z-Sigma Difference Scheme in Sigma Coordinate Ocean Models

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A key issue of using σ-coordinates in oceanic and atmospheric models is how to reduce error in computation of the horizontal pressure gradient. The concept of "hydrostatic inconsistency" is well known in the modeling community, i.e., for a given horizontal resolution, increasing the vertical resolution may not be numerically convergent.

Let (x*,y*,z) denote Cartesian coordinates and (x,y,σ) sigma coordinates, and H is the ocean depth. Horizontal gradients in z- and σ- coordinates are related by ∂/∂x* = ∂/∂x - σ∂H/∂x(1/H)∂/∂σ. Finite difference at the center of a grid cell can be viewed as an averaged value of the corresponding derivative δ/δx* = δ/δx - $\overline{\sigma \partial H / \partial x (1/H) \partial / \partial \sigma}$. The most common scheme uses δ/δx* = δ/δx - $\overline{\sigma \partial H / \partial x (1/H)}\, \delta / \delta\sigma$, which comes from taking ∂/∂σ out of the average. Since (1/H)∂/∂σ = ∂/∂z, and ∂p/∂σ is more affected by the topography than ∂p/∂z. Therefore, we propose a mixed z-σ difference scheme, δ/δx* = δ/δx - $\overline{\sigma \partial H / \partial x}\, \overline{(1/H) \delta / \delta\sigma}$, which separate the average of (1/H)δ/δσ from the average of σ∂H/∂x. Both error analysis and numerical computation show a drastic reduction of error by using this difference scheme.

South China Sea Prediction System

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Ocean circulation and thermal structure in the South China Sea is studied numerically using the Princeton Ocean Model with 20 km horizontal resolution and 23 sigma levels conforming to a realistic bottom topography. A 12 month control run was performed using climatological monthly wind stresses, realistic oceanic inflow/outflow at the open boundaries, and typical salt and heat fluxes as forcing terms. Sensitivity experiments were performed to investigate (1) wind effects, (2) non-linear effects, (3) open boundary inflow/outflow effects, and (4) topographic effects. Qualitative and quantitative descriptions are provided emphasizing the contribution of isolated factors to the physics of the South China Sea. Some important issues of the South China Sea modeling will also be discussed.

Coastal Model Comparisons

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This study compares several ocean circulation models in coastal applications. The comparison is restricted to 3-D, primitive equation, free-surface models on sigma-like vertical coordinate systems. The physical accuracy and the numerical character of the models are evaluated and discussed on a variety of test problems. The coastal study processes include wave propagation, upwelling and downwelling regimes, set up of wind driven circulation, and genesis and evolution of fronts.

One issue addressed is to determine the robustness and portability of the models. Simulations investigate how and if mixing algorithms, filtering and smoothing procedures contribute to the models' numerical stability at the expenses of the physical accuracy.

One of the common potential problem areas is the application of the horizontal diffusion operator acting on surfaces of constant sigma. The formulation might generate computational heating/cooling sources in regions of steep topography. Preliminary results evaluate the physical accuracy and computational efficiency of the geopotential diffusion operator introduced by Barnier et al. (1996, submitted to Deep Sea Res.).

The study processes indicate that the solutions may sensibly differ from model to model. That is primarily due to: 1) different response to the calibration of the physical and numerical parameters, 2) perturbations in the dynamical balances. In general, differences in the primary features (such as front location, strength of the coastal jet) can be adjusted by adequate calibrations. Representation of the secondary features (such as internal wave propagation, temperature and salinity anomalies) may depend upon different parameterizations and numerical treatments of the same physical terms that may alter the relative importance of the dominant processes.

On the Implementation of Passive Open Boundary Conditions to POM

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The objective of this study is to investigate the performance of several Open Boundary Conditions (OBCs) applied to the Princeton Ocean Model (POM). In this preliminary presentation only conditions applied to the barotropic mode are discussed. The focus is on passive OBCs i.e., conditions that are applied when the mean flow at the open boundary is unknown and the values of the variables must be assumed or extrapolated from the interior solution. Three types of OBCs are tested: a) radiation, b) characteristic methods, c) relaxation schemes. Numerical experiments are conducted in a zonal channel that include different forms of bottom topography. The experiments are designed to emphasize flow conditions dominated by either advection or radiation. Three sets of experiments are discussed: 1) Forcing by a uniform, alongshelf wind stress; 2) Forcing by a moving storm; 3) The barotropic adjustment of an initial perturbation in the sea surface elevation and velocity fields. The results of these experiments are compared with analytical solutions and the results of numerical experiments using cyclic boundary conditions, or expanded domains. The discussion is not limited to the OBCs, but also include references to their numerical implementation. It is well known that the imposition of OBCs to the primitive equations is an ill-posed problem (Oliger and Sundstrom, 1976), as such it is not surprising to find that no single OBC has the best performance in all the experiments. Nevertheless reasonable good results are obtained with a radiation-type condition proposed by Flather (1976) combined with a local solution approach used by Roed and Smedstad (1984); the characteristic method derived by Roed and Cooper (1987), and the flow relaxation scheme developed by Martinsen and Engedahl (1987).

Simulation of Barotropic and Baroclinic Tides of Northern British Columbia

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The tidal response of northern British Columbia coastal waters is studied through simulations with a three-dimensional, prognostic, primitive equation model. The model is forced at the boundaries with the principal semi-diurnal and diurnal constituents. Experiments with stratified and homogeneous fluid are compared. The barotropic response shows good agreement with previously published studies of tides in the region. A comparison with tide gauge measurements indicates that average relative rms differences between observations and the model elevation field are less than 5% for the largest constituents.

An internal tide is generated in cases where the model is initialized with a vertical stratification. Diagnostic calculations of the baroclinic energy flux are used to identify regions of generation and propagation of internal tidal energy. With a representative summer stratification, the integrated offshore flux is about 0.5 gigawatts, higher than previously estimated from theoretical models. Comparisons between observed and modeled M2 current ellipses are discussed for several moorings and demonstrate the significant influence of the internal tide.

Application of the Princeton Ocean Model to the Coastal Ocean of Florida

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This study addresses the application of the widely used Princeton Ocean Model (POM) for the prediction of tidal motion in the coastal ocean. The model domain for the POM included the coastal prediction ocean and outer continental shelf, slope, and upper rise areas along the coast of Florida to depths reaching 700 meters. Experimental runs of the POM were completed to optimize ocean boundary conditions with respect to prediction of tidal motions. Optimal boundary conditions for simulating tidal phenomenon in the coastal ocean using the POM were found to be a combination of the Orlanski-type boundary with an additional sponge-type boundary designed to assist in damping out wave reflection. Using optimal open boundary conditions, the POM was forced from cells located at the corners of the computational grid. Forcing was provided by a re-synthesized time series of tidal elevation calculated from tidal constituents specified from a Global tidal model. Results of the final numerical experiments conducted in this study using tidal forcing demonstrate that the POM is capable of providing very accurate predictions of tidal processes. Predicted time series of tidal elevation and tidal currents contained none of the distortions present in earlier experiments. A comparison of tidal constituents calculated from measured and predicted time series of tidal elevation along the Florida Coast showed excellent agreement between model results and measurements. The agreement is particularly good in the dominant M2 tidal constituent.

On the West Florida Shelf Circulation Studies

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A three-dimensional, primitive equation, numerical ocean model is being used in conjunction with an in-situ measurement program to investigate the circulation over the west Florida continental shelf. We have implemented the Princeton Ocean Model with an evenly spaced rectangular grid over the domain 87^{o}W to 81^{o}W zonally and 24^{o}N to 31.3^{o}N meridionally with horizontal resolution of about 4.6 km and 21 sigma layers vertically. Two types of numerical experiments will be reported on. First by using climatologies of monthly wind stress, twelve monthly depth-averaged horizontal current patterns, elevations and three-dimensional circulation structures were obtained. The model captured many observed features in the region, including the coastal jets, seasonal variations of the elevation near the coast and strong seasonal variability of the direction and the magnitude of the current along the shore. The results showed an offshore cross-shelf transport in winter and an onshore cross-shelf transport in summer. Accordingly there was an upwelling in winter and a downwelling in summer near the coast. Model results were compared with observations. The results strongly suggest that the Ekman dynamics may account for most of the transport. The stratification and baroclinicity are important in the west Florida continental shelf circulation. Second, the experiments of frontal system or tropical storm passage over the shelf were conducted. Significant difference of the impacts of the frontal system or tropical storm on the sea surface elevation and shelf circulation was found between two differently oriented frontal systems that translated in different directions.

Modeling the Seasonal Circulations in the Gulf Of Maine

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The three dimensional nonlinear prognostic Princeton Ocean Model is applied to the Gulf of Maine. The model is initialized with January mean conditions and forced at the open boundaries with the monthly temperature and salinity distributions produced by the NOAA East Coast Forecast System (Aikman et al., 1995). A regular annual cycle is established after three years of integration. External forcings include momentum and buoyancy fluxes at the air-sea interface, inflows of Scotian Shelf Water and Slope Water, and river runoffs. This study tries to assess the importance of the local forcing (runoff, winds and buoyancy flux) and the remote forcing (Scotian Shelf Water and Slope Water) on the initiation and the progression of the annual cycle of the circulations in the Gulf of Maine.

Modeling River Plumes and Red Tide in the Western Gulf of Maine

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In the western Gulf of Maine, "red tide" blooms (high concentrations of the toxic Dinoflagellate Alexandrium Tamarense) are often associated with a buoyant coastal plume formed by the outflow of several large river systems. The ability to realistically simulate these blooms is a major goal of environmental managers in this region, but presents significant technical and scientific challenges.

Extensive field surveys were conducted in the spring of 1993 and 1994 to map the spatial and temporal patterns of currents, nutrients, salinity, temperature and cell concentrations over a roughly 200 x 50 km (alongshore and cross-shore) domain. These surveys yield unprecedented levels of information on which to calibrate and test a numerical model of red tide transport and growth.

Using the Blumberg-Mellor hydrodynamic model coupled with a simple cell growth equation, we are conducting a suite of simulations varying the location and timing of cell introduction, offshore boundary conditions and representations of vertical mixing. The model is a limited to the western Gulf of Maine and is driven at the open boundaries by a combination by observations and Gulf-scale model output (Lynch and Naimie, 1993; Lynch, Holboke and Naimie, 1996).

Results to date show that the timing and location of the source are crucial for obtaining realistic magnitudes of cell concentrations. They also reveal that realistic modeling of plume behavior may be limited by the ability to correctly represent horizontal and vertical mixing processes and to specify realistic open boundary conditions.

POM in Virtual Reality : The Chesapeake Bay Virtual Environment

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The Chesapeake Bay Virtual Environment (CBVE), is a large-scale virtual world that incorporates at a basic level the use of the virtual environment to visualize time-dependent, three-dimensional, multi-variate datasets. CBVE integrates POM-based numerical simulations of the Chesapeake Bay with the visualization product Vis5d, the CAVE software environment and the Vanilla Sound Server (VSS) to create interactive, ensonified modeled data in a navigable, virtual environment. Although the use of Vis5D and a workstation allows one to visualize the model output in an intuitive fashion, CBVE becomes fully functional through the use of an interactive, semi- or fully-immersive virtual viewing device such as the CAVE or Immersadesk. These devices provide the graphical illusion of being in a three-dimensional space by displaying visual output in stereo and in a three-dimensional perspective according to head position, and by allowing navigation through the space. Viewing, navigating through and interacting with multidimensional fields (e.g., salinity, circulation vectors, larval fish distributions) in the virtual environment provides a sense of presence which greatly improves ones ability to understand inherently complex three dimensional processes.

During Supercomputing'95, CBVE was demonstrated on the Immersadesk to show the effects of winds, tides and river runoff on the general circulation features of the Chesapeake Bay and on the transport of passive larval fish into the Bay from the adjacent continental shelf. Our virtual environment consisted of color slices and contours of our simulated salinity fields, velocity vector representations of horizontal and vertical velocities and isosurface representations of larval fish densities, all overlaid upon a graphical representation of the Chesapeake Bay bathymetry. A control panel embedded in the 3D virtual space enabled us to select which data to display and to toggle animation on or off. The Immersadesk wand allowed us to navigate into the 3D space as well as to control 3D rotations of the data. As the final piece of our virtual world, we used the Vanilla Sound Server (VSS) to generate data derived sound so that our numerically generated salinity data was aurally represented. This enabled us to navigate to a point in the virtual environment where aural cueing indicated a region of increased salinities and observe the apparent relation between larval fish densities and salinity.

CBVE has already proven useful in the scientific investigation of how physical and environmental processes affect the circulation in the Bay as well as how this variability influences transport pathways and residence (retention) times of selected ecosystem components. Our ultimate product will incorporate runtime computational steering, interactive visualization, data ensonification and wide area information dissemination capabilities. The development and implementation of our application to date has been supported by the use of the SGI Power Challenge Array located at the National Center for Supercomputer Applications (NCSA) as well as the Information Wide Area Year (I-WAY) and the Global Information Infrastructure (GII) Testbed constructed for Supercomputing'95.

More information may be found at http://www.ccpo.odu.edu/~wheless.

Diagnostic simulations in the Santos Bight using the Princeton Ocean Model

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From January 25 to February 8, 1993, a hydrographic cruise on board the University of Sao Paulo R/V W. Besnard was carried out in the Santos Bight, between 23S and 27S, as part of the Brazilian WOCE program: the COROAS project. The temperature and salinity data collected during this cruise were used to initialize an implementation of the Princeton Ocean Model (POM) to the area surveyed, in a diagnostic study of the velocity field associated with the observed thermohaline structure. For forcing the barotropic component of the flow, two approaches were used. In the first, satellite altimetry data (TOPEX/POSEIDON) were applied in combination with climatological hydrographic data set (LEVITUS). In the second, only COROAS hydrographic data were used. The numerical simulations reproduced the Brazil Current structure suggested by the hydrographic data, with a velocity field comparing reasonably well other computations realized in the same context of the project. The model results showed a Brazil Current meandering along the shelf break region in a Rossby topographic wave pattern. This meandering appears to be associated with the mechanism by which nutrient-rich South Atlantic Central Water is upwelled and deposited over the continental shelf.

Simulation of Cross-Shelf Circulation Using POM-2D

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A two-dimensional version of the Princeton Ocean Model in the x-z plane (hereafter POM-2D) is used to study features of the cross-shore circulation on the Australian and Brazilian coasts.

POM-2D is a useful tool to study important cross-shelf processes, such as upwelling and downwelling. The use of fine grid resolution in both horizontal and vertical directions is easily accomplished without the larger computation time and costs that would result from the discretization of the alongshelf direction. A fine vertical resolution can accommodate enough grid points to resolve the surface mixed and bottom boundary layers. Another advantage is that POM-2D does not require alongshore open boundary conditions.

For the Australian application, the model is forced by idealized and observed winds. Vertical displacements of the isotherms at the base of the thermocline produced by the model are in good agreement with vertical displacements calculated from temperature data. For the Brazilian case study, the build up of the bottom boundary layer associated with the downwelling favorable Antarctic Intermediate Water flowing northward is reproduced by the model. The cross-shore circulation associated with upwelling favorable winds over the continental shelf is also compared with measured data.

Many factors, such as alongshore pressure gradient, surface heat flux, cross-shore variation of wind stress, and initial velocity and density fields, should be evaluated carefully if one is trying to reproduce the detailed cross-shelf structure of observed oceanographic fields.

Process Simulations on Shelf and Slope

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We use the Blumberg-Mellor model to examine the wind, river, and eddy-driven shelf/slope processes in the Faroe/Shetland Channel (Scotland west-coast), the Gulf of Mexico, and the Santa-Barbara Channel (U.S. west-coast). High-resolution grid of O(1-5km) is required to resolve the physics of meso-scale dynamics found on the shelf/slope.

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