# TECHNICAL PROPOSAL

“Mid-Atlantic Ocean Model Calculations”

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(BAA Solicitation [M09PS00004](#))

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SUMMARY

Princeton University offers to meet the objectives of MMS (sections C-3 of the Request for Proposal (RFP) Solicitation M09PS00004) to deliver gridded velocity fields (wind, surface current) to MMS for OSRA, for the period 1993-2008 from a relatively simple-to-run yet state-of-the-art, data-assimilated and data-validated model that will include the effects of wind, waves, rivers, tides, slope and shelfbreak currents, Gulf Stream, rings and eddies, as well as the large-scale Atlantic Ocean influences; the model will also be subjected to stringent sensitivity tests. The model and a user manual will also be delivered to MMS.

This proposal lays out a comprehensive plan of how we will meet these objectives. The model will consist of a high-resolution grid (with $\Delta=2\sim5\text{km}$ and a minimum of 26 vertical levels) over the Mid Atlantic nested within two coarser grids of the western Atlantic Ocean and the entire Atlantic Ocean respectively. The wind will be supplied from the high-resolution results ($\Delta\sim5\text{km}$) of a similarly downscaled model product (the WRF model). Wind-waves will be included for the first time by fully coupling them with the circulation model. Both the ocean and atmospheric models will be assimilated with satellite and in situ observations (e.g. altimeter, drifters, current-meter, QSCAT). An extensive ocean data set has been compiled for this proposal and they will be used to rigorously validate the model results. In order to ensure the robustness of the model results and physics, an extensive set of sensitivity and process experiments are also planned to systematically and carefully test the model.

As with past and on-going research projects with MMS, one of the greatest strengths of the Princeton team is our commitment to always connect the model to observations. It is also our commitment to publish our findings in peer-reviewed journal articles, for this (i.e. publication) is one of the processes that can help check the quality of our products.

The proposed efforts will be carried out by a group of scientists who are experts in geophysical fluid dynamics (ocean and atmosphere), physical oceanography and modeling, and who are well-trained in data assimilation, and also in observational and model data analyses. They are: Oey and Mellor (both at Princeton), Wang (at Stony Brook) and Ezer and Atkinson (both at ODU). They will be assisted by three research associates, Peng (from NCSU), Jose Balneo (ODU) and Zhang (to graduate from TAMU in March/2009) and one technical assistant Garner (ODU). Dr.Oey will additionally serve as the Program Manager. The scientists involved have previously served as PI’s and/or co-PI’s in various MMS projects, have actively published, and are familiar with past and latest advances in physical oceanography and air-sea processes, those of the Mid Atlantic and Atlantic Ocean in particular.

Deliverables include the wind and surface currents for the period 1993-2008 obtained from the model (see above), the model and relevant inputs and outputs, a model user manual, interim and final reports, and draft manuscript(s) to be submitted to peer-reviewed journal(s).
OBJECTIVES

To deliver gridded velocity fields (wind, surface current) to MMS for OSRA, for the period 1993-2008 from a relatively simple-to-run yet state-of-the-art, data-assimilated and data-validated model that will include the effects of wind, waves, rivers, tides, slope and shelfbreak currents, Gulf Stream, rings and eddies, as well as the large-scale Atlantic Ocean influences; the model will also be subjected to stringent sensitivity tests. At the same time, we aim to also provide an improved understanding of the physical oceanography of Mid Atlantic ocean region. The specific objectives are:

1. Modify an existing ocean circulation model to maximize skill in the Mid-Atlantic;
2. Conduct sensitivity testing and validation of the modified model;
3. Provide gridded velocity fields (wind, surface current) for the period 1993-2008 to MMS; and
4. Document the model and results through a model manual, final report, and submittal of a manuscript and/or a peer-reviewed journal article.

THE SCIENTIFIC TEAM

The scientific team consists of researchers well-versed in modeling and data assimilation and also in observational and model data analyses. We have previously worked together, served as PI’s and/or co-PI’s in various MMS projects, have actively published, and are familiar with past and latest advances in physical oceanography and air-sea processes in general, and of the Mid Atlantic and Atlantic Ocean in particular. Appendices list our resumes and past and present related projects.

BACKGROUND

The MMS plans to lease within the Mid-Atlantic Planning Area in its proposed 2007-2012 5-year program; specifically the region off the Virginia continental shelf and slope (Figure 1). Because of ocean currents and winds, an oil spill generally spreads far beyond the lease region and can potentially contact land. MMS’ Oil Spill Risk Analysis (OSRA) is a cornerstone foundation for evaluating impacts and alternatives in OCS (outer continental shelf) oil and gas leasing EIS (environmental impact statement) preparation and for evaluating mitigation, such as oil spill contingency plans. To run the OSRA computer program, reliable fields of ocean currents and winds which portray as realistically as possible the actual oceanic and atmospheric conditions over a certain period (years) are needed. One way to obtain a reliable estimate of ocean current fields and winds is through numerical simulations incorporating data-assimilation algorithms that combine physics with observations. At present, MMS does not have a functional circulation model for the Mid-Atlantic on which to base the OSRA, hence our goal in this proposal to develop and verify (against observations) such a model, and to deliver to MMS the code(s) as well as the numerical data of ocean currents and related forcing including the wind fields.
Princeton University has in past and ongoing projects conducted extensive research for MMS to develop such an advanced model and has provided to MMS the model and current estimates for the Gulf of Mexico region [please see five of seven reports by Oey and co-authors in the Project Manager section, and also please visit http://www.aos.princeton.edu/WWWPUBLIC/PROFS/ (click “Publications”) for recent MMS-supported peer-reviewed publications]. This proposal outlines plans to extend and improve our existing modeling capability to produce both the oceanic current and the atmospheric wind fields during the period 1993-2008 for the mid-Atlantic region. The Princeton’s model has been previously applied to the Atlantic Ocean and also to study the Gulf Stream [Ezer and Mellor, 1992, 1997; Ezer, 1999], and here a special focus will be placed on the proposed lease region (Figure 1) at a high model resolution (see below). Though the RFP requests a hindcast start-date of 1994, we have included 1993 because most of the satellite data is already available then for data assimilation.

Figure 1. Surface ocean current (black vectors) and wind (blue vectors) fields on Dec/23/2004 simulated by the Princeton Ocean Model superimposed on SST (color): (A) in the middle Atlantic region, and (B) focusing in the Virginia outer continental shelf and slope marked with the proposed Oil & Gas Lease Sale 220 pie-shape region. White contour indicates the Gulf Stream “north wall” while dark contours the 200 m and 4000 m isobaths.

A BRIEF REVIEW OF THE MID ATLANTIC PHYSICAL OCEANOGRAPHY

The Middle Atlantic Bight (MAB) including the “slope sea” and the Gulf Stream is one of the most studied regions of the world oceans. The slope sea is a narrow band of ocean that lies between the Gulf Stream and the continental shelf edge of the Middle Atlantic Bight. Over the shelf, the currents are driven by wind, fresh-water discharges from estuaries and rivers, and tides. Additionally, the slope-sea and Gulf Stream have an
important influence; its net effect may be in the form of a contribution to an alongshore pressure gradient sloping upward to the north, about $3.7 \times 10^{-8}$ [Lentz, 2008]. This is balanced primarily by an opposing mean wind stress and bottom stress. The resultant mean shelf flow is southward (Figure 2). Exactly how the alongshore pressure can penetrate onto the shelf remains a mystery however [Wang, 1982].

Southward flows also are observed over the shelfbreak and slope, in the form of two jets: (1) a shelfbreak (near-surface) jet with maximum speeds of $O(0.35 \text{ m/s})$, depth about 50 m, and a mean transport of approximately $0.4 \text{ Sv}$, and (2) a (near-surface) slope current, some 30 km further offshore, that has a transport of approximately $2.5 \text{ Sv}$, and depth extending to about 300 m. In between, the currents are relatively weak [Flagg et al. 2006]. There exists seasonal variations which appear to be related to the atmospheric forcing (wind stress curl) and a longer time scale also to the North Atlantic Oscillation.

**Figure 2.** Map of the Middle Atlantic Bight from Lentz [2008] showing locations of current time series longer than 200 days, mean depth-averaged current vectors (blue), and mean wind stress vectors (red). The 50-, 100-, and 1000-m isobaths, and the approximate location of the Oleander line [Flagg et al. 2006] are also shown.

In addition to the long-period variations, there exists significant short term motions (hours~days) which are important to OSRA since the dispersion of an oil spill is likely to
depend on these motions. Relevant papers on the short-period fluctuations include (for examples) (1) Gawarkiewicz et al [1990] who found intrusion of Gulf Stream waters to the mid-shelf, probably caused by a Gulf Stream filament; (2) Rasmussen et al. [2005] who examined Gulf Stream and slope influences on the outer shelf currents just to the north of the proposed lease area (i.e. observations at about 38°N) as a function of seasonal stratification; (3) Lentz [2001] who analyzed seasonal changes in currents on the North Carolina shelf; and (4) Churchill and Berger [1998] who studied southward shelf transports and how they relate to entrainment of the shelf waters into the Gulf Stream. This last study is particularly relevant to the present study, as it indicates clearly that the influence of the Gulf Stream spreads far northward from the region around Cape Hatteras.

In Figure 1 we show an example of model simulated sea-surface temperature that shows clearly the mesoscale variability associated with the Gulf Stream. The model result is from part of a hindcast calculation that was conducted for MMS for the Gulf of Mexico, but the model also included the entire Mid Atlantic (the model domain extends north to 50°N and east to 55°W). The model assimilates satellite altimetry data, and therefore reproduces a realistic-looking Gulf Stream (i.e. positioned correctly; compare http://fermi.jhuapl.edu/avhrr/gs/index.html). At the time shown, the Gulf Stream separated from Cape Hatteras with a cyclonic meander that can be seen to entrain less-saline outer-shelf and slope waters (see the RHS-panel enlarged region), directly affecting the proposed lease area. Note also the existence of a broad southward shelf flow, even though the wind was off-shelf (and therefore not likely to force southward currents). In this case, it is most likely that the offshore entrainment of shelf waters by the Stream’s cyclonic meander forces the shelf flow in a manner similar to that described by Churchill and Berger [1998].

The behaviors of the Gulf Stream can therefore greatly influence the shelf and slope currents. Bane et al. [1988] found that the southwestward flowing shelfbreak currents along the shoreward flank of the (slope-sea) gyre are directly related to the position of the Gulf Stream (typically 150 to 300 km seaward of the shelfbreak). The shelfbreak currents are strongest (~30-40 cm s⁻¹) and southwestward, when the Stream is within 150 km of the shelf edge. The shelfbreak currents are weak when the Stream is farther away (about 300 km away). Another revealing observation of the influence of the Gulf Stream (perhaps also in combination with the large-scale forcing outlined above) are tracks of drifters released from the dumpsite off the New York Bight. Figure 3 shows an example. Sixty drifters released at the “dumpsite 106” were tracked from May 1990 through March 1991. The drifters generally travel southwestward, though looping several times before they are entrained by the Stream. The general sense of the circulation agrees with the existence of shelfbreak and slope jets suggested by the observations off the New York Bight by Flagg et al. [2006]. Wei et al. [2008] have recently further analyzed the Oleander data and combine it with high-resolution satellite (SST) images to confirm the existence of eddies over the shelfbreak and in the slope sea.
In summary, over the shelf up to approximately the shelfbreak, currents in the Mid Atlantic are affected by tides, winds, river-borne buoyancy, and remote (large-scale) forcing. Further off-shelf in the slope sea, the influence of the Gulf Stream, rings and smaller frontal eddies and filaments are significant. Cross-slope interaction between the shelf and slope-sea occurs all along the MAB shelfbreak; however, the most vigorous shelf and deep-ocean interaction takes place in the confluence region near Cape Hatteras where the shelf meets the strong Gulf Stream. The interaction can significantly modify the currents off the Virginia coast in the lease area [Savidge and Bane, 2001; Savidge, 2004], and probably also affecting the circulation as far north as New Jersey (Figure 1). In addition, wind-generated surface waves affect surface currents [Mellor et al. 2008], and winds from strong tropical cyclones during active hurricane seasons are also important factors that need to be considered.

PROPOSED MODEL HINDCAST (1993-2008)

We propose a hindcast model calculation for 1993-2008 that is capable of addressing all these physical processes. In view of the importance of atmospheric forcing (wind and surface heat and mass fluxes) to the model simulation (and in particular, the wind to OSRA), we also propose to directly simulate the wind through dynamical downscaling at a higher resolution than the standard wind product such as the blended NCEP/QSCAT wind (http://www.cora.nwra.com/~morzel/blendedwinds__qscat.ncep.html). In the followings, we first describe our plans (task#3) for extending and improving the existing Princeton’s hindcast model for the Mid Atlantic (PROFS - http://www.aos.princeton.edu/WWWPUBLIC/PROFS/; e.g. Figure 1), for the 1993-2008 hindcast simulation. We next discuss the skill-assessment plans (task#4). The improvements will include (1) nesting of the PROFS’ western-Atlantic Ocean hindcast domain within the ECCO (Estimating the Circulation and Climate of the Ocean; an MIT-
JPL-SIO consortium model based on the MIT GCM with data assimilation) Atlantic Ocean domain in order to include long-term effects; (2) a data assimilation module based on the Ensemble Optimal Interpolation methodology with possible extension to Ensemble Kalman Filter algorithm; (3) an atmospheric (wind) modeling and data assimilation component; and (4) a current-wave coupled model. The skill assessments section will summarize existing observational data that we have assembled, followed by our plans on how the hindcast products are to be checked against these observations. We then summarize the PIs’ expertise and experiences. The program management, as well as facilities will next be presented. At the end we attach the PIs’ resumes and information and descriptions about their past projects.

**Modify an Existing Ocean Model to Maximize Skill in the Mid-Atlantic (Task 3)**

Princeton University has previously conducted model hindcast calculations for MMS, focusing thus far on the Gulf of Mexico and Florida Straits. However, our model domain encompasses the entire US east coast, the Mid Atlantic in particular (Fig.4).

Figure 4. The proposed fine-grid MA domain nested within PROFS which is in turn nested within the ECCO Atlantic Ocean Analysis domain. Colors show (an example of) sea-surface height (SSH) on Jan/01/2000, and the PROFS calculation includes additionally the surface velocity vectors plotted every 5 grid points. (The scales are different for ECCO and PROFS because of the need in the former to include a much lower SSH at higher latitudes.)
Our model is based on the Princeton Ocean Model (POM; [http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/](http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/)), and benefits from the latter’s users’ continued upgrades [e.g. non-hydrostatic option: Kanaarska and Maderich, 2003; PVM (Parallel Virtual Machine) 2-way nesting: Hukuda and Guo, 2004; pPOM w/nesting: Giunta et al. 2007; and wet & dry: Oey, 2005, 2006; Oey et al. 2007]. POM’s vertical level is terrain-following (the so-called sigma-grid; used also in other popular models such as the ROMS), which is ideal for resolving wind- (and wave) driven surface layers. The so-called sigma-level truncation error is reduced by removing a background density and also by using a fine-grid (O(2~5km), see below). We have moreover recently implemented a class of new and efficient fourth- and sixth-order compact schemes that further reduce this error by orders or magnitude [Berntsen and Oey, 2009; manuscript in preparation].

Our model and data-assimilation algorithm are relatively simple to use, yet they yield accuracies comparable to and often exceed those of other existing models with more complicated formulations. For the results of a recent evaluation of various ocean models in an eddy-rich region (Gulf of Mexico), using HYCOM, NCOM and POM, please visit [http://aos.princeton.edu/WWWPUBLIC/PROFS/deepstar_model_comparison.html](http://aos.princeton.edu/WWWPUBLIC/PROFS/deepstar_model_comparison.html).

We emphasize that, although the high-resolution hindcast model will be nested within the Atlantic basin model ECCO (details below), data assimilation (especially when using satellite data) determines the Gulf Stream and other mesoscale features in the high-resolution domain. The usefulness of the Atlantic basin model is that it serves to restrain the high-resolution solution by providing large-scale and long-term transports as well as overall heat and mass balances. This idea of regional and large-scale separation of scales is very powerful, because it allows us to focus valuable resources (man and computer) in the regional scales of interest and at the same time ensures that we do not drift away from climatologically reasonable states.

**Nested-Grid Modeling (Downscaling) using ECCO:**

A common practice in circulation modeling (ocean or atmosphere) is downscaling, in which a large-domain grid with generally coarser resolution is used to supply boundary conditions to a smaller-domain grid at a higher resolution. The advantage is that one can then focus in a particular region of interest at high resolution, while at the same time can feed the large-scale information into the focused region. The first successful nested-grid ocean modeling of this kind is Oey and Chen [1992a] who applied ideas originally borne out of regional atmospheric weather forecasting to simulate meso-scale oceanic eddies and current meanders off Norway. Oey and Chen’s technique is general – it is 2-way nesting that dynamically couples the parent-grid and the child-grid. The two-way technique gives “smooth” transition at the grid interface, but it requires running the model on the two grids simultaneously. More importantly, though it is possible to have the two grids use two different models, the algorithm is much simplified if the two grids use the same model. Recently, as part of the modeling work conducted for MMS for the Gulf of Mexico, we have simplified the two-way nesting into one-way, in which special techniques are used at the grid interface to ensure a smooth transition between the coarse and the fine-grid solutions [Oey and Zhang, 2004; Oey, 2008]. The advantage is that we
can now drive the fine-grid with any (good) large-scale ocean model results, though care must be taken to ensure accuracy [see e.g. Appendix 1]. One such model we have identified is ECCO (http://www.ecco-group.org/products.htm). The model covers the Atlantic Ocean (up to 78.5N) and provides data-assimilated analyses from 1993-present using the Kalman filter optimization. In our opinion, it is at present probably the best large-scale model ocean product on the market. We plan to use this product to drive the PROFS model domain (see Figure 4). ECCO, at 1/3~1 deg resolution, will not give us accurate simulations of the smaller-scale features in the Mid Atlantic; rather, ECCO will provide consistently balanced long-term, large-scale transports in and out of the PROFS domain, as well as overall heat and mass balances inside the high-resolution domain. Because data is continuously being assimilated, the ECCO field, though smooth, portrays a realistic Gulf Stream separation and transport downstream. These are some of the reasons that we have proposed to adopt the model for the large-scale forcing into PROFS.

In the PROFS domain the horizontal grid resolution is 5~12 km with 26 vertical sigma levels; this is nested within the ECCO domain (Figure 4). We then nest the Mid Atlantic fine-grid domain with a horizontal resolution of 2~5 km. The higher resolution (~2km) is over the Mid Atlantic shelf and slope. The vertical resolution of this highest-resolution domain will initially be the same at 26 vertical sigma levels; tests will be conducted to also use 51 levels. Because our sigma-grid already has a rather high resolution near the surface (of most importance to OSRA) the 51 levels may not be necessary. The higher resolution vertical grid is therefore used if only it results in significant improvements (after comparison with observations; see below).

Forcing to the Model, and Data Assimilation:

The hindcast simulation will cover the year 1993-2008, and uses as the forcing (1a) six-hourly winds from the blended NCEP/QSCAT product (http://www.cora.nwra.com/~morzel/blendedwinds_qscat.ncep.html) and also at a later stage of our research (1b) three-hourly winds from a high-resolution atmospheric model to be described below; (2) surface heat and salt fluxes (corrected by satellite SST); (3) weekly discharges from all major rivers along the east coast; (4) ECCO temperature and salinity fields as initial conditions and also to prevent long-term drift; (5) ECCO density and transport at the eastern PROFS open boundary in the Atlantic Ocean at 55°W (Fig.4); and (6) tides. Tides contribute to mixing and bottom frictional stresses that modify currents. They will be simulated explicitly according to the method described in Oey and Chen [1992b; see also Cummings and Oey, 1997 (which presents the first threedimensional calculation of baroclinic tides); Chen and Mellor, 1999].

To correctly simulate the positions of the Gulf Stream and rings, an efficient data-assimilation scheme (based on optimal interpolation, OI) is used whereby satellite altimetry and sea-surface temperature data are combined with the model dynamics to produce a hindcast field [sea surface height, currents, temperature, salinity and other diagnostic variables such as the turbulence eddy viscosities and diffusivities; Wang et al. 2003; Oey et al. 2005; Lin et al. 2007; Yin and Oey, 2007]. Data assimilation is the process of combining a physical model with observational data to provide a state analysis
of the system which is better than could be obtained using just the data or physical model alone. We have extensively checked the PROFS model outputs against observations and have shown that the simulations produce consistently more realistic results [than those using other types of assimilation scheme; see e.g. Oey et al. 2005, and also http://www.aos.princeton.edu/WWWPUBLIC/PROFS/deepstar_model_comparison.html], not only near the surface (see above references) but also in the deep portion of the water column (e.g. Figure 5). When compared to independent \textit{in situ} and ship data, the mean speed and direction (absolute) errors are $0.4$--$5 \text{ cm s}^{-1}$ ($1$--$10\%$ errors) and $10^\circ$--$20^\circ$ respectively, and amplitude and phase of model-to-observed complex (velocity) correlation are $0.76$--$0.86$ and $0.3^\circ$--$7^\circ$ respectively [Lin et al. 2007]. We have also conducted other extensive checks with our model, not only for its accuracy when compared against observations, but also for its ability to correctly simulate processes (i.e. dynamics; see publication list in http://aos.princeton.edu/WWWPUBLIC/PROFS/).

One of the most difficult oceanographic processes to simulate correctly is deep variability. As an example, Figure 5 shows a comparison of PROFS-generated (green) deep current ellipses at approximately 200 m above the bottom with those observed (blue) over a one-year period (2003-2004) in the Gulf of Mexico. Vectors show the 1-year means. The agreements between the model and observed ellipses are good at most stations, indicating that the model generally correctly simulates the deep energetic currents, and how the fluctuations align with respect to the sloping bottom. In the Gulf of Mexico, these are also first order characteristics that tell how well the model reproduces the direction of propagation of bottom-trapped topographic Rossby waves [see e.g. Oey and Lee, 2002; Oey, 2008]. The agreements in the means are not so good, but the 1-year period is too short to define a “mean” – i.e. the means are biased by one or two intense events.

![Figure 5](image)

**Figure 5.** Comparison between PROFS-generated (green) deep current ellipses (approximately 200 m above the bottom) with those observed (blue) over a one-year period (2003-2004) in the Gulf of Mexico. Vectors show the 1-year means. Dashed lines indicate isobaths.
The purpose of showing Figure 5 is that the model not only simulates surface features reasonably well [e.g. Fan et al., 2004; Lin et al. 2007; Yin and Oey, 2007], responses in the deep portions of the ocean are also quite well-represented [see also Lin et al. 2007]. This is important, for it suggests consistent momentum and mass balances and transfers in the model ocean, i.e. that our data assimilation algorithm does not introduce excessive spurious disturbances that can adversely degrade the accuracy of the solution. PROFS is one of the few models in peer-reviewed journals that have been subjected to rigorous model-data comparisons; to the best of our knowledge, PROFS is the only model that has also now been assessed for its skills in simulating deep processes.

The assimilation scheme above for PROFS will be supplemented by four recent developments: (1) a set of sub-modules with an algorithm that assimilates surface drifter data; the algorithm was thoroughly tested and shown to improve the hindcast currents from surface to about 500m below the surface [Lin et al. 2007]; (2) an improved satellite data-assimilation procedure utilizing ensemble breeding methodology [Yin and Oey, 2007]; (3) a set of sub-modules that enable “point-wise” (e.g. moorings) assimilation using optimum interpolation [Oey, 2007]; and (4) a set of sub-modules that assimilate satellite as well as mooring data using the ensemble optimum interpolation (ENOI) method [Evensen, 2003; 2006]. We are presently working (also for an MMS project) on extending the E NOI method to ensemble Kalman filter algorithm (ENKF) in which the error covariance adjusts dynamically in time with the model run.

**Atmospheric (Wind) Modeling:**

Wind drives ocean surface currents and waves, and affects the depth of the mixed layer hence also the vertical transfers of heat and salt. Through Ekman transport and geostrophy it also affects currents and temperature and salinity distributions of the entire ocean. Hindcasts of ocean currents therefore require accurate wind information. For the work thus far conducted for MMS, we have used various wind products (to force our ocean model); for examples, ECMWF, COAMPS (Navy’s wind), and NCEP/Qscat blended wind. The resolution of these products is generally coarse, and ranges from 25~100 km. Because of the presence of the Gulf Stream, and the U.S. continental land mass to the west, the ocean off Cape Hatteras is one of the most active air-sea interaction regions of the Atlantic Ocean [e.g. Cione et al. 1993]. Recent studies show that at least in some cases, high-resolution winds of the O(3~5km) resolution is necessary to resolve strong wind shears [e.g. Xue et al. 1995, 2000].

Because of the expected strong effects of the Gulf Stream on the winds, we propose to run an atmospheric model to derive the high-resolution wind data that will then be used to drive the ocean model. Currently, the highest resolution dataset with most reliability covering the area of this study and the period 1993-2008 is the NCEP North American Regional Reanalysis(NARR) at 32km. As with the ocean model component, we will employ nesting or downscaling to produce high-resolution surface wind field dataset based on NARR. One of the effective methods for downscaling analysis is called “dynamical downscaling” [Giorgi et al.,1993; Murphy, 1999], which employs a regional
mesoscale model to produce the desired high-resolution analysis with the model initial condition and boundary condition coming from the available course-resolution analysis. The new high-resolution analysis is generated based on the model dynamics and physics, and will contain small-scale details of the wind field. However, because the model is not perfect, it is inevitable that the output of the model run may contain errors comparing to the “truth”. To improve the quality of the surface wind field generated by the model, the sea surface wind retrieved from the Synthetic Aperture Radar (SAR) and the SeaWinds Scatterometer aboard the QuikSCAT satellite is assimilated into the model to minimize the error in the surface wind between the model output and observations using a 3-dimensional variational data assimilation (3DVAR) method.

The mesoscale atmospheric model, Weather Research and Forecast System (WRF), will be employed to downscale the course-resolution sea surface wind from NCEP NARR to fine-resolution grids over the ocean domain of this study. WRF model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs [Michalak, et al., 1998]. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. The NCEP NARR dataset is an extension of the NCEP Global Reanalysis which is run over the North American Region. The NARR model uses the NCEP Eta Model (32km/45 layer) together with the Regional Data Assimilation System (RDAS) which, significantly, assimilates precipitation along with other variables. The improvements in the model/assimilation have resulted in a dataset with substantial improvements in the accuracy of temperature, winds and precipitation compared to the NCEP-DOE Global Reanalysis. This dataset is available every 3 hours. Considering that there is still a large gap between the resolution of NCEP NARR dataset and the targeting high resolution (3km), a 3-nested-domain configuration for the model is proposed, with resolution of 27km, 9km, 3km for the outer, middle and inner domain, respectively (Figure 6). The NCEP NARR is used to generate the initial conditions and boundary conditions for the outer domain. Three-hourly outputs will be used to drive the ocean model.

To improve the quality of WRF, the sea surface wind retrieved from the Synthetic Aperture Radar (SAR) aboard on European ERS satellites and the SeaWinds Scatterometer aboard the QuikSCAT satellite is assimilated using 3-dimensional data assimilation (3DVAR) method. The SAR has a high resolution sensor (in the order of 4-500m). The wind data retrieved from SAR covering the ocean area of this study during 1993-1998 can be obtained freely or commercially through some agencies such as the Alaska SAR Facility and the Radar Data Center of Jet Propulsion Laboratory (JPL). After 1999, the QuickSCAT winds are available, and the SAR wind will be replaced by QuickSCAT winds for assimilation. The QuikSCAT winds are available at every 4 hours with a spatial resolution of 25km. As an example, Figure 7 shows the QuickSCAT sea surface winds.
Figure 6. Triple-nested grid with 3km high-resolution over the Mid Atlantic region used to model the atmospheric wind fields to be used in the ocean and surface wave models.

Figure 7. An example of the QuickSCAT sea surface winds to be used for data assimilation in WRF.
Current-Wave Coupled Model:

Waves introduce turbulence flux into the ocean surface (i.e. enhance mixing) and modify the model currents such that near-surface velocities are no longer logarithmic. This has important consequences for oil spill simulation and also for the development of the mixed layer. As waves are strained and refracted by currents, exchanges of mass, momentum, and energy occur between the waves and “mean” flow (i.e. flow with time and space scales large compared to inverse wave frequency and wavenumber). Longuet-Higgins and Stewart [1962, 1964] described the net “excess flux of momentum due to the presence of waves,” and called it the “radiation stress.” Previously, the wave interacting continuity and momentum equations were, a priori, vertically integrated [Phillips 1977] rendering them unsuitable for coupling with depth dependent numerical ocean circulation models. Mellor [2003, 2008] show that it is now possible to couple three-dimensional circulation models with wave models. The coupling includes depth dependent wave radiation stress terms, Stokes drift, vertical transfer of wave generated pressure transfer to the mean momentum equation, wave dissipation as a source term in the turbulence kinetic energy equation and mean current advection and refraction of wave energy.

To use Mellor’s coupled formulation, a wave model is required. There exist functional third generation wave models such as WAM [WAMDI Group 1988, Komen et al. 1994], WAVESWATCH [Tolman 1991] and SWAN [Booij and Holthuijsen 1999]. However, using these wave models would require about a two order of magnitude increase in computational effort over that required by the circulation model alone. Mellor et al. [2008] designed an efficient wave model that has now been coupled to the Princeton Ocean Model [POM; see also MMS Final Report Oey and Wang, 2008]. The model borrows a feature of the GLERL wave model [Schwab et al. 1984, originally devised by Donelan 1977] and other models [SWAMP group 1985] in that the energy distribution in frequency space is parameterized using the spectrum by Donelan et al. [1985], and which contains elements of the JONSWAP spectrum [Hasselmann et al. 1973]. The model avoids dealing with the wave-wave interaction process (the process is compensated by the specified spectral shape), and has the same level of complexity as circulation models whose four independent variables are $x, y, z, \theta$; the present wave model also has four independent variables, $x, y, \theta, t$; the wave propagation angle, $\theta$, will account for refraction due to bottom depth and current variations. Frequency is also dependent on $x, y, \theta, t$; in the wind-driven portions of $\theta$, the transport equation for frequency is forced by and asymptotes in time to the peak frequency of the parameterized spectrum; otherwise, the frequency is advected as swell. The wave model supplies estimates of wave heights, depth dependent wave radiation stress terms for the momentum equation which would feed back depth dependent velocity fields to the wave energy equation.

We propose to conduct the 1994-2008 hindcast using this [Mellor et al. 2008] coupled model, forced by the high-resolution wind from the WRF dynamic downscaling run. This coupled run will be compared with one that does not have the wave effects. These (and other runs which then serve also as model sensitivity experiments) are summarized next.
MODEL SENSITIVITY AND PROCESS EXPERIMENTS

The following experiments are planned, though they will most certainly not be run in the order indicated. To facilitate our thought process, we have listed them from the most complete (to be delivered to MMS) to other reduced sets designed to identify key model effects either physical or methodological. The first five sets below (bold and underlined) are of the highest priority, and all will be conducted with the model run to its full 16 years (1993-2008; except where stated in the “Partial” experiments below). The others are “research” items that constitute our “wish-list,” time permitted.

Exp.AFull: Full assimilation run – in which satellite SSHA (anomaly) and SST, drifters and selected (i.e. good quality with sufficiently long-time intervals > say 1 month) ADCP’s and hydrography will be assimilated; the WRF winds will be used and the full wave-current coupling will be invoked;

Exp.APAtial.1-5: Partial assimilation experiments 1 through 5 – reduce the full assimilation Exp.AFull so that each of the five data is taken out in turn in the assimilation (i.e. only four data types are used in each case): SSHA, SST, drifters, ADCP’s and hydrography; these will test the sensitivity and contribution of each type of data to the assimilated solution. The last three of these experiments (i.e. taken out drifters or ADCP’s or hydrography) will clearly be run and evaluated only for limited periods;

Exp.ASat: Partial assimilation using satellite SSHA and SST only;

Exp.ASSH: Partial assimilation using satellite SSHA only;

Exp.ANcepQ: Full assimilation run (Exp.AFull) but it is forced by the NCEP/QSCAT blended wind instead of the WRF; this will test the sensitivity of using a low-resolution wind field (i.e. of using the NCEP/QSCAT wind);

Exp.ANoWave: Full assimilation run (Exp.AFull) but without the wave-current coupling; this is an interesting run that will test the effects of waves. It is likely that other sub-experiments may also be necessary here, for example, include waves implicitly in the turbulence parameterization (but without the full coupling); driving the wave submodel with NCEP/QSCAT wind etc;

Exp.ANoWinda&b: Full assimilation run (Exp.AFull) but without the wind. Wind also has large-scale effects (e.g. on the shelf and slope circulation) so these experiments may also lead to rather profound consequences on the model solution;

Exp.AGS: Full assimilation run (Exp.AFull) but the shelf and slope will be unassimilated; two sub-experiments are (a) no rivers, and (b) no rivers nor winds. This will examine the effects of the Gulf Stream (and large-scale Atlantic forcing) on the shelf circulation – for example, is Cape Hatteras a sink?
In addition to these assimilated experiments, a closely related group of un-assimilated, “free-running” experiments are also planned. Interesting studies would be “Exp.FGS” (the ‘free’ counter-part of Exp.AGS), and a case with no Gulf Stream (i.e. coastal forcing, tides and wind only; this has no ‘assimilated’ counter-part). Together, they will constitute a comprehensive set that we believe will address not only model sensitivities (to the various forcing and physical components) and establish robustness of the model calculations, but will also illuminate and deepen our understanding of the physical oceanography of Mid Atlantic.

OBSERVATIONAL DATA AND SKILL ASSESSMENTS (TASK 4)

The accuracy of the time-varying model of the ocean circulation must be estimated. This section will detail (i) the available data, and (ii) our plans to use them to assess the accuracy of the modeled currents (and other prognostic and diagnostic fields).

As with past and on-going research projects with MMS, one of the greatest strengths of the Princeton team is our commitment to always connect the model, be it for realistic hindcasting or for process studies, to observational data. It is also our commitment to publish our findings in peer-reviewed journal articles, for we believe that this (i.e. publication) is one of the processes that can help check the quality of our products.

Figure 8 shows some of the available observations we will use for data assimilation and skill assessments; details of these data (types, locations, dates, links etc) are given in table 1; also http://www.aos.princeton.edu/WWWPUBLIC/PROFS/MMS_MA_Data_list.html. The SYNOP data is from 1988 through 1990; it cannot be used for the proposed hindcast period 1993-2008. But it is still a useful dataset for checking the general statistics of the modeled currents – shelfbreak and slope currents for example. The shipboard ADCP will be used for skill assessment (see below). The drifter (ARGO) data shown in Figure 8 do not include the dump-site releases (Fig.3, but these were pre-1993), or the shelf GLOBEC data [Jan/1995-Aug/1997; Lozier and Gawarkiewicz, 2001] which is shown separately in Figure 9. The ARGO (Gulf Stream and slope) and GLOBEC (shelf and shelf break) data will be useful for assimilation as well as for skill-assessment. The HF-Radar data is not entirely reliable; we will not assimilate them, but will use them (with care) for skill assessment [Mau et al. 2007]. Not shown in Figure 8 and Table 1 are (1) PRIMER (http://www.oce.uri.edu/ao/SAG/primer.htm) and (2) CMO: Coastal Mixing & Optics (http://www.whoi.edu/science/AOPE/cofdl/cmo/); these will also be included in the proposed model-data comparison effort.

Additionally, the following satellite data are also available:

1. www.avisio.oceanobs.com: AVISO along-track SSHA’s from ENVISO, Topex, ERS/2 and Jason satellites, as well as objectively-analyzed SSHA (i.e. OASSHA) fields; this site also provides wind and wave data, both along-track and gridded;
Figure 8. Clockwise from top left: NDBC buoy and current-meter mooring data (BIOME, COPE 3, FRONT, MMS-NorthCarolina, WOCE-ACM6, SYNOP-CentralArray), shipboard ADCP data (WOCE, CLIVAR, Hudson Canyon, Puerto Rico, GLOBEC, DAGST, BIOME, and Oleander (green line)), MACOORA (HF-Radar; http://cordc.ucsd.edu/projects/mapping/maps/), and Global Drifter Program Argo data (http://www.aoml.noaa.gov/envids/gld/index.php).

Figure 9. The GLOBEC 10-m (left panel) and 40-m (right panel) drifters released over a 32-month period from January 1995 to August 1997. [From Lozier and Gawarkiewicz, 2001].
2. \url{http://argo.colorado.edu/~realtime/welcome/}; Bob Leben’s website: this is a useful site that we often use for verifying AVISO and NOAA-AOML data; it also provides ocean color data;

3. \url{http://www.aoml.noaa.gov/hrd/}; NOAA-AOML, hurricane research division: objectively-analyzed hurricane winds; our model automatically interpolates this storm-following gridded data onto the model grid [Yin and Oey, 2007];

4. \url{http://www.ndbc.noaa.gov/}; NDBC buoys and C-Man: winds, SST, waves, air temperatures etc; most importantly (see Fig.8);

5. \url{www.usgodae.org}; USGODAE: satellite-derived objectively-analyzed SST fields;

6. \url{http://winds.jpl.nasa.gov/} and \url{http://manati.orbit.nesdis.noaa.gov/quikscat/}; ocean surface winds from SeaWinds Scatterometer, i.e. QuikScat data; available at the standard 25km resolution as well as some at 12.5 km;

7. \url{http://dcz.gso.uri.edu/avhrr-archive/archive.html}; this URI site provides high-resolution SST images.

Table 1. Observations since 1990 in the Northwest Atlantic area. (a) Moorings.

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Extensive model and model-data analyses, comparisons and interpretations will be conducted. We will compare the model results with data that have not been used in assimilation (however, comparisons with assimilated data will also be made to check that the assimilation does not degrade the model solution!). Model statistics will be checked against observed statistics early on in the research. Specifically, we will make point-wise comparisons from the outputs of our existing hindcast model run (e.g. that shown in Figure 1; see also more examples of this calculation including animations at ftp://aden.princeton.edu/pub/lyo/mms/ma/). The comparisons will include the annual mean, the velocity ellipses and the energy spectrum. These preliminary comparisons will help identify major weaknesses (if any) and biases of the existing model and provide
reference for evaluation of the high-resolution, more refined model hindcasts to be conducted in this project.

In addition to point-wise comparisons, the flow pattern (maps) will be evaluated using standard (spectra, EOF’s, correlations etc) as well as more sophisticated techniques (SVD [Bretherton et al. 1992], SOM – Self Organizing Maps [e.g. Richardson et al., 2003], Empirical Mode Decomposition Method [e.g. Lai and Huang, 2005]). The model-data can also be subjected to more rigorous analyses to compute vorticity and energy balances for example.

The following sub-tasks are planned:

1. Use the NDBC buoy data to validate the wind product;

2. Use the Oleander data to validate Gulf Stream eddies and other, secondary eddies in the Mid-Atlantic;

3. Use GLOBEC drifters deployed on the U.S. continental shelf to validate (modeled) surface trajectories;

4. Use the high-resolution SST images from AVHRR to check for eddies [e.g. Wei et al. 2008];

5. Use the MMS moorings off NC to validate southern MAB circulation; time permitted, repeat using the PRIMER and CMO data for middle MAB;

Additionally, it will be necessary to also check the large-scale fields:

6. Use Lentz’s [2008; Figure 2] ‘collection’ to validate the modeled mean and fluctuating circulation on the shelf, and to compare with simple wind, river and pressure-driven Ekman-type dynamics, selected HF-Radar data may also be used for this purpose;

7. Use a combination of the GLOBEC and ARGO data, the Oleander data, and the PRIMER and CMO data to validate the shelf, shelfbreak and slope currents [e.g. Flagg et al. 2006];

8. Use satellite SSH and SST to assess the accuracy of the modeled Gulf Stream path over the 1993-2008 period.

For “item#8,” the GS mean path and variability can be compared with SYNOP – even though (and unfortunately) this was an earlier observational program. Seasonal and interannual variations in the GS position can be assessed using the Oleander data. These observations show considerable variations of up to 150km in the position of the GS with time periods of ~2-7 years that may relate to variations in transports of cold shelf waters from the Labrador Sea. However, decadal variations in the subtropical gyre can also
cause long-term variations in the GS position and transport [Ezer, 1999]. This evaluation assess the ECCO-PROFS nesting procedure in capturing these large-scale variations.

For “items#2 and #4,” eddy statistics and strength will also be evaluated by examining flow characteristics across the eddies using the WOCE and ARGO data. These data can be used to evaluate how well the model is able to produce the basic subsurface structure of the GS and eddies including temperature and salinity profiles of the upper 2000m. In the case of the ARGO floats, by comparing the data with model profiles, we can provide statistics of model errors from all floats over the deep regions of the Mid Atlantic.

In “item#7,” the dynamics of the modeled shelf and shelfbreak fronts can be compared with observations of fronts and the interaction of Mid-Atlantic shelf waters with warmer GS waters, including detrainments (i.e. offshore) of the shelf water [e.g., Churchill and Berger, 1998; Lozier and Gawarkiewicz, 2001; Savidge and Austin, 2007].

**PROVIDE GRIDDED SURFACE CURRENT AND WIND FIELDS TO MMS (TASK 5)**

The gridded surface current and wind fields for the period 1993-2008, other fields requested by the COR (Dr. Walter Johnson; near the time of delivery), all (ocean only) model “RESTART” files, standard plot and print outputs, all forcing and input files necessary to execute and restart the (ocean) model, will be provided to MMS. While the wind fields will be part of the deliverables, the WRF atmospheric model itself will not, since it would require considerably more effort to prepare the user documentation, which in any case is available from http://www.wrf-model.org/index.php.

**PROVIDE DOCUMENTATION (TASK 6)**

A technical report documenting the (ocean, same below) model’s input fields, the model’s physics and numerical methods employed, and the observations, methods, and results of the accuracy verification of the output currents will be produced. In addition, a user’s manual documenting the computer code of the model will be produced. The manual will also document the other ancillary computer programs for MMS scientists who are knowledgeable about ocean modeling. As in our previous deliverable procedure for the Gulf of Mexico model, Dr. Oey (and associates) will be happy to visit MMS offices to provide MMS scientists assistance in running the model.

As mentioned above, it is also our commitment to publish our findings in peer-reviewed journal articles, for this (i.e. publication) is one of the processes that can help check the quality of the products delivered to MMS.

**EXPERIENCE AND COMMITMENT OF KEY PERSONNEL**

Dr. Oey will commit two months per year to this project. Dr. Oey’s is an ocean modeler with interest in process modeling to isolate and uncover ocean-circulation dynamics and mechanisms, as well as data assimilation that combines observations with model physics
to improve ocean hindcast and forecast. He is and has served as a PI and/or co-PI of various MMS-sponsored projects: Gulf of Mexico, Cook Inlet Alaska and Santa Barbara Channel. With these MMS supports, Dr. Oey and colleagues have written papers that contribute to improved understanding of Gulf-Caribbean interaction including ring-separation from the Loop, TRW’s, shelf-slope exchanges, eastern boundary currents, and ocean hindcast/forecast (please visit http://aos.princeton.edu/WWWPUBLIC/PROFS/). Dr. Oey will oversee the overall progress and direction of the project to ensure that each task is performed and accomplished in a timely manner. He will contribute in all aspects (design, implementation, execution, testing and validation) of the proposed model hindcast, model-data assimilative and skill-assessment analyses. He will also be principally responsible for the progress and final reports, as well as contributing to manuscript-writings for submission to peer-reviewed journals. In particular, Dr. Oey will be the principal architect of the proposed nested-grid modeling, and will oversee the WRF modeling effort by Dr. Peng (see next). He will supervise and be assisted by two very able young scientists (each will commit full time to this project): (1). Dr. Peng (currently at NCSU) who holds a Ph.D degree in meteorology from FSU, is familiar with downscaling using WRF, and is also an expert in 4DVAR and adjoint data assimilation methodologies [he was a key scientist in developing the POM adjoint model; Peng and Xie, 2006; Peng et al. 2007]; and (2). Mr. Zhang, a GPA4.0 grad-student in physical oceanography expected to complete his Ph.D in March 2009 under the supervision of Dr. DiMarco.

Dr. Dong-Ping Wang will commit one month per year to this project. He is an expert in Mid Atlantic ocean region, and is at the forefront of data analysis and modeling efforts in the Middle Atlantic shelf and slope including the analysis of Gulf Stream eddies. Dr. Wang was a pioneer in U.S. east coast physical oceanographic research, and was instrumental in developing many of the fundamental ideas of shelf processes (e.g. continental shelf waves etc). Drs. Wang and Oey have previously worked, and are currently working together in various MMS-sponsored research projects. Dr. Wang’s task in this project will be to conduct model data validation, and to provide insights into Mid Atlantic ocean processes.

Dr. Mellor will commit three weeks per year to this project. He was one of the original developers of POM and has continued to improve the model since its inception. Dr. Mellor co-developed the well-known Mellor-Yamada turbulence closure scheme used in (or as an option to) almost every existing ocean and atmospheric models. Dr. Mellor recently developed the fully-coupled wave-current model in POM, and will be the principal architect, with the help of Dr. Oey and Mr. Zhang, to tailor the model to the proposed Mid Atlantic region. This wave-current coupled modeling effort will also benefit from a one-year visit to Princeton (beginning March/2009) by Dr. Hitoshi Tamura of the Japan’s Frontier Research Center for Global Change/JAMSTEC. Dr. Tamura is a recent graduate of Tokyo University where he conducted wave-current coupled modeling research. He will be fully supported by a fellowship from the Japanese government.

Dr. Tal Ezer will commit one month per year to this project. He is an expert in ocean modeling and data analysis in general, and in the Atlantic Ocean in particular. Dr. Ezer
conducted many key process (numerical) experiments and data analyses of the Gulf Stream problems including short and long-term variability; he is also particularly familiar with satellite data processing and assimilation schemes. Dr. Ezer has also previously worked closely with Dr. Oey in various research projects including two MMS projects: the Cook Inlet modeling effort and the Gulf of Mexico hindcast effort. Dr. Ezer will oversee the model data validation effort to be conducted at ODU; he will principally be assisted by Dr. Jose Blanco – a very able research scientist at ODU. Dr. Blanco will commit six months per year to this project, and will compile the observational data and analyze them and the model data in the model validation efforts. He has extensive experience with data from the Mid-Atlantic shelf as part of a NOAA project conducted out of Wallops Island NASA facility.

Dr. Atkinson will commit two weeks per year to this project. He is well-known for his extensive sea-going observational data collection cruises in the Atlantic, and also for his extensive analyses and publications of the data. Dr. Atkinson has previously worked with Dr. Oey on NSF and DOE-supported projects in the Gulf Stream region. He has also previously conducted research for MMS. Dr. Atkinson will oversee the data-collection process for model validation purposes. He will work closely with Drs. Ezer and Blanco, and will be assisted by Ms. Teresa Garner who operates the CODAR systems in the southern part of the Mid-Atlantic Bight and has worked with modelers in adapting the CODAR data for assimilation into semi-operational models.

PROGRAM MANAGEMENT PLAN

Project Manager

Dr. Oey will serve as the project manager. Dr. Oey has managed a number of recent MMS projects and has authored and/or co-authored many of the final reports. Examples of these reports are listed below:


Additionally, Dr. Oey has also authored and/or co-authored various peer-reviewed publications that have directly resulted from the above-listed (and other) MMS projects – please see the list in his resume.

**Data Management**

**Observational Data**

ODU will manage the physical oceanographic observational data acquired by this study. The majority of the data listed in Table 1 is already in the database management system and any new data acquired in this project will be added and subject to standard, well established, QA/QC procedures. Data distribution will use primarily netcdf files. ODU internally uses Matlab for data management, analysis and display. Data are backed up daily and held offsite, and will be made available to Princeton using a secured ftp site.

**Model Data**

All model data is stored permanently at the GFDL automatic (robot) archiving system. A dedicated and secured high-speed link between AOS/Princeton and GFDL exists and this link allows rapid access to the data whenever we need them. Model data will be made available to ODU and Stony Brook for validation through a secured ftp site.
### Project Schedule

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Interpretation, Synthesis and Technical Reports:

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Task # 1:  
Task # 2:  
Task # 3:  
Task # 4:  
Task # 5:  
Task # 6:  

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Project Cost-Tracking & Deliverables Management

As a major research university, Princeton has in place a comprehensive cost tracking system so that appropriate routine accounting products are provided to the Program Manager, Dr. Oey. This will provide the information by which rates of expenditures and total can be tracked to assure operation within any proposed budget. In cost tracking, Dr. Oey will be supported by Ms. Laura Rossi, the departmental business manager. Ms Rossi has extensive experience using the Princeton cost tracking system. At the beginning of the program, the PM will identify all deliverables, what they are to include and when they are due. Using this information, Dr. Oey will "back schedule" to provide the program participants with a schedule of deliverables that identifies when material should be available to the prime contractor so that the proposed program schedule can be maintained.

The MMS Contract Report Specifications will be used to assure deliverables that are consistent with MMS requirements.

Meetings & Reports

Quarterly progress reports will be submitted to MMS. In addition, we expect regular communications (formats to be decided; e.g. teleconferences or PI travels to Herndon) with the COTR and other interested scientists and managers, to report and discuss progress, problems and possible solution strategies. We will also present progress at the MMS ITM in New Orleans. A meeting with the SRG is also anticipated.

Facilities and Resources

Princeton University has excellent library and technical support facilities. The university’s environment is particularly conducive to learning and research. Aside from multiple work stations and graphical expertise at the AOS Program, Princeton University facility, NOAA’s Geophysical Fluid Dynamics Laboratory (GFDL) provides us a free
access to their computing facilities, which includes one of the most powerful multiprocessor supercomputer available today.

**Computer Budget Explanations**

In anticipation of the increased computing requirements for this project, we request funds to purchase a multi-processor “mini-supercomputer” and disk space. The machine will replace Dr. Oey’s 12-year old workstation and will supplement our computing resources at GFDL.

**PAST PERFORMANCE, FACILITIES AND RESOURCES**

Please see Appendices.

**REFERENCES**


Mellor, G.L., M. A. Donelan, and L.-Y. Oey, 2008: A surface wave model for coupling


Oey, L-Y., 2005: A wetting and drying scheme for POM. *Ocean Mod*, 9, 133-150.


Rasmussen, L. L., G. Gawarkiewicz, W. B. Owens, and M. S. Lozier, 2005: Slope water,


Appendix 1: Minimizing Open-Boundary Errors in Nesting

Attached in this appendix is a little write-up (which the author deems incomplete to be submit-able) on how one can find the “best” boundary conditions in nested-grid modeling. It has been formatted and updated slightly for this proposal.

A Method for Finding the “Best” Open-Boundary Scheme (FindBOBS) for Coastal Downscaling

L.-Y. Oey
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lyo@princeton.edu
July, 2005

Abstract

A novel technique for finding the best open boundary scheme (OBS) for any regional and coastal ocean models is given. The only requirement is the availability of a larger-area parent-grid model. Such a parent model is at the core of the concept of coastal downscaling. By embedding a smaller nested region within the parent grid using the same grid, one can unambiguously define the corresponding OBS errors. The problem of finding the best OBS then amounts to a minimization of a predefined error (cost function) subject to the constraints set by the model and the OBS. The feasibility of the idea is demonstrated by finding the best OBS for a simple tidal problem in a channel.

Introduction

The emergence of basin-scale, data-assimilative ocean models (e.g. GNCOM - Global NCOM, http://www7320.nrlssc.navy.mil/global_ncom/) offers the exciting prospect of incorporating offshore forcing information into regional models. However, to-date, the problem of finding the ‘best’ combination of open-boundary schemes (hereinafter OBS) (in the sense of minimizing some pre-defined error norm) in regional modeling is often more of a subjective decision than science. Part of the difficulty is that in general the exact solution is unknown. A popular strategy is to test OBS in idealized domains (e.g. Chapman, 1985) and extrapolate the technique(s) to real cases. The solutions are then compared against observations and one chooses an OBS-combination that minimizes, for example, some mean-square error $E_2 = L_2(u - u_o)$, where $L_2$ is the L2-norm, $u$ is the model solution and $u_o$ is observation. The difficulty is that $E_2$ contains local truncation errors, initial and model physics errors in addition to OBS errors. While matching with observations should still be the ultimate goal, it is highly desirable in coastal downscaling to separate out and minimize the OBS errors. I give here a novel technique (dubbed FindBOBS) that works with any regional model.

Methodology

I first cite an example, next formalize the technique, then demonstrate the method with an actual (barotropic) calculation using POM with simple OBS. Consider the PROFS
(Princeton Regional Ocean Forecast System) domain for the western north Atlantic and a
nested region for the Gulf of Mexico (Figure 1). The numerical construction of such a
nested model is straight-forward (e.g. Oey and Chen, 1992). The nested Gulf of Mexico
implementation is described in Oey and Zhang (2004) who used doubled resolution in the
Gulf than in the parent grid (Figure 1). However, suppose both the nested and parent
models are run using exactly the same coarse grid as the parent’s. Since the two models
are identical, differences in the overlapped interior (i.e. the Gulf) are the OBS errors. In
other words, by definition, the western north Atlantic model is the “observation” and both
truncation, initial and model physics errors cancel, exactly (c.f. Isaacson and Keller,
1966). We have previously used this “trick” in assessing the accuracy of boundary
conditions in regional models (e.g. Oey, 1998ab).

Figure 1. The Oey et al.’s (2003) northwest Atlantic Ocean model domain (the parent grid
with grid-sizes $\Delta \approx 5-15$ km) and the nested, doubled-resolution Gulf of Mexico region
(enclosed by the dashed line, $\Delta \approx 3-5$ km; e.g. Oey and Zhang, 2004).

**Formalization:**

Consider any model and two domains, a large one $R$ (the parent) governed by $N(u) = f,$
$G(u) = g$ at $\partial R,$ and a smaller one $R_n$ (nested within the parent, i.e. the child) governed by

\[
N_n(u_n) = f_n, \quad \text{at } R_n, \tag{1a}
\]
\[
B_n(u_n, u; \alpha) = b_n, \quad \text{at } \partial R_n \tag{1b}
\]

plus appropriate initial conditions. Here, $N =$ model operator (e.g. finite difference
representation of the primitive equations, say), $f$ lumps together all the inhomogeneous
terms, $G$ and $B_n$ are boundary operators with inhomogeneous terms $g$ and $b_n$ respectively,
$\partial R$ is the boundary, subscript ‘$n$’ denotes nest (i.e. the child), and $\alpha$ denotes different
OBS’s. $\alpha$ can be considered as a parameter, in general a vector, used in a particular OBS.
Now let the parent and child grid sizes be the same, i.e. \( N_n = N \) and \( f_n = f \), and let \( \partial R_n \) be coincident with one or more grid surfaces within the parent domain \( R \). Then \( e_n = u_n - u \) gives the grid-point error due to the OBS \( \alpha \), and the problem of finding the best OBS reduces to finding \( \alpha \) that minimizes some norm of \( e_n \), say the L2-norm \( L_2(e_n; \alpha) \). The procedure can be coded.

Define a cost function, say,

\[
J(\alpha) = \int \int \int \int_{R_n} (u - u_n)^2 \, dx \, dy \, dz \, dt
\]

and minimize \( J \) subject to the constraints equations (1a,b). The goal is then to find \( \nabla_\alpha J \) and use it (together with \( J \) and \( \alpha \)) in a minimization algorithm such as the Limited Memory Quasi-Newton method, L-BFGS (Liu and Nocedal 1989). The \( \nabla_\alpha J \) is found by solving the adjoint equation. Rather than discretizing the continuous forms of the adjoint equations of (1), it is easier to code the adjoint directly from the discretized forms of the model equations using the techniques detailed in Giering and Kaminski (1998).

**The Method in a Simple Case when \( \alpha \) is a Scalar:**

I show the procedure in a simple case of a rectangular channel forced by tide at its southern boundary (Figure 2). The Princeton Ocean Model (POM) is used assuming barotropic dynamics. (Some portion of the computed domain in Fig.2 can turn from wet to dry (and vice versa) but this is irrelevant in this general method.) A parent-grid calculation is first conducted using the full domain shown in Fig.2, forced by tidal current specified at \( y = 0 \) at 12 hours period for 5 days. A nested-grid calculation using the same grid sizes but with the southern boundary placed at \( y = 75 \) km is then conducted using the following radiation OBS for the normal velocity component (Oey and Chen, 1992):

\[
V_n(x_n, y_n=0, t_n) = M(V(x, y, t)) - \alpha \left( \frac{g}{H} \right)^{1/2} [\eta_n(x_n, y_n=0, t_n) - M(\eta(x, y, t))], \text{ at } y = 75 \text{ km};
\]

where \( \alpha \) is the parameter to be determined and \( M \) is an interpolator that maps the parent-grid values to the nested grid (for example, \( M \) maps sub-sampled \( V \) to the nest). Two additional (but secondary) OBS are also required, one for the free surface \( \eta \) and the other one for the tangential velocity \( U_n \). These are specified using the formulations given in Oey and Chen (1992; i.e. with no adjustable parameter). In this simple case, \( \alpha \) is a scalar and its determination is straight-forward. We can either compute \( \partial J / \partial \alpha \approx \Delta J / \Delta \alpha \), where \( \Delta \alpha \) is a small perturbation, or write a shell-script to run the nested model through a range of \( \alpha \)'s.

We choose root mean square (RMS) error \( (V_n - V) \) to be the cost function to be minimized and Figure 3 shows \( \langle \text{RMS}(V_n - V) \rangle \) as a function of \( \alpha \), where \( \langle . \rangle \) denotes time averaging over the 5 days integration. (A similar curve is obtained if \( \text{RMS}(\eta_n - \eta) \) is minimized, while error in \( U_n \) is an order of magnitude smaller). The optimum \( \alpha \approx 0.3 \), consistent with a partially standing wave in the channel (the \( \alpha = 1 \) gives perfect propagation). In this case, FindBOBS correctly picks out an OBS that is compatible with the physical problem. It should be noted that the
commonly used $\alpha = 1$ actually gives worse result, and is only slightly more accurate than the ‘clamped’ boundary condition with $\alpha = 0$.

Figure 2. Parent and nested domains of the tidal calculation used to demonstrate FindBOBS. Topography and initial sea levels are shown. Note the initially dry portion of topography just south of the sill. See text for details.

Figure 3. Root mean square error as a function of the OBS parameter $\alpha$ for the tidal channel problem shown in Fig. 2.
Acknowledgements

This study was supported by the Minerals Management Service under contract #1435-01-04-CT-35279. LYO appreciates the encouragements of the Program Manager Dr. Walt Johnson. Computing was conducted at GFDL/NOAA

References

Oey, L.-Y. 1998b: Subtidal energetics in the Faroe-Shetland Channel: Coarse-grid model experiments. JGR, 103, 12,689-12,708.
Resume: Lie-Yauw Oey (lyo@princeton.edu)

Education
1978  Princeton University, Ph.D.
    Thesis: Numerical simulation of shock wave-turbulent boundary layer interaction
1974  London University, B.Sc. 1st Class Hon.
    Thesis: Laboratory experiment of turbulence behind bluff bodies

Appointments
1984-1988  Assoc. Professor, Skidaway Inst. & ODU; Research - Gulf Stream
1994-present  Scientist, Princeton Univ.; Research- Shelf/Slope Circ, Semi-encl. Seas

Professional Activities & Awards

Recent Publications
1. Chang, Wu & Oey, 2009: Bimodal behavior of the seasonal upwelling off the northeastern coast of Taiwan, JGR, in press.


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George L. Mellor
Princeton University, Atmospheric and Oceanic Sciences Program

Education
S.B. Massachusetts Institute of Technology, June, 1952
S.M. Massachusetts Institute of Technology, September, 1954
Sc.D. Massachusetts Institute of Technology, January, 1957

Experience
6/94 - present Princeton University: Professor Emeritus and Senior Research Scholar, Program in Atmospheric and Oceanic Sciences
9/65 - present Member of various review panels and advisory committees.
9/58 – present Consultant to various industries
9/57 - 6/94 Princeton University: Professor, Department of Mechanical and Aerospace
1/57 - 9/57 Curtis Wright Turbomotor Division
9/53 - 1/57 M.I.T. Gas Turbine Laboratory
6/52 - 9/53 Pratt & Whitney Aircraft

Societies
AGU (Fellow), AMS (Fellow), Sigma Xi, TOS

Awards
NSF Science Faculty Fellow, Cambridge University, 1962-63.
NAS Scientific Exchange Fellow, Institute of Oceanology, Moscow, 1970-71
CNOC Chair in Oceanography, Naval Postgraduate School, Monterey, CA, 1983.
Visiting Professor, Technical University of Delft, 2002 and 2004

Listings
American Men and Women of Science
Who's Who in America

Recent Papers

**Other Activities**

Professor Mellor was a creator of the Princeton Ocean Model (POM), and, together with Dr. Tal Ezer, continues to support code and users guide modifications, web site maintenance (mostly by Ezer) and internet advice to users. There are currently over 3000 users worldwide; these include experienced scientists in federal organizations and inexperienced graduate students. This proposed research will significantly enhance POM so that it will include the prediction of surface waves and their interaction with the three-dimensional currents. The enhanced POM is now available and will shortly be on the POM web site.

Mellor is the author of about 150 journal articles and an undergraduate/graduate textbook, “Introduction to Physical Oceanography”. He has been or is a member of various civic organizations.

**Collaborators**

John Allen, Oregon State University; Alan Blumberg, Stevens Institute of Technology; Mark Donelan, University of Miami; Tal Ezer, Old Dominion University; Sirpa Häkkinen, Goddard Space Flight Center; James Herring, Dynalysis of Princeton; Hyun-Chul Lee, GFDL; Christopher Mooers, University of Miami; Leo Oey, Princeton University; Richard Patchen, Dynalysis of Princeton

**Graduate Students, Post-doctoral Scientists**

Mellor has advised 18 Ph.D and 6 MSE graduate students and 15 postdoctoral scientist
Curriculum Vitae

Tal Ezer
Old Dominion University
Center for Coastal Physical Oceanography

Education:
1989 Ph.D. Physical Oceanography, Florida State University
1984 M.Sc. Atmospheric Sciences, Hebrew University
1981 B.Sc. Physics and Mathematics, Hebrew University

Professional Experience:
2007-present Associate Professor, Old Dominion University
2007-present Affiliated Faculty, Virginia Modeling, Analysis & Simulation Center
2007-2009 Visiting Research Collaborator, Princeton University
1989-2007 Research Staff/Scholar, AOS Prog., Princeton University
1985-1989 Research Assistant, Florida State University
1981-1985 Research Scientist, National Institute of Oceanography, Israel
1974-1978 Officer, Israeli Air Force

Professional Societies: AGU, TOS, MTS

Other Professional Activities:
Co-Editor (2001-present), Ocean Dynamics (Springer Publ.)
Convener, various international meetings (latest: PICES2008, Dalian, China);

Professional Experience/Qualifications related to this proposal:
Have been doing scientific research in ocean modeling for 25 years, including leading
studies on modeling of the Gulf Stream and the Atlantic Ocean (see references below). Involved in the development of data assimilation schemes and the first NOAA’s
operational ocean forecast system for the US east coast. Have been part of various
multi-institutional modeling projects in the Atlantic Ocean such as ONR-supported
Data Assimilation and Model Evaluation Experiments (DAMEE) and NSF-supported
Climate Process Team (CPT). Since 1991 Managed the Princeton Ocean Model
(POM) users group of over 3500 users from 70 countries and provided technical
support to users.

Selected publications relevant to this proposal
Ezer, T., R. Hobbs and L.-Y. Oey, On the movement of beluga whales in Cook Inlet,
Alaska: Simulations of tidal and environmental impacts using a hydrodynamic
Oey, L.-Y., T. Ezer, C. Hu and F. Muller-Karger, Modeling and satellite observations of
baroclinic tidal flows and inundation processes in Cook Inlet, Alaska, Ocean
Ezer, T., Topographic influence on overflow dynamics: Idealized numerical simulations
and the Faroe Bank Channel overflow, J. Geophys. Res., 111, C02002,


Dr. LARRY P. ATKINSON
Eminent Professor and Samuel and Fay Slover Professor of Oceanography
Date of Birth: August 6, 1941
Place of Birth: Ames, Iowa

EDUCATION:
1964 B.S. University of Washington, Seattle
1967 M.S. University of Washington, Seattle
1972 Ph.D. Dalhousie University, Halifax, Nova Scotia, Canada

EXPERIENCE:
1966-1968 Research Associate, Duke University Marine Laboratory
1972-1985 Faculty, Skidaway Institute of Oceanography
1985-1992 Smith Professor and Eminent Scholar, Old Dominion University, Department of Oceanography
1990-2003 Director, Center for Coastal Physical Oceanography, Old Dominion University
1992-1997 Chair, Department of Oceanography, Old Dominion University
1992-present Samuel and Fay Slover Professor, Department of Oceanography, Old Dominion University

EDITORSHIPS:
1993-1997 Managing Editor, Oceanography

AWARDS:
1990 Elected Fellow of the American Association for the Advancement of Science
1990 State Council on Higher Education in Virginia, Outstanding Researcher nominee

MEMBERSHIPS:
American Geophysical Union, American Association for the Advancement of Science, The Oceanography Society, The American Meteorological Society, The Marine Technology Society

RECENT RELEVANT PUBLICATIONS

RELEVANT SERVICE
Biographical Sketch
WANG, DONG-PING

Address: Marine Science Research Center
State University of New York
Stony Brook, New York 11794

Phone: (631) 632-8691; (631) 632-8820 (FAX); e-mail: dong-ping.wang@sunysb.edu

Education:
Ph.D., Physical Oceanography, Rosenstiel School of Marine and Atmospheric Science,
University of Miami, 1975
B.S., Physics, National Tsing-Hua University, Taiwan, 1970

Appointment: Professor, Marine Sciences Research Center, State University of New
York at Stony Brook, since 1985

Previous Positions: Oceanographer, Argonne National Laboratory, 1980-1985;
Research Scientist, 1979-1980; Associate Research Scientist,
1977-1979; Assistant Scientist, 1976-1977; Chesapeake Bay
Institute, The Johns Hopkins University

Honors: Convener, US-Korea Workshop on Ocean Prediction and Forecasting, 2002;
Co-Editor, Journal of Oceanography, 1998 – present;
Advisory Professor, East China Normal University, China, 1997 - present;
Visiting Professor, Universitat de les Illes Balears, Spain, 1997;
Visiting Professor, Ocean Research Institute, University of Tokyo, 1995;
Kirby Laing Fellow, University College of North Wales, U.K., 1994;
Editors' Citation for Excellence in Refereeing-JGR-Oceans, 1993;
Visiting Professor, Ocean Research Institute, University of Tokyo, 1992;
Visiting Professor, Universitat de les Illes Balears, Spain, 1990;
Senior Summer Fellow, Naval Research Lab, Stennis Center, 1987;
CNOOC Chair in Ocean Prediction, Naval Postgraduate School, 1985

Thesis Advisor for:
Ph.D.: Wen-Ssn Chuang (1979), Joaquin Tintore (1988), Dake Chen (1989), Moon-Jin
Park (1990), Jose Gomez (1993), Chung-Wu Wang (1993), Chin-Wen Chang
(1996), Sidney Fauria (1997), Chi-Shao Chen (1998), Jayvee Maria Udarbe
M.S.: David Kravitz (1979), Sanjay Gupta (1992), Jen-Chi Mau (1992), Maureen Dunn

Current Graduate Students: Fanghua Xu (Ph.D.)
Publications (last 5 years):


Current and Past Related Projects

Lie-Yauw Oey, Research Scholar

Location of Research: Princeton Univ., Prog. in Atmos & Oceanic Sci, 300 Forrestal Rd, Sayre Hall, Forrestal Campus

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Langrangian Data Assimilation in Ocean Model Calculations</th>
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</thead>
<tbody>
<tr>
<td>Supporting Agency</td>
<td>U.S. Minerals Management Service 1435-01-04-CT-35729</td>
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<tr>
<td>Person-month/year</td>
<td>1.5 months</td>
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<tr>
<td>Amount</td>
<td>$281,649</td>
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<td>Duration</td>
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<tr>
<td>Contract Officer</td>
<td>Michael Hargrove</td>
</tr>
<tr>
<td>Contract Officer #</td>
<td>(703)787-1367</td>
</tr>
<tr>
<td>Tech. Representative</td>
<td>Dr. Walter Johnson</td>
</tr>
<tr>
<td>Tech. Representative #</td>
<td>(703)787-1642</td>
</tr>
<tr>
<td>Address</td>
<td>U.S. Department of the Interior 381 Elden Street Herndon, VA 20170-4817</td>
</tr>
<tr>
<td>Description</td>
<td>The objective is to develop, test and verify (against observations) methodologies that assimilate Lagrangian data into an ocean model. The method(s) is then used in conjunction with algorithm(s) that assimilate satellite and in situ (e.g. moored) data to produce current (and density) fields that are presumably more “accurate” when compared against independent observations. This work is described in details by Lin, Oey and Wang [2007], and also by Oey [2007: “Lagrangian Data Assimilation in Ocean Model Calculations.” Final Report, OCS Study MMS 2007-028, U.S. DOI Minerals Management Service, Herndon, Virginia. 80pp.]</td>
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<table>
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<tr>
<th>Project Title</th>
<th>What Drove the High-Speed Deep Currents over the Sigsbee Escarpment</th>
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</thead>
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<tr>
<td>Supporting Agency</td>
<td>U.S. Minerals Management Service 1435-01-05-CT-39053</td>
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<tr>
<td>Person-month/year</td>
<td>2 months</td>
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<td>Amount</td>
<td>$274,878</td>
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<tr>
<td>Duration</td>
<td>01/10/05 – 3/31/07</td>
</tr>
<tr>
<td>Contract Officer</td>
<td>Michael Hargrove</td>
</tr>
<tr>
<td>Contract Officer #</td>
<td>(703)787-1367</td>
</tr>
<tr>
<td>Tech. Representative</td>
<td>Dr. Alexis Lugo-Fernandez</td>
</tr>
<tr>
<td>Tech. Representative #</td>
<td>(504) 736-2593</td>
</tr>
<tr>
<td>Address</td>
<td>U.S. Department of the Interior Minerals Management Service Gulf of Mexico OCS Regional Office New Orleans, LA 70123</td>
</tr>
<tr>
<td>Description</td>
<td>The original objective as indicated in the project title was to explain why high-speed deep currents were observed over the Sigsbee escarpment, through model data-assimilative and adjoint</td>
</tr>
</tbody>
</table>
analyses. However, as is often the case in any scientific enquiry, our research has ventured into something broader. To understand the deep energies at Sigsbee, we were compelled to explain why they get there in the first place. We found that deep cyclones play a very important role, and that they are preferentially produced north of Campeche Bank through deep instability of the Loop Current. In contrast to what we had believed before that frontal eddies around the northern edge of the Loop produced topographic Rossby waves (TRW’s) at Sigsbee, we find that westward-propagating deep cyclones are responsible in producing the observed short-period TRW’s. A side (but equally significant) result of this research is our discovery of a coupled deep-surface mode for Loop Current “necking” and eddy-shedding. This work is described in details by Oey [2007; submitted MS; contact lyo@princeton.edu for a copy].

Project Title: Model Waves and Currents Produced by Hurricanes Katrina and Rita
Supporting Agency: U.S. Minerals Management Service 0106CT39731
Person-month/year: 3 months
Amount: $547,545
Duration: 06/01/06 – 6/30/08
Contract Officer: Olivia Adrian
Contract Officer #: (703)787-1151
Address: U.S. Department of the Interior
381 Elden Street
Herndon, VA 20170-4817
Tech. Representative: Dr. Carole Current
Tech. Representative #: (504)736-3259
Address: Gulf of Mexico OCS Region
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394
Description: The objective is to study the intense currents in the Gulf of Mexico produced by waves and wind-driven currents as a result of hurricanes Katrina and Rita in 2005. Our approach is to first develop pre-hurricane ocean analysis fields that can accurately portray the positions of the Loop Current and rings, and also to develop accurate hurricane wind fields – this first task has resulted in one publication: Yin and Oey [2007]. We next simulate waves and surface currents produced by hurricane Katrina [Wang and Oey, 2007; submitted MS]. This gives detailed distribution of the intense wave fields, and also shows that inertial currents were very intense to the right of the storm. We then examine how both Katrina and Rita generate inertial-current energies that were channeled by the Loop and rings to the subsurface, as deep as 500 m below the surface. This last study is discussed in a draft MS:
PAST EXPERIENCE/PAST PERFORMANCE REFERENCE INFORMATION FORM

Tal Ezer, Associate Professor

Location of Research:  Old Dominion University, Center for Coastal Physical Oceanography, 4111 Monarch Way, Norfolk, VA 23508

Project Title:  Numerical modeling of tides and inundation processes in Cook Inlet (Alaska) in support of Beluga population and migration studies

Supporting Agency:  NOAA/ Alaska Fisheries Science Center

Person-month/year:  1 month

Amount:  $54,998

Duration:  9/01/07 – 9/30/09

Contract Officer:  Randall Brown

Contract Officer #:  206-526-6226

Tech. Representative:  Dr. Roderick Hobbs

Tech. Representative #:  (206)526-6278

Address:  National Marine Mammal Laboratory

             Alaska Fisheries Science Center

             National Oceanic and Atmospheric Administration

             7600 Sand Point Way, NE

             Seattle, WA  98115-6349

Description:  The objective is to compare inundation model results with satellite tracked belugas movement data in order to study the environmental impact on the belugas. The Cook Inlet model, previously developed with support from MMS and in collaboration with L. Oey of Princeton (Oey et al., 2007) provides data of water level and the movement of tidal fronts over large mudflats, where direct data are not available. Significant correlations were found between the model predictions of the movement of fronts and the location of the whales (Ezer et al., 2008).

References:


Project Title: Collaborative Research, Gravity Current Entrainment Climate Process Team
Supporting Agency: NSF/ subcontract from Princeton University
Person-month/year: 1 month
Amount: $20,976
Duration: 9/1/2007-8/31/2009
Contract Officer: Laura Rossi
Contract Officer #: 609-258-6378
Tech. Representative: Dr. Sonya Legg
Tech. Representative #: (609)258-6378
Address: Program in Atmospheric & Oceanic Sciences
Princeton University
300 Forrestal Road
Princeton, NJ  08540
Description: This collaborative research involves several national laboratories, such as NOAA/GFDL, NCAR and WHOI, and aims to improve mixing processes in climate models, and in particular, the modeling of overflows in the Atlantic Ocean and associated deep water mass formations. As part of this project, high resolution mixing simulations have been done by Ezer; these experiments evaluate the importance of various parameters and forcing mechanisms. This is the last year of a 5y NSF project started at Princeton.

References:
Project Title: Red Sea – Dead Sea Water Conveyance Study Program
Supporting Agency: World Bank/Coyne et Bellier, France
Person-month/year: 1 month
Amount: $98,540
Duration: 6/1/2008-5/30/2010
Contract Officer: Francois Halgand
Contract Officer #: 33-141850103
Tech. Representative: Dr. David Meehan
Tech. Representative #: 33-141850103
Address: Coyne et Bellier
9, allée des Barbanniers
92632 Gennevilliers Cedex France
Description: This study is part of an international project to evaluate the environmental impact of the planned canal to connect the Red Sea with the Dead Sea. In particular, the focus of the research is on mixing processes of different water types with extremely different chemical compositions and densities. Ezer serves as a mixing expert consultant to the World Bank, helping to coordinate the research efforts between various institutions, universities and laboratories in the Middle East.
PAST EXPERIENCE/PAST PERFORMANCE REFERENCE INFORMATION FORM

Larry Atkinson, Eminent Professor and Samuel and Fay Slover Professor of Oceanography

Location of Research: Old Dominion University, Center for Coastal Physical Oceanography,
Room 3127, CCPO, Innovation I Building, Norfolk, VA 23529

Project Title: Rutgers University – “Phased deployment and operation of the Mid-Atlantic Regional Coastal Ocean Observing System (MARCOOS)”
Supporting Agency: Rutgers University
Address: Institute of Marine and Coastal Sciences, 71 Dudley Road, New Brunswick, NJ 08901
Contract number: Rutgers MARCOOS TO#005 AMD#12
Date of Contract: 10/1/07
Date work was begun: 10/1/07
Date work was completed: in progress
Estimated contract Price: $200,000
Final amount invoiced: n/a
Technical point of contact: Courtney Kohut, Institute of Marine and Coastal Sciences • 71 Dudley Road, New Brunswick, NJ 08901-8525
Contracting POC: Same
Location of work: Norfolk, VA
Description of contract work: “Phased deployment and operation of the Mid-Atlantic Regional Coastal Ocean Observing System (MARCOOS)”
Current status: in progress.
Facilities and Resources

Princeton University has excellent library and technical support facilities. The university’s environment is particularly conducive to learning and research. Aside from multiple work stations and graphical expertise at the AOS Program, Princeton University facility, NOAA’s Geophysical Fluid Dynamics Laboratory provides us a free access to their computing facilities, which includes one of the most powerful multiprocessor supercomputer available today.