North Atlantic Basin Modeling and Prediction for DAMEE-NAB

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LONG-TERM GOAL

An eddy-resolving nowcast/forecast system consisting of a 1/8ºglobal system with embedded systems, 1/32º subtropical Atlantic (9-47ºN) including the Caribbean and Gulf of Mexico and 1/16º Pacific north of 20ºS.

OBJECTIVES

The goal is an eddy-resolving prediction system for the North Atlantic Basin from 9 to 47ºN, which includes the Caribbean and Gulf of Mexico. This project represents continued participation of NRL in the Data Assimilation and Model Evalution Experiment – North Atlantic Basin (DAMEE-NAB) project supported by ONR with a focus on model-data comparisons and data assimilation. NRL has had two unique roles in DAMEE-NAB. The first was to investigate the impact of using extremely high horizontal resolution, the highest ever for basin-scale ocean modeling, because of the exceptional efficiency of the NRL Layered Ocean Model. The second was to assess different wind products as potential forcing for Atlantic Ocean models by investigating linear ocean model response to the different wind sets.

APPROACH

The modeling effort is aimed at eddy-resolving models for the subtropical Atlantic Ocean and associated model development in collaboration with other projects. A wide variety of model-data comparisons are performed for evaluation of data assimilative and non-assimilative model experiments. Hydrodynamic and thermodynamic versions of NLOM are used with grid resolutions of 1/4º to 1/64º for each variable and 5 to 6 lagrangian layers in the vertical. The model has a free surface and allows diapycnal mixing, isopycnal outcropping and inflow/outflow through ports in the model boundaries. A version which includes a mixed layer and sea surface temperature is under development. The model runs efficiently and interchangeably on all DoD HPC platforms designed to handle applications this large, including massively parallel distributed memory computers and multi-processor shared memory computers. In general, NLOM is the most efficient ocean model in existence in terms of computer time per model year.

The altimeter heights will be assimilated using a combination of optimum interpolation, statistical inference, and nudging. However, the methods will depend upon the model chosen. Past experience with parameter optimization in a Gulf Stream regional system indicates that substantial improvements in

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performance can be obtained by empirically adjusting parameters used in the assimilation methods. More advanced methods of assimilation, such as the adjoint and Kalman filtering techniques, have not yet reached a state where they are practical alternatives.

Linear solutions are used for assessment of different wind products for potential ocean model forcing because they represent a deterministic oceanic response to the wind forcing and because they have well understood dynamics which represent the lowest order response to wind forcing, i.e. Sverdrup (1947) flow for the ocean gyre interiors which are closed by Munk (1950) western boundary layer currents.

WORK COMPLETED

Two papers were submitted for a special issue of Deep-Sea Research devoted to DAMEE-NAB. The first investigates the impact of 1/8º, 1/16º, 1/32º, and 1/64º ocean model resolution on model-data comparisons for the Gulf Stream system between the Florida Straits and the Grand Banks. The 1/64º simulation (Fig. 1) is a first of a kind simulation, the highest horizontal resolution to date for a model of a major ocean basin. It was performed under an FY98 DoD High Performance Computing Challenge grant of computer time. Model-data comparisons included 1) the Gulf Stream mean pathway and its variability using GEOSAT-ERM and TOPEX/POSEIDON (T/P) altimetric analyses of Gulf Stream axis and IR analyses of the Gulf Stream north wall, 2) the mean position, eastward extent and amplitude of the Gulf Stream nonlinear recirculation gyres using surface dynamic height from the Navy's GDEM oceanic climatology, 3) mean transports of upper ocean and abyssal currents, especially the Gulf Stream and the Deep Western Boundary Current, 4) rms sea surface height variability from T/P (Fig. 2), and 5) abyssal eddy kinetic energy from current meter data. In addition, initial experiments were performed using a 1/32º thermodynamic version of the subtropical Atlantic model.

The second paper investigated linear Atlantic ocean model response to 11 different wind sets and a linear, Munk western boundary layer representation of the global thermohaline circulation. The wind stress climatologies used in this study were: 1) smoothed Hellerman and Rosenstein (HR, 1983), 2) unsmoothed HR, 3) Comprehensive Ocean-Atmosphere Data Set (COADS) (da Silva *et al.*, 1994a,b), 4) Isemer and Hasse (1987), 5) European Centre for Medium-Range Forecasts (ECMWF) 1000 mb from 1981-1993, 6) ECMWF 10 m from 1985-1994, 7) ECMWF 1000 mb from 1983-1986 (ECMWF, 1995), 8) ECMWF 1000 mb re-analysis from 1979-1993, 9) ECMWF 10 m re-analysis from 1979-1993 (Gibson *et al.*, 1997), 10) Fleet Numerical Meterorology and Oceanography Center (FNMOC) 7/90-6/95 (Hogan and Rosmond, 1991), and 11) National Centers for Environmental Prediction surface stress re-analysis for 1979-1995 (Kalnay *et al.*, 1996).

Atlantic region data assimilation was performed in the context of T/P altimetric data assimilation into a 1/4º global ocean model in collaboration with 6.2 project Basin Scale Ocean Prediction Systems and 6.4 project Ocean Data Assimilation. Particular attention was focussed on results obtainable from a 1/4º model with insufficient horizontal resolution for Gulf Stream separation and an inaccurate Gulf Stream mean pathway. Results from track by track assimilation were compared with assimilation of complete field OI analyses of SSH obtained using T/P data over a 10-day repeat interval.

RESULTS

The paper about the impact of ocean model resolution (1/8º to 1/64º for each variable) on model-data comparisons showed that while 1/16º resolution is a major step toward realistic simulations, 1/32º resolution is required for realistic and robust results. This includes Gulf Stream separation from the coast at Cape Hatteras, the Gulf Stream pathway between Cape Hatteras and the Grand Banks, the large-scale C-shape of the subtropical gyre, and the oceanic variability in the upper ocean and the abyssal layer.

The paper about the ocean model response to different wind forcing and a linear, Munk western boundary layer representation of the global thermohaline circulation showed that the latter makes a substantial contribution to the Gulf Stream transport and is essential for realistic circulation patterns in the Caribbean and western tropical Atlantic. Overall, a smoothed version of the Hellerman and Rosenstein (1983) and the COADS (da Silva, 1994a,b) wind stress climatologies, with the global thermohaline component added, gave the best results for the Gulf Stream region, including Florida Straits transport close to the well-observed value.

When assimilating satellite altimeter data into a 1/4º model with insufficient resolution for Gulf Stream separation and an inaccurate Gulf Stream mean pathway, complete field assimilation gives stronger constraint on the model and gives a better representation of the Gulf Stream, as well as improved results within the Gulf of Mexico. The weaker constraint of track by track assimilation allows the inaccurate 1/4º model Gulf Stream dynamics to "fight" the data too much. In principle, track by track assimilation is preferable because it is synoptic (whereas, the OI analyses are not) and because it uses the model as a dynamic interpolator.

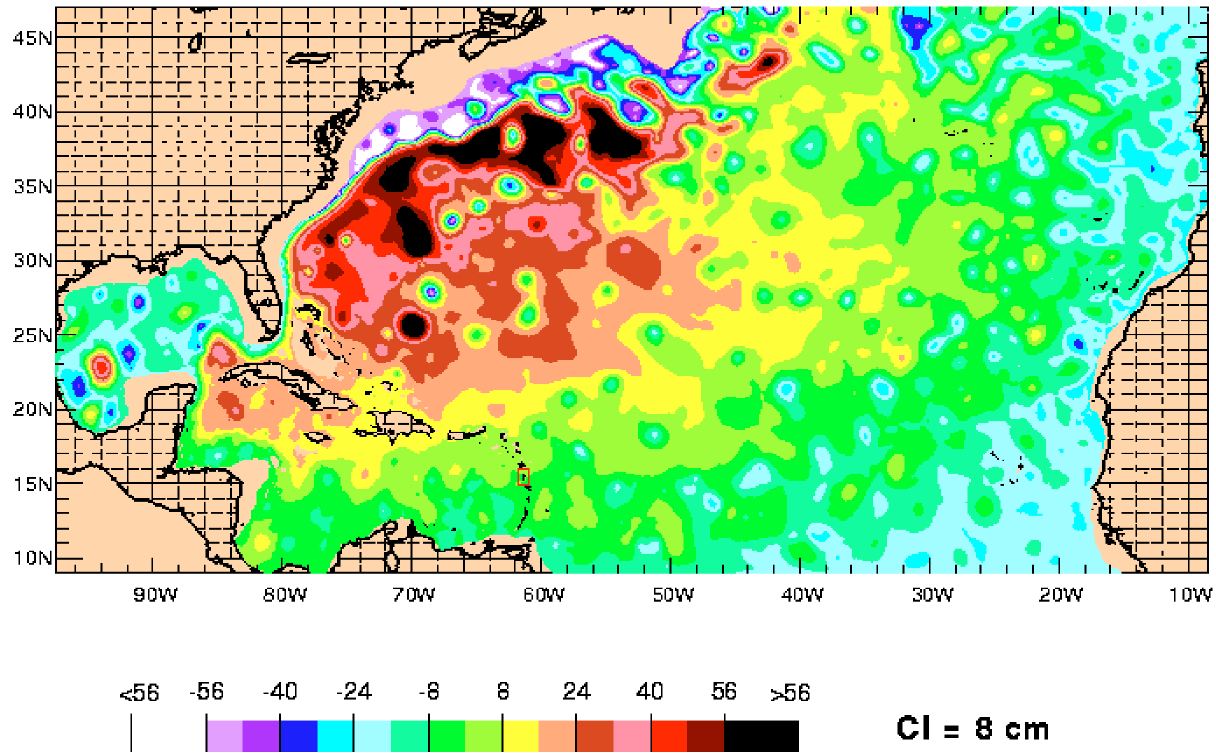

Figure 1. Whole domain snapshot of SSH from a 1/64º 5-layer Atlantic simulation forced by the Hellerman-Rosenstein monthly wind stress climatology and the global thermohaline circulation.

IMPACT/APPLICATION

Simulation of realistic Gulf Stream separation from the coast at Cape Hatteras and a realistic Gulf Stream pathway between Cape Hatteras and the Grand Banks is a "Holy Grail" problem in ocean modeling, where many have tried and failed. Resolution requirements were assessed for realistic simulation of the Gulf Stream system and it was found that 1/32º resolution is required for robust realistic results. Resolution of 1/16º is the highest used outside NRL for Atlantic basin-scale ocean modeling. The linear Atlantic simulations can be used 1) to aid in the evaluation of wind sets for forcing ocean models and 2) to assist modellers in assessing and understanding the impact of nonlinearity and additional model physics and dynamical processes. The linear simulations provide a baseline for comparison which has well understood dynamics.

The plan is to embed a 1/32º Atlantic model into a 1/8º global model for transition as part of an operational global ocean nowcast/forecast system with transition to FNMOC by the end of FY01. This would include participation in the Global Ocean Data Assimilation Experiment (GODAE) as a pilot program, where the NRL effort is represented on both the international and U.S. Scientific Steering Teams. The system will include assimilation of real-time altimeter data received from NAVOCEANO's

Altimeter Data Fusion Center. It would be an upgrade to an existing 1/4º global ocean model which already assimilates real-time altimeter data from T/P and ERS-2 (and soon probably from the Navy's GFO) and which is already running in real time at FNMOC.

TRANSITIONS

A 1/4º 6 layer finite depth thermodynamic global ocean model was transitioned to FNMOC in FY98 via the data assimilation group. This model is now running in real time with T/P and ERS-2 altimetry data assimilation. The system is being prepared for OPTEST and is expected to be operational in FY99.

RELATED PROJECTS

This 6.1 project and a collaborative 6.2 project, Basin-Scale Ocean Prediction Systems, are NRL participants in ONR's DAMEE-NAB project. The DAMEE-NAB project is multi-institutional. In addition to NRL, it includes Mississippi State University (Dave Dietrich and Avichal Mehra), MIT (Paola Rizzoli's group), Princeton University (Tal Ezer and George Mellor), Rutgers University (Scott Glenn and Dale Haidvogel's group), UCLA (Michael Ghil's group), U. Miami (Eric Chassignet's group) and the University of Southern Mississippi (Ziv Sirkes and Bob Willems). None of these participated directly in the NRL effort. In addition, this project has collaborated with other projects: 6.1 Dynamics of Low-Latitude Western Boundary Currents, 6.1 Forced Upper Ocean Dynamics, 6.1 Topographic and Thermodynamic forcing, 6.4 Ocean Data Assimilation, 6.4 Large-Scale Ocean Models and Data Assimilation in Ocean Prediction (in collaboration with J. Moura and A. Asif at Carnegie Mellon University).

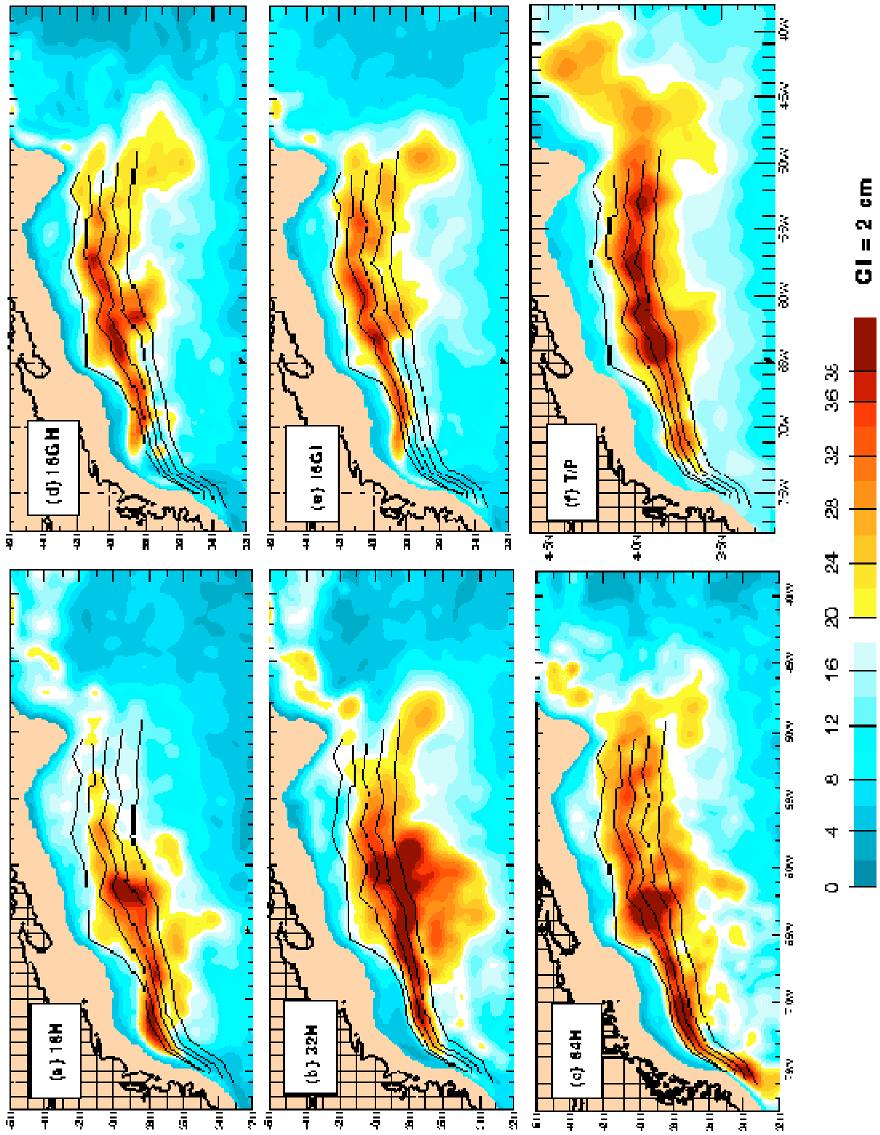

Figure 2. SSH variability (color) in the Gulf Stream region from (a) 1/16º 5-layer Atlantic simulation 16H, (b) 1/32º 5-layer Atlantic simulation 32H, (c) 1/64º 5-layer Atlantic simulation 64H, (d) 1/16º 6-layer global simulation forced by Hellerman-Rosenstein monthly climatological winds (simulation 16GH), (e) 1/16º 6-layer global simulation over 1990-1996 that was forced by interannual winds (simulation 16GI) and (f) T/P altimetry over the time period 1993-1996. All of the simulations also included constant global thermohaline forcing. Superimposed on each is the mean (center line), lines a standard deviation away from the mean on either side and extreme (outer lines) of the Gulf Stream axis as determined from T/P altimetry by Lee et al. *(1997). The contour interval of the SSH variability is 2 cm.*

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