Ocean Model Development for COAMPS

Paul Martin
Naval Research Laboratory
Stennis Space Center, MS 39529
phone: (228) 688-5447 fax: (228) 688-4759 email: martin@nrlssc.navy.mil

Document Number: N0001402WX20836

LONG-TERM GOALS

Develop a coupled ocean-atmosphere prediction system that can be used for hindcasting and forecasting coastal and mesoscale environments. This system is referred to as the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The atmospheric component of this system was developed by the Atmospheric Dynamics and Prediction Branch of the Naval Research Laboratory (NRL) and is currently in use at NRL and at the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) (Hodur 1997).

OBJECTIVES

The objectives of this project are to (a) develop an ocean model that contains some of the best features of existing coastal ocean models, meets the Navy's needs for conducting simulations and predictions in littoral and mesoscale environments, and is scaleable on multi-processor computers in common use by the Navy, (b) validate the performance of the ocean model, and (c) fully couple the ocean model with the atmospheric model within the current COAMPS program architecture.

APPROACH

COAMPS consists of coupled ocean and atmospheric models (Hodur et al., 2002). The ocean model needs to be able to accommodate the wide range of environments and processes that will be encountered in operational use, including complex coastlines and bathymetry, wind and density-driven currents, tides and storm surge, river outflows and coastal runoff, and flooding and drying. The purpose of this project is to develop an ocean model to provide these capabilities. The ocean model being developed in this project is referred to as the Navy Coastal Ocean Model (NCOM).

Based on results from the Coastal Model Comparison study conducted by the NOMP Ocean Model Performance and Evaluation Project at NRL (Martin, et al., 1998), it was proposed that the ocean model to be developed for COAMPS consist of the following main elements: (a) the basic physics and numerics of the widely used Princeton Ocean Model (POM), (b) the combined sigma/z-level vertical grid system used in NRL's Sigma/Z-level Model (SZM), (c) a program structure fully consistent with COAMPS, and (d) some additional capabilities and refinements.

A combined sigma/z-level grid system provides some additional flexibility over a sigma coordinate or a z-level system in setting up a vertical grid for a particular region. With the combined grid system, sigma coordinates are used down to a user-specified depth, and z-level coordinates are used below. The z-level grid, which is generally more robust in regions of steep bottom slopes than sigma

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Ocean Model Development for COAMPS**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,,Stennis Space Center,,MS, 39529**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Develop a coupled ocean-atmosphere prediction system that can be used for hindcasting and forecasting coastal and mesoscale environments. This system is referred to as the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). The atmospheric component of this system was developed by the Atmospheric Dynamics and Prediction Branch of the Naval Research Laboratory (NRL) and is currently in use at NRL and at the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) (Hodur 1997).

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

coordinates, can be applied at the depths below which steep bathymetry may cause difficulty with sigma coordinates. The combined grid system also allows comparisons to be made between sigma and z-level coordinates for a particular domain to identify problems that may be occurring with either coordinate system.

COAMPS has a code architecture that is mainly defined by two attributes: (1) model variables are passed via subroutine argument lists rather than by common blocks and (2) model array space is dynamically allocated at run time. The reason for these attributes is to allow the same model code to calculate different nested grids for both the atmospheric and ocean models within a single program, and to avoid having to recompile the program for different simulations with different grids. To utilize the full capability for which COAMPS was designed, an ocean model being developed for use in COAMPS needs to be structured to be consistent with the COAMPS code architecture. Most existing ocean model codes are not structured in this way.

It was desired to include some additional capabilities in NCOM that are not currently available in POM. These include an explicit source term to simplify inclusion of river and runoff inflows, options for forcing by the local tidal potential and the surface atmospheric pressure gradient, the choice of either the Mellor-Yamada Level 2.5 turbulence closure scheme as used in POM or the simpler and more efficient Mellor-Yamada Level 2 scheme, and options for higher-order finite differences.

Because of the increasing use of multi-processor computers by Navy operational and research centers, NCOM has been developed to be scalable on commonly used multi-processor computers. Alan Wallcraft of NRL, who has significant experience with scalable model design, has been assisting in this effort. Alan's work on NCOM is funded by the Common High Performance Computing Software Support Initiative (CHSSI).

NCOM is being validated by testing its ability to correctly simulate basic physical processes and by comparing model simulations in some real environments with observations. Coupling between NCOM and the COAMPS atmospheric model is being tested in the Mediterranean.

The coupling of NCOM with COAMPS is very much a joint effort with NRL Monterey, and several personnel from the atmospheric modeling group at NRL Monterey are involved in this effort including Richard Hodur, Xiaodong Hong, Julie Pullen, Jim Cummings, Sue Chen, and Jim Doyle. The NRL Monterey effort is funded separately and is being reported separately. This report is focused mainly on the work done at NRL Stennis, but some of the tasks reported here involve joint work.

WORK COMPLETED

A Fortran code for NCOM has been developed that is fully consistent with the COAMPS code architecture, i.e., that includes dynamic allocation of array space, passes all model variables through subroutine argument lists, and provides for an arbitrary number of levels of grid nesting. The model contains options for Smagorinsky or grid-cell Reynolds number horizontal mixing, Mellor-Yamada Level 2 or 2.5 vertical mixing, 2nd-order centered or 3rd-order upwind advection, and 2nd- or 4th-order baroclinic pressure gradient and Coriolis calculations.

NCOM has a flux coupler to access COAMPS atmospheric fields for surface forcing. Software has been set up to provide automated input of rivers from a global, climate river data base (which contains 981 rivers) into an arbitrary model domain. The NCOM code is fully scaleable, except for feedback from the nested grids to the main grid, runs on the SGI Origin 3000, Cray T3E, IBM SP, and Sun E10000, and provides a choice of MPI, SHMEM, and OpenMP for I/O and communication between processors. A basic description of NCOM is provided in Martin (2000). A user's guide for NCOM is available and has been updated to include recent changes to the model.

In FY02, the flux coupler was modified to provide an option for computing latent and sensible heat fluxes using the NCOM-predicted SST and COAMPS output surface wind speed and air temperature and humidity fields. Simulations were conducted in the Mediterranean Sea to test the forcing of NCOM with COAMPS atmospheric fluxes. The testing included forcing with latent and sensible heat fluxes output directly by COAMPS and with latent and sensible heat fluxes computed from bulk formulas using COAMPS surface wind, air temperature, and humidity fields and the NCOM SST. Seasonal and annual averages of the COAMPS surface fields and air-sea fluxes for the Mediterranean for 1999 were computed to look at temporal means and to compare with climatological means (Martin and Hodur 2002).

Some idealized tests were conducted to provide additional testing of NCOM: the formation and spreading of deep convection, gravity current flow down a slope, and the propagation of a barotropic equatorial Rossby soliton.

Some improvements were made to NCOM this year through work in other projects. The calculation of transports though vertical sections was made easier to use and scaleable. An option for Flux-Corrected-Transport (FCT) advection (Zalesak 1979), which avoids advective overshoots, was implemented for scalar fields. An option was provided for running in double precision.

RESULTS

Simulations of the Mediterranean using bulk formulas and the NCOM SST to compute latent and sensible heat flux were compared with previous simulations using heat fluxes output by COAMPS. A previous problem of excessive cooling in the northern Adriatic Sea in winter was reduced but not eliminated. Low COAMPS surface air temperatures during Bora events tend to maintain strong cooling fluxes, which reduce predicted SSTs below observed values.

Seasonal and annual averages of the hourly COAMPS air-sea fluxes over the Mediterranean Sea for 1999 were computed and compared with the climatology of May (1982, 1986) and other estimates. The surface windstress fields compare quite well with the climatology in terms of magnitude and direction and the representation of known wind features. The COAMPS mean surface heat flux is -37 W/m^2, which represents about 30 W/m^2 more cooling than estimates of the long-term mean heat flux for the Mediterranean of about -7 W/m^2 based on the Gibraltar inflow (Bethoux 1979, MacDonald et al. 1995) and is outside the interannual range of the mean heat flux of -25 to 15 W/m^2 estimated by Garrett et al. (1993). The COAMPS mean surface heat flux is, however, similar to other estimates that have been made using standard bulk formulas, which tend to predict too much cooling (Send et al., 1999). The COAMPS mean surface moisture flux (evaporation minus precipitation) is 109 cm/y, which is higher than previous estimates of 40 to 95 cm/y (Astraldi et al., 1999).
overshoots would be useful.

Idealized convection tests were conducted both with and without the Mellor-Yamada vertical mixing turned on. If the vertical mixing is turned off, convection occurs due to advective overturning rather than by vertical mixing. The advective overturning mixes more slowly than the Mellor-Yamada turbulent mixing schemes. Mixing with the Mellor-Yamada Level 2 and Level 2.5 mixing parameterizations was similar. The vertical convection/mixing results in the development of a geostrophic ring current, which then spreads the vertically mixed water horizontally through baroclinic instabilities.

The test of gravity flow down a slope was conducted as described in Haidvogel and Beckmann (1999) with both sigma and z-level vertical coordinates. With resolution typically used in ocean model simulations, the down slope flow is not well resolved vertically and tends to be strongly dissipated by mixing. Sigma coordinates performed better than z-levels in terms of the dissipation of the gravity current and the propagation speed of the front.

The test of the propagation of a barotropic equatorial Rossby soliton was conducted as described in Haidvogel and Beckmann (1999). The propagation of the Rossby soliton was improved with the use of higher-order advection and Coriolis interpolations. The best result was 8% reduction of the initial soliton amplitude after 40 (non-dimensional) time units using 4^{th}-order advection and Coriolis interpolations and with Laplacian and biharmonic mixing turned off. With 2^{nd}-order interpolations, the amplitude reduction after 40 time units was 14%.

IMPACT/APPLICATIONS

The ocean and the atmosphere are strongly coupled in coastal regions, and a combined ocean-atmosphere modeling system is frequently the optimal means of hindcasting and forecasting coastal areas. COAMPS is being developed by NRL to provide a high-resolution, coupled ocean-atmosphere prediction capability.

The payoff from this ocean model development project will be a functional and flexible model for ocean prediction that can be run by itself or can be run fully integrated with an atmospheric model within the COAMPS framework.

TRANSITIONS

NCOM has been integrated into COAMPS and is being tested in the Mediterranean with surface forcing fields from the COAMPS atmospheric model. This work is being done jointly by NRL Stennis and NRL Monterey.

As part of the COAMPS system, NCOM's transition route into operations is through 6.4 SPAWAR funding for COAMPS and the 6.4 Small-Scale Oceanography Program.

A global version of NCOM has been transitioned to the 6.4 SPAWAR Global Modeling Project at NRL. This model uses a curvilinear grid to cover the entire global ocean including the arctic.

NCOM is being used in the development of East-Asian-Seas (EAS) and Inter-American Seas (IAS) operational ocean models. These are using MODAS data assimilation, NOGAPS atmospheric forcing, and boundary conditions from the global NCOM model.

NCOM is being used in NRL's CoBALT (Coupled Bio-physical-dynamics Across the Littoral Transition) Project to simulate ocean processes off the U.S. west coast.

RELATED PROJECTS

NRL-Monterey is being funded by NOMP to assist in the development of NCOM and the installation of NCOM into COAMPS.

A joint project between NRL-Stennis and NRL-Monterey, entitled "Ocean Data Assimilation for COAMPS", is developing an MVOI ocean data assimilation system for COAMPS.

Dr. Alan Wallcraft of NRL, working under the CHSSI Program, has been helping to parallelize the NCOM code.

The NRL 6.1 Base Enhancement Project is developing a large-to-small-scale modeling system in the Inter-American Seas and Gulf of Mexico and will be testing NCOM nesting and relocatability.

REFERENCES

Astraldi, M., S. Balopoulos, J. Candela, J. Font, M. Gacic, G.P. Gasparini, B. Manca, A. Theocharis, and J. Tintore, 1999: The Role of Straits and Channels in Understanding the Characteristics of the Mediterranean Circulation. *Progress. in Oceanography*, *44*, 65-108.

Bethoux, J.P., 1979: Budgets of the Mediterranean Sea. Their Dependence on the Local Climate and on the Characteristics of the Atlantic Waters. *Oceanologica Acta*, *2*, 157-163.

Garrett, C., R. Outerbridge, and K. Thompson, 1993: Interannual Variability in Mediterranean Heat and Buoyancy Fluxes. *J. of Climate*, *6*, 900-910.

Haidvogel and Beckmann, 1999: *Numerical Ocean Modeling.* Imperial College Press, London, 320 pp.

Hodur, R. 1997: The Naval Research Laboratory Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev*., *125*, 1414-1430.

Martin, P. J., G. Peggion, and K. J. Yip, 1998: A Comparison of Several Coastal Ocean Models. NRL Report NRL/FR/7322-97-9672, Naval Research Laboratory, Stennis Space Center, MS 39529, 96 pp.

Martin, P. J., 2000: A Description of the Navy Coastal Ocean Model, Version 1.0. NRL Report NRL/FR/7322-00-9962, Naval Research Laboratory, Stennis Space Center, MS 39529, 40 pp (in press).

May, P.W., 1982: Climatological Flux Estimates in the Mediterranean Sea: Part 1. Winds and Wind Stresses. NORDA Report 54, Naval Research Laboratory, Stennis Space Center, MS, 58 pp.

May, P.W., 1986: A Brief Explaination of Mediterranean Heat and Momentum Flux Calculations. Unpublished document, Naval Research Laboratory, Monterey CA, 7 pp.

Macdonald, A.M., J. Candela, and J.L. Bryden, 1995: An Estimate of the Net Heat Transport through the Strait of Gibraltar. In *Coastal and Estuarine Studes: Seasonal and Interannual Variability of the*

Western Mediterranean Sea, edited by P.E. LaViolette, American Geophysical Union, Washington, D.C., 373 pp.

Send, U., J. Font, G. Krahmann, C. Millot, M. Rhein, and J. Tintore, 1999: Recent Advances in Observing the Physical Oceanography of the Western Mediterranean Sea. *Progress in Oceanography, 44*, 37-64.

Zalesak, S.T., 1979: Fully Multidimensional Flux-Corrected Transport Algorithms for Fluids. *J. Comp. Phys., 31*, 335-362.

PUBLICATIONS

Martin, P. J. and R.M. Hodur, 2002: Mean COAMPS Air-Sea Fluxes over the Mediterranean during 1999. NRL Report, submitted (a draft is available). Naval Research Laboratory, Stennis Space Center, MS 39529. 34 pp.

Hodur, R.M., X. Hong, J.D. Doyle, J. Pullen, J. Cummings, P. Martin, M.A. Rennick, 2002: The Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Oceanography, 15*, 88-98.