J1.4 RECENT DEVELOPMENTS OF THE COUPLED OCEAN/ATMOSPHERE MESOSCALE PREDICTION SYSTEM (COAMPS)

Teddy Holt[1], Jerome Schmidt[1], Sue Chen[1], James Doyle[1], Richard Hodur[1], Douglas Westphal[1], Xiaodong Hong[1], Julie Pullen[1], Ming Liu[1], James Cummings[2], Arthur Mirin[3], and Gayle Sugiyama[3]

[1]Naval Research Laboratory, Monterey, CA
[2]Naval Research Laboratory, Stennis Space Center, MS
[3]Lawrence Livermore National Laboratory, Livermore, CA

1. INTRODUCTION

The Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) developed by the Naval Research Laboratory (NRL) is a complete, state-of-the-art, mesoscale prediction system. It consists of atmospheric and ocean data assimilation (including data quality control), analysis, initialization, and a nonhydrostatic atmospheric forecast model coupled to an aerosol model, a hydrostatic ocean model, and an ocean wave model (Hodur 1997).

The atmospheric system has been used for operational mesoscale forecasting since 1996, providing products to the meteorological community from both a supercomputer central site (Fleet Numerical Meteorology and Oceanography Center) as well as regional sites using workstations (Naval centers, Universities, and Government Agencies). In addition, COAMPS has been used extensively for a wide range of research purposes for both idealized as well as real data simulations (Haack and Burk 2001, Haack et al 2001, Doyle and Shapiro 2000, Doyle et al. 2000, Dorman et al. 2000, Liu et al. 2000, Burk and Haack 2000, Westphal et al. 1999).

2. RECENT DEVELOPMENTS

The most visible change in the system that has affected all components of COAMPS has been a restructuring of the software to allow for flexibility to run on either distributed memory or shared memory architectures, or a combination of both. Through the use of Message Passing Interface (MPI) and OPEN-MP, COAMPS can be run efficiently across vector, parallel, or symmetric multi-processor (SMP) machines by simply changing options at runtime. Extensive care has been taken to ensure bit-reproducibility across all machine architectures. Performance results from atmospheric forecasts using multiple processors show COAMPS scales extremely well to the maximum number of processors used.

2.1 Atmospheric model

Several components of the atmospheric analysis and forecast model have recently been improved:

*Corresponding author address: Dr. Teddy R. Holt, Naval Research Laboratory, Code 7533, Monterey, CA 93943-5502; e-mail: holt@nrlmry.navy.mil

i. NAVDAS—The atmospheric analysis that is currently based on a multi-variate optimum interpolation (MVOI) scheme will be replaced with a variational scheme. A description of the Navy Atmospheric Variational Data Assimilation System (NAVDAS) developed for COAMPS is described in detail by Sashegyi et al. (2001) later in this volume (Joint paper 2.2) and will not be discussed in detail here.

ii. Aerosols—A generalized aerosol module has been imbedded in the atmospheric forecast component of COAMPS. This method of in-line coupling uses the COAMPS variables without temporal or spatial averaging and allows investigation of aerosol phenomena under rapidly changing conditions, such as in the planetary boundary layer during sunrise or sunset. The implementation allows for two-way interaction of aerosols between grids. This is advantageous because some aerosol types such as mineral dust or sea salt are generated by fine-scale features. The two-way interaction allows the aerosols generated by small-scale processes on the innermost mesh to be advected onto the coarser meshes. Mineral dust microphysical processes have been added to the generalized equations for simulations of dust storms in Southwest Asia, East Asia, and Africa. To date, studies have been conducted of the sensitivity of dust production to model terrain, roughness, resolution and flux formulation. A comparison with surface observations of dust storms in China with the simulated dust emission during the springtime dust season has revealed the importance of accounting for the dependence of stress on wind shear and thermal stability. Many dust storm modelers still do not consider this affect. It is likely that some influence of these near-source variations will be detectable far downwind in the simulations of long-range transport and size-dependent processes. A study with a complete dust model may show that these differences are amplified downwind when the focus is on local size distributions, size-dependent physical processes, and long-range transport. This possibility will be investigated using comprehensive dust aerosol microphysics imbedded inside COAMPS.

iii. Moist physics— The standard COAMPS moist physics package consists of the Kain and Fritsch (1990) cumulus scheme and the Rutledge and Hobbs (1983) bulk microphysical scheme (subsequently referred to as the RH83 scheme). The RH83 scheme is a simple bulk model based on the Lin et al. (1983) formulation with single moment prediction of mixing ratio for five microphysical variables (vapor, pristine ice, snow, rain, and cloud water). The primary assumptions used in this scheme include the use of the Marshall and Palmer (1948) size distribution, the Kessler (1969) autoconversion, and the Fletcher (1962) formulization for the nucleation of pristine ice. Terminal velocities are computed for the rain and snow fields while the remaining fields are treated as scalar tracers. The adjustment to saturation with this scheme first consists of updating the scalar microphysical and potential temperature fields for advection, diffusion, and mixing processes. Once updated, the scalar fields then undergo additional adjustments due to the various source terms as outlined by RH83, with updates occurring sequentially on a process-by-process basis.

Several modifications of this scheme have recently been implemented into COAMPS. In addition to the five scalar fields of the original scheme, predictive equations for graupel (Rutledge and Hobbs 1984, referred to as RH84) and drizzle (Khairoutdinov and Kogan 2000, or KK2000) have been added. These schemes have been included to improve our prediction of coastal stratus and mesoscale convective systems. The KK2000 drizzle parameterization requires additional prognostic equations for cloud and rain water number concentration as well as ambient aerosol number concentration and, as such, will likely serve as the basis of a full two-moment bulk microphysical scheme in COAMPS. Coupling of this scheme to more advanced aerosol models is in progress. The RH84 graupel scheme improves the liquid/ice conversions that were lacking in the original RH83 scheme. In addition, other aspects of the ice prediction have been modified through the inclusion of the Meyers et al. (1992) ice nucleation, homogeneous freezing and ice multiplication processes (Hallet and Mossop 1974), and by incorporating a non-zero fall speed for the pristine ice.

Improvements have also been sought between the moist physics and the model dynamics. First, the original sequential adjustment to saturation scheme has been replaced by the implicit scheme of Soong and Ogura (1973). All processes now also have equal access to the available vapor present at the beginning of the time step. All rates are normalized to insure against the over depletion of any given species. Secondly, a hybrid time differencing scheme has been incorporated that treats the advection of the scalars on a forward time step. The time differencing for the momentum terms remains on a leapfrog time step. The hybrid time differencing scheme allows for the use of positive definite advection schemes for the microphysical species such as that described by Bott (1989). Finally, modifications have been made to the turbulence closure scheme used in COAMPS for mixed-phase clouds. The goal here is to find a single thermodynamic variable for use in both mixed-phase deep convective and boundary layer stratus type cloud situations. Recent experience suggests that a closure for the buoyant production term in our level 2.5 prognostic turbulent kinetic equation (Mellor and Yamada, 1974) using the ice-liquid potential temperature described by Cotton and Anthes (1989) may well serve this goal.

iv. Land-surface processes— Land-surface processes are current parameterized in COAMPS using the 94 categories provided by the U.S. Geological Survey (USGS) Earth Resources Observation System (EROS) Data Center 1-km resolution global land cover characteristics database. The EROS data set, in conjunction with 10-day composites of Normalized Difference Vegetation Index (NDVI) data for four seasons of 1995-1996 are used to derive a seasonally varying global 1-km database of surface parameters for roughness, albedo, and ground wetness.

Improvements currently being developed for the COAMPS land-surface package include a multi-layer soil and vegetation model and an urban canopy parameterization. The strategy to develop the new package is through the use of a combination of observations, databases, and scientific development. Recent field programs provide new data sources for surface variables that can be used for validation and calibration of parameterizations and models, and satellite data are now used to generate databases of surface parameters with increasing resolution. In addition, with resolutions of 1 km or less, it is imperative to address the parameterization of urban areas.

v. Moving nests— An option to allow for moving inner nests has been implemented into the newly coded MPI/OPEN-MP system. This feature is particularly useful for naval operations as well as forecasting features such as tropical cyclones or squall lines. The user has flexibility in specifying how the nests will be moved, to allow for pre-determined movement with a naval battle group for instance, or to follow the maximum vorticity, surface pressure, precipitation maximum, etc. of the feature. By allowing for the nest to follow the feature of interest, much smaller nests can be used than with a fixed inner nest. Thus, moving nests can provide tremendous savings in computer resources, but still retain high horizontal resolution.

2.2 Ocean model

The ocean data assimilation system currently being developed at NRL uses an analysis based on a 3-D multi-variate optimum interpolation (MVOI) scheme and the primitive equation Navy Coastal Ocean Model (NCOM) forecast model (Martin 2000) with a hybrid sigma-z coordinate system.

i. Analysis component-- The ocean MVOI analysis can be used to construct 2D and 3D ocean fields. The 2D analysis fields are sea surface temperature (SST), altimeter sea surface height (SSH), and sea ice concentration, while the 3D analysis fields are temperature, salinity, geopotential, and the u- and v-velocity components. The analysis is multivariate in geopotential and velocity while temperature and salinity are analyzed simultaneously as uncorrelated scalar variables. SST analyses are created using MCSST retrievals, surface ship, and fixed and drifting buoy data. Subsurface temperature and salinity analyses use XBTs, CTDs, PALACE floats, synthetic soundings of salinity and temperature, fixed buoys, and thermistor chain drifting buoys. Sea ice concentration is analyzed using SSM/I data while altimeter SSH analyses rely on TOPEX and ERS2 data. All data are subject to quality control (QC) procedures. These include location (speed) tests for drifters and ship observations, instrumentation error checks for XBTs and floats, vertical gradient and vertical consistency checks for profile observations, cross-validation checks, background field checks (versus climate and the previous analysis/forecast), land/sea boundary checks, and aerosol bias detection for satellite SST retrievals using the COAMPS aerosol module.

ii. Forecast component-- The COAMPS ocean model NCOM, is based on the incompressible, hydrostatic, primitive equations. NCOM includes options for 2nd-order and 3rd-order accurate advection on the staggered C grid, using a flux conservation formulation. The vertical coordinate can be sigma, z, or sigma-z. Either Mellor-Yamada level 2 or level 2.5 vertical mixing can be used. The ocean free-surface is solved for implicitly.

A flux coupler has been developed that allows for the exchange of energy (i.e., surface fluxes of heat, momentum, and moisture) between the COAMPS atmospheric and ocean models. The coupler is capable of interpolating fields between two grids with different model resolutions and different map projections. One-way coupling from the atmosphere to the ocean has been extensively tested in the Mediterranean Sea. Using the flux coupler with hourly atmospheric forcing, COAMPS was able to simulate many observed features of the general ocean circulation, such as the sub-basin scale gyres, intense coastal boundary currents, and cyclonic and anti-cyclonic motion over the northern and southern parts of the Mediterranean Sea, respectively. The seasonal cycle of the circulation as well as its transient characteristics is also evident in the long-term model integration.

In addition to the ocean analysis, a complete set of pre-processing software has been developed for the COAMPS ocean component. An automated procedure for generating a common grid and bathymetry for the ocean analysis and forecast model has been developed. Consistent land/sea tables are generated for the atmospheric and ocean grids. Run-time options for the ocean grid include spherical, polar stereographic, Lambert conformal, Mercator, or Cartesian.

iii. WAM— The atmospheric portion of COAMPS has been coupled in an interactive mode to the 3rd generation (cycle 4) of the Wave Model (WAM) (WAMDI Group 1988). The coupling methodology follows Janssen (1991) and Doyle (1995) and includes the processes represented by mutual interaction of the wind waves and boundary-layer stress. The roughness length used in the coupled simulation is represented by,

$$z_o = \beta \frac{\tau}{g\rho(1 - \tau_w/\tau)^{0.5}} \quad (1)$$

where τ is the total stress and τ_w is the wave-induced stress. The constant β is chosen as 0.01 implying that (1) reduces to the standard Charnock relationship. For a young windsea, the effective Charnock parameter can be enhanced by an order of magnitude. The simultaneous coupling is physically achieved through communicating the atmospheric stress to the wave model every WAM time step. An iterative technique is then used to calculate τ_w based on the 10-m wind speed, drag coefficient and τ.

A number of simulations of mesoscale phenomena that are modulated by air-sea interaction processes have been performed using the fully coupled COAMPS-WAM system including three major tropical cyclones and a topographically forced Bora event over the Mediterranean Sea. In these applications, the wave and atmospheric models were integrated simultaneously and on identical grids with horizontal grid increments ranging from 12 km to 5 km. The impact of the wave-induced stress was largest for the strongest of the three tropical cyclones, Mitch. The central pressure in the coupled simulation in this particular case was 8 hPa more intense than the uncoupled simulation due to larger surface heat flux effects. Significant wave height maxima were typically ~15% lower in the coupled simulations. Overall, the results suggest that in order to accurately simulate the air-sea interface, a coupled atmosphere/ocean wave model system is needed, in particular for extreme events.

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