Final Technical Report, OSU Component

Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean

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The object of this component has been to implement a fully functional version of the Princeton Ocean Model (POM) for applications to three-dimensional wave-averaged circulation in the nearshore surf zone. POM (Blumberg and Mellor, 1987) is a time-dependent, three-dimensional, finite-difference numerical model for the hydrostatic primitive equations. The Mellor-Yamada (1982) turbulence parameterization scheme is embedded. The model is formulated in terrain following vertical sigma-coordinates and in orthogonal, curvilinear horizontal coordinates. The model implemented here, referred to as Nearshore POM, is a subroutine of the NearCom master program. The version of POM used as a starting point is POM2k. This program, POM2k, and complete documentation are available from the POM web site.

`http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom`

The full functionality of POM has been retained and all modifications are included as run-time selectable options so that the linked model can be run without wave forcing in a mode identical to standard POM. Breaking waves affect the wave-averaged mean current in several ways. The first is by the transfer of momentum from the waves to the mean current. This is represented in depth-integrated models by forcing by the gradients of the wave radiation stress tensor. The proper three-dimensional formulation of the wave forcing is currently an active research subject and significant effort has been directed toward this problem as described in Newberger and Allen (2004). Other effects are the increased near surface turbulent kinetic energy (TKE) caused by the breaking waves and increased bottom stress felt by the mean current when waves are present. Parameterized representations of each of these effects have been included in nearshore POM.

1. Modification of the POM structure and initialization

The main program of POM has been modified to be a subroutine that is called from the NearCom master program. All time stepping has been made consistent with the POM subroutine being repeatedly called from the master program. The variables passed from the wave and sediment subroutines are checked at each return to the circulation subroutine and updated if necessary. The minimum time interval between returns to the master program is one POM internal time step. Time steps specified in the POM input file are adjusted to be consistent with the calling increment specified in the input to the master program. Variables that may be required by the wave and sediment modules are loaded into the master program's pass arrays at the end of each call to the circulation module. Vector quantities are rotated, if necessary, into a specified orientation before returning to the master program. A new subroutine has been added to run on the first call to the circulation module which initializes all arrays and parameters for the run. User modification of the POM subroutine, "Setup", may be required to set the conditions for a particular simulation. An input file, pom.input, is required to select the options and parameters, discussed below, that are required for each run. Any required input data files are also specified in pom.input. POM includes the option to write a restart file at specified intervals and to read an old restart file during the initialization call to the circulation module. Within the NearCom framework the restart will be entirely seamless whenever the wave module includes a compatible restart capability.

2. Bottom stress

Effects of wave-current interaction in the wave bottom boundary layer are represented by parameterizations included in either of two separate submodels (Styles and Glenn, 2000; Mellor, 2002) that have been implemented as options. The form of bottom stress used is selected by setting the value of an integer flag, ibot, in the input file. POM includes bottom stress parameterized as a quadratic drag law (ibot=1). A bottom roughness z_0 must be specified. The Styles and Glenn (2000) wave-current boundary layer submodel (ibot=0) calculates bottom stress given the mean current at a specified level above the bed, the wave near bottom orbital velocities, wave period and direction. The bottom roughness can be specified or can be calculated by the submodel based on the value of the Shield's parameter and specified sediment properties. Mellor (2002) has developed a parameterization for the increase of near-bed TKE production in the presence of waves (ibot=-1). This formulation uses the quadratic drag law, but includes increased vertical diffusion near the bed. The wave inputs required for this model are the same as for the Styles and Glenn (2000) submodel.

3. Turbulent kinetic energy surface boundary condition

POM includes a two equation turbulence closure (Mellor and Yamada, 1982) with equations for q^2, twice the TKE, and $q^2 l$, q^2 times a turbulent length scale l. The original surface boundary conditions are (isurf=1)

$$q^2 = B_1^{2/3} u_\star, \qquad q^2 l = 0, \tag{1}$$

where $u_\star$ is the turbulent friction velocity determined from the imposed surface stress, i.e., from the wind stress. B_1 is a constant determined in the derivation of the turbulent closure. Following Craig and Banner (1994) we replace these boundary conditions at the surface (isurf=0) by

$$K_q \frac{\partial q^2}{\partial z} = 2\alpha u_\star^3, \quad q^2 l = q^2 z_s, \tag{2}$$

where $u_\star$ is the turbulent friction velocity calculated from the imposed surface stress arising from wave breaking and α is a specified constant determined from observations. The vertical eddy coefficient for q^2 is K_q. Appropriate values of the surface roughness z_s required in the boundary condition for $q^2 l$ are not well known. The nearshore POM implementation includes options for specifying a constant z_s across the surf zone or for specifying z_s as a fraction of the root mean square wave height. We note that recently Mellor and Blumberg (2004) have used an implementation of the Craig and Banner (1994) boundary condition with a wave parameterization dependent on wind stress in a simulation of deep water mixing in the presence of waves.

4. Forcing

The research problem of determining appropriate wave forcing for a three-dimensional primitive equation model such as POM is described in Newberger and Allen (2004). Here we note the changes to the program required to implement this forcing. The wave forcing has three components. The first is a surface stress that is related to the dissipation in the breaking waves. This stress is implemented by specifying the wave-induced stress in place of, or in addition to, the surface stress from winds already in POM. The second is a body force term in the momentum equations. This force is added to the non-linear terms in the internal mode calculation and depth-integrated for inclusion in the external mode. It is found that the body force includes a component related to the non-dissipative gradients in the radiation stress tensor and also a wave-current interaction term that is updated at each internal mode time step. The final component of the wave forcing is a non-zero surface value of the sigma-coordinate vertical velocity ω resulting from spatial gradients in the Eulerian wave mass transport (Hasselmann, 1971). This requires an additional term in the mean surface elevation equation in the external mode and modification of the vertical advection terms in the momentum equations.

5. Other options in nearshore POM

Rotation (Coriolis force) as on an f-plane may be included by setting the parameter f_0 to a non-zero value in the input file.

The effects of stratification may be included either by including a scalar equation for the potential density σ_Θ (istrat=1) or by including equations for both potential temperature Θ and salinity S and calculating the in situ density ρ at each time step (istrat=2). The buoyancy gradient required in the turbulent closure is calculated appropriately for either σ_Θ or for ρ. The default is istrat=0, no stratification.

The advection of strictly positive scalar quantities (q^2, $q^2 l$, σ_Θ, S or Θ) can be calculated by centered differences as in standard POM or by using a positive definite advection scheme (Smolarkiewicz, 1984). The Smolarkiewicz scheme is slower than the centered difference which is the default. Based on numerical experiments the Smolarkiewicz scheme with one correction step seems to be an acceptable choice.

A constant wind stress may be included by entering the appropriate values in the pom.input file. A time-varying wind stress may be read from a file specified in pom.input. Spatially varying wind stress is not implemented in this version.

6. Interfacing with the master program

The POM circulation module requires estimates of the wave height H, wave dissipation D, wave number vector $\mathbf{k}$, absolute frequency ω_a, near-bottom orbital velocity, wave celerity c, and group speed c_g from the wave module. If circulation-sediment interactions are specified in the input for the master program, the undisturbed water depth will be adjusted whenever the depth parameter is updated. It is assumed that any depth adjustment will be frequent enough that each depth change is small.

POM will supply depth-averaged currents and mean surface elevation to the wave module if the wave-circulation interaction option is specified in the master input file. The framework to pass the full three-dimensional current field is available, but has not been required. Velocities, evaluated either at a specified distance above the bottom or as depth-averages, can be passed to the sediment module.

7. Output from POM

The original version of POM2k includes the option of writing output to netcdf files. The framework is included in nearshore POM, but has not been used. As currently formulated, the data is written to unformatted files with one file for each field written. The option to average selected fields over a specified time period is included. The averaging period is required to be less than or equal to the output interval for the averaged fields. The three-dimensional fields written include u, v, ω, q^2, S, Θ and σ_Θ. Two-dimensional fields include the mean surface elevation η and surface and bottom stresses. The terms in the two-dimensional and three-dimensional momentum balances may be optionally calculated and saved. The terms in the momentum balances may be averaged in time as well. Time series of velocities at selected points may be written to a formatted file. Time series are typically output at time intervals frequent enough to resolve the time variation of the flow. Input parameters in pom.input determine the output intervals, location and interval for time series output and whether the optional balances and time-averaged fields are calculated and saved.

8. Combined Nearshore and Inner Shelf Modeling

Initial studies indicate that the capabilities of nearshore POM may be extended to effectively model the combined nearshore and inner shelf region. In the nearshore region the effects of wave breaking are dominant, but wind forcing (Feddersen, et al.,1998) and stratification may also be important. The time and space scales of the stratified, wind-driven inner shelf flow cannot be practically modeled with the relatively small grid sizes and time steps ($\Delta x, \Delta y < 5$ m, $\Delta t < 1$ s) required to resolve the wave-forced region. Preliminary results with a nested model version of nearshore POM are encouraging. An outer model forced by measured time varying winds and surface heat flux is run for time periods typical for wind events, e.g. ten days. A nested, higher resolution nearshore model with offshore boundary conditions and initial conditions from the outer model is run for short, several hour, time periods to calculate the effects of combined wind, heat flux and wave forcing on the nearshore flow. Non-uniform stretched grids are utilized in both domains so that the shore-normal grid sizes coincide at the outer boundary of the nearshore grid. This, plus the location of this boundary well outside the surf zone, assures that the boundary conditions are consistent with the nearshore grid. Significant differences were found in the nearshore region between the nested solution with wind, heat flux and wave forcing and a nearshore solution obtained with wave forcing only.

9. Additional studies

Coordinated, related research into modeling wave-resolved, nearshore suspended sediment transport utilizing field measurements from DUCK94 has been completed and reported in Henderson, Allen and Newberger (2004). The results of this study emphasize the need for incorporating appropriate parameterizations into wave-averaged models for wave-dependent suspended sediment transport processes in the wave bottom boundary layer.

10. Publications

Publications reporting research fully or partially supported by this grant are the following:

Henderson, S.M., J.S. Allen and P.A. Newberger, 2004, Nearshore sandbar migration predicted by an eddy-diffusive boundary layer model. *J. Geophys. Res.*, **109**, C06024, doi:10.1029/2003JC002137.

Newberger, P.A. and J.S. Allen, 2005, Forcing a three-dimensional, hydrostatic primitive-equation model for application in the surf zone, Part I: Formulation. manuscript in preparation

Newberger, P.A. and J.S. Allen, 2005, Forcing a three-dimensional, hydrostatic primitive-equation model for application in the surf zone, Part II: Applications and comparison with data. manuscript in preparation

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