Interaction between off-shore circulation and near-shore processes during extreme weather events

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Overview

Historically, the studies of the near-shore processes and off-shore circulation have been performed with two different types of models. Water level, watersheds, or estuarine dynamical models were implemented locally with off-shore open boundary conditions provided by separately integrated models of coastal dynamics. The coastal circulation models usually have rigid boundaries along the isobath 5-10m. We believe that such separate implementation of numerical models breaks very important dynamical feedbacks between near-shore processes and coastal currents, especially under the extreme weather conditions. Such feedback processes include the effects of the wind and wave induced transports, wave-currents interaction in the shallow regions, turbulence and mixing. During the extreme weather events, the storm surges modify the water levels not only in the vicinity of the shore but hundreds kilometers off the coast. The destructive wave action during the storm surges is to high extent caused by the wave field developed off-shore. The environmental impact of the storm surge flooding depends on the salinity of the storm surge water, which in turn depends on the involvement of the coastal waters in the surge. Off-shore fresh water and sediment transports during and immediately after the storm produce tremendous effect on the cross-shelf fluxes of different properties and change coastal dynamics.

We are developing the combined near-shore/off-shore modeling system based on **Princeton Ocean Model** (POM). The system incorporates:

▪the **wave model** (WM) by Mellor and Donelan (2006) to take into account interactions of wave motion and coastal circulation, and

▪the **wetting and drying scheme** (WAD) developed by Oey (2005, 2006) to simulate the moving land-sea boundary.

Currently we are working on coupling of POM and WM.

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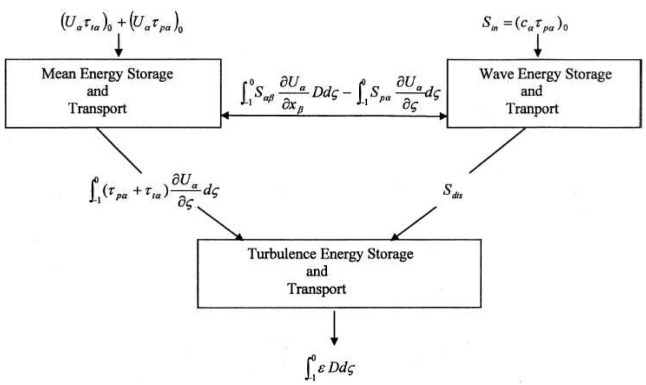

FIG. 1. The energy flow diagram for a barotropic system. The final dissipation, $\int_{-1}^{0}\varepsilon D\,d\varsigma$, is a source term in the thermal energy equation (not shown).

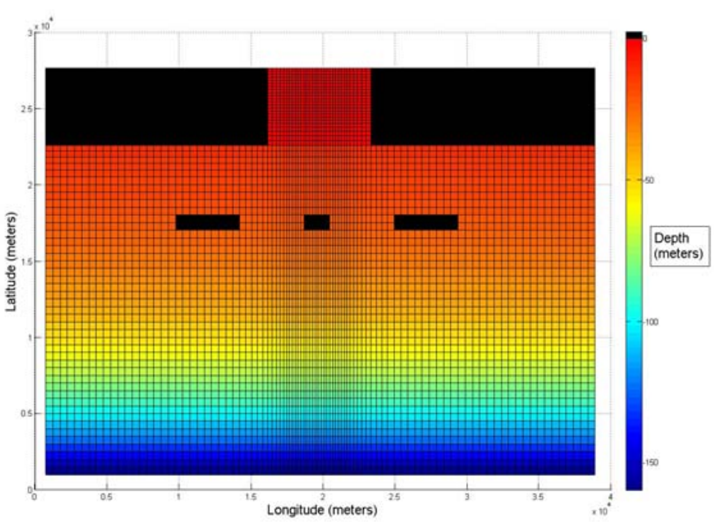

Fig. 2 Model grid and bottom topography for the test region

Wave model + POM

The WM was quite recently developed by Mellor and Donelan (2006). The current version of the WM improves substantially the description of the momentum transfer in the upper ocean layer by modifying the turbulence energy equation and corresponding calculation of the coefficient of turbulent mixing in the upper ocean. At the same time it takes into account the influence of wind-driven currents on the wave motion.

The basic equations of POM/WM coupled system are:

- The continuity equation (POM standard)
- The horizontal momentum equation:

$$\frac{\partial DU_\alpha}{\partial t} + \frac{\partial}{\partial x_\beta}[D(U_\beta U_\alpha + \overline{S}_{\alpha\beta})] + \frac{\partial}{\partial \zeta}(\Omega U_\alpha - \overline{S}_{p\alpha}) + \epsilon_{\alpha\beta z} f_z D U_\beta + D\frac{\partial}{\partial x_\alpha}(g\hat{\eta} + \hat{p}_{atm}) + D\frac{\partial \hat{p}}{\partial x_\alpha} - \zeta\frac{\partial D}{\partial x_\alpha}\frac{\partial \hat{p}}{\partial \zeta} = \frac{\partial \tau_{t\alpha}}{\partial \zeta} + \frac{\partial \tau_{p\alpha}}{\partial \zeta},$$

where

$$\overline{S}_{\alpha\beta} = E_\theta\left(\frac{k_\alpha k_\beta}{k^2}F_1 + \delta_{\alpha\beta}F_2\right),$$

$$\overline{S}_{p\alpha} = F_3\frac{\partial E_\theta}{\partial x_\alpha} + F_4 E_\theta\frac{\partial k_p D}{\partial x_\alpha}$$

- The wave energy equation:

$$\frac{\partial E_\theta}{\partial t} + \frac{\partial}{\partial x_\alpha}[(\overline{c}_{g\alpha} + \overline{u}_{A\alpha})E_\theta] + \frac{\partial}{\partial \theta}(\overline{c}_\theta E_\theta) + \int_{-1}^{0}\overline{S}_{\alpha\beta}\frac{\partial U_\alpha}{\partial x_\beta}d\zeta - \int_{-1}^{0}\overline{S}_{p\alpha}\frac{\partial U_\alpha}{\partial \zeta}d\zeta = S_{\theta in} - S_{\theta Sdis} - S_{\theta Bdis},$$

where

$$\overline{c}_\theta = \frac{gF_{c\theta}}{2c_p\cosh^2 k_p D}\left[\sin\theta\frac{\partial D}{\partial x_1} - \cos\theta\frac{\partial D}{\partial x_2}\right] + \frac{k_\alpha}{k}\left[\sin\theta\frac{\partial \overline{u}_{A\alpha}}{\partial x_1} - \cos\theta\frac{\partial \overline{u}_{A\alpha}}{\partial x_2}\right],$$

$$\overline{u}_{A\alpha} = \int_{-1}^{0}U_\alpha\frac{\partial F_5}{\partial \zeta}d\zeta,$$

$$\tau_{t\alpha} = -\overline{< w'u'_\alpha >}, \qquad \tau_{p\alpha} = \overline{\tilde{p}_{w\eta}\frac{\partial \tilde{\eta}}{\partial x_\alpha}}F_{SS}F_{CC},$$

$$S_{\theta in} = c_\alpha\tau_{p\alpha}(0).$$

-The heat and salt advection diffusion equations (POM standard)

-The POM turbulence energy equations (Mellor, Yamada) with additional generation terms:

$$\frac{\partial Dq^2}{\partial t} + \frac{\partial}{\partial x_\alpha}(DU_\alpha q^2) + \frac{\partial}{\partial \zeta}(\Omega q^2) + 2\frac{\partial}{\partial \zeta}[\overline{< w'(u_1'^2 + u_2'^2 + w'^2) >} + \overline{< w'p' >}] = 2(\tau_{t\alpha} + \tau_{p\alpha})\frac{\partial U_\alpha}{\partial \zeta} + 2s_{dis} - 2D\epsilon.$$

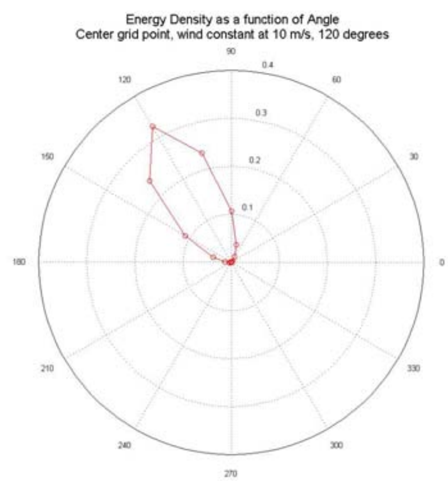

Fig.3 Spectrally averaged energy density as a function of angle for the constant wind at 10m/s, 120 degrees