SIMULATION OF MOUNTAIN FLOW IN A NESTED MESH MODEL: PROBLEMS ENCOUNTERED AND POSSIBLE SOLUTIONS

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The prediction of mesoscale cyclonic development in the lee of mountain barriers is a problem area which has not benefited from advances in computer and modeling technology during the past decade. A numerical model capable of simulating such disturbances requires in some geographical areas a horizontal mesh size of 50-100 km, a time step on the order of one minute (explicit) and at least 20 levels in the vertical (if aspect ratio arguments linking horizontal to vertical grid spacing are applicable). Economic considerations prohibit this type of grid layout on the planetary wave scale of several thousand kilometers. A practical alternative is to use a fine-mesh overlay on an otherwise coarse-mesh model in the vicinity of the mountain barrier.

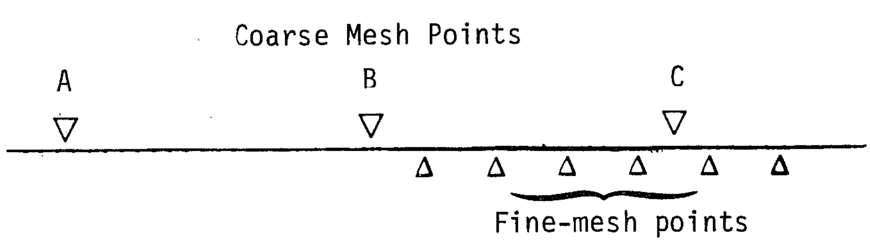
Numerical stability in a nested-mesh model is generally not a problem (Ciment, 1971). Of greater concern is the "transparency" of the gird interface to gravity waves radiating out from the topographic obstacle (Browning, et al., 1973). A selectively damping time differencing scheme of the Matsuno or Lax-Wendroff type (Phillips and Shukla, 1973; Bleck, 1977; Phillips, 1979) is often considered necessary to prevent a buildup of gravitational wave energy in the fine-mesh domain.

The flow of information between the two grid domains can be either one-way (in the sense that the coarse-mesh forecast provides boundary conditions for the fine mesh) or two-way. With reference to the accompanying figure, the two-way mode (which this author favors) stipulates that fine-mesh results interpolated to point C are used for carrying out coarse-mesh finite-difference operations at B which in turn provide boundary conditions for the fine mesh.

Due to the small size of the fine-mesh domain, forecast results are extremely sensitive there to flux variations of various quantities (especially mass) across the interface. Therefore, the two grids should be juxtaposed so as to allow exact transfer of this flux information. The logical choice for a grid interface thus is a line of coarse-mesh flux grid points coninciding with a line of fine-mesh flux points. With proper staggering of grid points (example: Arakawa's C grid), boundary conditions for the fine mesh can then be posed exclusively in terms of fluxes of mass, temperature, moisture, etc., whereas height, temperature and moisture values themselves remain unspecified at the fine-mesh boundary.

Boundary conditions for the velocity components (as opposed to mass flux components) are probably less critical as long as they only affect the inertial terms in the mementum equations.

Figure:



Care should be taken to assure that grid values interpolated to point C are not unduly influenced by fine-mesh scales of motion. In particular, the fine-mesh bottom topography in the strip between B and C (and a short distance beyond) should contain no scales unresolvable in the coarse mesh. This will minimize aliasing problems in finite-difference calculations at B.

In the author's experience, the most serious problem facing the mountain flow modeler is unrelated to the grid nesting concept. It concerns our inability to initialize the flow pattern over and near the mountain barrier on a scale commensurate with the scale of the barrier itself. A measure of this shortcoming is the strength of the orographic anticyclone forming over the mountain range during the first few hours of integration.

Since a dynamic concept for initializing air flow over mountains is lacking at present, our only recourse seems to be to adhere as closely as possible to the observations taken in the vicinity of the mountain barrier. In particular, we should try to design objective analysis schemes which make better use of wind information in specifying the mass field. The author is presently testing the following scheme which is an extension of the well-known "backward" use of the balance equation.

Objective analysis schemes (with the exception of certain global fitting schemes) express a grid point value u_o by a linear combination of nearby observations u_i:

$$u_o = \sum_{i=1}^{n} \alpha_i u_i$$

where $\alpha_i = \alpha(x_o, y_o, x_i, y_i)$. This expression can be partially differentiated with respect to the grid point location (x_o, y_o) to yield values of both $\partial u/\partial x$ and $\partial u/\partial y$ at the grid point:

$$\left(\frac{\partial u}{\partial x}\right)_o = \sum_{i=1}^{n} \left(\frac{\partial \alpha_i}{\partial x_o}\right) u_i$$

$$\left(\frac{\partial u}{\partial y}\right)_o = \sum_{i=1}^{n} \left(\frac{\partial \alpha_i}{\partial y_o}\right) u_i$$

The weights $\partial\alpha_i/\partial x_o$ and $\partial\alpha_i/\partial y_o$ in these expressions can be easily computed, even for sophisticated analysis schemes like optimum interpolation.

The resulting scheme does more than simply combine two analysis steps into one: it determines the exact slope of the gridded u field at the grid point, as opposed to an average slope over twice the grid interval, and therefore shows considerably more detail on the scale of the station separation than a conventionally derived field of $\partial u/\partial x$ or $\partial u/\partial y$. This advantage presumably is carried over into the field of geostrophic vorticity which can be inferred from the balance equation if $\partial u/\partial x$, $\partial u/\partial y$, $\partial v/\partial x$, $\partial v/\partial y$ are known, and further on into the geopotential field which can be derived from the above by two-dimensional relaxation of a Poisson equation.

The approach suggested here goes one step further for the sake of vertical consistency. A geostrophic potential vorticity field can be constructed by dividing the geostrophic absolute vorticity values by (independently analyzed) layer thickness-which essentially is the second vertical derivative of the geopotential. The resulting concoction of horizontal and vertical derivatives of geopotential can be rewritten as a three-dimensional Poisson equation which can be solved by three-dimensional relaxation.

The laminar structure of the atmosphere can be optimally taken into account in this scheme by carrying out the analysis procedure in isentropic space. Orographic features enter into the relaxation process through the lower boundary condition which is of the mixed type if surface pressure is left unspecified. (However, surface potential temperature must be specified in the relaxation process). The entire process is identical to the one used by Bleck (1973) in his potential vorticity prediction model.

The intent is to initialize flow conditions in the fine mesh through relaxation on that mesh, as opposed to interpolation down from a coarse-mesh analysis as was done in Bleck (1977). Provided the surface potential temperature field is adequately determined, this fine-mesh relaxation hopefully will lead to greater dynamic consistency.

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