A Global Nonhydrostatic Semi-Implicit Semi-Lagrangian Variable Resolution Atmospheric Model

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We have replaced the uniform resolution of the global nonhydrostatic semi-implicit semi-Lagrangian (SISL) model described by Semazzi et al (1995) and Qian et al (1998), with a stretched variable grid mesh based on Fox-Robinowitz et al (1997), to investigate the performance of the model in simulating nonhydrostatic motion at sufficiently high spatial resolution.

The core set of simulations consist of three pairs of identical adiabatic twin experiments. Starting from zonal initial motion, disturbances are generated by introducing an isolated meso-scale $(\leq 10km)$ Witch of Agnesi mountain at the bottom of the atmosphere along the equator. For each pair of simulations, a binary switch in the model has been used to suppress or retain the terms in the governing equations responsible for nonhydrostatic dynamics. In these experiments, the spatial and temporal resolution were systematically modified to assess the performance of the global model in reproducing the well known classical orographic meso-scale hydrostatic/nonhydrostatic gravity wave solutions.

In the control pair of identical twin experiments, a modest Courant number of 0.5 $\left(\Delta x = \Delta y = 400m,\, \Delta t = 10s,\, and\, U = 20ms^{-1}\right)$ was adopted. The nonhydrostatic version of the model produces the familiar meso-scale stationary gravity wave train anchored to the isolated mountain (bottom panel). The wave has a distinct vertical tilt that is consistent with the classical Long's analytical solutions and with numerical solutions based on limited-area meso-scale nonhydrostatic models. When the nonhydrostatic terms of the model are suppressed, the axis of the resulting gravity wave train rests perpendicular to the mountain top (top panel) thus consistent with the classical theory of meso-scale gravity wave dynamics (Smith 1980). In the second pair of identical twin experiments (figures not shown) the Courant number was increased from 0.5 to 3.0 by changing the time step from 10s to 60s. The corresponding solutions for both the hydrostatic and nonhydrostatic versions of the model are stable although the Courant number significantly exceeds unity. In the third pair of identical twin experiments (figures not shown) the Courant number of 3.0 was retained but the time step was increased from 60s to 300s, and the spatial resolution from 400m to 2,000m. In this case with relatively coarser spatial resolution the solutions are virtually identical for both the hydrostatic and nonhydrostatic versions of the model. Further details about this study may be found in Pouliot et al (2000).

The results show that the performance of the global SISL model is consistent with meso-scale models in the generation of orographically forced hydrostatic and nonhydrostatic gravity waves. This demonstration represents an important step toward the goal of developing efficient multi-scale global nonhydrostatic meso-scale models capable of producing stable solutions at unprecedented large Courant numbers and free of artificial lateral boundary conditions or the need to impose the hydrostatic balance constraint. The computational cost associated with the inclusion of the nonhydrostatic terms in the model is relatively insignificant for the present calculations. The new global scheme is suitable for addressing a variety of unique problems concerning the role of nonhydrostatic dynamics in modulating the global circulation of the atmosphere.

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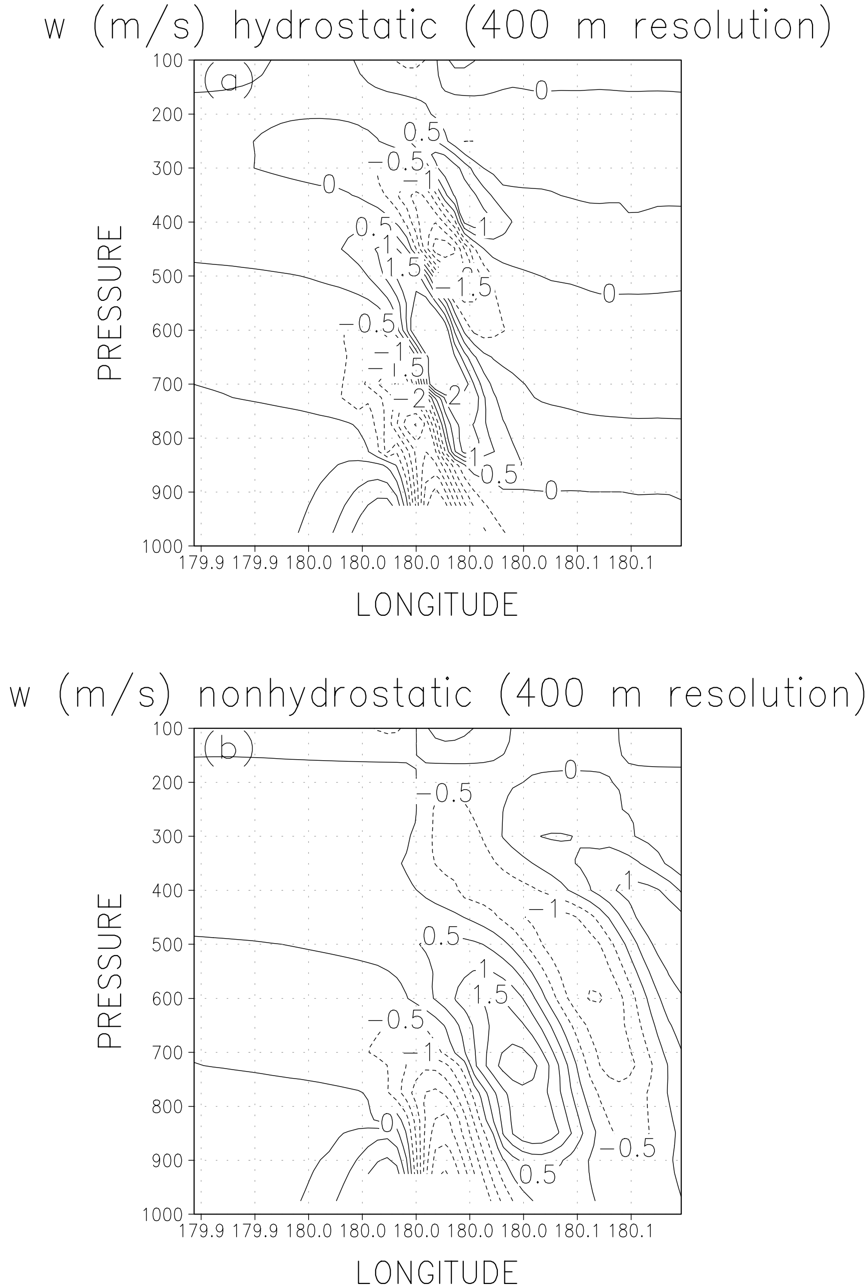

Control case: Idealized orography experiment with, $\Delta x = \Delta y = 400m$, $\Delta t = 10s$, $and\, U = 20ms^{-1}$. Vertical velocity at the Equator (m/s), (a) hydrostatic, and (b) nonhydrostatic after 6 hours. Idealized bell-shaped Witch of Agnesi 3-dimensional mountain with half-width of 2km and maximum height of 500 m. The other two cases are, (i) [$\Delta x = \Delta y = 400m$, $\Delta t = 60s$, & $U = 20ms^{-1}$], and (ii) [$\Delta x = \Delta y = 2000m$, $\Delta t = 300s$ $and\, U = 20ms^{-1}$], and the results are summarized above.