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Multi-scale Eulerian model within the new National Environmental Modeling System

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The unified Non-hydrostatic Multi-scale Model on the Arakawa B grid (NMMB) is being developed at NCEP within the National Environmental Modeling System (NEMS). The finite-volume horizontal differencing employed in the model preserves important properties of differential operators and conserves a variety of basic and derived dynamical and quadratic quantities. Among these, conservation of energy and enstrophy improves the accuracy of nonlinear dynamics of the model.

Within further model development, advection schemes of fourth order of formal accuracy have been developed. It is argued that higher order advection schemes should not be used in the thermodynamic equation in order to preserve consistency with the second order scheme used for computation of the pressure gradient force. Thus, the fourth order scheme is applied only to momentum advection.

Three sophisticated second order schemes were considered for upgrade. Two of them, proposed in Janjic(1984), conserve energy and enstrophy, but with enstrophy calculated differently. One of them conserves enstrophy as computed by the most accurate second order Laplacian operating on stream function. The other scheme conserves enstrophy as computed from the B grid velocity. The third scheme (Arakawa 1972) is arithmetic mean of the former two. It does not conserve enstrophy strictly, but it conserves other quadratic quantities that control the nonlinear energy cascade.

Linearization of all three schemes leads to the same second order linear advection scheme. The second order term of the truncation error of the linear advection scheme has a special form so that it can be eliminated by simply preconditioning the advected quantity. Tests with linear advection of a cone confirm the advantage of the fourth order scheme. However, if a localized, large amplitude and high wave-number pattern is present in initial conditions, the clear advantage of the fourth order scheme disappears. In real data runs, problems with noisy data may appear due to mountains. Thus, accuracy and formal accuracy may not be synonymous.

The nonlinear fourth order schemes are quadratic conservative and reduce to the Arakawa Jacobian in case of non-divergent flow. In case of general flow the conservation properties of the new momentum advection schemes impose stricter constraint on the nonlinear cascade than the original second order schemes. However, for non-divergent flow, the conservation properties of the fourth order schemes cannot be proven in the same way as those of the original second order schemes. Therefore, nonlinear tests were carried out in order to check how well the fourth order schemes control the nonlinear energy cascade. In the tests nonlinear shallow water equations are solved in a rotating rectangular domain (Janjic, 1984). The domain is covered with only 17 x 17 grid points. A diagnostic quantity is used to monitor qualitative changes in the spectrum over 116 days of simulated time.

All schemes maintained meaningful solutions throughout the test. Among the second order schemes, the best result was obtained with the scheme that conserved enstrophy as computed by the second order Laplacian of the stream function. It was closely followed by the Arakawa (1972) scheme, while the remaining scheme was distant third. The fourth order schemes ranked in the same order, and were competitive throughout the experiments with their second order counterparts in preventing accumulation of energy at small scales.

Finally, the impact was examined of the fourth order momentum advection on global medium range forecasts. The 500 mb anomaly correlation coefficient is used as a measure of success of the forecasts.

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Janjic, Z. I., 1984: Non-linear advection schemes and energy cascade on semi-staggered grids. Monthly Weather Review, 112, 1234-1245.