Comments on "A Nonhydrostatic Version of the Penn State–NCAR Mesoscale Model: Validation Tests and Simulation of an Atlantic Cyclone and Cold Front"

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The nonhydrostatic model described by Dudhia (1993) uses a rather efficient numerical technique for time integration. It consists of a split-explicit method using a small time step \( dt \), in addition to the time step \( dt \). The small time step is chosen using the CFL condition with respect to horizontal grid length \( dx \) and the fastest waves in the model. As the vertical grid length \( dz \) is often chosen much smaller than \( dx \), an implicit treatment of some terms, which are responsible for the vertical propagation of the fast waves, is necessary.

According to Dudhia (1993) the treatment of the velocity components \( u \) and \( v \) is entirely explicit with time step \( dt \), with the implicit treatment being reserved for the fields \( w \) and \( p \). Similar approximations are used in many nonhydrostatic models. Practical use of such models often leads to instabilities associated with the occurrence of steep orography (Ikawa 1988).

The equation for \( u \) to be solved by the small time step given by Grell et al. (1993) is

\[
\frac{\partial u}{\partial t} + \frac{m}{\rho} \left( \frac{\partial p^*}{\partial z} - \frac{\sigma}{p^*} \frac{\partial p^*}{\partial \sigma} \right) = S_u.
\]

Here \( S_u \) is the term coming from the large time step \( dt \); \( p^* \), depending not on \( t \), is the reference pressure defining the coordinate \( \sigma \). Note that the coefficient of \( \partial p^*/\partial \sigma \) is entirely geometry dependent and does not depend on time. Therefore, \( \sigma \) differences \( d\sigma \) can be expressed in terms of \( dz \). The stability of this discretization depends on \( \alpha = \partial\sigma/\partial x|_\sigma \). The terms with the vertical derivative of \( u \) and \( v \) induce a CFL condition of the form

\[
\alpha \frac{dt_c, }{dz} \leq \eta,
\]

with \( c \), being the sound velocity and \( \eta \) being a factor not too different from 1, depending on the finite-difference scheme used. The condition becomes stringent for reasonably steep orography (large \( \alpha \) and large aspect ratio \( \delta = dx/dz \)). It may reduce the efficiency of operational nonhydrostatic models.

For operational nonhydrostatic models it is necessary that they require not much more computation time than a hydrostatic model on the same grid. Such efficiency would require \( \epsilon = dt_c, /dx \) to be of the order of one, where \( \alpha \) and \( \delta \) are determined by the application, and cannot be chosen for stability reasons. The planned operational nonhydrostatic local model model LM of DWD with \( dx \approx 2 \text{ km} \) would cause \( \alpha \) to be in the order of 1. Models of a similar kind are now routinely used in climate evaluation mode in order to plan the impact of human activities, like buildings. Presently special numerical methods (step mountains) are used in this scale, but for the future it is planned to use LM also for this purpose. In climate evaluation mode \( dx \approx 100 \text{ m} \) or even smaller could be used, which would make possible any value of \( \alpha \).

REFERENCES

