Nonhydrostatic modeling using a quasi-Lagrangian vertical coordinate

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1. Introduction

We present a nonhydrostatic model that solves a finite difference form of the compressible, nonhydrostatic Euler equations in a generalized vertical coordinate. The model, described in Toy and Randall (2009), uses a hybrid coordinate that is a height-based, terrain-following σ coordinate near the surface with a smooth transition to potential temperature (θ) in the free atmosphere. Potential temperature is a quasi-Lagrangian vertical coordinate since the vertical velocity $\dot{\theta}$ is zero under adiabatic conditions. This potentially reduces the error associated with modeled vertical transport. Where the flow is turbulent, or where the static stability is negative, the model vertically advects mass across coordinate surfaces in such a way as to prevent the grid from becoming too irregular or closely vertically spaced in a manner similar to the Arbitrary Lagrangian-Eulerian (ALE) method (Hirt et al. 1974).

2. Model results

The first test is a 2D simulation of the 11 January 1972 Boulder, Colorado windstorm (Doyle et al. 2000). The model produces similar wave patterns when run with the σ and the hybrid vertical coordinate. To compare the accuracy of the vertical transport with each coordinate, the model was initialized with a passive tracer, uniformly applied in the horizontal, and exactly correlated with potential temperature. The initial concentration has a value of 1 or 0. Due to adiabatic conditions, the correlation between the tracer and potential temperature should remain constant. Figure 1 shows that the hybrid coordinate run exhibits less error than the sigma-coordinate in the upper (θ-coordinate) domain.

Figure 2 shows a hybrid-coordinate model simulation of a moist thermal rising in a conditionally unstable environment. The horizontal grid spacing is $100\,\text{m}$ and the average vertical spacing is also $100\,\text{m}$. Note that the cloudy updraft penetrates coordinate surfaces, and that the isentropes are separated from these surfaces because the model automatically behaves in an Eulerian manner in the turbulent region. In the clear, environmental air to the sides of the cloud, the model levels overlay the isentropes in a quasi-Lagrangian manner.

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* The National Center for Atmospheric Research is sponsored by the National Science Foundation.

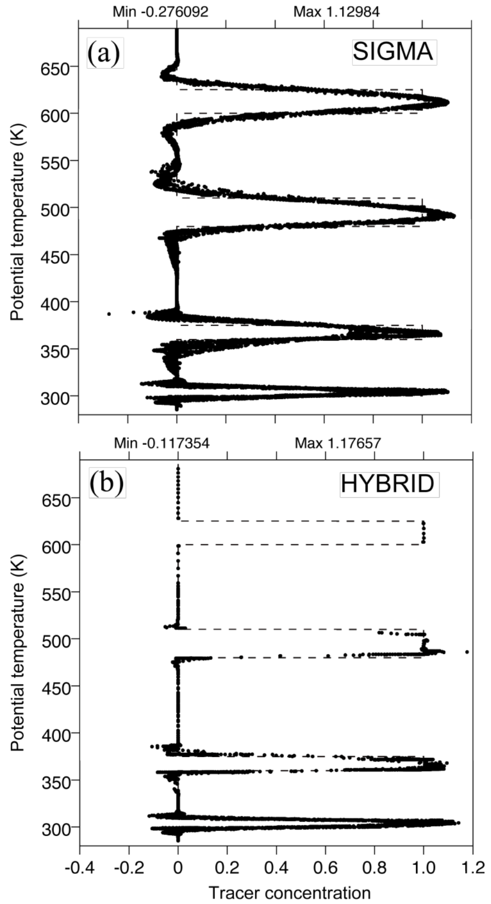

Fig. 1. Scatterplots of passive tracer concentration vs potential temperature at time t=70 min for the 11 Jan 1972 Boulder, Colorado windstorm with (a) the σ and (b) the hybrid vertical coordinate. Dashed lines represent the "true" solution.

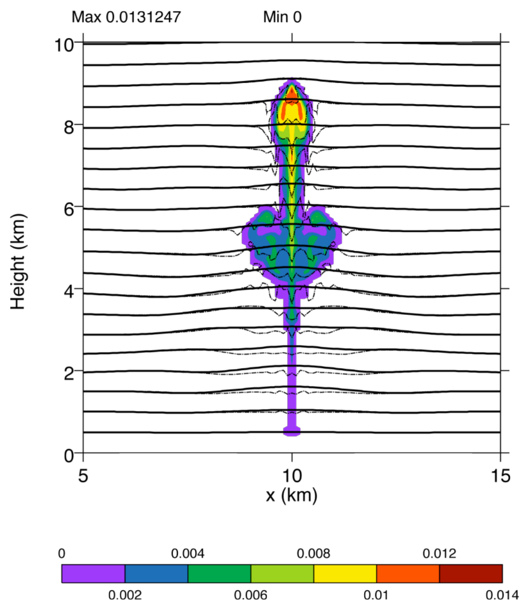

Fig. 2. Cloud water mixing ratio (color contours), isentropes (dashed lines) and model coordinate surfaces (bold lines) for the moist thermal experiment with the hybrid vertical coordinate.

3. Summary

We have developed a nonhydrostatic model able to simulate fine-scale, turbulent motion using the quasi-Lagrangian θ vertical coordinate in combination with an adaptive grid. Using this method improves the representation of vertical transport compared to the Eulerian σ coordinate.

Acknowledgements

The author would like to thank Joe Klemp and Bill Skamarock for their comments and advice during the development of this model, as well as David Randall for his support during the early stages of the work.

References

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