The use of a hybrid vertical coordinate in the CMC-MRB Global Environmental Multiscale (GEM) model

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1. Introduction

Terrain-following coordinate framework has been introduced in atmospheric models in the late fifties and has been commonly used until recent research revealed the detrimental impact of such coordinate in computing the horizontal pressure-gradient term especially over steep orography. More recently it has been shown that the problem is highly amplified when using mesoscale NWP models (Schär et al., 02). Following, a hybrid vertical coordinate, which is terrain-following at low levels but tends continuously to pressure surfaces at upper levels, has been introduced in the Global Environmental Multiscale (GEM) Model developed by the Meteorological Research Branch (MRB) in partnership with the Canadian Meteorological Center (CMC) of Environment Canada (Côté et al., 98). Several studies have shown that the use of constant pressure surfaces in the stratosphere is more efficient for middle atmosphere studies and modeling than sigma surfaces, and very convenient for data assimilation (Laprise et al., 90). According to many Numerical Weather Predictions (NWP) operational centers, as the European Center for Medium-Range Weather Forecasts (ECMWF), this significant change is an important numerical improvement in the ongoing development of an integrated forecasts and data assimilation system.

2. The hybrid coordinate system and the extension of GEM in the stratosphere

The hybrid coordinate introduced in the GEM model is based on the Laprise and Girard (90) formulation, where the pression depends on a reference pressure set to 800 hPa and a coefficient *r* which controls the continuous transition from sigma surfaces at low levels to pressure surfaces at upper levels. The slope of the hybrid surfaces decreases rapidly with height hence limiting the truncation errors in the pressure gradient over steep terrain in the stratosphere. In order to assimilate new type of stratospheric data above 60 km, the GEM model was extended to the stratosphere with 80 hybrid levels up to 0.1 hPa.

3. Climate simulations of GEM

The new (hybrid coordinate) and old (eta coordinate) codes have been compared using NCEP analyses to produce a DJF climate of the stratospheric version of the model starting from 1978 to 1995. Zonal mean flow averages for January show that the models are zonally very similar with little differences in the stratospheric zonal wind in the tropics. Comparisons of the results against NCEP analyses point out some deficiencies of the GEM model to correctly simulate the physical phenomena in the tropospheric equatorial regions. Some effort are done at the RPN-MRB to improve the physical parametrizations of the model. In addition, the statistics show a strong tendency of the model to underestimate the zonal wind in the stratospheric winter hemisphere. This may be explained by the use of a gravity-wave drag scheme recently implemented in the operational model with a top level set to 10mb which significantly improves the analyses in this version of GEM but may not be adapted for stratospheric studies.

4. Behavior of the hybrid model in the upper stratosphere

In stratospheric regions where the wind increases with height the distortion over mountains of the sigma surfaces from the horizontal increases and leads to numerical errors in computing the pressure gradient term, hence generating spurious vertical waves in the upper layers of the stratosphere. Recent work of Trenberth and Stepaniak from NCAR (Trenberth et al., 02) shows such spurious structures in the horizontal divergent wind over the Andes in the NCEP reanalyses and suggested to switch to hybrid coordinate to avoid such problem. In the context of the hybrid

GEM model validation in the stratosphere, we compute the horizontal divergent wind for both versions (eta and hybrid) and found the same bahavior observed by Stepaniak and Trenberth with the eta version, that is spurious structures over steep orography, especially over the Andes, in the upper levels of the model from 1mb to 0.1 hPa which completely vanished using the hybrid version of GEM. Such spurious structures are also present in the zonal wind and temperature above steep terrains in the eta version but disappear in the hybrid version of the model, which clearly shows the benefit of the hybrid formulation in the stratosphere.

5. Conclusions

A hybrid vertical coordinate has been successfully introduced in the GEM model to replace the "terrain-following" eta coordinate used in the model since 1997. Using a stratospheric version with 80 levels up to 0.1 hPa, a DJF climate initiated by the NCEP analyses has shown some deficiencies of the model in the tropics and a tendency to underestimate the stratospheric jet in the winter hemisphere, which is under investigation at the RPN-MRB. Results above 1 hPa show significative improvement of the hybrid formulation over eta formulation due to reduced interpolation errors computing the pressure gradient term over steep orography. A stratospheric hybrid version of the 3D-Variational data assimilation of the CMC-MRB is now available and the next step will be to produce a complete analysis cycle in order to validate the model against analyses, and further to assimilate additional observations in the stratosphere (AMSU-A, AIRS,..).

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6. References

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