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MESOSCALE MODEL EVALUATION OF A NEW INTEGRATION SCHEME FOR THE MET OFFICE UNIFIED MODEL

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1. INTRODUCTION

The Met Office uses one model code for all its operational NWP and climate modelling, the Unified Model (UM), (Cullen 1993). There are several configurations that are run routinely; Global model at various resolutions and limited-area models over different regions. The current scheme is reaching the end of its shelf life and as such a new dynamical core has been under development for a number of years. This has also given us the opportunity to consolidate to one version of each physical parameterization rather than continue to support multiple versions of each scheme.

The model may be run in several different configurations. Separate code exists for 1-d column, 2-d shallow water and 2-d slice although the latter is similar to the full 3-d code apart from the parallelisation features. The parallel 3-d code may be run either globally or as a limited-area model. The global configuration includes 3DVAR which is currently being included in the limited-area configuration.

2. OUTLINE OF NEW DYNAMICS SCHEME

The main features of the new dynamics scheme are:

- Non-hydrostatic equations with height as the vertical coordinate.
- Charney–Philips grid staggering vertically, i.e. potential temperature on same levels as vertical velocity including top and bottom boundaries where vertical velocity is zero.
- C grid staggering horizontally, i.e. u-component east-west staggered from temperatures and v-component north-south staggered.
- Vector Semi-Lagrangian advection scheme.
- Semi-implicit time-scheme without the removal of a basic state profile and with an appropriate solver for a variable coefficient problem
- No artificial horizontal diffusion needed to maintain stability.

The procedure used for solving the equations is a predictor-corrector method similar to that used by Cullen (1989). Initial estimates of the wind components, potential temperature and humidity variables are obtained by semi-Lagrangian advection using the two time-level scheme of Bates et al (1993). Only current time-level information is used in the right-hand side terms. These estimates are used to construct a set of correction equations. To obtain a correction equation for the (3-dimensional) pressure we require that the equation of state be satisfied at the new time-level and we linearise the equation of state with respect to the differences between the time-levels. We manipulate these correction equations to obtain a 3-dimensional variable coefficient Helmholtz-type equation for the (Exner) pressure correction. Once the pressure correction is known we can then derive the corrections and hence the new time-level values for the other variables. The physics parametrizations are called before the correction step so that the dynamics and physics increments are used in calculating the balanced state at the new time-level. A description of the scheme is given in Cullen et al (1998).

We solve the Helmholtz equation by using a generalised conjugate residual (GCR) method (Eisenstat et al (1983)) suggested by Smolarkiewicz and Margolin (1994) with preconditioning to speed convergence. A vertical preconditioning is adequate provided the vertical gridlength is significantly smaller than the horizontal gridlength. In global configurations we use an ADI (alternating direction implicit) preconditioner as proposed by Skamarock et al (1996) in the longitudinal and vertical directions, since these directions possess most of the variation in the pressure correction

3. IDEALISED TESTS

A range of idealised tests have been conducted at high resolution in both 2-d slice and 3-d LAM configurations. These mainly consist of flows over

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prescribed orography such as the Witch of Agnesi. Results have been compared against published results or against another high resolution model developed for large-eddy modelling in the Met Office. These tests have also been used to test various choices of vertical grid structure, algorithmic changes and parameter settings.

Results from these tests show that the new scheme compares well with other models. One particular study has shown that the scheme is sensitive to the way in which the vertical coordinate transforms from terrain-following at the surface to horizontal at some prescribed level. As a result, the gradual flattening now begins at the first level and changes quadratically in the normalised coordinate. Other tests also show that the current assumption of an isentropic bottom layer (used to provide temperature values at the bottom wind values on the Charney-Phillips grid) leads to problems when the bottom layer is relatively thick and the temperature profile is isothermal as might be expected. The problems can be minimised by making sure the bottom layer is not too thick. These tests are normally conducted with a free-slip lower boundary (inviscid). In the full model with active physics, the effects of both free-slip and the isothermal bottom layer are mostly subsumed by the effects of the physics.

4. REAL DATA CASE STUDIES

A small number of real data case studies have been completed. Generally, the new dynamics compares favourably with the UM and it is expected that for resolutions down to about 10km, the new scheme will at least match the current operational UM performance overall.

At higher resolutions, where non-hydrostatic effects become more important, it is clear that there are several issues needing to be addressed:

(i) The resolution ratio of the driving model to the LAM. Current UM Global:mesoscale is approximately 6:1.

(ii) The lateral boundary conditions updating. Typically, boundary values from the driving model are saved at fixed intervals and the timestep values needed are time-interpolated between two intervals. The current UM mesoscale model uses 1 hourly lateral boundary files.

(iii) Parameter settings for the dynamics: semi-Lagrangian trajectories and interpolation, solver convergence criteria.

(iv) Tuning of physics, in particular the role of convection.

(v) Vertical resolution

(a) FASTEX , IOP16

FASTEX IOP16 case is a fast moving, rapidly deepening, secondary wave cyclone. In Lean (2000) the performance of the New Dynamics is assessed. The tests have been at resolutions from ~12km to 2km and from 30 to 90 vertical levels.

The study shows that subjectively the New Dynamics is at least as good as the UM at the same resolution. Many features are sharper and more coherent (see Figures 1 and 2) than in the UM. Limited verification against dropsondes shows that at 12km the new dynamics is better than the UM and at 4km it is slightly better still. The 2km model is about the same as the 4km one.

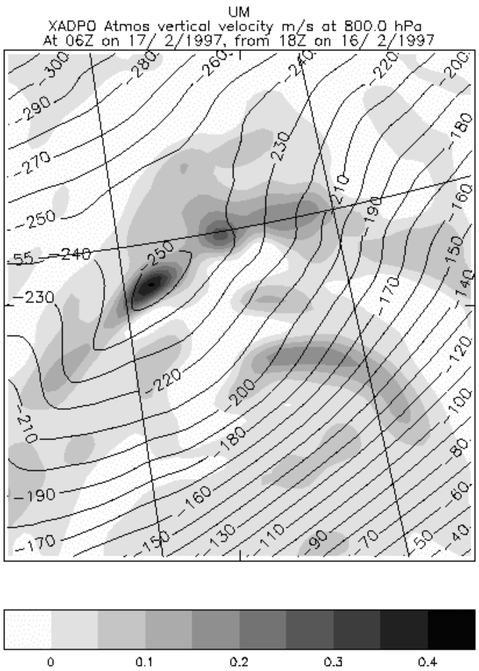

Figure 1, 12km UM

At 4km and 2km there are signs of explicit convection occuring in the cold air outbreak behind the system. The model runs satisfactorily without the convection scheme but the scale of the cells are subjectively more realistic with it switched on. With the 90 vertical level 2km runs it is possible to see multiple slantwise circulations.

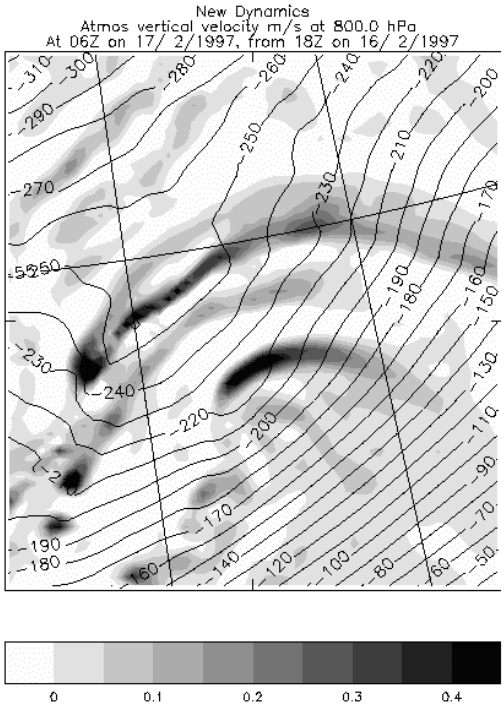

Figure 2, 12km New Dynamics

(b) WIDESPREAD PERSISTENT FOG

The full results of this case study are presented in Clark (2000). The report details initial experience running the New Dynamics at high horizontal resolution (4 km and 2 km) with one case of widespread fog. Results are compared with results at the current operational resolution, using both the New Dynamics and the current, hydrostatic UM.

The New Dynamics at operational resolution performs generally better objectively and subjectively than the hydrostatic UM with the same physics. Sensitivity to vertical resolution is not strong at operational (12 km) resolution. The New Dynamics has been successfully run at 4 km and 2 km resolution. Both produce very good short (6-12h) forecasts compared with the 12 km model, though the benefit of going from 4 to 2 km is not clear. A 12 h forecast covering the whole UK at 4 km would be a practical proposition, given the additional computing power required to add this to our current operational suite. The higher resolution runs, however, exhibit problems with excessive deepening, thickening and lifting of fog as time progresses, and eventually perform worse than lower resolution runs. The reason for this behaviour is unknown, but possible explanations include inaccurate initial conditions or excessive entrainment through the fog top in the boundary layer scheme.

5. CONCLUSIONS

The New Dynamics has shown itself to be usable at high resolution as one would hope with a non-hydrostatic model. The dynamical formulation seems to produce reasonable results even at the highest resolutions although for operational use the results at 4km are more than acceptable and going to higher resolution did not improve the overall forecast. Many of the features of the flow appear to be better and realistically captured by the new dynamics.

6. REFERENCES

Bates, J.R. Moorthi, S. and Higgins, R.W., (1993).
A global multilevel atmospheric model using a vector semi-Lagrangian finite-difference scheme. Part1: Adiabatic formulation.
Mon. Wea. Rev., ***121***, 244-263.

Clark, P.A., (2000).
A Case Study of High Resolution Fog Forecasts with the New Dynamics
NWP Division Technical Report No. 337.

Cullen, M.J.P., (1989).
Implicit finite difference methods for modelling discontinuous atmospheric flows.
J. Comp. Phys. ***81****, 319-348.*

Cullen, M.J.P., (1993).
The unified forecast/climate model.
Met. Mag, . 122, 81-94.

Cullen, M.J.P., Davies, T. and Mawson, M.H., (1998).
A semi-implicit integration scheme for the Unified Model.
NWP Division Working Paper No. 154.

Eisenstat, S.C., Elman, H.C. and Schultz M.H., (1983).
Variational iterative methods for non-symmetric systems of linear equations
SIAM J. Num. Anal. ***20***, 345-357.

Lean, H.W., (2000).
Tests of New Dynamics Model on the Fastex IOP16 Case.
NWP Division Technical Report No. 320.

Skamarock, W.C., Smolarkiewicz, P.K. and Klemp, J.B. (1996).
Preconditioned conjugate-residual solvers for Helmholtz equations in non-hydrostatic models.
Mon. Wea. Rev., ***125***, 587-599.

Smolarkiewicz, P. K. and Margolin L.G. (1994) .
Variational Elliptic Solver for Atmospheric Applications.
Los Alamos Report LA-12712-MS.