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DATA ASSIMILATION & FORECAST TESTS 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.

A range of idealised tests have been conducted in both 2-d slice and 3-d LAM configurations. These mainly consist of flows over 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. Dynamical core tests of the global model have also been conducted. These tests have also been used to test various choices of vertical grid structure, algorithmic changes, parameter settings and numerical convergence.

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

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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. OUTLINE OF 3DVAR SCHEME

The Met Office 3DVAR data assimilation system, Lorenc et al (2000) is a variational data assimilation scheme which has been operational since March 1999 and replaced the analysis correction scheme. The variables used are horizontal and vertical wind components, potential temperature, density, pressure and specific humidity. These are consistent with a non-hydrostatic, height co-ordinate model (e.g. New Dynamics).

The increments to the New Dynamics variables are calculated and then an Incremental Analysis Update (IAU) scheme, Bloom (1996), is used. The analysis increments are added 1/Nth at a time over N timesteps. For the global model we choose these to cover a 6-hour period centred on the nominal analysis time.

The 3DVAR system can be used for both global and Limited-area grid point models and will be extended to 4D-Var based on the New Dynamics.

4. REAL DATA TESTS

The global configuration has been tested by either running 5 or 6 day forecasts using data interpolated from the current operational UM or by running for several years or more in an AMIP (Atmospheric Model Intercomparison Experiment) climate test. The tests have not been used to tune the physics but they have been useful in identifying problems which in the case of the dynamics have been addressed. One problem was the tendency for the model to generate excessive flow to the South of the Himalayas and to decelerate the Southeast Asian jet. It was found 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. There was also a problem with excessive drying of the tropical lower stratosphere particularly in climate runs. This problem is rectified if a quintic interpolation rather than cubic is used in the vertical interpolation of moisture in the semi-Lagrangian advection. The climate version of the New Dynamics has a performance close to that of the current UM with the same physics package. One notable area of improvement is in the ability of the New Dynamics to maintain extensive stratocumulus sheets off the coasts of California, Chile and Southwest Africa.

5. DATA ASSIMILATION TRIALS

Leading up to pre-operational trials, the new dynamics is being evaluated against the current UM in trials using 3DVAR but at a slightly reduced horizontal resolution to allow testing of a range of issues. We are running just one month of data assimilation in 6-hourly cycles and running one forecast per day out to 6 days. Two periods are being used; December 1999 and July 2000.

Results from the trials are verified in a manner similar to operational verification. A global index, formed from skill scores, measures the performance of the global forecasts over three large regions - the tropical belt and northern and southern hemispheres outside the tropics. Key forecast products such as surface pressure, lower atmospheric thickness (which varies with its average temperature), aviation level winds and low level tropical winds are verified each month and combined to form the index value.

Several problems have been uncovered and rectified during the trials. This included control of humidity increments near the tropopause. After each trial has been run the results are analysed and improvements have been suggested. In the latest trial run, the New Dynamics performance does not yet quite match the current UM overall, although further improvements are in the pipeline.

Typically, NWP developments (improvements in the model, data assimilation and use of observations) have realised an increase in skill of around 2.5% per annum. In these trials the new dynamics and new physics combined is about 3% worse than the operational control in winter and 2% worse in summer. A winter trial with the operational dynamics and new physics is 4% worse with most of the deterioration in the tropics. Subsequent improvements to the new physics combined with operational dynamics reduces the gap to below 2% but the new physics changes have not yet been trialed with the new dynamics. Results from other sensitivity tests on both physics changes and data assimilation changes lead us to believe that we should be able to at least match the verification scores of the current operational system by the autumn.

The trials are also verified subjectively, and the winter period is of particular interest due to the occurence of several intense cyclogenesis events, two of which are described in the section below.

6. INDIVIDUAL TEST CASES

Significant improvements have been noted in the forecasting of winter storms during December 1999. The so called "Danish storm" (3rd December 1999) and the "French storms" (26th and 27-28th December 1999) all occur in the trial period.

For more information on the storms Ulbrich et al. (2001) and Pearce et al. (2001) explain in more detail.

These storms were particularly poorly forecast by all the operational models. The results of the New Dynamics trial have been quite encouraging. In the case of the Danish storm we have seen improvements in pressure at the centre of the low of 14mb for a 72 hour forecast (see Figure1) and also improvements out to T+144.

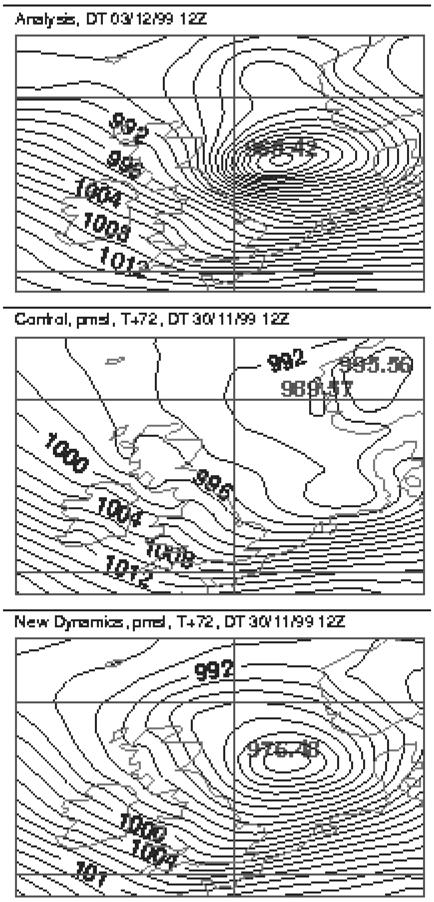

Fig1. Comparison of T+72 forecasts, Danish Storm

The French storms were particularly severe, gusts of over 45m/s (100 mph) were recorded at many places, and there was severe damage caused over a wide swathe of France. Almost all the forecast models did a very poor job of forecasting these events until almost the short term. As with the Danish storms the New Dynamics pre-operational trial has been run and compared with the current operational set up. In almost all forecasts from the 21st December onwards the New Dynamics run is better than the control and for the T+96 forecast on the 22nd December it has the centre of the low better by 24hPa (see figure 2,next page). The trial has a central value of 975hPa, the control has a central value of 999hPa and the analysis had a central pressure of 972hPa. The position and depth of the low centre for the T+120 forecast on the same day are equally impressive.

7. CONCLUSIONS

The pre-operational trials have shown that the New Dynamics formulation has slightly worse objective scores than the current operational model. However with some physics parameterization improvements due shortly and the recalculation of the 3DVAR covariance coefficients we believe that the new formulation should be operational shortly. It can also be seen that for some individual forecasts the new formulation can provide significant improvements.

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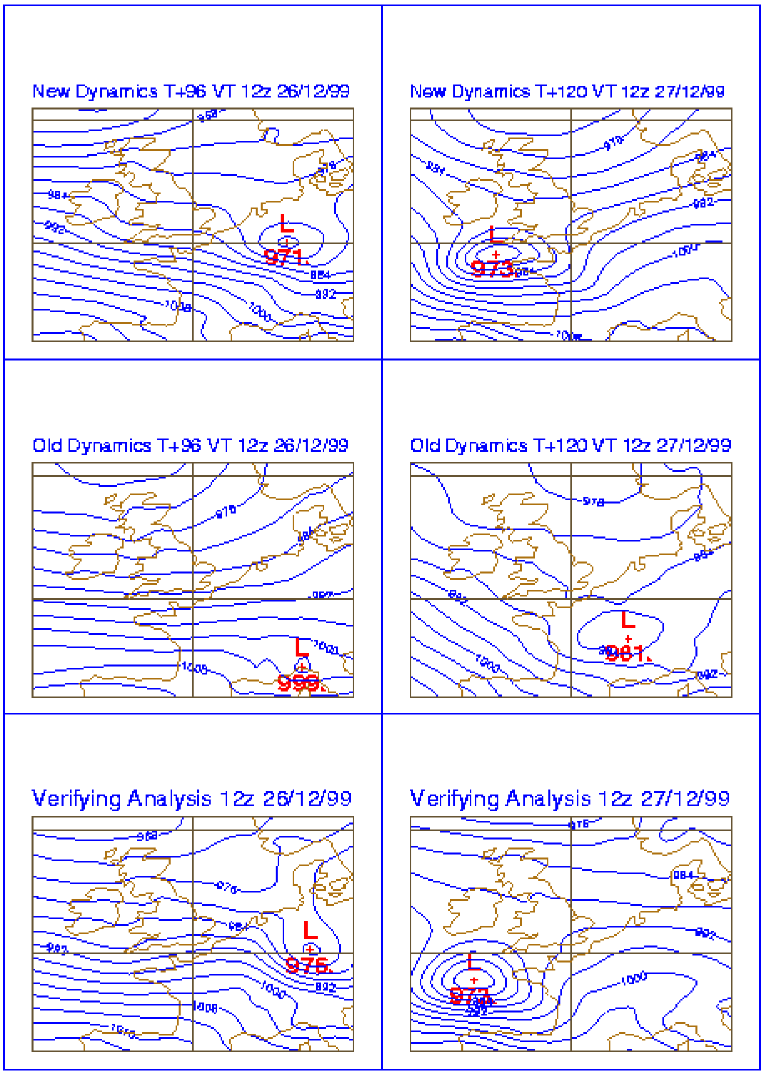

Figure 2. December 22nd Forecast, French storms