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THE USE OF SYNOPTICALLY DEPENDENT BACKGROUND ERROR STRUCTURES AND A GEOSTROPHIC CO-ORDINATE TRANSFORM IN 3D VARIATIONAL DATA ASSIMILATION.

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1. INTRODUCTION

The aim of the Geostrophic Co-ordinate Transform (GCT) and Errors of the Day (EotD) is to make better use of the existing observational network and existing Met Office data assimilation systems (3D Variational Data Assimilation, (3D VAR), Lorenc 2000) particularly in order to improve forecasts of extra-tropical cyclones in the North Atlantic region.

The 3D VAR scheme attributes a region of influence to an observation, in which the three-dimensional distribution associated with the observation is assumed to be isotropic. This means that the correlation between two points depends only on the magnitude of their separation and not on its direction. The isotropic assumption means that 3D VAR attributes the same distribution to the observation whether the observation is located near a frontal zone or not. The result is that any observation assimilated near a frontal zone may cause a weakening of the baroclinic region relative to reality through its representation in the VAR increment field (the output of VAR).

To remedy this, the GCT scheme aims to incorporate flow-dependence into the assimilation by allowing the distribution of the observation to be anisotropic on the VAR grid. This is achieved by transferring the data analysis into a geostrophic co-ordinate system which is not regular like the VAR grid but has a distortion determined by the geostrophic wind component on the (x,y) plane. The frontal discontinuity in the VAR co-ordinate system appears more regular in the distorted geostrophic co-ordinate system and thus violates the isotropic assumption less. Once analysed, the fields are then transformed back to the VAR grid.

The 3D VAR scheme requires knowledge of the background error correlations in order to produce the best analysis. Estimation of these errors is currently achieved by 24 hour and 48 hour forecast differences averaged over a two week period and so fails to give an indication of the daily variation in the magnitude and structure of the errors. The EotD scheme uses an Error Breeding System (EBS) and is being trialed as a route to better estimate the background 'Errors of the Day'. It provides the errors as three-dimensional 'bredmodes' which originate as forecast differences between low-resolution short-range forecasts run from perturbed analyses. Bredmodes represent regions of the model atmosphere which have grown rapidly in the preceding time period and so represent areas which are likely to be associated with the greatest background errors. Given a suitable bredmode structure, the EotD scheme allows the distribution of the observation within VAR to change according to the local bredmode structure, so that observational information can have a greater or lesser influence depending on the inferred local background error. (The error-breeding technique has been used operationally at NCEP since December 1992 to provide analysis perturbations for ensemble prediction applications).

The aim of this research is to assess both the Met Office GCT and EotD schemes relative to 3D VAR. It aims to establish whether both schemes are (1) assimilating observations in a meteorologically sound way, and (2) having a positive, negative or neutral impact on individual storm forecasts.

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The work discussed in this paper is the result of initial trials performed with the current Met Office Unified Model (Cullen 1993), Geostrophic Co-ordinate Transform code and Error Breeding System code.

At the time of writing, work is in progress by the author to develop new Error Breeding code to facilitate a better interface between the EBS and the new non-hydrostatic version of the Unified Model currently under development at the Met Office. As a result, this discussion is intended to be a brief introduction to the concepts that will be presented at the symposium.

2. THE ERROR BREEDING SYSTEM

Figure 1 shows a schematic of the error breeding cycle. Cycle 1 of the process begins with an initial operational analysis A1, which is reconfigured to a lower resolution. Small random perturbations are then added and subtracted to the control analysis in order to produce a pair of low resolution perturbed analyses (A1+ and A1-). A forecast is run from each of the perturbed analyses for a chosen 'breeding period' (6 hours at the Met Office) so that two background fields are produced (F1+ and F1-). A difference file is then calculated from the pair of background fields (Fd), and the forecast fields within the file are normalised so as to breed error structures of a specified magnitude. The result is an error-bred forecast difference called the 'Bredmode' which is used as an indicator of the three-dimensional synoptically dependent background error structure (SBES).

The bredmode is then fed to the next cycle of error breeding and provides the degree of perturbation for the next control analysis (A2). The mode is also supplied to the 3D-VAR analysis where it is used in the minimisation of the cost function and the production of a new control analysis.

The bredmodes developed in the early cycles are initially dominated by random fluctuations, but during subsequent cycles the forecast differences become dominated by the most unstable, rapidly growing states. For this reason the error breeding cycle requires a 'spin-up' period of 2 to 3 weeks until the random modes have diminished.

Perhaps the most obvious way in which to incorporate the bredmode information into 3D-VAR would be to relate the bredmodes to the background error covariance matrix directly, thereby feeding through to VAR the necessary information of the location of larger and smaller background errors. However, in reality the production of these synoptically-dependent background error variances is non-trivial and would require more sophisticated computing than is currently operationally achievable.

An alternative method of introducing the bredmode information is to add extra bredmode based degrees of freedom during the assimilation. In the operational 3DVAR system, the analysis is produced by a best fit of the model state to the observations and the background. By allowing extra bredmode degrees of freedom, the analysis is produced by a best fit of the model state to the observations and background, and an additional pattern like that of the bredmode. Thus the process works by fitting the observations to the background as usual, but then additionally nudging the analysis towards the error-bred structures.

The bredmode information that represents the synoptically dependent error structure is essentially the difference between two forecasts. This means the bredmode structures should be in reasonable balance and that their introduction into the VAR system should not introduce significant noise. Also, the bredmodes are generated on a lower resolution grid than that used in the UM, which leads to horizontally smoothly varying modifications to the analysis increments. Thus no significant detrimental effect should be introduced via the mechanics of the process itself.

Figure 2 shows a bredmode structure (θ_l) for 1200 UTC on the 24th December 1999. At this time a strong baroclinic zone existed across the northern Atlantic Ocean, orientated east-west from Newfoundland to the UK. This provided an ideal case study in order to see how each system (VAR, GCT and EBS) behaved near frontal zones.

3. PSEUDO SINGLE OBSERVATION TESTS

The aim of this section is to address the effectiveness of the GCT and EBS in the modification of the VAR analysis increments. For this purpose single observation tests were carried out at different positions in the model in relation to frontal zones and extra-tropical cyclones. Single Observation tests consist of assimilating a pseudo increment of a variable within the model atmosphere. The size of the increment chosen in these tests is of the order of magnitude that one would expect for real observations.

The pseudo single Observation Test discussed here consisted of a potential temperature increment of 1K (error of 1.7) on model level 11 (approximately 525hPa) at 47N 30W. Figure 3 shows the (θ_l) increment analysis field on model level 11 for the VAR system, VAR with the GCT (VAR+GCT) and VAR with the EBS (VAR+EBS) (θ_l is used as θ is unavailable in trial output). Also shown is the intensity distribution on this model level for the analysis increments for each scheme, illustrating the number of grid boxes with each increment value. Figure 4 shows vertical cross sections through the line AB as indicated for each of the three schemes.

As discussed earlier, the VAR scheme attributes a three-dimensional region of influence to the observation, in which the distribution associated with the observation is assumed to be isotropic. This can be seen by the distribution of the VAR single observation test in Figure 3 which represents its horizontal influence (although VAR attributes a purely spherical distribution, the pattern looks slightly oval due to the map projection). The isotropic assumption is clearly evident in the vertical also (Figure 4). The distribution of the observation is the same as though there were no frontal zone, and is largely spherical.

Although an increment of potential temperature was placed within the troposphere, the cross sections in Figure 4 indicate the presence of a region of cooling in the stratosphere, vertically above the increment. This is the sort of response that one would hope for within the assimilation system, as it is indicative of (geostrophic) balance information being propagated through the analysis by the background covariances. The wind and temperature fields that result from an incremental temperature perturbation are qualitatively consistent with those attributable to a potential vorticity anomaly located vertically between the temperature dipole.

The effect of the GCT scheme is that the observation is no longer spread uniformly around the insertion point. For purposes of comparison, consider the point on Figure 3 at which the increment value on model level 11 drops to ~10% it's maximum value. The distribution for the GCT scheme extends ~70% further into the warm air to the south than that with the VAR scheme. The extent to the north in the GCT is roughly halved relative to VAR, whereas the distribution along the front remains largely the same.

The graph on Figure 3 shows that the intensity distribution for the GCT is similar to that for VAR, although there appears to be a relative reduction in the higher value analysis increments (0.3 to 0.35) for the GCT and an increase of the GCT relative to VAR either side of this. This is evidence that the GCT is successfully redistributing the observational information rather than amplifying or attenuating it. In cross section the GCT has distorted the distribution so that it appears to flow up the frontal zone which may be seen on the right of the panel. This results in more of the increment being assimilated on the warm side of the front (i.e. the side of the front on which the observation has been placed), and is consistent with the distribution shown in Figure 4.

Figure 3 also shows that in this case the EBS has the effect of increasing the horizontal analysis increments along the frontal zone relative to VAR, whilst maintaining the meridional extent. In addition, the intensity profile for the EotD is approximately 50% larger than both the GCT and VAR schemes. This is a product of the bredmode intensity pattern (compare distribution with that shown in Figure 2) in which the observation increment pattern is superimposed upon the larger high intensity bredmode structure distribution, thus increasing the relative number of all increment values.

In this case, the EotD scheme therefore has had the effect of both boosting (by the number of gridboxes with higher increment values) and extending the horizontal observation influence along the frontal zone. In cross section (Figure 4), the VAR+EB analysis increments are elongated vertically along the baroclinic region with respect to the VAR analysis increments, and influence of the observation is seen at far lower levels in the troposphere than either the VAR or VAR+GCT cases. The cross section also shows that the increased intensity of the EBS analysis increments measured on model level 11 is true on all model levels relative to the VAR and GCT cases. All this behaviour is in accordance with that expected from the relevant bredmode and the design intentions of the EotD scheme

4. FUTURE WORK

Once the new EBS code is complete, tests will be carried out in order to assess the performance of both the EotD and GCT.

5. ACKNOWLEDGEMENTS

The current version of the EBS code as discussed in this paper was written and developed by Dale Barker. A new version of the code is currently being developed by the author. The GCT code was written by Mark Dubal.

6. REFERENCES

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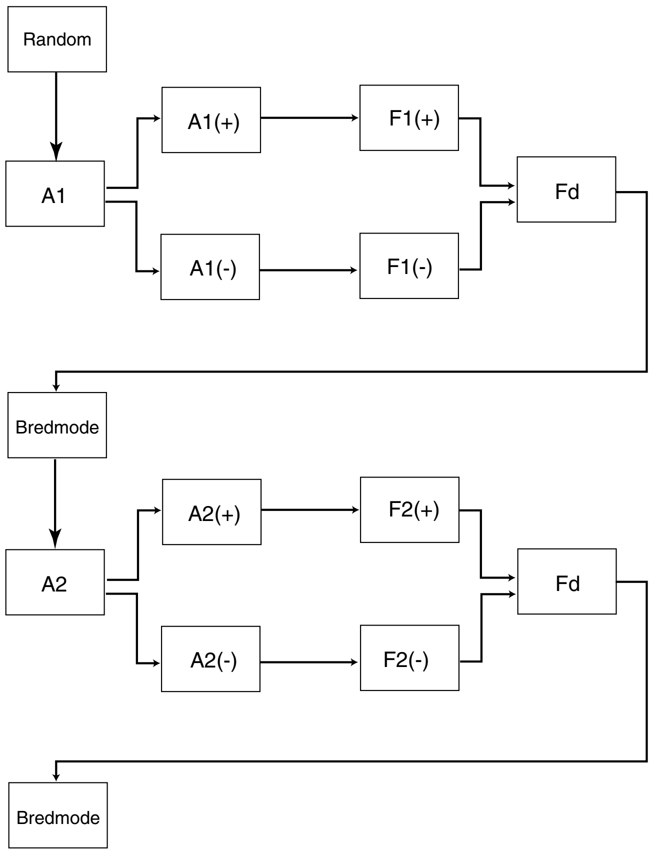

Figure 1 Schematic of the Error Breeding System. The labels are referred to in the text.

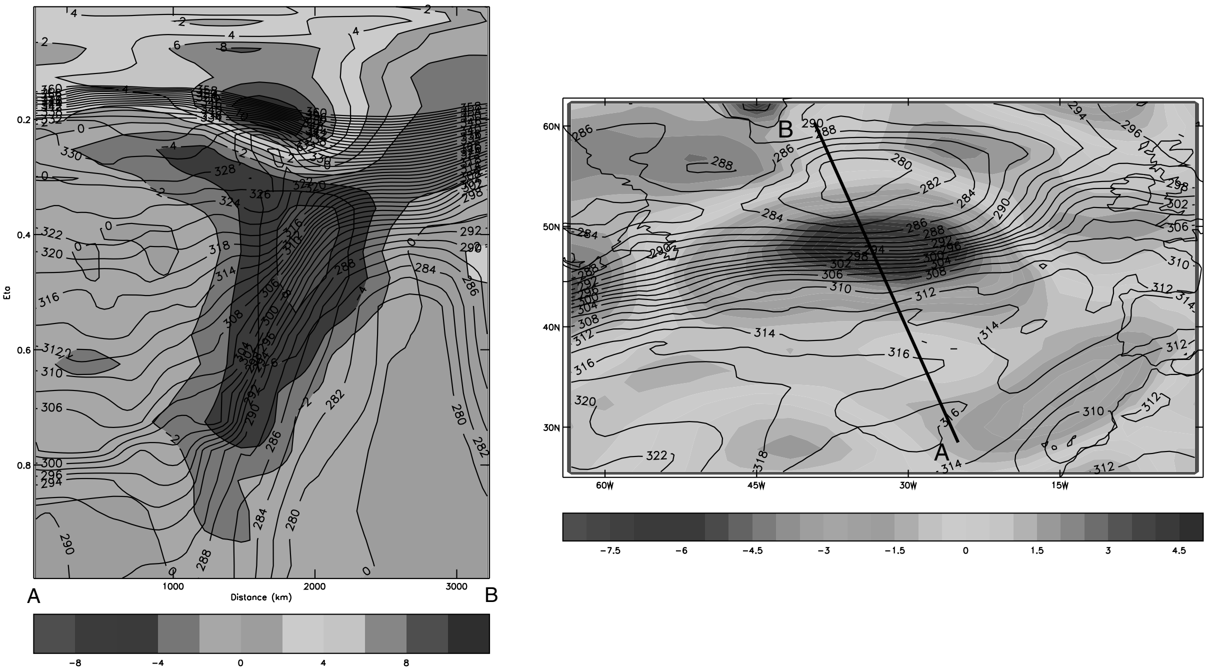

Figure 2 Cross Section (left) through the bredmode structure on model level 11 (right). The black contours show the Met Office Unified Model θ_l analysis (plan view on model level 11).

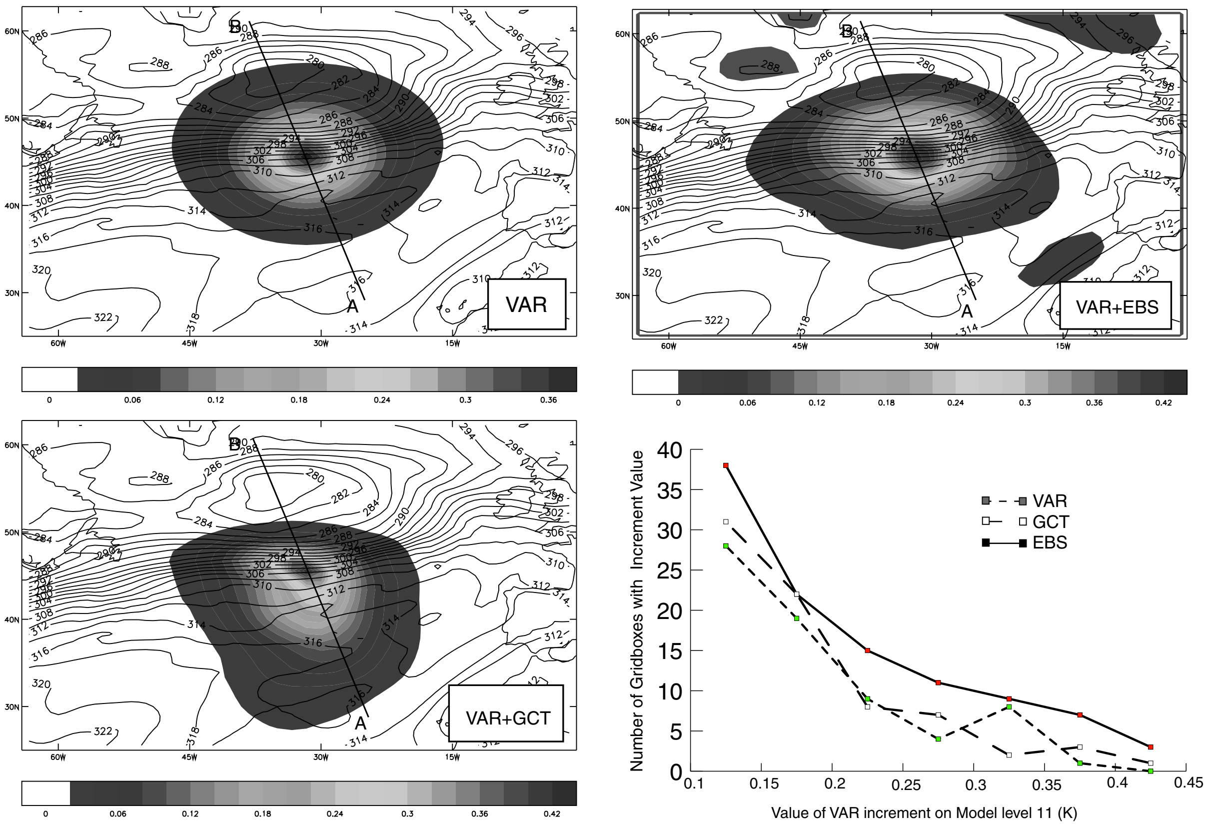

Figure 3 **Single Observation tests (θ increment of 1, error 1.7, model level 11) for VAR, VAR+GCT and VAR+EBS near a frontal zone in the North Atlantic, 1200 UTC 24th December 1999. The coloured field shows the θ_l analysis increments output by VAR in each case as a result of the single observation. The black contours show the UM θ_l analysis on model level 11. The graph shows the intensity distribution of the analysis increments on model level 11 for each case.**

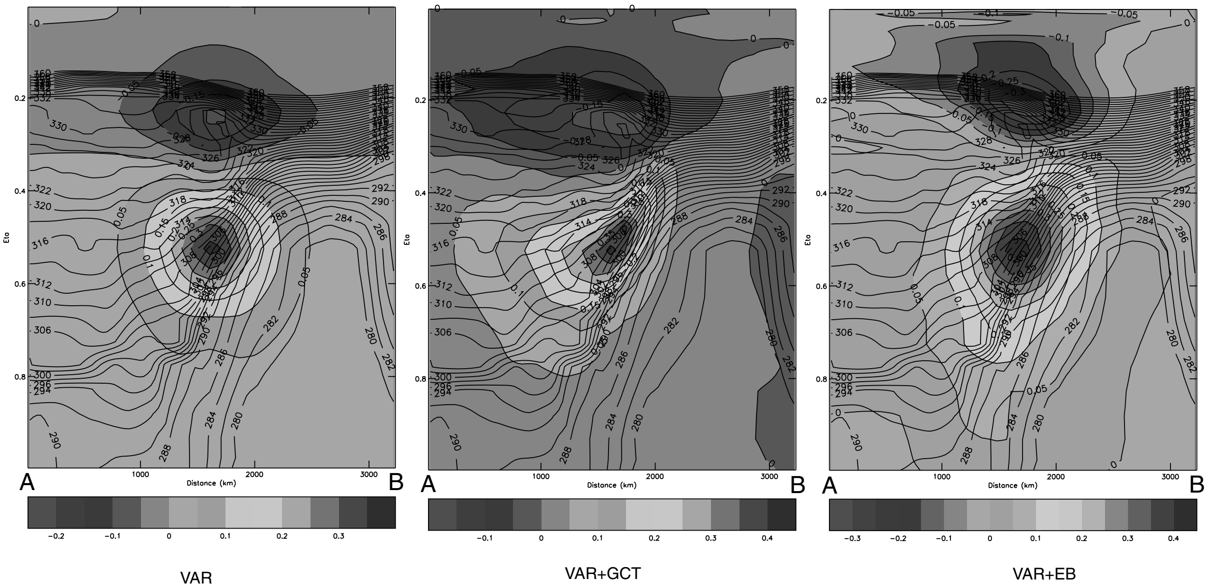

Figure 4 Cross sections (colour field) through AB shown in Error! Reference source not found. for VAR, VAR+GCT and VAR+EBS. Black contours show UM θ_l analysis.