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RECENT DEVELOPMENTS OF THE MET OFFICE GLOBAL 3D-VAR SYSTEM

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1. INTRODUCTION

The Met Office 3-Dimensional Variational analysis (3D-Var) system was implemented operationally in the Met Office global forecast suite in March 1999. It was implemented in the mesoscale (local area) suite in October 1999 and in the troposphere-stratosphere suite in November 2000 (see Swinbank et al, P1.8, this volume). Lorenc et al (2000) describe the global 3D-Var system as originally implemented, this presentation will describe changes since then. The forecast model has 30 levels in the vertical and a horizontal grid-point spacing of about 60 km. The global 3D-Var analysis is performed at reduced horizontal resolution (T107 or about 120 km grid).

The changes are listed in Table 1, the figures in brackets give some indication of the magnitude of the impact on forecast verification – the more positive the better – values of 10 or less are considered small. However other measures of performance (such as fit of six-hour forecasts to observations) and improvements to the robustness of the system were also considered. The changes are tested individually, at slightly lower forecast resolution, then those selected are tested together at full resolution. As can be seen in Table 1, the overall impact can be either less (Oct 99) or more (Feb 2001) than the sum of the parts. This is due mainly to non-linear interactions between the changes or possibly sampling variations, in general the impact is similar at the two forecast resolutions.

Compared with the previous Analysis Correction scheme, 3D-Var improved verification against observations much more than verification against analyses – however the nature of the analyses used for verification changed significantly making meaningful comparison of analysis verification difficult. The introduction of NOAA-15 ATOVS gave more improvement when verified against analyses, and a broadly similar impact overall.

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March 29th 1999, (+152)
  Introduction of 3DVAR and use of NOAA-15 ATOVS.
July 20th 1999, (+29)
  Covariances: shorter vertical scales (+14)
  Inclusion of ATOVS over Siberia (+9)
  Thinning of scatterometer winds (+10)
October 19th 1999, (+82)
  Direct assimilation of (A)TOVS Radiances (+45)
  Use of Surface Wind from SSM/I (+9)
  Improved use of synop surface pressures (+38)
  Updated covariance statistics (+35)
  Thinning and error tuning of aircraft (+5)
  Use of South Pole radiosonde wind (+7 &)
  Remove scatterometer winds over ice (+23 &)
December 20th 1999,
  ERS scatterometer winds omitted as Y2K precaution.
May 16th 2000, (+56)
  Time interpolation of background (+20)
  Covariances: longer scales, esp. stratospheric (+41)
  Correction to use of (A)TOVS radiances (-7)
February 13th 2001, (+26)
  Second SSM/I satellite (+8 &)
  Use of wind profiler data (-6)
  Increased use of AMSU-A radiances (-5 &)
  Modified humidity covariances (+5)
April 18th 2001, (+50 &)
  NOAA-16 ATOVS + AMSU(B) (+50 &)

Table 1. Values in brackets are improvements in weighted skill scores averaged over two trial periods and combining verification against analyses and observations. (& - more limited verification available)

2. USE OF SATELLITE SOUNDINGS

Use of NOAA-15 ATOVS data (via a 1D-Var retrieval system) was implemented in March 1999, along with 3D-Var, see English et al (2000). The soundings are thinned to a resolution of about 200 km. The major changes since then have been the direct use of (A)TOVS radiances (Oct 99) and the assimilation of ATOVS moisture (AMSU-B) channels and data from the second ATOVS satellite NOAA-16 (Apr 2001). Assimilation of some tropospheric channels over Siberia also gave some benefit. The major changes gave most benefit in the Southern Extratropics, the introduction of NOAA-16 performed best at medium range (3-days and longer), but direct use of radiances was beneficial at all forecast ranges at least for mass fields. There have also been a number of updates to the bias corrections used – sometimes monthly, sometimes less frequently – these can have a non-negligible effect on the forecast skill scores.

3. OTHER CHANGES TO OBSERVATION USAGE

There have been various changes to the use of satellite surface winds. Initially we were assimilating ERS scatterometer winds at full resolution, they were thinned from July 1999. It was realised that most 'winds' over sea-ice were being assimilated (dating back to an increase of model resolution in January 1998), this was corrected in October 1999. Because the scatterometer processing used an obsolescent computer the data were withdrawn in December 1999 being replaced, with some overlap, by use of retrieved SSM/I surface wind speeds. Reintroduction of ERS scatterometer winds with dealiasing within 3D-Var was ready for implementation in early 2001 but postponed because of problems with the satellite data products. Roughly speaking the ERS and SSM/I winds have similar impacts (verified against analyses SSM/I had a larger positive benefit). Addition of data from a second satellite, of either type, gives less benefit than data from the first, but greater robustness: wind speeds from a second SSM/I were included from February 2001.

As discussed by Ingleby (1995) it is preferable to use station level pressure, rather than mean sea level pressure (mslp), from surface stations; however this is hampered by some incorrect station height values in the international station list. In October 1999 we increased the proportion of station level pressures used and introduced empirical corrections for some station heights. This gave a substantial improvement to the skill scores (partly because almost half the total weight is placed on mslp forecasts). Use of radiosonde data is largely unchanged – work is in progress on improving the treatment of radiosonde relative humidity biases (Sharpe and Macpherson, P4.1, this volume).

Satellite cloud and water vapour motion winds are assimilated at a resolution of about 200 km. Attempts have been made to use them at higher resolution but these gave slightly worse results, probably due either to the observation error being specified too small or to problems of observation height assignment and correlated errors (Butterworth and Ingleby 2000). Attempts to use SSM/I total column water vapour have also given slightly disappointing results to date.

Time interpolation of background fields or 'first-guess at appropriate time' was introduced in May 2000. This had a modest positive impact on the skill scores, but gave an improved forecast of one major storm over Europe in its trial period.

More details of the changes and the verification results are available in Bell et al (1999) and Bell et al (2000).

4. BACKGROUND ERROR COVARIANCES

The changes to the representation of background error covariances in 1999 are described briefly in section 4 of Ingleby (2001), this paper largely documents the covariances operational from October 1999. The covariances are calculated from forecast differences (the NMC method) and the October 1999 change was a recalculation of the statistics using more recent data – showing that this can have a moderate effect.

In May 2000 three changes were made:

a) to use rotated (localised) vertical modes in the stratosphere – this increased horizontal length scales there (note that the relationship between horizontal and vertical covariances is different in the Met Office system to that in the ECMWF and NCEP systems, see section 3c of Ingleby, 2001).

b) to increase horizontal length scales generally. The initial implementation used Second Order AutoRegressive (SOAR) functions in the horizontal with length scales based on, but shorter than, those from the NMC method. These have been replaced by spectra intermediate between the SOAR and the forecast difference spectra.

c) to reduce implied standard deviations in the tropics by about 20%.

The resulting changes in verification were large – mainly beneficial when verified against observations, particularly for height. The impact on verification against analyses was more mixed, and was negative in the tropics – partly offset by change c). At short-range in data-sparse areas the analyses are not independent of the forecasts (from the same run) that they are used to verify, and this penalises changes that tend to increase the size of average analysis increments.

The covariances in the stratosphere are much less geostrophically balanced than those in the extratropical troposphere (also true of the ECMWF system, Bouttier and Fisher, pers. comm.). Efforts have been made to increase the balance, but to date slight degradations in the troposphere have outweighed slight improvements in the stratosphere from these experiments. In the 3D-Var system the covariances are more globally consistent than in the previous Analysis Correction scheme, but as a corollary it is usually impossible to change one aspect of the covariances in isolation.

5. VERIFICATION TIMESERIES

Figures 1 and 2 show four-year time series of verification against radiosonde 500 hPa heights for the Northern and Southern Extratropics respectively. There is a clear seasonal cycle, more pronounced in the Northern Extratropics, of larger errors in winter – although note that skill relative to persistence is actually higher in winter. In January 1998 there was an increase in horizontal and vertical resolution of the forecast model and there was some tuning of the 'physics' later that year. Since then the main changes have been those described here. This is partly because much work has been put in on a new dynamical formulation – the 3D-Var scheme has now been adapted to work with this (see Malcolm et al, J2.9A, this volume).

It is clear that forecasts from all three centres shown have improved in the last four years. The month-to-month noise makes detecting the effect of individual changes more difficult. There is a hint that the October 1999 changes improved the Met Office Southern Hemisphere forecasts, but apart from that the improvements appear gradual rather than instantaneous. For winds at 250 hPa (not shown) the March 1999 changes appeared to give a decrease in errors in the Southern Extratropics.

6. CONCLUSIONS AND FUTURE WORK

Since the introduction of 3D-Var in March 1999 there have been significant improvements to Met Office forecast verification, particularly for the Southern Extratropics and at medium range. To some extent there was a backlog of work waiting for 3D-Var implementation, but it also corresponded to the availability of ATOVS data. Some changes needed several iterations before they could be implemented and others have not yet proved acceptable for operational implementation.

The (A)TOVS and background error covariance changes have played a major role in the improvements. The other observational changes have mainly given smaller impacts, with the exception of a change to the use of surface pressure data. Use of 'first guess at appropriate time' has arguably had more impact on forecasts of extreme events than on average verification. A cautionary note is provided by the fact that correcting an error in scatterometer quality control gave larger improvement than many other observational changes. Whilst the data assimilation system is making better use than ever before of the observations it also appears more sensitive to errors in the observations that have not been screened out.

Beyond the work related to the new dynamics formulation, and associated grid changes, effort will focus on moisture analysis and on synoptic dependence of forecast errors. Various ways of treating synoptic dependent errors in 3D-Var are being tried, and a working version of 4D-Var has just been produced. Work will continue on making best use of satellite data, including a new bias correction scheme and preparations for AIRS and IASI.

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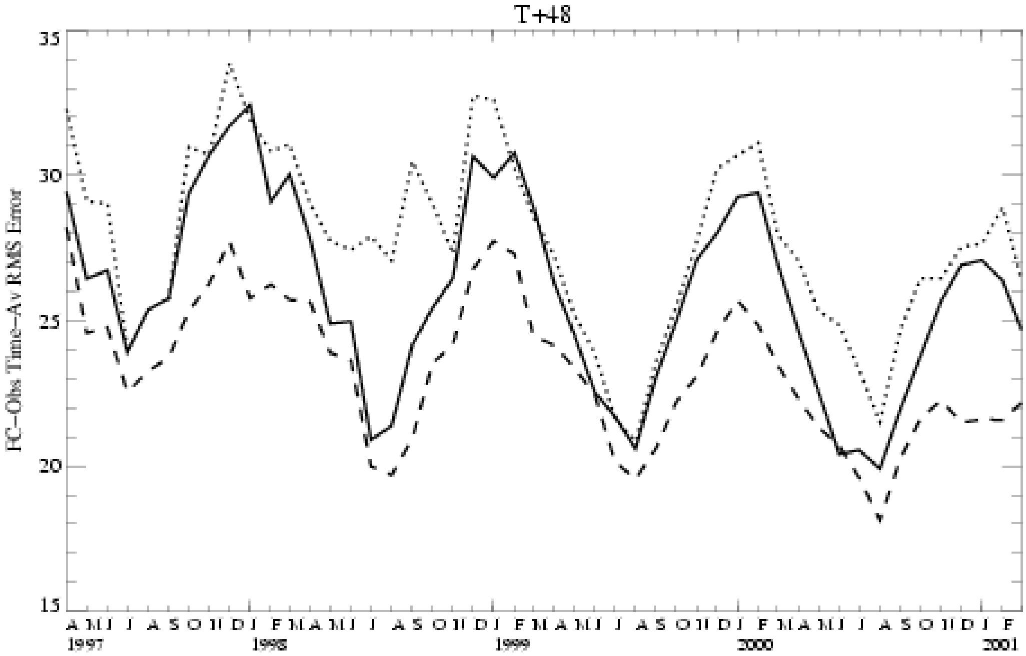

Figure 1. Verification of 48-hour forecasts of 500 hPa height against radiosonde observations: Northern Extratropics (30-90° N). Dashed line ECMWF, dotted line NCEP, solid line Met Office forecasts.

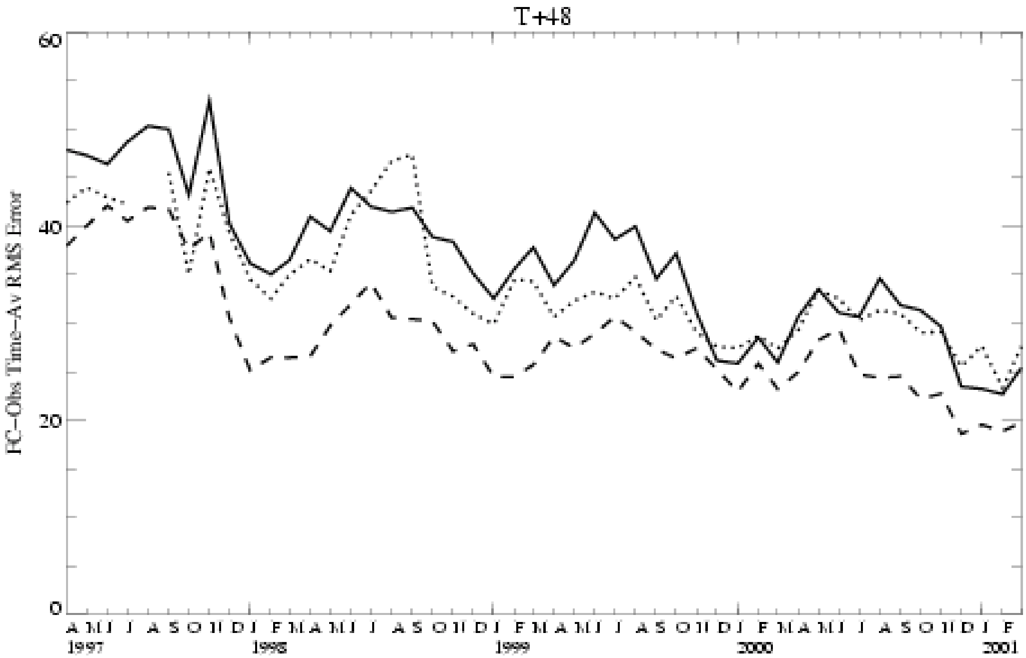

Figure 2. As figure 1 but for Southern Extratropics (30-90° S).