Stratospheric Data Assimilation at the Met Office - progress and plans

Richard Swinbank, Michael Keil, David Jackson and Adam Scaife

NWP, Met Office
Bracknell, RG12 2SZ, United Kingdom
richard.swinbank@metoffice.com

Abstract

The Met Office has been running a data assimilation system based on troposphere-stratosphere data assimilation model since 1991. This paper describes recent developments of the Met Office stratospheric data assimilation system. The current stratospheric data assimilation system, introduced in November 2000, is based on a 3D variational method. In collaboration with the Data Assimilation Research Centre, a version of the system is being developed to assimilate ozone measurements from both operational and research satellites. Migration of the stratospheric data assimilation system to the new, semi-Lagrangian, dynamical core is almost complete, and operational implementation is planned for October 2003.

1. Introduction

Since 1991 stratospheric analyses have been produced at the Met Office using a data assimilation system based on a low-resolution configuration of the Unified Model extending from the surface to the lower mesosphere. The first version of the stratospheric data assimilation system was based on the analysis correction scheme (Lorenc et al, 1991), in which the model was nudged towards observation values over a period of a few hours. The original data assimilation system (Swinbank and O'Neill, 1994) was primarily developed to support the NASA Upper Atmosphere Research Satellite (Reber, 1993) project; the stratospheric analyses helped to validate and interpret the measurements from the UARS instruments. Since 1995, stratospheric analyses have been produced as part of the operational forecast suite.

The current stratospheric assimilation system (Swinbank et al, 2002) was introduced in November 2000, based on a 3D variational (3D-VAR) scheme that was originally implemented in the operational global forecast model in 1999 (Lorenc et al, 2000). At the same time, we introduced the assimilation of radiances from the TOVS and ATOVS satellite sounders, while the original system had assimilated temperature retrievals. The implementation of 3D-VAR led to significant improvements in the quality of the stratospheric analyses, as exemplified by increases in forecast skill.

In collaboration with the Data Assimilation Research Centre, a version of the system is being developed to assimilate ozone measurements from both operational and research satellites. Initial trials using HIRS and SBUV data show promising results. Section 2 will focus on results from the ozone assimilation system.

The assimilation model used for the stratospheric data assimilation system is a special configuration the Met Office Unified Model (Cullen, 1993). The lower model levels have always followed the levels used for tropospheric applications, such as operational weather forecasting and climate prediction. Additional levels have been added in the stratosphere, coupled with an extension of the model lid to the lower mesosphere. The current operational stratospheric model has 40 levels, with the lower levels coinciding with those used by the 30-level global forecast model that was in operational use until recently. The stratospheric data assimilation model uses a much coarser horizontal resolution than the standard global forecast model - 2.5 degrees latitude by 3.75 degrees longitude.

In parallel with the developments to the data assimilation system, considerable improvements have also been made to the assimilation model over the past decade. A range of improvements introduced into the climate and operational forecast models has also been included in the stratospheric model. In addition to that, a parametrization of non-orographic gravity wave drag (the Ultra Simple Spectral Parametrization) has recently been introduced (Scaife et al, 2002). This has improved the model climatology, notably in the upper stratosphere and mesosphere. This scheme enables us to parametrize the gravity waves that are largely responsible for driving the equatorial quasi-biennial oscillation (QBO), and hence simulate the QBO in a free-running general circulation model (Scaife et al, 2000).

A major development to the Unified Model has been the development of a new, semi-Lagrangian dynamical core (Cullen et al, 1997), designed to improve the model performance. In 2002 the New Dynamics (ND) was implemented in the global and mesoscale operational forecast models. Due to some technical difficulties, implementation in the stratospheric assimilation model has been delayed. Section 3 gives some of the details of the recent, successful, pre-operational trials with the ND version of the stratospheric assimilation model.

2. Ozone Assimilation

The 3-D VAR stratospheric assimilation system has been extended to assimilate ozone measurements, in addition to other meteorological observations. Although the ozone assimilation has not yet been implemented operationally, we anticipate a number of potential benefits for numerical weather prediction. First, a better ozone field should lead to improved assimilation of radiances from such instruments as HIRS, AIRS and IASI. Second, the forecast model's radiative heating rates should be more realistic. Third, ozone observations could potentially give information about the wind fields, particularly in the upper troposphere lower stratosphere (UTLS) region.

The ozone assimilation system will also be used to assimilate data from research satellites. The ozone assimilation system was used to run an observing system simulation experiment to assess the likely impact of measurements from the proposed SWIFT (Stratospheric Wind Interferometer for Transport studies) instrument (Lahoz et al, 2003). SWIFT will measure both winds and ozone in the stratosphere. As part of the EU-funded ASSET project, the Met Office will be working with the Data Assimilation Research Centre, ECMWF, and a range of other partners on the assimilation on measurements from Envisat. The project will encompass the assimilation of water vapour and other trace species, as well as ozone.

The ozone assimilation system has been described by Jackson and Saunders (2002), but we will give a short description, and some preliminary results, in this paper. The ozone assimilation is univariate, i.e. independent of the meteorological assimilation variables. Ozone is advected using the Unified Model tracer transport scheme. The assimilation scheme has the option to use a simple parametrization of chemical sources and sinks of ozone; however, that is not used in the results presented here. Initially, the background error covariances were based on those used at ECMWF. In some later experiments, the error variances were increased above the mid-stratosphere.

Experiments have been run to assimilate ozone measurements from both HIRS (channel 9) and SBUV instruments. HIRS-9 gives information about ozone primarily in the upper troposphere and lower stratosphere. SBUV retrievals give some information about the vertical distribution of ozone, primarily in the middle and upper stratosphere; the retrievals give information on ozone concentration in layers, but the lowest layer stretches from 16 hPa down to the surface.

Three ozone assimilation experiments were run, using HIRS-9 and SBUV separately, then both together. The assimilated ozone data were verified by comparing the results with independent total column ozone measurements from GOME (Figure 1). Because of the effect of clouds and the surface, the HIRS-9 data observations have more effect in the southern hemisphere (SH) and tropics. The left-hand plots of Figure 1 show that, over a period of 10 days, the HIRS-9 data is successful at reducing the positive bias in the simulated ozone data. The RMS error is also reduced, but to a lesser extent. The SBUV data on its own has very little impact on the bias in the SH, but there were hardly any SBUV observations in the SH during the test period. The experiment assimilating both SBUV and HIRS-9 generally gives intermediate results. In the northern hemisphere (NH), the differences between the three experiments are smaller, but the best results are obtained by combining both sets of observations.

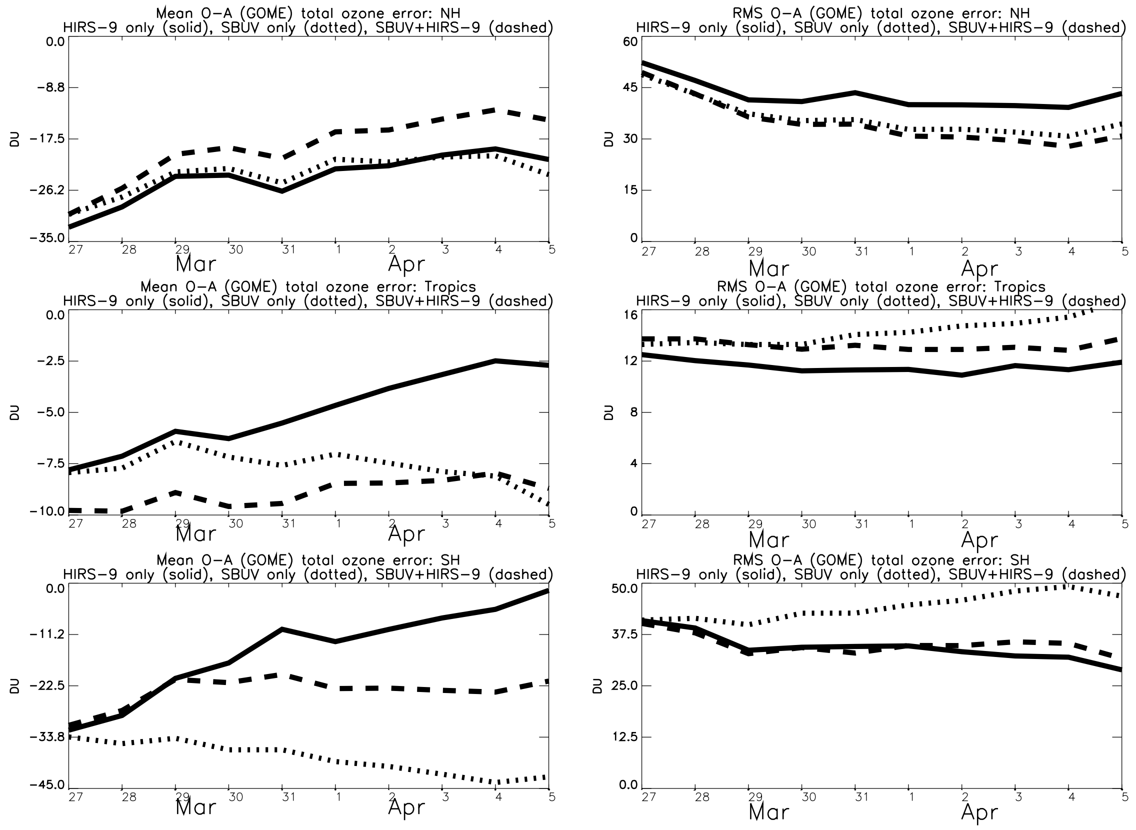

Figure 1: Comparison of total column ozone (Dobson units) from the ozone assimilation experiments with observations from GOME. Solid lines: HIRS-9 experiment; dotted, SBUV experiment; dashed, HIRS-9 and SBUV. Top row, NH; centre, tropics; bottom row, SH; left, mean difference; right, RMS error.

Figure 2 compares ozone profiles from the three experiments with collocated HALOE data. Stratospheric HALOE observations are accurate, high vertical resolution ozone profiles. But, since it is a limb-occultation instrument, coverage is sparse. The results show that the use of SBUV observations gives significant improvements over HIRS-9 in the middle and upper stratosphere. We conclude that a combination of both HIRS-9 and SBUV is required to give the best information about both the total column ozone and its vertical distribution.

Work is currently in hand to adapt the ozone assimilation system to the ND stratospheric model, as described in the next section.

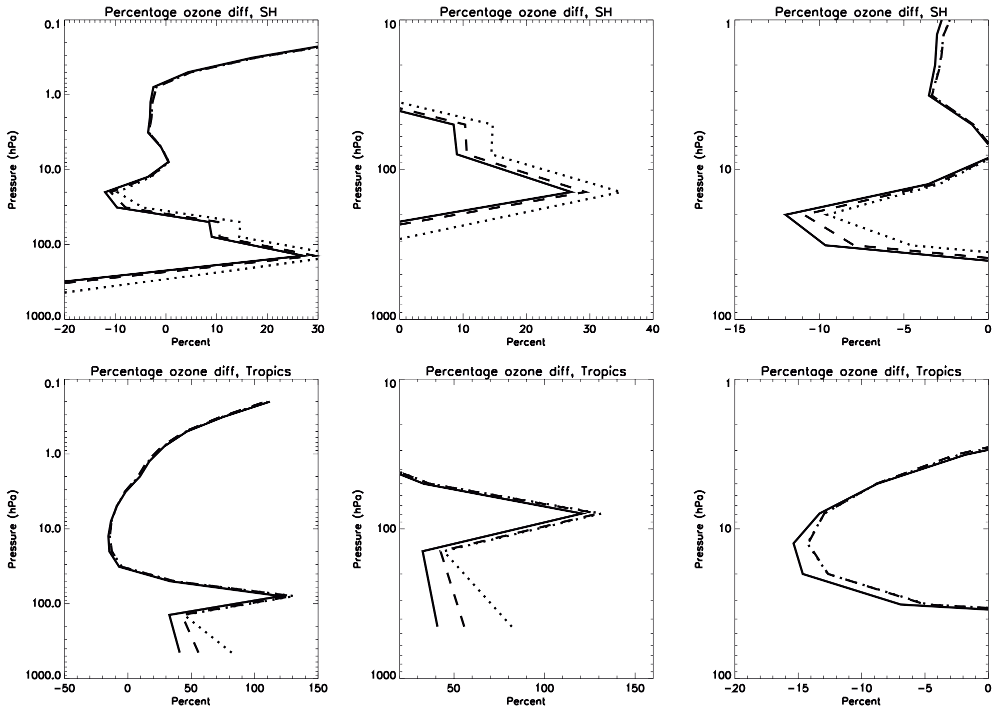

Figure 2: Percentage difference from HALOE measurements for the ozone assimilation experiments. Solid lines: HIRS-9 experiment; dotted, SBUV experiment; dashed, HIRS-9 and SBUV. Top row, SH; bottom row, tropics. The left hand plots show the full pressure range (1000-0.1 hPa), while the other plots show magnified views of 1000-10 hPa (centre) and 100-1 hPa (right).

3. New Dynamics

Over recent months, the stratospheric data assimilation system has been ported to the New Dynamics (ND) version of the Unified Model. The new stratospheric data assimilation system uses a model configuration with 50 levels, with the model lid at about 63km (or 0.1 hPa); the lowest 30 levels are the same as used by the standard 38-level global forecast model. Various technical problems were encountered in the pre-operational trials of the ND stratospheric system, which was not surprising given the major changes made to the dynamical core of the model. A particular problem was the specification of the background error covariances.

In common with many other forecast centres, the Met Office uses the so-called NMC method (Parrish and Derber, 1992) to estimate the background error covariances to be used by the 3D-VAR system. The differences between T+24 and T+48 forecasts verifying at the same time are used as a proxy for the forecast errors. The initial forecasts were run from initial data interpolated from the 40-level model grid. The resulting error variances were very large at the uppermost levels (as illustrated by the temperature standard deviations shown in Figure 3a). This led to some large analysis increments - large enough, in SH winter, to cause multiple model failures.

This problem was solved by only using assimilation increments up to level 40 (about 10 hPa), avoiding the very large increments at the upper levels. Of course, this system was not appropriate for operational use, but forecasts that were run from the resulting analyses enabled a new set of error covariance statistics to be calculated (Fig 3b). Up to level 40, the error covariances were similar to those originally calculated, but higher up the variances are much smaller. These sets of covariance statistics were used to run the first set of trials for June 2001 (SMTR1) and December 2002 (WNTR1). Parallel control experiments were also run, using the assimilation system based on the old dynamical core.

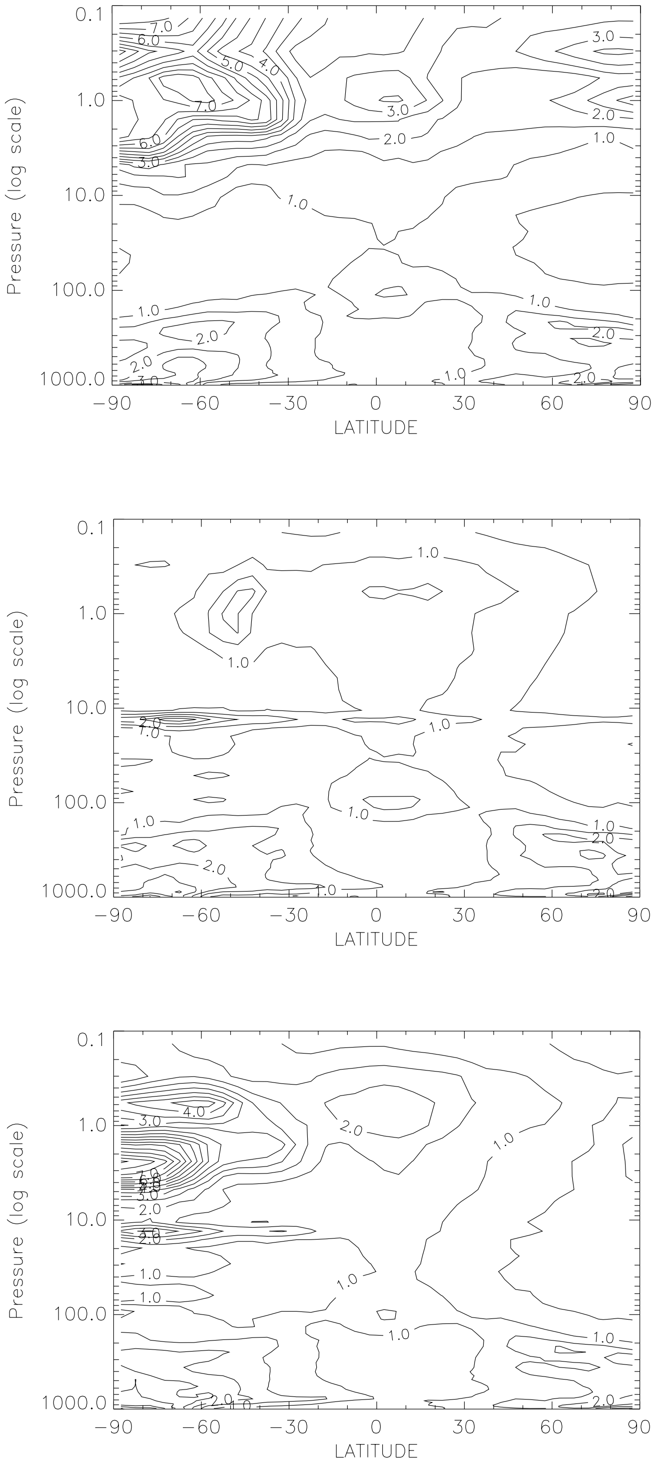

Figure 3: Temperature error standard deviations for the June 2001 trials. a) original error covariances; b) using assimilation increments only up to level 40; c) recalculated using forecasts from the first trial, SMTR1.

To summarise the overall performance of the new configuration, summary verification statistics have been produced. Table 1 summarises the results of verifying forecasts against radiosonde observations. The performance within a pressure layer (1000-100hPa or 100-10hPa) and region (NH, SH, tropics) has been calculated at each forecast time for geopotential height, wind and temperature. Table 1 gives the percentage of times in which the trial results were better, worse or neutral. The overall performance of both ND trials was significantly better than the corresponding control runs. In general, the height fields showed consistent improvements, while the temperature and wind results were less clear-cut.

Level (hPa)	SMTR1	Control	Neutral	WNTR1	Control	Neutral
Combined total	81%	6%	12%	67%	15%	18%
100-10	72%	7%	20%	56%	22%	22%
1000-100	91%	5%	4%	78%	7%	15%

Table 1: Summary of verification of trials against radiosonde observations.Left hand columns refer to June 2001 experiments, and righthand columns to December 2002 experiments Percentages show where a) trial (SMTR1 or WNTR1) performed better, b) control performed better and c) there was a neutral impact.

Since the error variances used by trials were artificially reduced above about 10 hPa, a second-generation set of error covariances were calculated from forecasts run during the trials SMTR1 and WNTR1. The resulting error covariances are illustrated by Fig 3c. The second generation of error covariances are similar to the original set (Fig 3a) in the upper stratosphere, but without the high variances near the model lid.

A further set of trials (SMTR2 and WNTR2) was run using these new error covariances. Figure 4 illustrates some sample forecast verification results from both sets of trials, and the control run, verified against the corresponding analyses. At most levels, there is little difference in performance between each pair of trials. The ND forecasts and analyses are more similar to one another than they are to the control run. Over most levels the second-generation covariance statistics give a slight advantage, but there is degradation in performance towards 1 hPa.

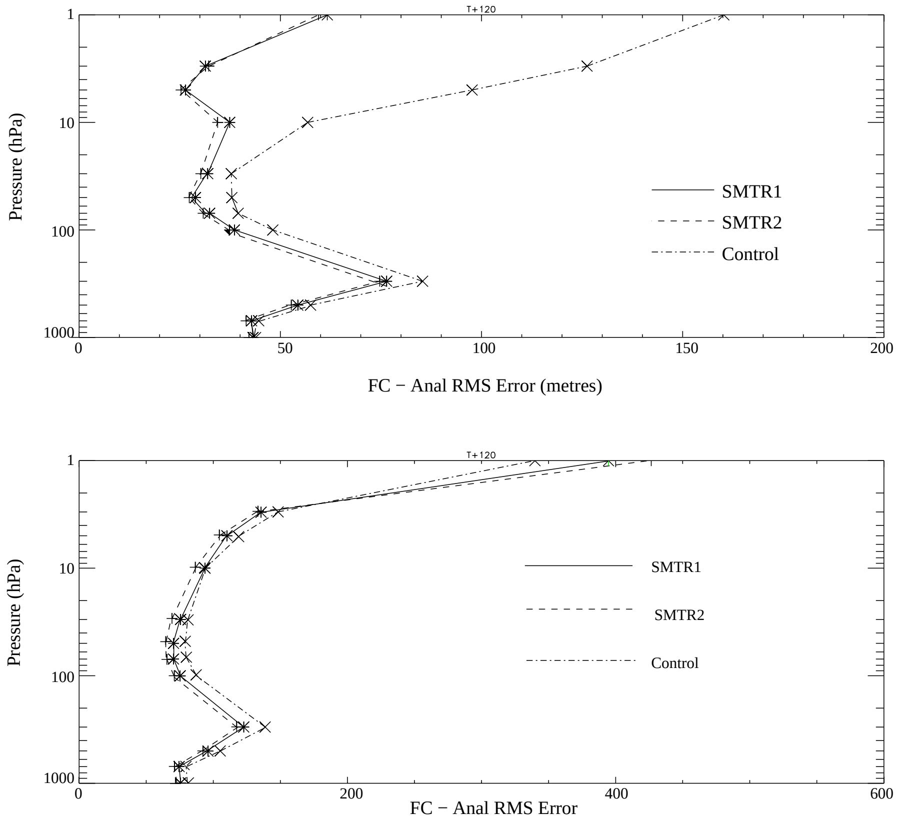

Figure 4: RMS difference between T+120 forecasts and the corresponding analysed fields for geopotential height for the June 2001 trials. Upper panel: NH; lower, SH

As a result of these successful trials, it is planned to implement the ND stratospheric assimilation system in October 2003. The results from the second pair of trials indicate that there it is likely to be beneficial to reduce the error variances at the uppermost levels. This will be the subject of further investigation.

4. Future Plans

Building on the successful trials of the ND stratospheric system, work has now commenced on the development of an extended global assimilation system. This proposed configuration has the same high horizontal resolution as the standard global forecast model, but extends into the mesosphere, using the same 50 levels used in the new stratospheric assimilation system. It is anticipated that this configuration will lead to more optimal use of satellite soundings, and enable all global analysis and forecast products to be produced from a single model configuration.

The development of this enhanced resolution global model is the first of a number of steps that will be taken to make best use of the new NEC SX-6 Met Office supercomputer. The Met Office 3D-VAR assimilation system was designed to be extended to 4D-VAR. Currently development work on 4D-VAR is well in hand. It is anticipated that both 4D-VAR and further resolution improvements will be implemented during the next few years.

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