TECHNICAL MEMORANDUM

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Assimilation of ozone retrievals from the MIPAS instrument on board ENVISAT

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Abstract

Ozone retrievals from SBUV/2 and GOME instruments have been assimilated in the operational ECMWF system since April 2002. In March 2002 ESA launched the ENVISAT satellite, on board of which are several instruments allowing the retrieval of ozone profiles. One of these instruments is MIPAS, a limb sounder that gives ozone profiles from about 70km down to 7 km. The assimilation of MIPAS ozone profiles was tested at ECMWF, and was found to have a positive impact on the ozone analysis while the impact on the forecast scores was neutral. As a result, the assimilation of MIPAS ozone retrievals was included in the operational ECMWF system in October 2003. This paper describes the impact of the assimilation of MIPAS ozone profiles on the ECMWF ozone analysis.

1 Introduction

Ozone retrievals from satellites have been assimilated in the operational ECMWF system since April 2002. Dethof and Hólm (2003) described the ECMWF ozone model and analysis, and discussed aspects of the quality of the analysed ozone fields, concentrating on fields from the ECMWF 45-year reanalysis project (ERA-40). The ozone data used in the operational assimilation system are ozone layers from the SBUV/2 (Solar Backscatter Ultra Violet) instrument on NOAA-16. These data are given as 12 ozone layers and are combined at ECMWF into 6 layers (0.1-1 hPa, 1-2 hPa, 2-4 hPa, 4-8 hPa, 8-16 hPa, 16 hPa-surface) to reduce observation correlations. Total column ozone retrievals from GOME (Global Ozone Monitoring Experiment) on ERS-2 provided by KNMI's Fast Delivery Service (Valks et al. 2003) were also assimilated from April 2002 to June 2003. This means that the ozone data which have been assimilated in the ECMWF system up to present are in effect total column data, as the lowest SBUV layer spans from 16 hPa to the surface. The assimilation of ozone retrievals in such broad layers can lead to problems with the vertical structure of the analysed ozone field if there is a systematic bias between the model and the data (Dethof and Hólm 2003). In these situations there is not enough vertical resolution in the observations to assign the analysis correction to the right levels. Instead, the information about how to distribute the analysis correction increment in the vertical has to come from the background error covariances. The background errors, however, only describe random errors and not systematic ones, and when systematic biases are interpreted as random errors by the analysis, this can lead to corrections being applied to the wrong level.

It was hoped that the ozone analysis could be improved by assimilating ozone data with a higher vertical resolution than the data used initially in operations. The information about the vertical structure of the correction to the ozone field would then come from the data, and would not have to be inferred from the background error statistics. Such ozone data became available after the launch of the ENVISAT satellite on 1 March 2002. ENVISAT carries several instruments that allow the retrieval of ozone profiles, the GOMOS (Global Ozone Monitoring by Occultation of Stars), MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) and SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY) instruments. The assimilation of MIPAS ozone retrievals has been tested at ECMWF, and the results are described in this paper.

MIPAS is a limb-viewing high-resolution Fourier-transform spectrometer (ESA 2002). It measures atmospheric emissions in the mid-infrared part of the spectrum between 4.15 and 14.6 microns, allowing the retrieval of concentration profiles of more than 20 atmospheric trace gases. The six main species (O_3, H_2O, HNO_3, CH_4, N_2O and NO_2) as well as temperature and pressure profiles are routinely retrieved by ESA. MIPAS provides global coverage, including coverage of the polar regions, independent of illumination conditions. The MIPAS retrievals give profile information at about 14 levels, from the model top at 0.1 hPa down to about 200 hPa with a vertical resolution of 3-5 km.

This paper describes results from the assimilation of MIPAS ozone retrievals in the ECMWF system. Section

2 describes the impact of the assimilation of MIPAS ozone retrievals on the ECMWF ozone field and on the forecast scores. Section 3 looks at the evolution of the 2003 Antarctic ozone hole in ECMWF analyses in which MIPAS data are assimilated, and Section 4 gives the conclusions.

2 Impact of the assimilation of MIPAS ozone profiles

2.1 Experiment setup

A number of assimilation experiments are run to assess the impact of the assimilation of MIPAS ozone profiles on the ECMWF ozone field and on the forecast scores. The MIPAS data used in the experiments are the near-real-time (NRT) level 2 data produced by ESA (data product MIP_NLE_2P). All experiments are run at horizontal resolution T159, with minimizations run at T45 and T95, and use a 6-hourly 4D-variational assimilation system (version CY26R3 of the ECMWF system). Exp-1 and Exp-2 are started on 1 February 2003, 0z, and run for 28 days. Exp-1 is the control experiment, in which no MIPAS ozone profiles are assimilated. In Exp-2, MIPAS ozone profiles are assimilated. The operationally used ozone data are assimilated in both experiments. These are ozone layers from SBUV/2 on NOAA-16 (assimilated at solar zenith angles less than 84°), and total ozone from GOME (assimilated between 40°N and 50°S). The other two experiments follow the same setup, but are started on 20 August 2003, 0z, and run for 30 days. These experiments are referred to as Exp-3 (no MIPAS ozone profiles assimilated) and Exp-4 (MIPAS ozone profiles assimilated). GOME data were not available during August and September 2003. First-guess checks and variational quality control are carried out for all the ozone data. The first-guess check is set so that data with $y - Hx_b > 6(\sigma_o^2 + \sigma_b^2)^{1/2}$ are rejected, where y is the observation value, Hx_b the observation operator applied to the background value, σ_o the observation error and σ_b the background error, which is currently set to 20% of the background value.

2.2 Results of the February experiments

A timeseries of zonal mean MIPAS observations in Dobson Units (DU) in a layer between 20 and 40 hPa is shown in Figure 1 (top panel), illustrating the data availability during February 2003. No MIPAS data are available on 2 February and from 20 to 23 February, and there are generally fewer data during the midnight cycles (21z - 3z) than during other cycles. MIPAS data coverage extends right up to the poles. Hardly any data are available in the tropics in February 2003. The middle plot of Figure 1 shows the analysis departures in DU (observations minus analysis values) for the layer 20-40 hPa from Exp-1. Positive departures are found in the tropics and mid latitudes, negative departures near the poles. The analysis departures of Exp-2 (bottom panel of Figure 1) are smaller than those of Exp-1, illustrating that the analysis is drawing to the MIPAS data.

The impact of the assimilation of MIPAS ozone profiles on the total column ozone field is assessed by comparing the analysed ozone fields from Exp-1 and Exp-2 on 28 February 2003 with independent TOMS data (Figure 2). Note that while the analysed ozone fields are at 12z, TOMS needs 24 hours to cover the whole globe and the map shown is a daily composite. During northern hemisphere (NH) winter, the ECMWF total ozone values at high northern latitudes are systematically too large compared to independent observations (Dethof and Hólm 2003). This is possibly a result of changes to the large scale overturning circulation due to the assimilation of satellite data, causing ozone to accumulate at high latitudes. This bias can be seen in Figure 2. The zonal mean ozone values in Exp-1 are about 40 DU higher at high northern latitudes than TOMS data. Ozone values in Exp-1 are also higher than TOMS data south of 70°S. When MIPAS ozone profiles are assimilated, this difference is reduced, and the ozone field of Exp-2 agrees better with TOMS data. The impact of the assimilation of MIPAS ozone data is largest north of 60°N where total column ozone in Exp-2 is up to

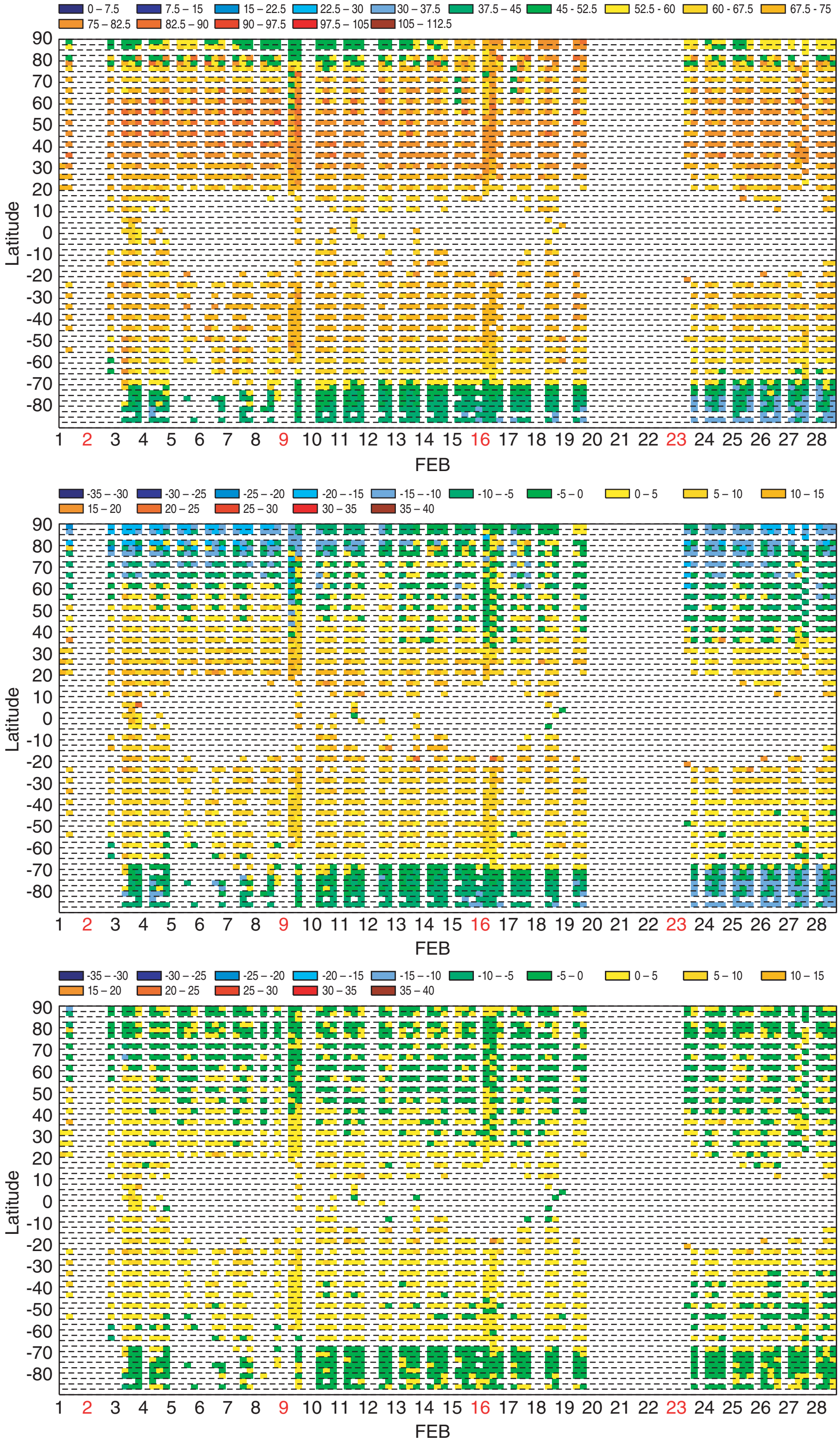

Figure 1: Timeseries (1 to 28 February 2003) of zonal mean MIPAS observation values (top), and analysis departures from Exp-1 (middle) and from Exp-2 (bottom) in DU for a layer between 20 and 40 hPa.

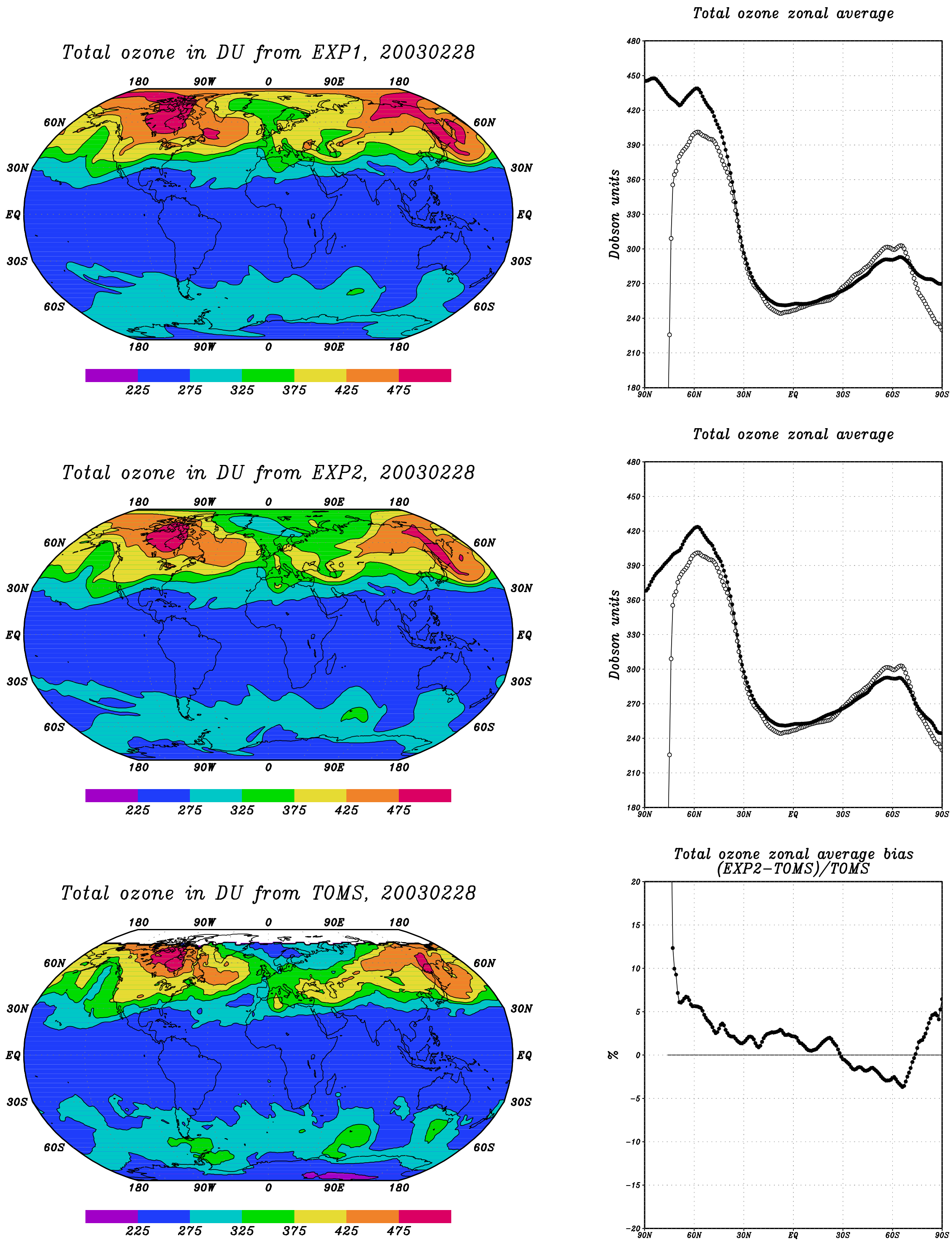

Figure 2: Left: Total column ozone in DU on 28 February 2003 from the control experiment Exp-1 (top), from the MIPAS assimilation experiment Exp-2 (middle), and from gridded daily TOMS data (bottom). Right: The two top panels show the zonal mean ozone values from the experiments (solid line) and from TOMS data (open circles), the bottom panel shows the relative difference in % between Exp-2 and TOMS.

60 DU lower than in Exp-1, and south of 70°S where Exp-2 is up to 40 Du lower than Exp-1.

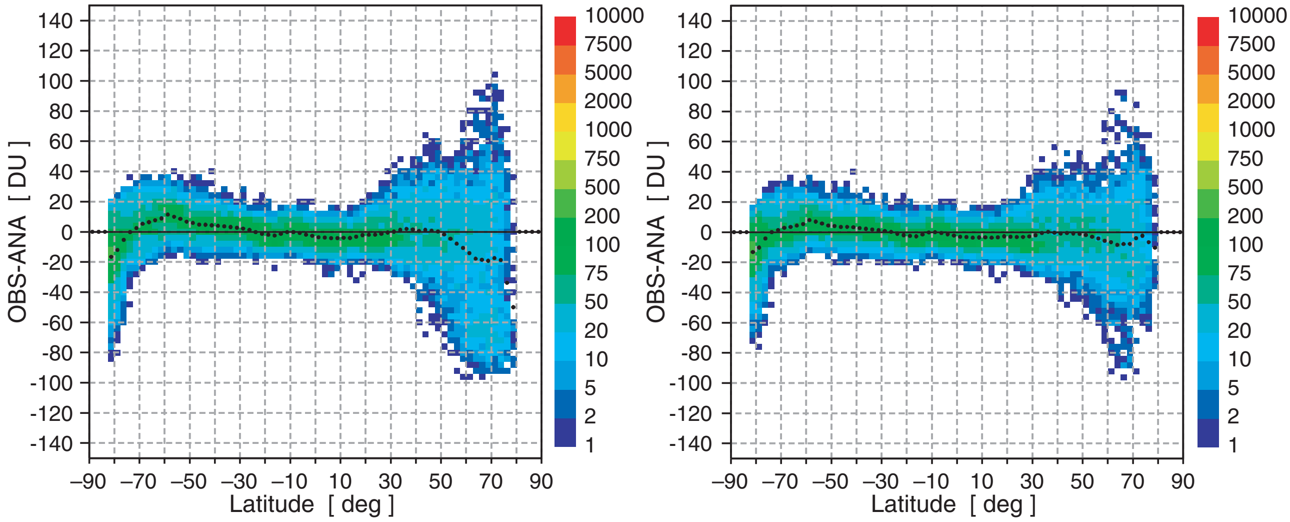

Figure 3: Scatter plot of SBUV/2 analysis departures (layer 16 hPa to surface) against latitude in DU in February 2003 from Exp-1 (left) and Exp-2 (right). The colour of the boxes gives the number of observations per bin.

Another data set for comparisons are SBUV/2 data from NOAA-16, which are also assimilated at ECMWF. SBUV/2 analysis departures for February 2003 are calculated for Exp-1 and Exp-2 for the layer between 16 hPa and the surface, which contains the bulk of the ozone column, and scatter diagrams of the departures are shown in Figure 3. The largest differences between the experiments are seen north of 60°N (especially over northern Asia and northern Europe, not shown). Because the SBUV/2 data are blacklisted at high solar zenith angles, they can not correct the model error on their own. When MIPAS data are assimilated the departures are reduced and the analysis agrees better with the SBUV/2 data. The global and monthly mean SBUV/2 analysis departures are reduced from -2.8 DU to -2.0 DU, and the standard deviation of the analysis departures is reduced from 18.6 DU to 13.2 DU, showing a better fit of the analysis to the SBUV/2 data if MIPAS data are assimilated.

Figure 4 shows a vertical cross section from 90°N to 90°S of the differences in the zonal mean ozone fields from Exp-2 and Exp-1 on 28 February 2003, 12z. The ozone data are plotted in milli Pascal (mPa), which is proportional to the number density and allows one to compare the contributions from different layers to the total column in log pressure coordinates. When MIPAS ozone profiles are assimilated, ozone values are reduced above 100 hPa north of 40°N, and also between 5-100 hPa south of 60°S. Between 50°N and 60°S ozone values are increased in the stratosphere, with maximum impact around 30 hPa.

In order to assess if the changes to the vertical structure of the analysed ozone field in Exp-2 are an improvement, ozone profiles from both experiments are compared with independent ozone sonde observations. The two top panels in Figure 5 show ozone profiles from the NH stations Ny-Ålesund (79°N, 12°E) on 9 February and Legionowo (52°N, 21°E) on 19 February 2003. The bottom panels show profiles from the tropical station Sepang Airport (3°N, 102°E) on 17 February, and the Antarctic Neumayer station (71°S, 8°W) on 26 February 2003. The ECMWF ozone profiles are the analysis profiles from the grid point closest to the sonde location at the closest analysis time. The assimilation of MIPAS ozone data has a large impact on the shape of the analysis profiles at Ny-Ålesund. The analysis profile from Exp-2 agrees well with the sonde, while the one from Exp-1 overestimates the ozone values above the ozone maximum. At Legionowo the assimilation of MIPAS ozone profiles leads to increased ozone values around the ozone maximum. Again this agrees better with the sonde. The impact on the Antarctic profiles is smaller than in the NH, but the analysis profiles agree better with the sondes above the ozone maximum if MIPAS ozone data are assimilated. At Sepang Airport, the analysis ozone

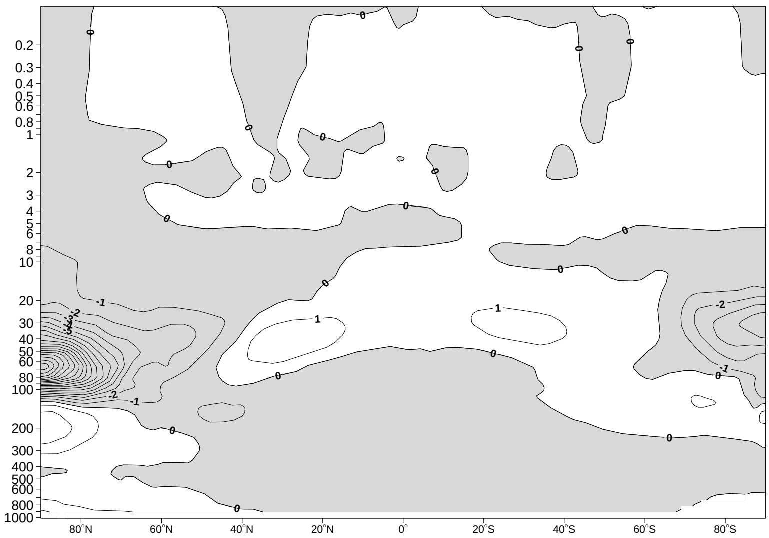

Figure 4: Vertical cross section of zonal mean ozone differences in mPa between Exp-2 and Exp-1 on 28 February 2003, 12z. Contour interval is 1 mPa, negative values are shaded.

values are higher at the ozone maximum when MIPAS data are assimilated, but the differences are very small.

Forecast verification scores are calculated for Exp-1 and Exp-2 in order to assess the overall impact of the assimilation of MIPAS ozone profiles on the ECMWF assimilation system. Scores for 200 hPa vector wind root mean square errors are shown in Figure 6. The impact on the forecast scores at 200 hPa is neutral. The same is seen at other levels (not shown). A map of the differences in 48-hour forecast error RMS (Exp-2 minus Exp-1) for 200 hPa geopotential is shown in Figure 7. Green and blue shading denotes lower errors in Exp-2. This figure confirms that the impact of the MIPAS data on the forecast of the meteorological fields is small. This was expected, because the ozone assimilation is univariate, and an ozone climatology, instead of the model ozone field, is used in the model's radiation scheme. Hence, a change in the ozone analysis should not affect the meteorological fields or numerical forecasts strongly.

A completely different picture emerges when looking at a map of differences in 48-h total column ozone forecast error RMS in DU (using the 26R3 e-suite as control) shown in Figure 8. The assimilation of MIPAS ozone profiles has a big impact on the forecast of total column ozone. The ozone forecast errors are reduced in the extratropics when MIPAS data are assimilated, with the largest impact (over 30 DU in places) in the NH. The lower forecast errors in Exp-2 illustrate the initial conditions are important for the ozone forecast, and that an improvement to the analysed ozone field carries through into the forecast up to at least day 5.

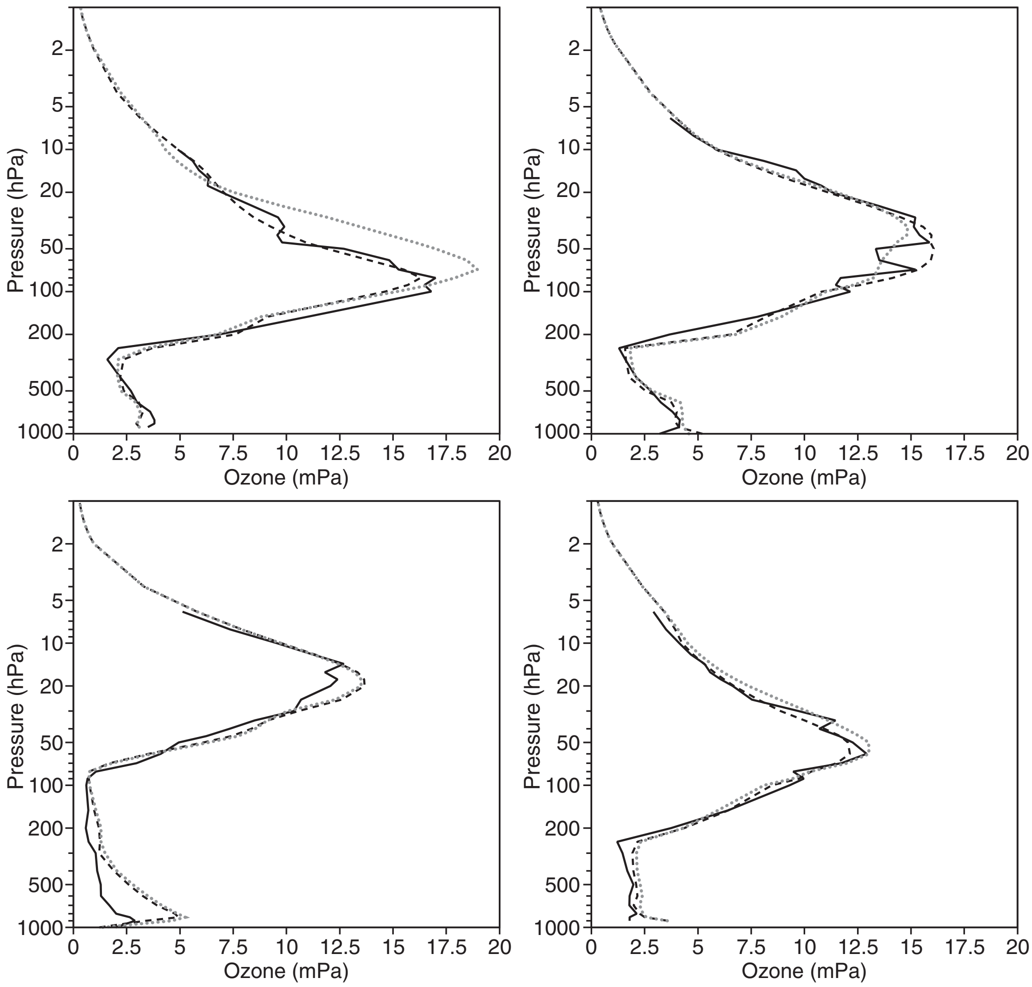

Figure 5: Ozone profiles in mPa from sondes (thick solid), Exp-1 (dotted), and Exp-2 (dashed) from the NH stations of Ny-Ålesund (79°N, 12°E) on 9 February (top left), Legionowo (52°N, 21°E) on 19 February (top right), the tropical station of Sepang Airport (3°N, 102°E) on 17 February (bottom left), and the Antarctic station of Neumayer (71°S, 8°W) on 26 February (bottom right).

3 Results of the August experiments

The August experiments confirm that the assimilation of MIPAS data has a positive impact on the analysed ozone field. Figure 9 compares total column ozone from Exp-3 (control) and Exp-4 (MIPAS data assimilated) with TOMS data on 20 September 2003. Most features of the total column ozone field are well reproduced in both experiments. However, Exp-3 is about 50 DU higher than TOMS data over the Antarctic and does not reproduce the low values of the Antarctic ozone hole. It is known that the ECMWF model has a positive bias over the South Pole at this time of year (Dethof and Hólm 2003), and the chemistry parameterization is not able to reduce ozone values to the very low values seen in observations. The southern edge of the SBUV data coverage lies around 67°S in the middle of August and around 77°S in the middle of September. The SBUV data are also not used at solar zenith angles greater than 84°S. Consequently, no ozone data are assimilated over the South Pole in Exp-3, and the ozone field is purely determined by the ozone chemistry parameterization and the dynamics. In the tropics and in the NH the agreement between Exp-3 and TOMS is better. In Exp-4, with the assimilation of MIPAS ozone profiles, the ozone hole is better reproduced than in Exp-3. Differences between Exp-4 and Exp-3 reach values of up to 40 DU in places. Because MIPAS measures in the infrared it can observe during the polar night, and the MIPAS data coverage goes right up to the poles. Hence, the data

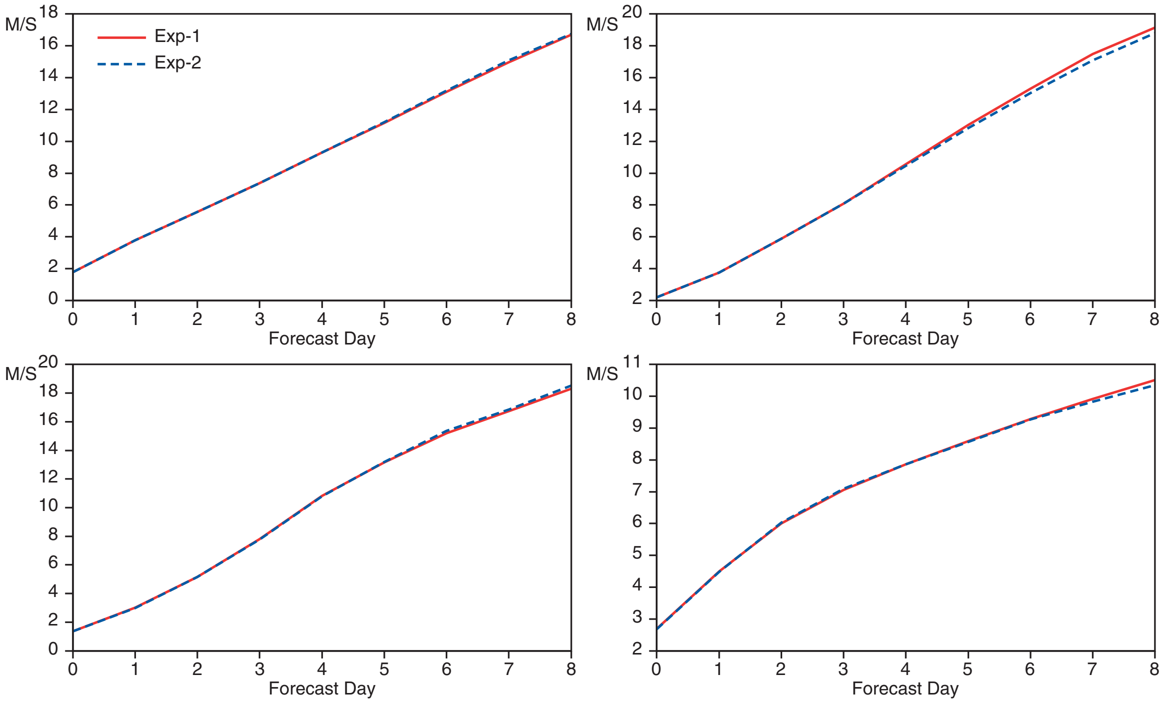

Figure 6: Forecast verification scores for 200 hPa vector wind root mean square errors from Exp-1 (solid) and Exp-2 (dashed) over 28 cases in February 2003 for the NH (top left), the SH (top right), Europe (bottom left) and the tropics (bottom right).

can correct for the model's too high ozone values over the South Pole. The total column ozone values in the NH and in the tropics are slightly higher in the zonal mean in Exp-4 than in Exp-3, but still agree to within 5% with the TOMS data between 85°N and 60°S.

Scatter plots of SBUV/2 analysis departures against latitude (not shown) confirm that the MIPAS data have the largest impact south of 60°S where SBUV/2 analysis departures are reduced. The global and monthly mean SBUV/2 analysis departures are reduced from -5.4 DU to -5.3 DU and the standard deviation of the analysis departures from 16.0 do 13.5 DU when MIPAS data are assimilated.

Figure 10 shows a vertical cross section from 90°N to 90°S of the differences of the the zonal mean ozone fields from Exp-4 and Exp-3 on 20 September 2003, 12z. The figure confirms that the impact of assimilating the MIPAS data is largest at the South Pole, where zonal mean ozone values in Exp-4 are up to 10 mPa lower between 30-150 hPa than in Exp-3. Between 10-30 hPa values are higher at the South Pole in Exp-4 than in Exp-3. At the North Pole values are reduced in Exp-4 between 5-60 hPa. Around the equator, the largest impact is seen around 30 hPa where it is negative, but apart from this, ozone values between 60°N and 50°S are generally higher in Exp-4 than in Exp-3 above about 100 hPa and below 5 hPa.

Ozone profiles from Exp-3 and Exp-4 are compared with ozone sondes from Ny-Ålesund on 27 August, from Sepang Airport on 1 August, and from Neumayer on 26 August and 11 September 2003 (Figure11). Note that the analysis profiles at Sepang Airport come for the operational ECMWF analysis (no MIPAS data assimilated) and the CY26R3 e-suite (MIPAS ozone data are assimilated), because no ozone sondes from Sepang Airport were available between 20 August and 20 September 2003. The assimilation of MIPAS ozone data has a large impact on the shape of the analysis profile at the Antarctic Neumayer station, where ozone values are considerably lower in Exp-4 and agree better with the ozone sondes than the profiles from Exp-3. However, even in Exp-4, the ECMWF ozone values are not as low as the sonde values between 40-80 hPa at Neumayer on 11 September. The reason is that the quality control implemented for the ozone analysis rejects some of the

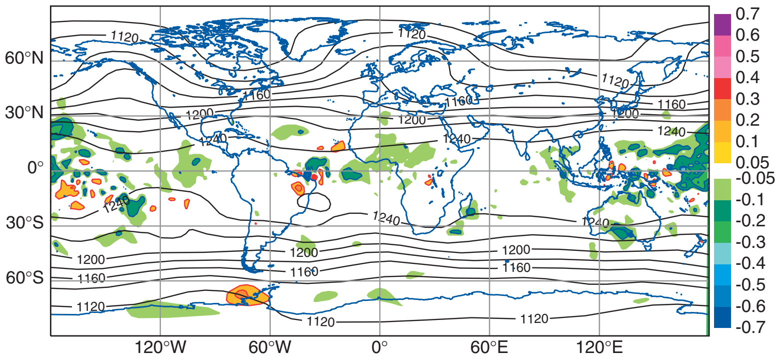

Figure 7: Differences of RMS of forecast error between Exp-2 and Exp-1, for 48-hour forecasts of 200 hPa geopotential (in deca metres) for the period 20030201 to 20030228, 12z. Green and blue (orange) shading indicates smaller (larger) errors in Exp-2 than in Exp-1.

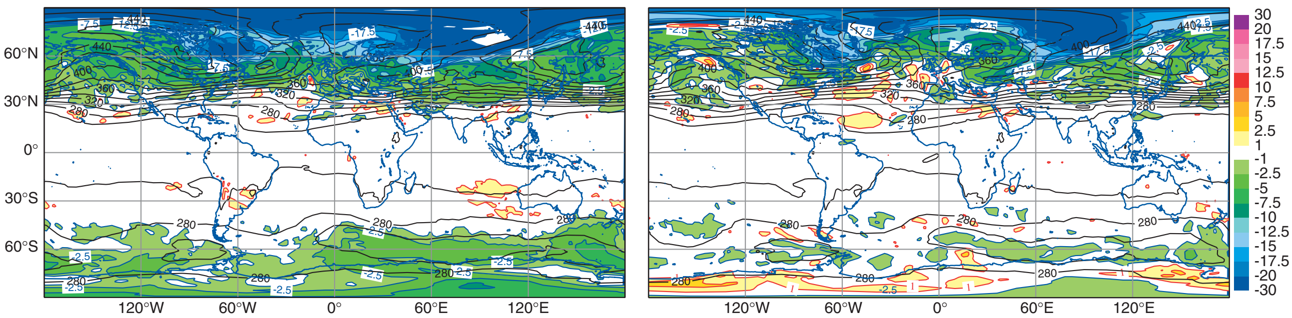

Figure 8: Differences of RMS of forecast error between Exp-2 and Exp-1, for 48-hour forecasts of total column ozone (in DU) for the period 20030201 to 20030228, 12z (left), and for 120-hour forecasts (right). Green and blue (orange) shading indicates smaller (larger) errors in Exp-2 than in Exp-1. Area integrated values for 48-hours forecasts -15.63 DU for 90-60°N, and -2.5 DU for 60-90°S. Area integrated values for 120-hours are -10.1 DU for 90-60°N -10.1 DU, and -0.32 DU for 60-90°S.

MIPAS data, because they show very low values that are too different from the model's first guess values. The impact of the assimilation of MIPAS ozone data on the ozone profiles in the NH at Ny-Ålesund is smaller than over the Antarctic, but positive. The profiles from Sepang Airport show that in the tropics the agreement with sondes at the ozone maximum is worse when MIPAS data are assimilated, and that the analysis values at the ozone maximum are too high. Further studies confirm that this difference is a direct result of the assimilation of the MIPAS ozone data, which are higher than the ECMWF values around the tropical ozone maximum (Dethof 2003), and is not due to other changes that were included in the the CY26R3 e-suite.

As in the February experiments, forecast verification scores for Exp-3 and Exp-4 confirm that the assimilation of MIPAS ozone profiles has a neutral impact on the forecast scores. Maps of differences in forecast error RMS (not shown) for geopotential at 200 hPa for 48-hour forecasts confirm that the impact is small. The impact on the ozone forecast is large and positive again in August/September, as can be seen by the differences in 48-hour and 120-hour total column ozone forecast error RMS for Exp-4 minus Exp-3 (Figure 12). The forecast errors are reduced when MIPAS data are assimilated, especially in the extratropics, and at this time of year the impact is largest in the SH, where we also saw the largest impact on the analysed ozone field.

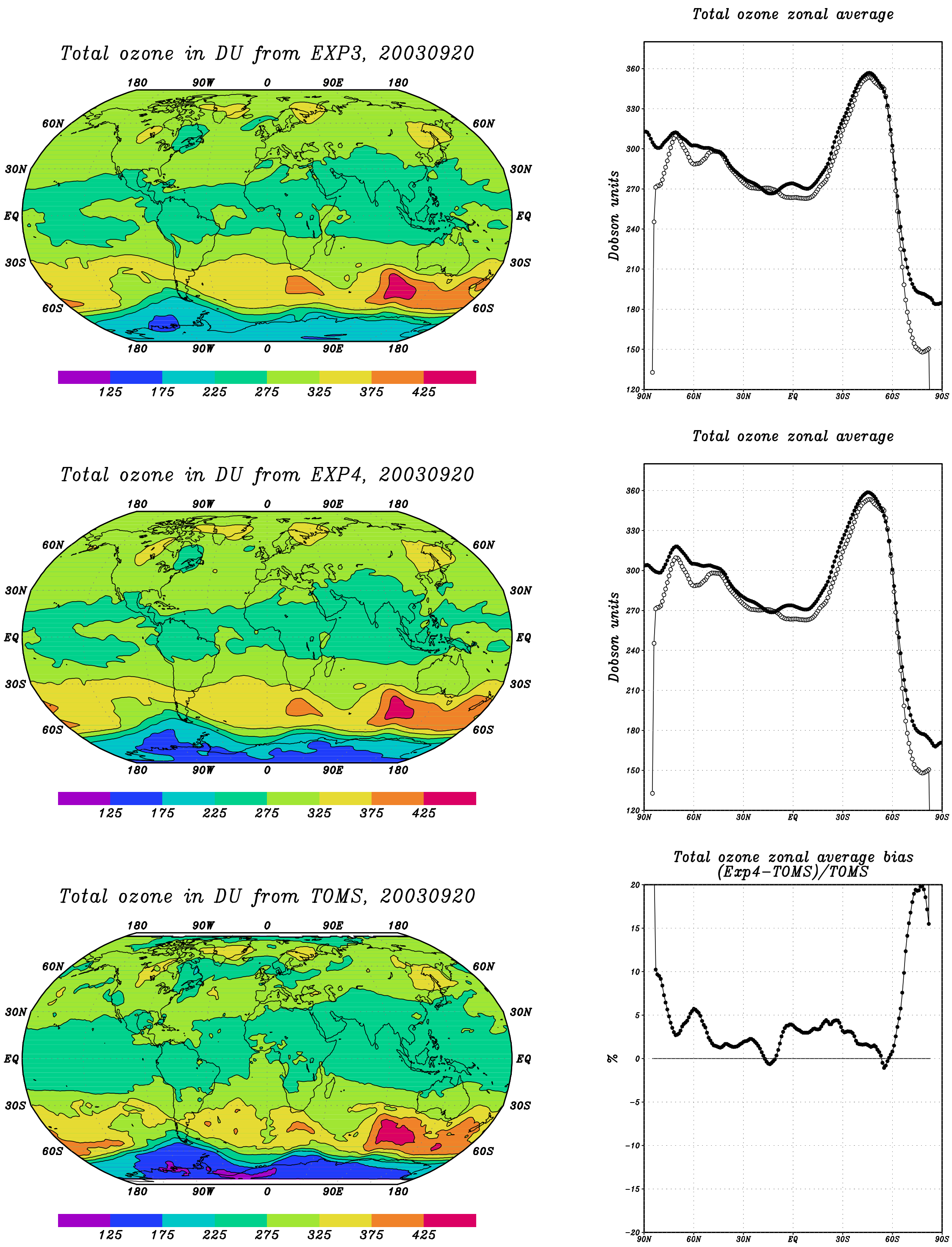

Figure 9: Like Figure 2, but for Exp-3 and Exp-4 on 20 September 2003.

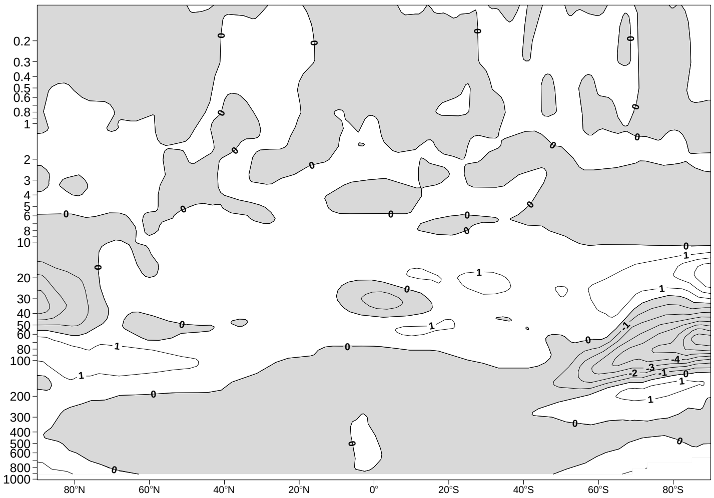

Figure 10: Vertical cross section of zonal mean ozone differences (Exp-4 minus Exp-3) in mPa between on 20 September 2003, 12z. Contour interval is 1 mPa, negative values are shaded.

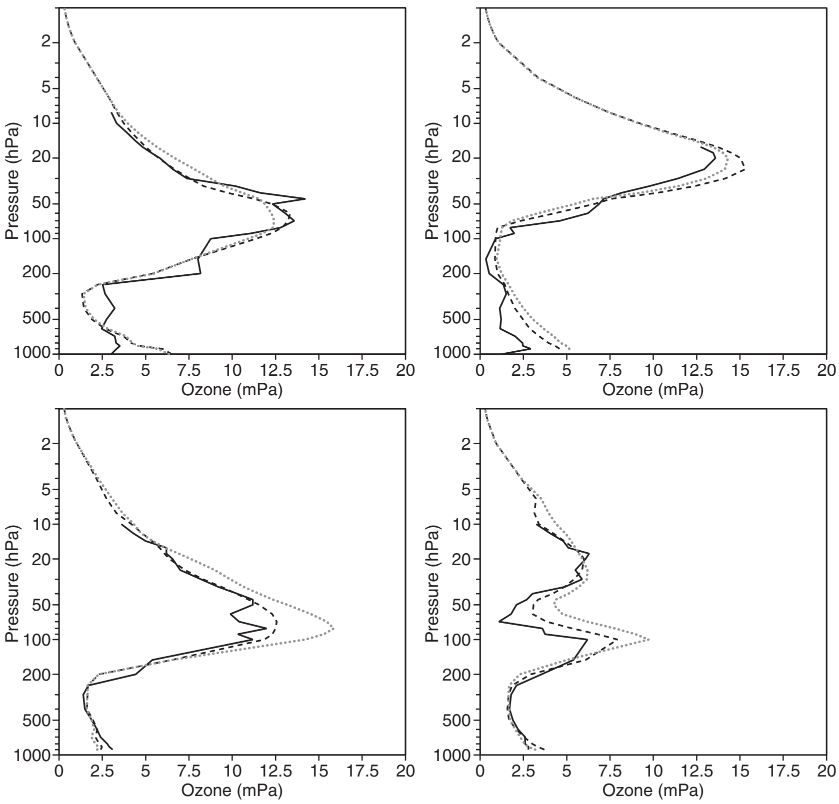

Figure 11: Ozone profiles in mPa from sondes (thick solid), Exp-3 (dotted), and Exp-4 (dashed) from the NH stations of Ny-Ålesund (79° N, 12° E) on 27 August (top left), the tropical station of Sepang Airport (3° N, 102° E) on 1 August (top right), and from the Antarctic station Neumayer (71° S, 8° W) on 26 August (bottom left) and on 11 September (bottom right).

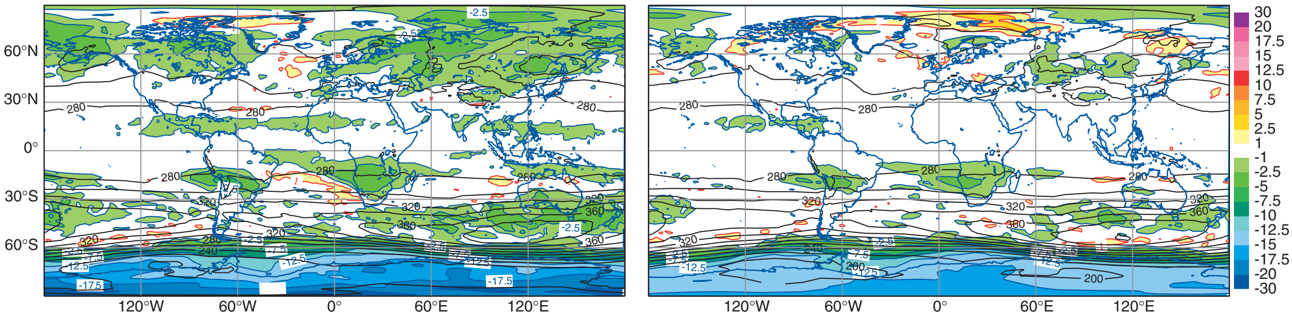

Figure 12: Differences of RMS of forecast error between Exp-4 and Exp-2, for 48-hour forecasts of total column ozone (in DU) for the period 20030820 to 20030920, 12z (left), and for 120-hour forecasts (right). Green and blue (orange) shading indicates smaller (larger) errors in Exp-2 than in Exp-1. Area integrated values for 48-hours forecasts -1.68 DU for 90-60°N, and -11.82 DU for 60-90°S. Area integrated values for 120-hours are 0.03 DU for 90-60°N, and -10.38 DU for 60-90°S.

4 The evolution of the 2003 ozone hole in the ECMWF analyses

In Section 2 it was shown that the assimilation of MIPAS ozone profiles in the ECMWF system improves the analysed ozone field. In this section, ozone fields from the operational ECMWF system from 7 October onwards (CY26R3, horizontal resolution T511) and from pre-operational test runs of cycle 26R3 from 1 June to 6 October 2003, all of which include the assimilation of MIPAS ozone profiles, are used to follow the 3-dimensional evolution of the 2003 Antarctic ozone hole. The 2003 ozone hole grew rapidly during August and reached a record size at the end of September, before decreasing during October. It was much stronger than the 2002 ozone hole when the polar vortex split in September and the area covered by the ozone hole in October was only about half of the area normally covered during this month.

Figure 13 depicts a timeseries of zonal mean total column ozone in DU from TOMS data (top) and from the ECMWF analyses (bottom) from 1 June to 15 November 2003 and shows the development of the ozone hole during September and October. The ECMWF ozone field agrees well with TOMS. The main differences are found between about 40-70°S where ECMWF ozone values are higher than TOMS values. The onset of the ozone hole is very well captured in the ECMWF analyses, and zonal mean ozone values below 200 DU are observed south of 70°S from 9 September until the end of October.

To follow the 3-dimensional evolution of the 2003 ozone hole, vertical cross sections across the South Pole along 140°E are plotted on the 1st of each month from August to December 2003 (Figure 14). On 1 August (Figure 14a) total column ozone values over the Antarctic have minimum values between 225 and 275 DU. The cross section shows a layer of high ozone values (up to 26 mPa) between 40-100 hPa. This layer is getting thinner during August, and on 1 September (Figure 14b) ozone values south of about 65°S are considerably lower than in previous weeks with the largest depletion around 70°S. This is the edge of the polar night, where ozone depletion begins as sunshine returns to the polar region, and heterogenous reactions on the surfaces of polar stratospheric clouds destroy ozone. The corresponding map of total column ozone shows that the lowest ozone values (175 to 225 DU) are found along the polar night edge, while values over the South Pole are still above 225 DU. During September the ozone layer south of 60°S is further depleted, and at the beginning of October (Figure 14c) ozone over the South Pole is almost completely destroyed between 40-100 hPa. Here, values are now lower than 4 mPa compared to values greater than 24 mPa at the beginning of August. Almost the entire area south of 80°S now has total column ozone values below 175 DU. During October the area of the ozone hole decreases and total column values begin to increase. On 1 November (Figure14d), the ozone hole is elongated along 80°W, and ozone values are above 175 DU everywhere. The layer with values below 4 mPa has been reduced in the vertical, and ozone values between 20-80 hPa have increased. On 1 December (Figure

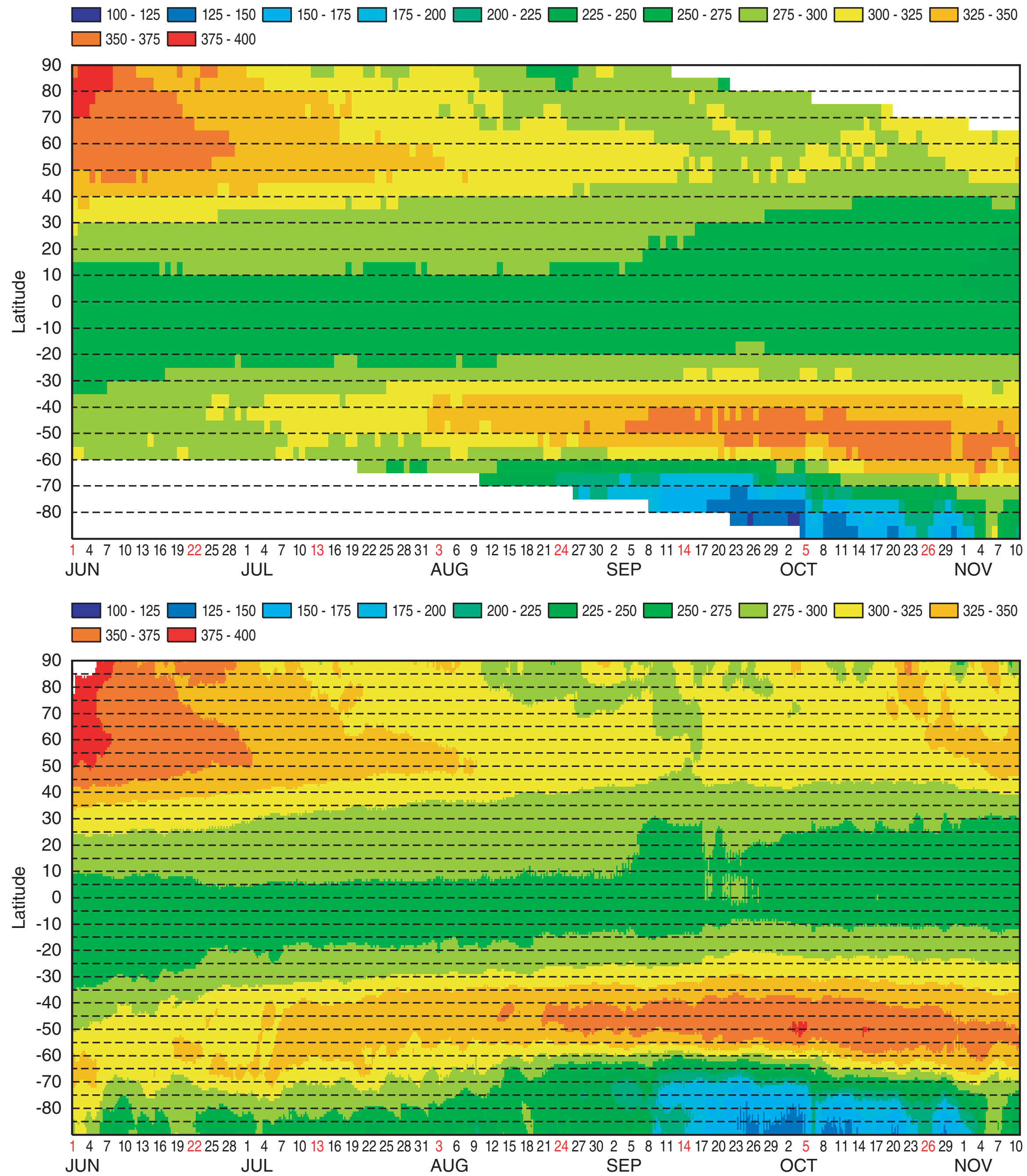

Figure 13: Timeseries of zonal mean total column ozone in DU from TOMS (top) and ECMWF analyses (bottom) from 1 June to 10 November 2003.

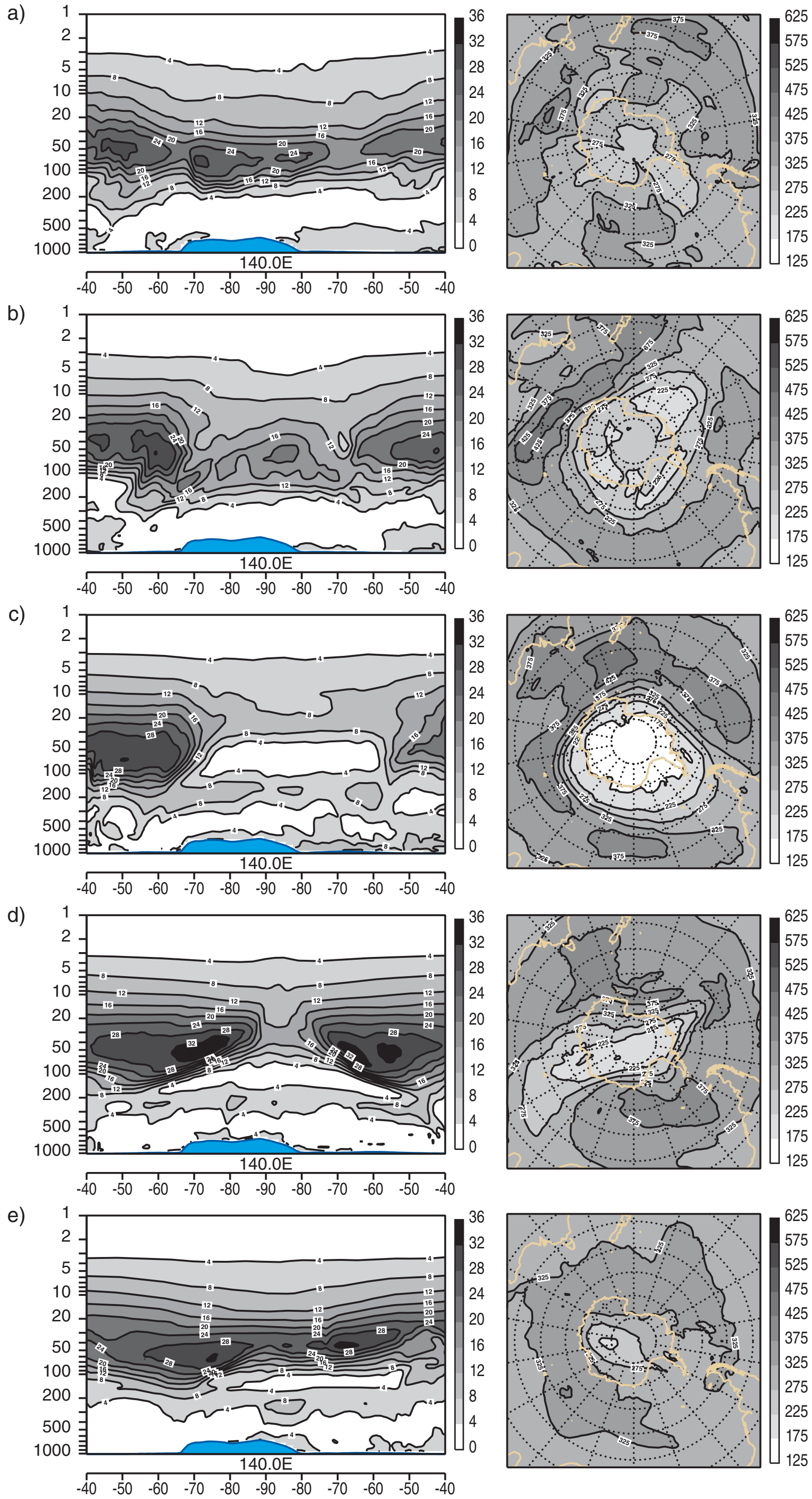

Figure 14: Left: Vertical cross sections of ozone in mPa along 140°E across the South Pole on 1 August, 1 September, 1 October, 1 November, and 1 December 2003. Right: Total column ozone field in DU for the same days.

14e) total column values over the South Pole are greater than 275 DU over most of the Antarctic. The cross section shows that ozone values at the ozone maximum are greater than 24 mPa now. However, there is still a thin layer with values less than 4 mPa around 150 hPa.

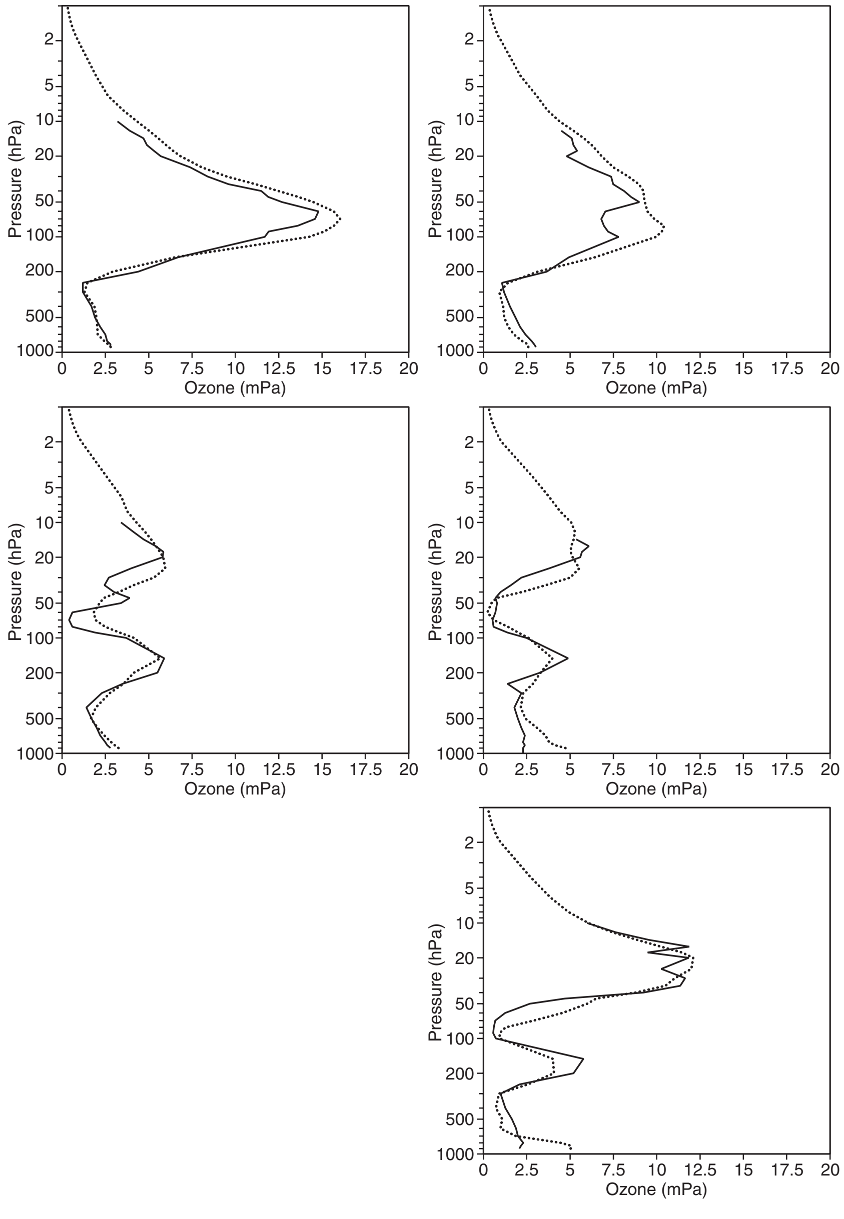

Figure 15: Ozone profiles in mPa at the Neumayer station from sondes (solid) and ECMWF analyses (dotted) on 7 August, 1 September, 18 September, 1 October, and 27 October 2003 (from top left to bottom right).

To validate the cross sections, ozone sonde profiles from the Neumayer station are compared with ECMWF analysis profiles (Figure 15) on several days between 7 August and 27 October 2003. Unfortunately, no sondes were available for November. Generally, the analysis profiles show a good agreement with the sondes. The changes seen in the ozone profiles confirm what was seen in the analysis cross sections in Figure14. At Neumayer, values at the ozone maximum are reduced from 15 mPa at the beginning of August to about 8 mPa at the beginning of September. By the middle of September ozone values between 30-100 hPa are strongly reduced, and at the end of September ozone is almost completely depleted between 40-100 hPa. During October, ozone values above 40 hPa increase again, but ozone values remain low between 60-100 hPa.

These comparisons illustrate the power and benefits of an assimilation system. By combining the information from satellite data with a numerical model, dynamically consistent 3-dimensional ozone fields are constructed, which can then be used for further studies and analyses.

5 Conclusions

The assimilation of ozone retrievals from the MIPAS instrument on ENVISAT was tested at ECMWF. It leads to an improvement of the ECMWF ozone analysis in the extratropics, both in the total column ozone field and in the vertical ozone distribution while the impact on the forecast scores is neutral. In the tropics, MIPAS ozone values are larger than ECMWF values around the ozone maximum (Dethof 2003). Comparisons with ozone sondes and TOMS data show that the fit to the independent data is slightly degraded when MIPAS ozone profiles are assimilated, suggesting that MIPAS ozone values in the tropics are too high around the ozone maximum.

Assimilation experiments have shown that in February 2003 the impact of assimilating MIPAS ozone profiles is strongest at high latitudes of the NH, where total ozone values are reduced, giving a better agreement of the ECMWF ozone field with independent TOMS data and ozone sondes. In August and September 2003 the impact is strongest in the SH, where the representation of the Antarctic ozone hole in the analysis is improved when MIPAS ozone data are assimilated.

The main reason the assimilation of MIPAS ozone profiles has a positive impact on the vertical structure of the analysed ozone field over most of the globe is the higher vertical resolution of the MIPAS profiles, compared to the ozone data previously used at ECMWF. Information about the vertical structure of the analysis correction comes from the data, and does not have to be inferred from the background error statistics. Furthermore, it is beneficial that MIPAS provides day and night time measurements, including coverage of the poles during the polar night. Owing to the positive impact on the ozone analysis, the assimilation of MIPAS ozone profiles was included in the operational ECMWF system in October 2003.

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