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Contract Report to the European Space Agency

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January 2010

Author: Rossana Dragani

Annual report for ESA contract 21519/08/I-OL:
Technical support for global validation of ENVISAT data products

European Centre for Medium-Range Weather Forecasts
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Abstract

This report discusses the results from the operational validation and monitoring of level 2 data retrieved from the atmospheric instruments on board Envisat performed at ECMWF during 2009 in support to the ESA activities. Owing to instrumental problem, the MIPAS Level 2 dissemination was stopped in March 2004.

The NRT TOSOMI TCO produced at KNMI and distributed via the ESA funded PROMOTE consortium was the only SCIAMACHY product continuously disseminated during 2009. The TOSOMI operational assimilation was stopped in December 2008 with the start of a SCIAMACHY decontamination period, but not immediately restarted afterwards as Observing System Experiment (OSE) showed the potential degration led by these data on the ECMWF temperature and geopotential forecasts and ozone analyses. In September 2009, the ECMWF Integrated Forecasts System (IFS) was updated to model cycle CY35R3, that included, among several other features, the extention of the Variational Bias Correction (VarBC) scheme to retrievals. A new OSE study performed using the newly available VarBC showed that the bias corrected TOSOMI data could still provide useful information, improve the quality of the ozone analyses and marginally the quality of the ECMWF temperature and geopotential forecasts scores. Following these new results, the operational assimilation of TOSOMI restarted in September 2009.

The dissemination of GOMOS Level 2 profiles continued during most of 2009. However, the GOMOS instrument suffered of a number of anomalies that mostly affected its pointing system, and that led to a much reduced amount of available data in the Stratosphere. Only in December the number of observations was almost comparable with that disseminated in January 2009 (before the anomalies started). Based on the data availability, the temperature profiles showed a good level of agreement with the ECMWF temperature first guess and analyses, with generally negative departures up to -1% (-2K) in the stratosphere, and about -4% (-8K) in the mesosphere. The NRT GOMOS ozone profiles showed a level of agreement with their model within -10 and +15% in most of the stratosphere (for p<40hPa) in the tropics and at midlatitudes, but larger in the lower stratosphere and in the mesosphere. The quality of the GOMOS water vapour profiles was generally poor at all levels, and latitudinal bands, with stratospheric values typically from one to four orders of magnitude larger values than their model equivalent.

1 Introduction

The present report summarises the results from the global validation and monitoring of ENVISAT atmospheric data products performed at ECMWF under the ESA funded project 17585-CCN-1. These products, usually referred to as the Meteo products, are retrieved at ESA and available to ECMWF on their ftp servers in near-real time (NRT) in BUFR format. As far as the ENVISAT atmospheric instruments are concerned, the products formally included in the present contract are temperature, ozone and water vapour profiles from MIPAS (MIP_NLE_2P) and from GOMOS (GOM_RR__2P), as well as total column ozone retrievals from SCIAMACHY nadir measurements (SCI_RV__2P). The current project (contract 21519/08/I-OL, "Technical support for global validation of Envisat data products") runs for a period of three years from January 2008 to December 2010, and continues the work carried out under ESA contracts 14458/00/NL/SF (Dethof, 2003), 17585/03/I-OL (Dethof, 2004; da Costa Bechtold and Dethof, 2005), 17585-CCN-1 (Dragani, 2006, 2008), and 21519/08/I-OL (Dragani, 2009). The present report discusses the interim results from the monitoring and assimilation of the ENVISAT L2 atmospheric data products during the period January to December 2009.

The ECMWF deterministic model is a global spectral model. It benefits from a current horizontal resolution truncation of T799, which corresponds to about 25 km grid spacing, and 91 vertical levels with the model top at 0.01 hPa (corresponding to an altitude of about 80 km). The model uses a four-dimensional variational (4D-Var) scheme (Rabier et al., 2000) to assimilate observations at 6- and 12-hourly time windows. The ECMWF assimilation system has two main 6-hour 4D-Var (early-delivery) analysis and forecast cycles for 00 and 12 UTC and two 12-hour 4D-Var analysis and first-guess forecast cycles. The 0000 UTC analysis of the 12-

hour 4D-Var analysis uses observations in the time window 2101-0900 UTC, while the 1200 UTC analysis uses observations in the time window 0901-2100 UTC. These analyses are run with a delayed-cut-off time of 14 hours (with respect to the nominal analysis times), in order to use the maximum possible number of observations. The 6-hour 4D-Var analyses have a shorter cut-off time (4 hours) and the analysis observation windows are 2101-0300 UTC for the 00 UTC analysis and 0901-1500 UTC for the 12 UTC analysis. All the observation monitoring, ENVISAT data monitoring included, is done in the delayed-cut-off analyses (Dethof, 2004) and (Haseler, 2004).

Because ozone is fully integrated into the ECMWF forecast model and analysis system (Dethof and Hólm, 2003) as an additional three-dimensional model and analysis variable, the ECMWF model can be used to monitor ozone retrievals from the ENVISAT instruments in addition to temperature and water vapour. The forecast model includes a simple ozone parameterization, which is an updated version of the Cariolle and Déqué (1986) scheme (hereafter CD86). Compared with CD86, the ECMWF ozone parameterization includes an additional term which parameterizes the depletion of ozone in the polar regions by heterogeneous reactions. At present, ozone is included uni-variately in the ECMWF data assimilation system. This means that there are no ozone increments from the analysis of the dynamical fields, even though the assimilation of ozone observations will modify the wind field in 4D-Var through the adjoint calculations. The univariate treatment was chosen to minimize the effect of ozone on the rest of the analysis system. For the same reason, the model's ozone field is not used in the radiation scheme, where an ozone climatology (Fortuin and Langematz, 1995) is preferred instead.

As far as the ozone model bias is concerned, the ECMWF model still overestimates TCO at high latitudes especially during the spring season (ozone hole) and underestimates it in the tropics. There are also some problems with the vertical ozone structure in particular at high latitudes in the winter hemisphere (Dethof and Hólm, 2004).

During the period January to December 2009, the ECMWF operational model system was upgraded twice to model cycle CY35R2 on 10 March, and to model cycle CY35R3 on 8 September, respectively. Several changes were introduced in cycle CY35r2. From the point of view of the physics and parameterizations, a revised snow scheme, including diagnostic liquid water storage and a new density formulation, as well as an optimization of radiation scheme were implemented. Thanks to the collaboration with D. Cariolle, an updated set of coefficients used in the ozone chemistry was also introduced. Several changes were also included in the use of satellite data. The active assimilation of IASI humidity channels started together with a more consistent use of AIRS and IASI humidity channels. The cloud detection scheme for HIRS radiances was revised, and the radiative transfer model (RTTOV) was update from version 8 to version 9. In addition, the weight in the assimilation of GPS radio occultation data (GPSRO) was increased above 26km and they are now used up to 50km.

Most of the changes that were implemeted in cycle CY35R3 related to the data assimilation system. In this context, a weak-constraint formulation of 4D-Var that now takes into account systematic model errors in the stratosphere was introduced. The humidity formulation in 4D-Var was complitely revised, and its background error statistics improved. The satellite data exploitation continued with an improved assimilation of land-surface sensitive channels, and of cloud-affected radiances from infra-red instruments, in addition to the assimilation of total column water vapour data over land retrieved from MERIS on board of ENVISAT. A variational bias correction scheme (VarBC) for retrieved products was also introduced in September 2009. This scheme, also used for radiance bias correction, is currently applied to MERIS total column water vapour, as well as to all the assimilated ozone products, with the only exception of the SBUV/2 ozone data that are instead used to anchor VarBC.

As far as the ozone assimilation is concerned, NRT ozone retrievals from the NOAA-17 and NOAA-18 SBUV/2

(Solar Backscatter Ultra Violet) instruments have been assimilated in the operational ECMWF system since 6 November 2007. Data from their predecesor, the NOAA-16 SBUV/2, were assimilated operationally from April 2002 until 21 October 2008, when following instrument anomalies the data quality was defined not suitable for operational use. The SBUV/2 data are produced by NOAA and available from NESDIS[1]. They are given as 20 ozone profiles and then combined at ECMWF into 6 fixed ozone layers (0.1-1 hPa, 1-2 hPa, 2-4 hPa, 4-8 hPa, 8-16 hPa and 16 hPa-surface) to reduce the observation error correlation. Apart from the SBUV/2 ozone retrievals, NRT SCIAMACHY ozone columns produced by KNMI[2] and distributed via the ESA's funded PROMOTE-2 consortium were actively assimilated in the ECMWF system from 28 September 2004 until 18 December 2008, when an instrument decontamination period started which was anticipated by KNMI to result in a bias in the ozone total column product. Because of instrumental biases affecting this product, the active assimilation of SCIAMACHY TCO could only restart with CY35R3 (September 2009) when the VarBC scheme became available. NRT OMI total column ozone data have been assimilated since June 2008. The active assimilation of this product was switched off during the period between 27 January and 18 March 2009 due to instrumental anomalies that affected a number of pixels. The assimilation of OMI was then restarted when it was proven that by removing the anomaly-affected pixels the quality of the (remaining) data was still suitable for operational use.

SBUV/2 and KNMI SCIAMACHY data are not used at solar zenith angles greater than 84°, and OMI data are not used at solar zenith angles greater than 80°. Variational quality control and first-guess checks are carried out for all assimilated data. Temperature retrievals are not assimilated at all in the system, although this field is strongly constrained by the assimilation of radiances. The radiance assimilation does not include the assimilation of the ozone band in the infrared.

This report presents the results from the monitoring of NRT total column ozone (TCO) retrieved from SCIAMACHY measurements, as well as NRT ozone, water vapour and temperature profiles retrieved from GOMOS observations. Owing to instrumental problems, NRT MIPAS Level 2 retrievals have not been available since 27 March 2004, and so this report does not discuss the monitoring of MIPAS products. This report is structured as follows: Section 2 gives an indication of the operability of ESA and KNMI products during 2009, and compares it with that of the past few years. Section 3 summarizes the results of the monitoring and assimilation of SCIAMACHY total column ozone retrievals; section 4 shows results of the monitoring of GOMOS data. Conclusions are presented in the last section.

2 Operability of ESA and KNMI products during 2009

This section provides an indication of the operability of both ESA and KNMI product at ECMWF during 2009, in the same way it was produced by Dragani (2008, 2009).

To assess the operability of these products then, we have compared the data volume received within the analysis cut-off times with the total amount of data received. As anticipated above, ECMWF has two main 12-hour 4D-Var analysis and forecast cycles for 00 and 12 UTC (referred to as early-delivery) and two 12-hour 4D-Var analysis and first-guess forecast cycles (referred to as delayed-cut-off). The passive monitoring is performed with a delayed cut-off configuration, while the data actively assimilated - depending on their timely availability - are used in both the delayed-cut-off and early delivery suites.

In the delayed-cut-off, the 00 UTC analysis makes use of all the observations available in the Report Data Base

[1] See `http://orbit-net.nesdis.noaa.gov/crad/sit/ozone/` for more information.

[2] See either `http://www.temis.nl/products/o3total.html` or `http://www.gse-promote.org/` for further information.

(RDB) within the assimilation window between 2101 and 0900 UTC. These data are extracted in two phases. Data between 2101 and 0300 UTC are extracted from RDB at 1345 UTC; while data between 0301 and 0900 UTC are extracted from RDB at 1400 UTC. The 12 UTC analysis makes uses of all the observations available in RDB within the assimilation window between 0901 and 2100 UTC. Data between 0901 and 1500 UTC are extracted from RDB at 0145 UTC; while data between 1501 and 2100 UTC are extracted from RDB at 0200 UTC (Haseler, 2004).

The early delivery analyses make use of only six-hour observation windows. The 00 UTC analyses are obtained by assimilating all data within the assimilation window between 2101 and 0300 UTC that are available in RDB by 0400 UTC. The 12 UTC analyses are obtained by assimilating all data within the assimilation window between 0901 and 1500 UTC that are available in RDB by 1600 UTC. All the observations that fall into a given observation window but are not available in the RDB by the early delivery cut-off times can still be used in the delayed-cut-off analyses. We also note that the information from the data that cannot be actively assimilated in the early delivery system (but arrive in time for the delayed-cut-off) still indirectly affects the (early delivery) analyses as the first guess used in the assimilation are the three-hour forecasts from the delayed-cut-off.

Figures 1 and 2 show the data volume received by ECMWF within the analysis delayed-cut-off times given above relative to the total amount of data downloaded for TOSOMI and GOMOS, respectively. Values of 100% correspond to the total amount of data received within the analysis cut-off times. In contrast, 0% values mean that either there was an instrument unavailability or the total data volume was received after the cut-off times. It should be noted that because the information on the uploading times is only available on the remote (ESA and KNMI) servers for a short period (up to one week), it is not possible to cross-compare the uploading and downloading times for long periods. Therefore, delays in the data acquisition (values that are less than 100%) could be related either to delays in the data processing, or to server access problems.

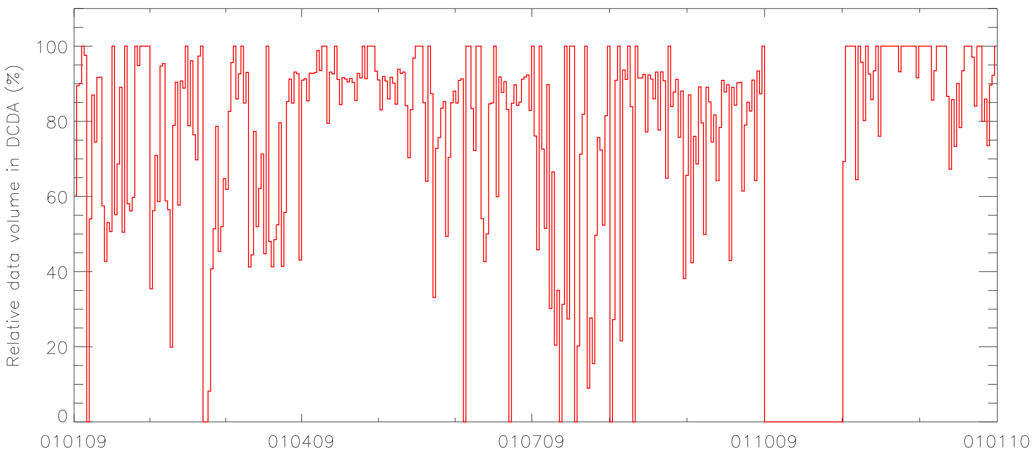


Figure 1: The 2009 time series of the TOSOMI total column ozone daily data volume received in time for the delayed-cut-off relative to the total daily data volume received. Values are in %.

Table 1 gives the annual mean percentage of data volume received in time for the delayed-cut-off analyses during 2009, and the corresponding annual mean values since 2006. Annual plots for the operability of ESA and KNMI products for the years from 2006 to 2008 were presented in Dragani (2008, 2009).

The best timeliness was found to be that of GOMOS products, with the 2009 value of 97.1% being the highest in the last four years. In contrast, the timeliness of the TOSOMI product has been degrading over the last four years from 89% in 2006 to 81% in 2009, with a drop of 8% in the last four years. It should be noted that in 2009

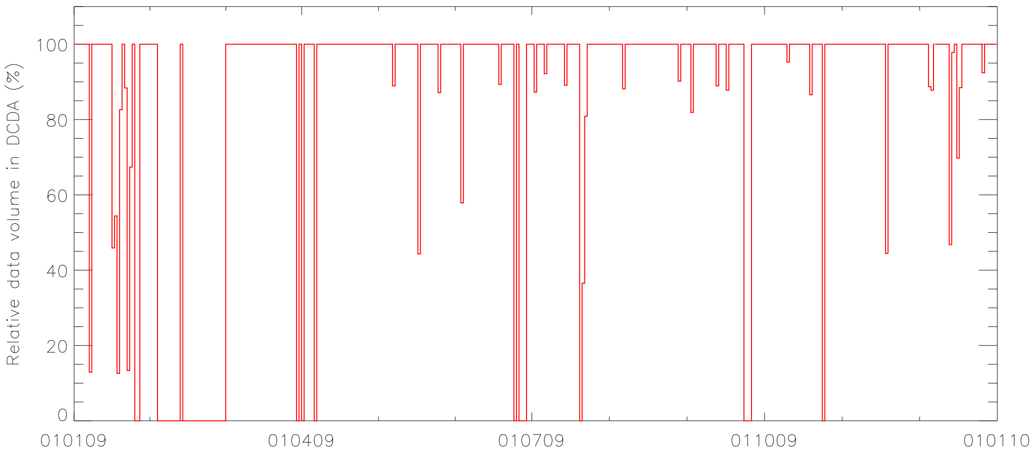


Figure 2: Like in figure 1, but for GOMOS data.

Year	GOMOS	TOSOMI
2006	96.1%	89.0%
2007	94.7%	83.1%
2008	96.4%	80.7%
2009	97.1%	81.0%

Table 1: Annual mean of the data volume received by ECMWF within the delayed cut-off times relative to the total amount of data delivered. Periods of total data unavailability (such as during instrument unavailability) were not included in the annual mean.

there was a small increase in the data volume arrived on time of +0.3% on average compared with 2008. These results were presented and discussed at two PROMOTE User meetings held at ACRI, in Sophia-Antipolis, France, on 16 March 2009 and in Frascati, Italy, on 29-30 October 2009, respectively.

3 Monitoring and assimilation of SCIAMACHY NRT total column ozone retrievals

SCIAMACHY (Burrows et al., 1988) measures sunlight transmitted, reflected and scattered by the Earth's atmosphere or surface in the ultraviolet, visible and near infrared wavelength region (240-2380 nm) at moderate spectral resolution (0.2-1.5 nm). SCIAMACHY provides global measurements of various trace gases including ozone in the troposphere and stratosphere, as well as information about aerosols and clouds. SCIAMACHY measurements are performed in three viewing modes: nadir, limb and occultation. Depending on the type of measurement mode, global coverage is achieved within 3 to 6 days, e.g. nadir measurements yield global coverage in about 6 days.

NRT total column ozone retrievals from the nadir measurements in the UV/VIS (SCI_RV__2P) were produced operationally by ESA until 8 May 2006. These retrievals were monitored passively[3] at ECMWF in the operational suite from February 2003 until the dissemination of the Level 2 products was stopped. The latest results

[3] Data go into the system, statistics are calculated e.g. statistical analyses of the differences between the model's first-guess or analysed fields and the observations, the so-called departures, but the data is not assimilated into the ECMWF model.

from the monitoring of ESA SCIAMACHY TCO for the period 1 January to 8 May 2006 were discussed by Dragani (2006).

In addition to the NRT ESA TCO, ECMWF has also been receiving NRT total column ozone data retrieved by KNMI from the nadir measurements in the UV/VIS spectral range and distributed via the ESA funded PROMOTE-2 consortium (the so-called TOSOMI product) since March 2004. This product differs from the operational ESA one as the retrieval procedure makes use of the Ozone Monitoring Instrument (OMI) Differential Optical Absorption Spectroscopy (DOAS) algorithm (Veefkind and de Haan, 2002), instead of a GOME Data Processor-like algorithm. Owing to the unavailability of the NRT ESA SCIAMACHY TCO retrievals, it was agreed that the TOSOMI product should be regarded as the operational ESA Level 2 total column ozone retrieval from SCIAMACHY (Minutes of the ENVISAT progress meeting held at ECMWF on 6 December 2006).

The TOSOMI product was passively monitored at ECMWF from March 2004 to 27 September 2004. Based on the positive impact that these data could make on the ECMWF ozone analyses, especially in the Antarctic polar vortex region (Dethof, 2004), the operational assimilation of this product started on 28 September 2004, when the model was updated to cycle CY28R3. On 18 December 2008, the TOSOMI assimilation was temporarily turned off as the SCIAMACHY instrument underwent a decontamination period that could have affected the quality of the ozone retrievals (R. Van der A, KNMI, personal communication). Nonetheless the dissemination from KNMI continued without disruptions during the entire period. It is anticipated that assimilation experiments performed with the data received immediately after the SCIAMACHY decontamination period showed that the assimilation of this product could lead to degraded forecasts, as well as degraded ozone analyses compared with independent, unassimilated observations. These results will be discussed in section 3.2. A possible reason for such a degradation was believed to be the inter-instrumental biases affecting the ozone observations, and in that case the assimilation of SCIAMACHY TCO could be contemplated again only when a ozone bias correction scheme could be used. A variational bias correction scheme (VarBC) for retrieval products in general, and ozone in particular, was tested during the first half of 2009, and then operationally implemented in cycle CY35R3 in September 2009. In section 3.3, it will be shown that with VarBC the assimilation of SCIAMACHY TCO can still be beneficial and lead to small improvements both on the temperature and geopotential forecasts scores and on the ozone analyses.

A summary of the monitoring of TOSOMI total column ozone during 2009 is provided in sections 3.1. Results from two sets of assimilation experiments will be discussed in sections 3.2 and 3.3, respectively. The results for the period January-December 2008 were discussed in Dragani (2009).

3.1 Monitoring of NRT TOSOMI SCIAMACHY ozone column retrievals produced by KNMI

The TOSOMI product was routinely monitored at ECMWF during the entire 2009. Figure 3 presents the timeseries of globally averaged NRT TOSOMI ozone data, its averaged departures, standard deviations, and number of data actively assimilated with respect to the number of available observations for the periods January to June 2009 (l.h.s. panels), and July to December 2009 (r.h.s. panels), respectively. Focussing on the second panels from the top (showing the fist guess and analysis departures), one can recognize five different behaviours, as follows:

- **1 - 9 Jan:** The SCIAMACHY first-guess and analysis departures are negative and about -5DU, SCIAMACHY values being lower that the ECMWF ozone first guess and analyses. These residuals are consistent with what observed at the end of December 2008 (see figure 4) after the active assimilation of SCIAMACHY was turned off and its subsequent four-day spin-up period ended.

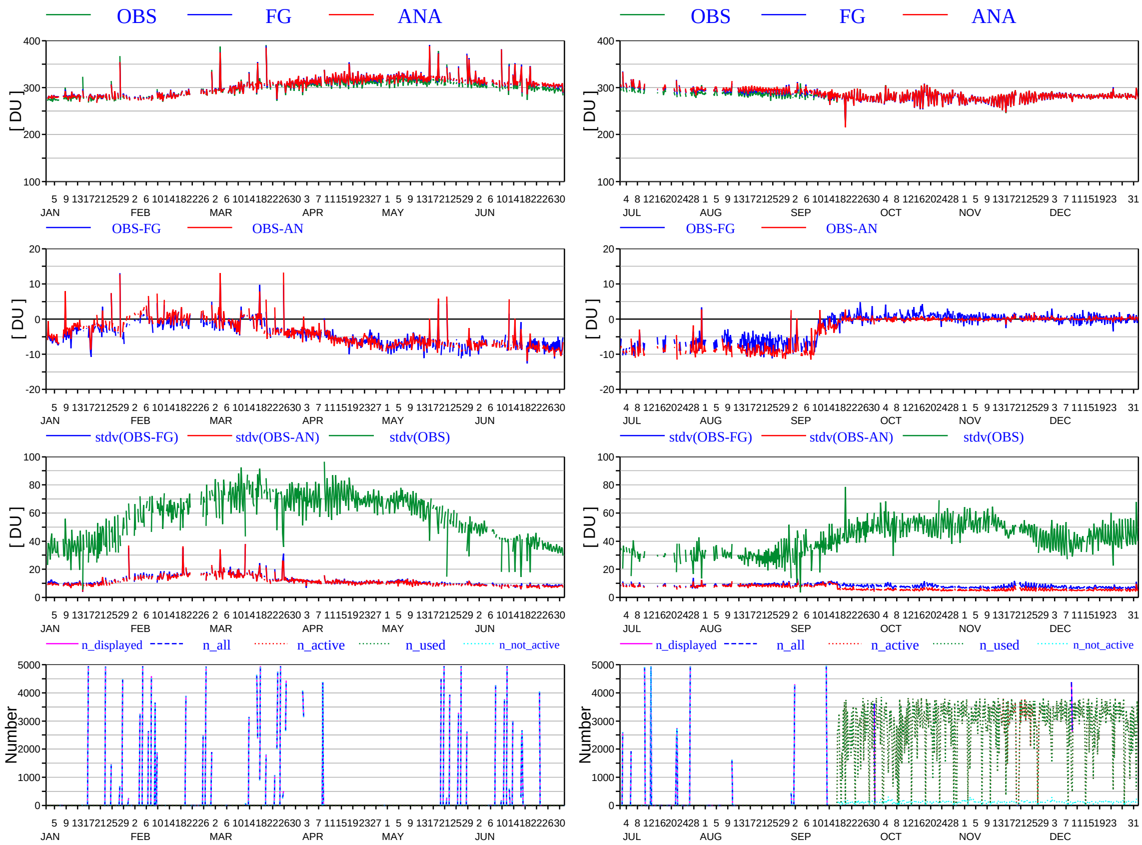


Figure 3: Timeseries of globally averaged data covering the periods 1 January to 30 June (left panel), and 1 July to 31 December 2009 (right panel). The top panels of each figure show TOSOMI SCIAMACHY NRT total ozone observations, first-guess and analysis values, the middle panels first-guess and analysis departures and the bottom panels the standard deviations of SCIAMACHY and of first-guess and analysis departures. All ozone values are in DU.

- **10 - 28 Jan:** The SCIAMACHY first-guess and analysis departures decreases from about -5DU to a mean value of about -3DU. The reduction in the first-guess and analysis departures was caused by the assimilation of some OMI pixels that were found to be affected by anomalies at a later stage. This apparently better agreement between the ECMWF ozone field and the corresponding SCIAMACHY observations should not regarded as an objective improvement in the quality of the ECMWF ozone first-guess and analyses. Eskes et al. (2005) showed that the KNMI SCIAMACHY TCO product is biased compared with co-located observations, and in particular that these retrievals were found to be -1.7% lower than ground-based measurements and about -1.5% lower than GOME TCO data.

- **29 Jan - 18 Mar:** On 28 January 2009, the assimilation of OMI data was completely turned off as a consequence of the anomalies affecting some of the pixels. The active assimilation of OMI was only restarted after isoliting and removing the anomaly-affected pixels, and proving that the remaining pixels were still beneficial. During this period the ozone analyses were only weakly constrained by the NOAA-17 and NOAA-18 SBUV/2 partial column ozone.

- **19 Mar - 8 Sep:** After the activation of OMI assimilation, the SCIAMACHY first-guess and analysis departures increased again to about -7DU. As noted above, this should not be regarded as or it is not necessary an indication of degradation of the ozone analyses given the bias affecting SCIAMACHY data.

- **9 Sep - onwards:** On 8 September 2009, ECMWF implemented a new operational cycle (CY35R3) that among several other features included the extention of the variational bias correction scheme (VarBC), already used for radiances, to retrieved products in general, and ozone in particular. The operational availability of VarBC allowed ECMWF to restart the assimilation of SCIAMACHY TCO that still proved to be beneficial in improving both the forecasts scores and the ozone analyses. These results will be discussed in details in section 3.3.

As also reported by Dragani (2008, 2009), the standard deviation of the observations (green line in the third row panels from the top of figure 3) during the second half of the year shows slightly smaller mean values, as well as a smaller variability than that seen during the first six months. Also the standard deviations of the first-guess and analysis departures (blue and red lines in the third row panels from the top respectively) are slightly reduced after the assimilation of SCIAMACHY TCO restarted in September 2009. This reduction, although apparently small (typically 1 to 2 DU smaller), still represents about 10-20% of the annualy mean value.

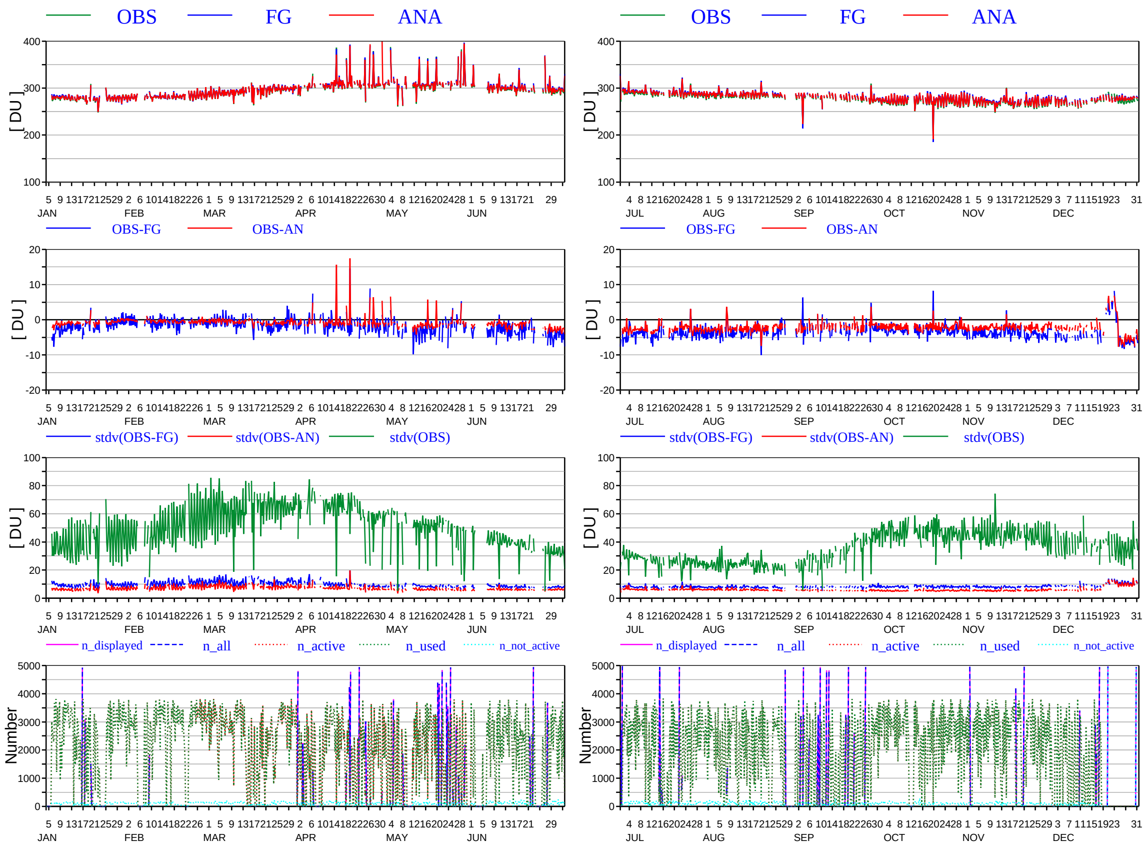


Figure 4: Like in figure 3, but for 2008.

The generally good behaviour of the TOSOMI data can also be seen in the timeseries of the zonal mean first guess departures shown in figure 5. On average the first-guess departures (top panel in figure 5) are within ±10 Dobson Unit (DU) at most latitudes, that represents about 3% of the global mean total column ozone value. However, a lower level of agreement between the model and the observations near the end of the illuminated part of the orbits is observed especially in the winter hemisphere, and it is more pronounced in the NH than in the SH.

The lower level of agreement at high latitudes reflects in the observation standard deviations (bottom panel in figure 5) which exhibit higher values than average at the same locations in the winter hemisphere. Here, the observation standard deviation can reach values of 50 to 70 DU. In the tropics the observation standard deviation exhibits smaller values, typically around 10DU[4] or less.

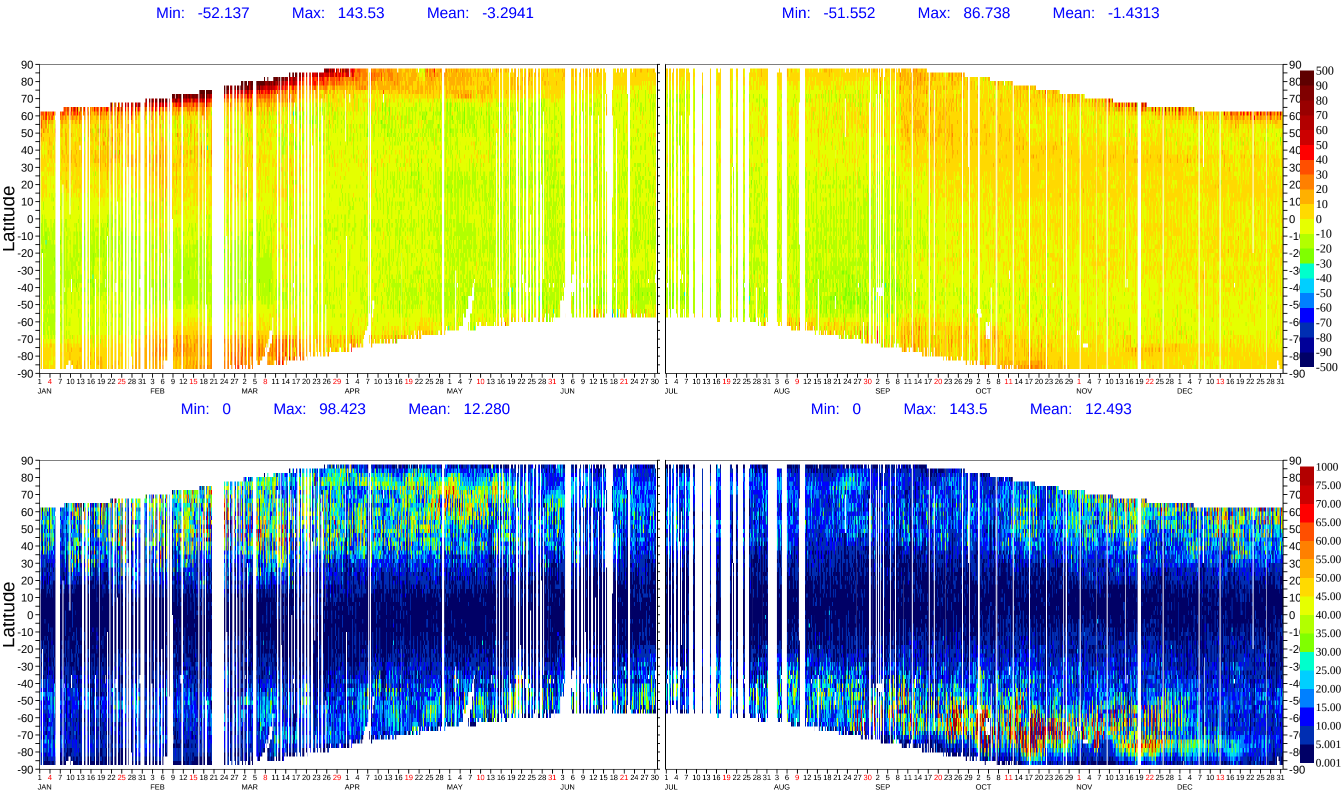


Figure 5: Time series of the zonal mean NRT SCIAMACHY first-guess departures (top panel) and of the zonal mean NRT SCIAMACHY standard deviation (bottom panel) during 2009. All ozone values are in DU.

Comparisons with total column ozone data from other UV instruments also show the generally good quality of these observations. Figure 6, in particular, shows the comparison between the time series of the zonal mean SCIAMACHY total column ozone (top panel) and of the zonal mean OMI total column ozone (bottom panel) for the whole 2009. The OMI data used in the comparisons are the NRT total column ozone distributed by NASA. On average, figure 6 shows a good level of agreement between SCIAMACHY and OMI total column ozone. Some differences can be found in the tropics, where SCIAMACHY usually exhibits lower values than OMI throughout the year, and at high latitudes where the OMI ozone values are lower than those for SCIAMACHY. It should be noted that UV nadir sensors like OMI and SCIAMACHY[5] are prone to provide less accurate measurements near the end of the illuminated part of the orbits, as noted in the bottom panel of figure 5, and therefore the large differences at these latitudes should be of a less concern provided that the poorer quality of the data reflects in the observation errors.

Figure 7 shows the time series of the zonal mean difference between SCIAMACHY TCO and MetOp-A GOME-2 TCO for 2009. The GOME-2 TCO used here is the operational TCO product provided in NRT by EUMETSAT. In this comparison, the differences are smaller and about 10DU at most latitudes on average, with the exception of the end of the illuminated part of the orbits in the NH during spring 2009, where the differences were up to 60DU. In contrast to the comparison with OMI TCO, figure 7 shows that SCIAMACHY has on average larger TCO values than GOME-2.

[4] This is consistent with what was found in the 2006, 2007, and 2008 studies (Dragani, 2006, 2008, 2009).

[5] The SCIAMACHY TCO used are those retrieved from the nadir measurements only.

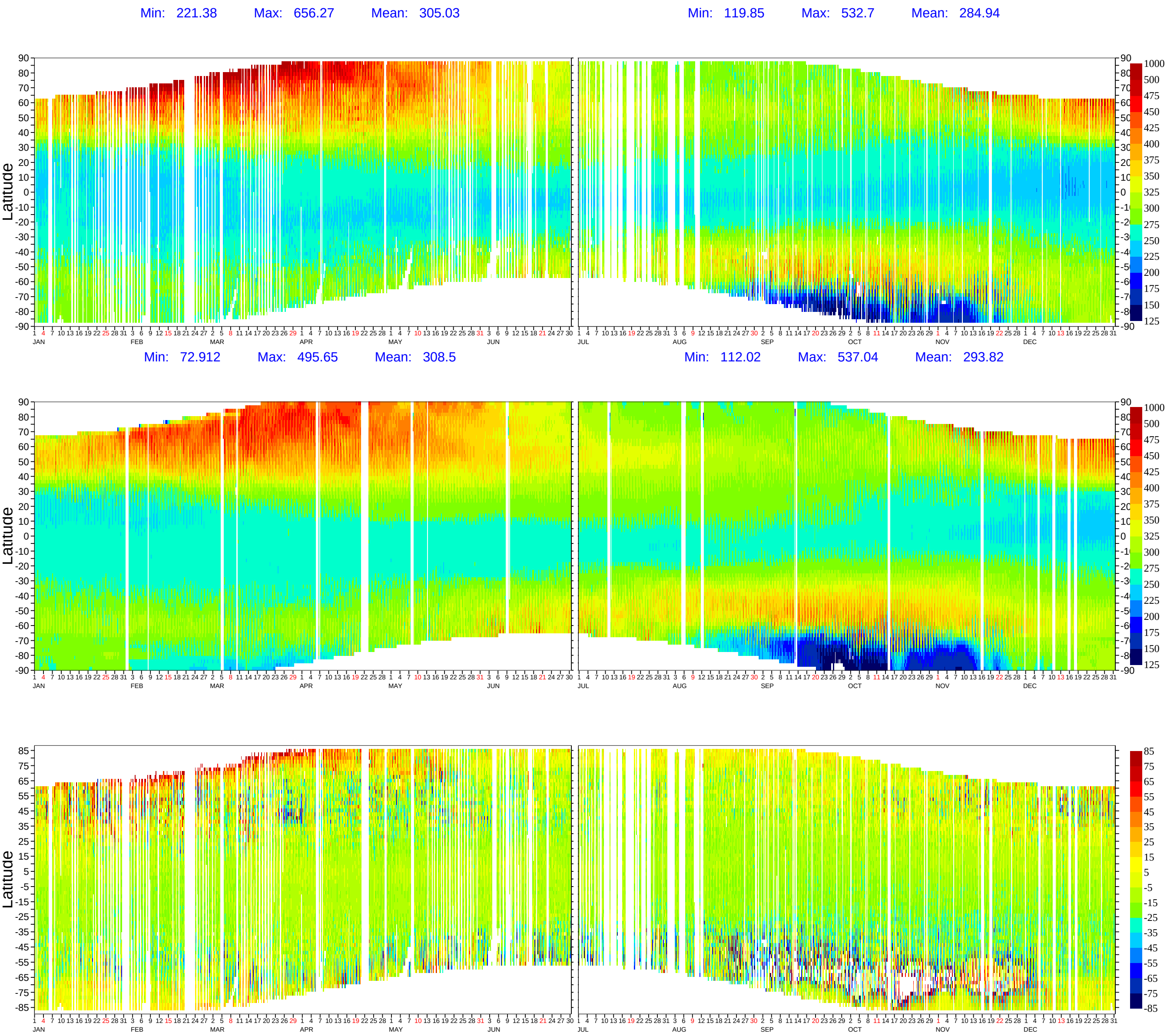


Figure 6: Time series of the zonal mean NRT SCIAMACHY ozone (top panel), OMI total column ozone (middle panel), and their difference (bottom panel) for 2009. All ozone values are in DU.

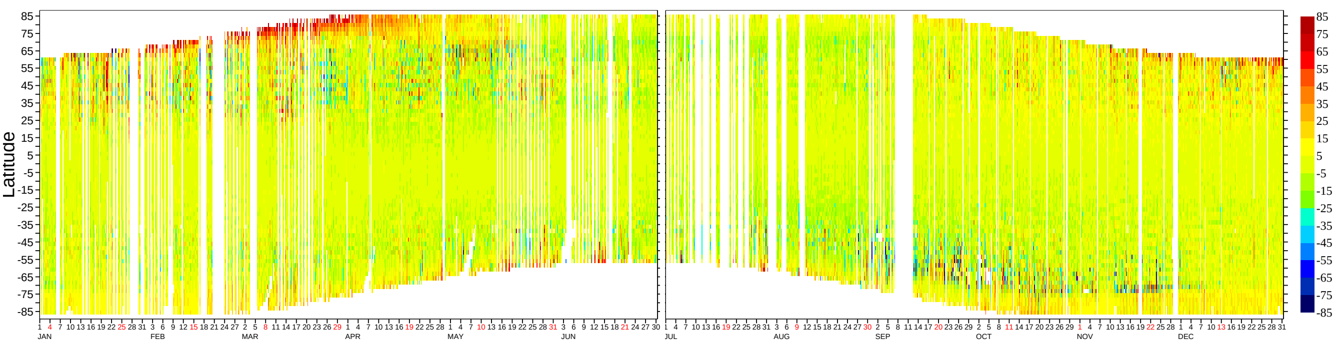


Figure 7: Time series of the zonal mean difference between SCIAMACHY TCO and GOME-2 TCO for 2009. Values are in DU.

3.2 Assimilation of NRT TOSOMI SCIAMACHY ozone column retrievals produced by KNMI after the instrument decontamination (without VarBC)

After the decontamination of SCIAMACHY was terminated, nearly a two-month assimilation experiment was run aiming at verifying that neither the forecasts scores nor the quality of the ozone analyses could be degraded by the potential restart of the assimilation of the TOSOMI product. Two assimilation experiments covering the period from 8 January to 28 February 2009 were performed at a resolution of T159 on the standard 91 vertical levels from surface up to 0.01hPa. All the radiance data assimilated operationally were also used in these experiments. Regarding the ozone products, the NOAA-17 and NOAA-18 SBUV/2 partial column ozone were actively assimilated in the control experiment (referred to as CTRL). Because of the anomaly found in the OMI data, this product was not assimilated. A variational bias correction (VarBC) scheme was used to correct the biases in the level 1 data but not in the retrieved products. A perturbation experiment (referred to as SCIA) was also run, using the same configuration of the CTRL experiment, the only difference being the assimilation of the TOSOMI ozone data in addition to the SBUV/2 products. SCIAMACHY nadir measurements have a typical horizontal resolution of 30 km (along track) x 60 km (across track), but its retrievals were pre-thinned to a horizontal resolution of 1°x 1° before the assimilation, as it was normally done in the operational assimilation system. Comparisons of the ozone analyses from both the CTRL and SCIA experiments with independent, unassimilated ozone data were performed to assess the impact of TOSOMI on their quality. In addition, the impact of the assimilation of TOSOMI on the temperature and geopotential height forecasts scores was also assessed. These results are discussed below.

Figure 8 shows the RMS fit of the ozone analyses from the two experiments to MLS ozone profiles. The larger the RMSE the worse is the agreement between the MLS ozone profiles and the co-located ozone analyses. The assimilation of TOSOMI data degraded the fit to MLS data at most vertical levels and latitudinal bands. This degradation appears particularly strong at high latitudes in both hemisphere, but also in the tropical lower stratopshere. Similar comparisons were also performed against ozone sonde profiles. These results are shown in figure 9, and they generally confirm those found in figure 8, particularly the degradation at high latitudes. The degradation in the tropics found in the comparisons with ozone sondes seems to be less important than that from the comparison with MLS data. Conversely, the degradation at midlatitudes showed in figure 9 appears less negligible than that in figure 8.

In addition to the degradation in the quality of the ozone analyses, also the temperature and the geopotential height forecast skills were reduced by the assimilation of TOSOMI. Figures 10 and 11 show the control normalized RMS error forecast for the CTRL minus SCIA experiments expressed as function of the forecast day and evaluated in the temperature and geopotential height, respectively. In both figures, panels a) refer to the RMS error forecast at 200hPa (a), while panels b) show similar plots at 500hPa. Negative mean values (given by the solid black line) mean that the assimilation of SCIAMACHY increases the RMS error forecast and therefore degrades their quality. The error bars give the statistical significance of the results by providing the range of variability around the mean with a confidence level of 95%. The assimilation of TOSOMI was found to degrade the temperature forecasts around 200hPa between days 2 and 3, and at 500hPa from days 1 to 4. The impact on the geopotential height appears less important. At 200hPa, after an initial improvement between days 1 and 2 led by the assimilation of TOSOMI, a small but statistically significant degradation was found between days 2 and 5. Such a degradation was also seen to extend to the middle troposphere around 500hPa.

It was believed that the degradation led by the assimilation of TOSOMI data could be related to the already documented bias of this product (Eskes et al., 2005) rather than to a consequence of the instrument decontamination. This was confirmed by the results from new assimilation experiments that were run after the implementation of the VarBC scheme was extented to level 2 products in general, and ozone in particular. These results are discussed in section 3.3.

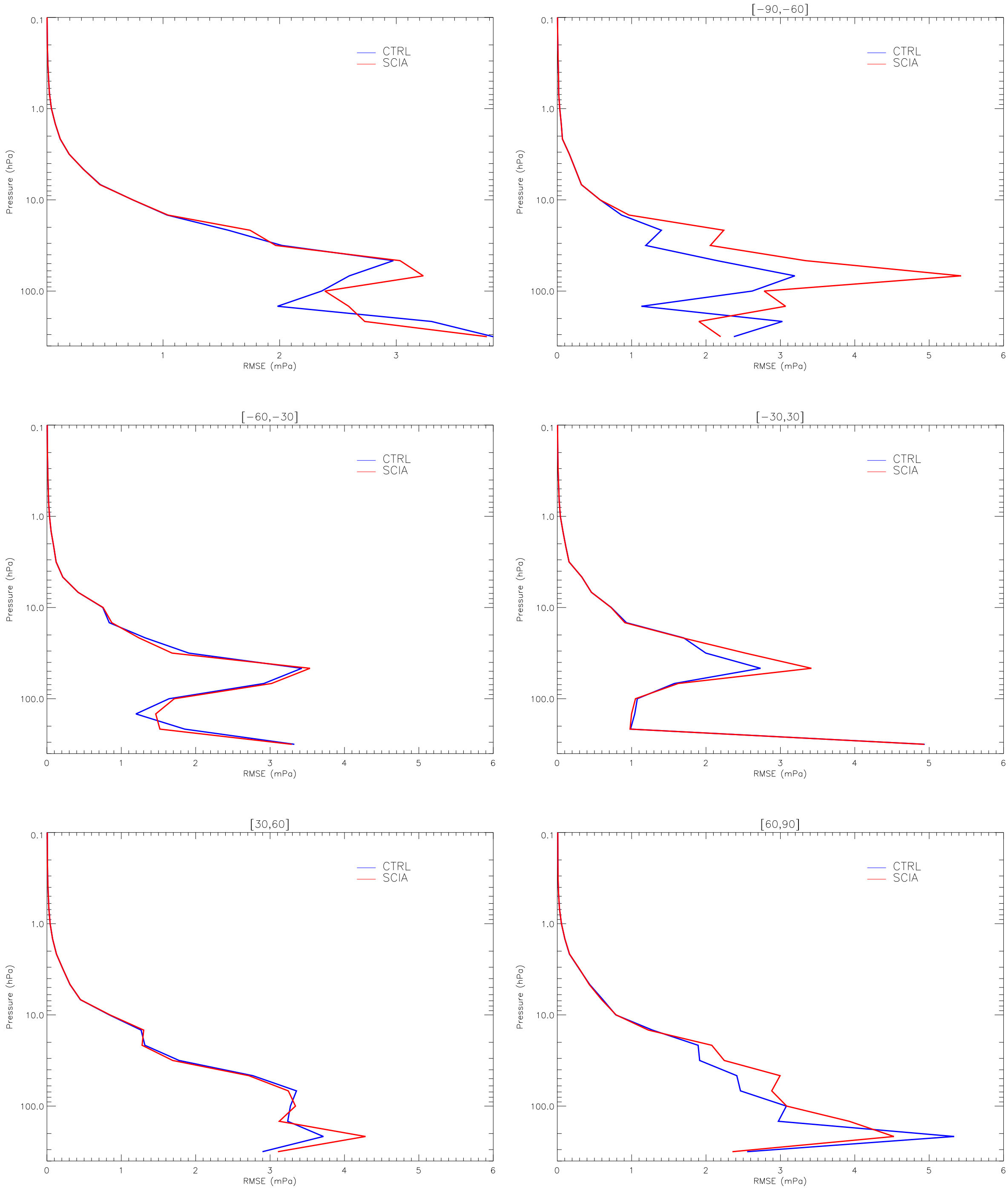


Figure 8: RMS fit of the CTRL (blue lines) and SCIA (red lines) mean ozone analyses and the mean MLS ozone profile. The average period is that from 8 January to 28 February 2009. Top left panel shows the global mean comparison, while all other panels refer to mean over limited latitudinal bands as stated in each panel's title. Data are in mPa.

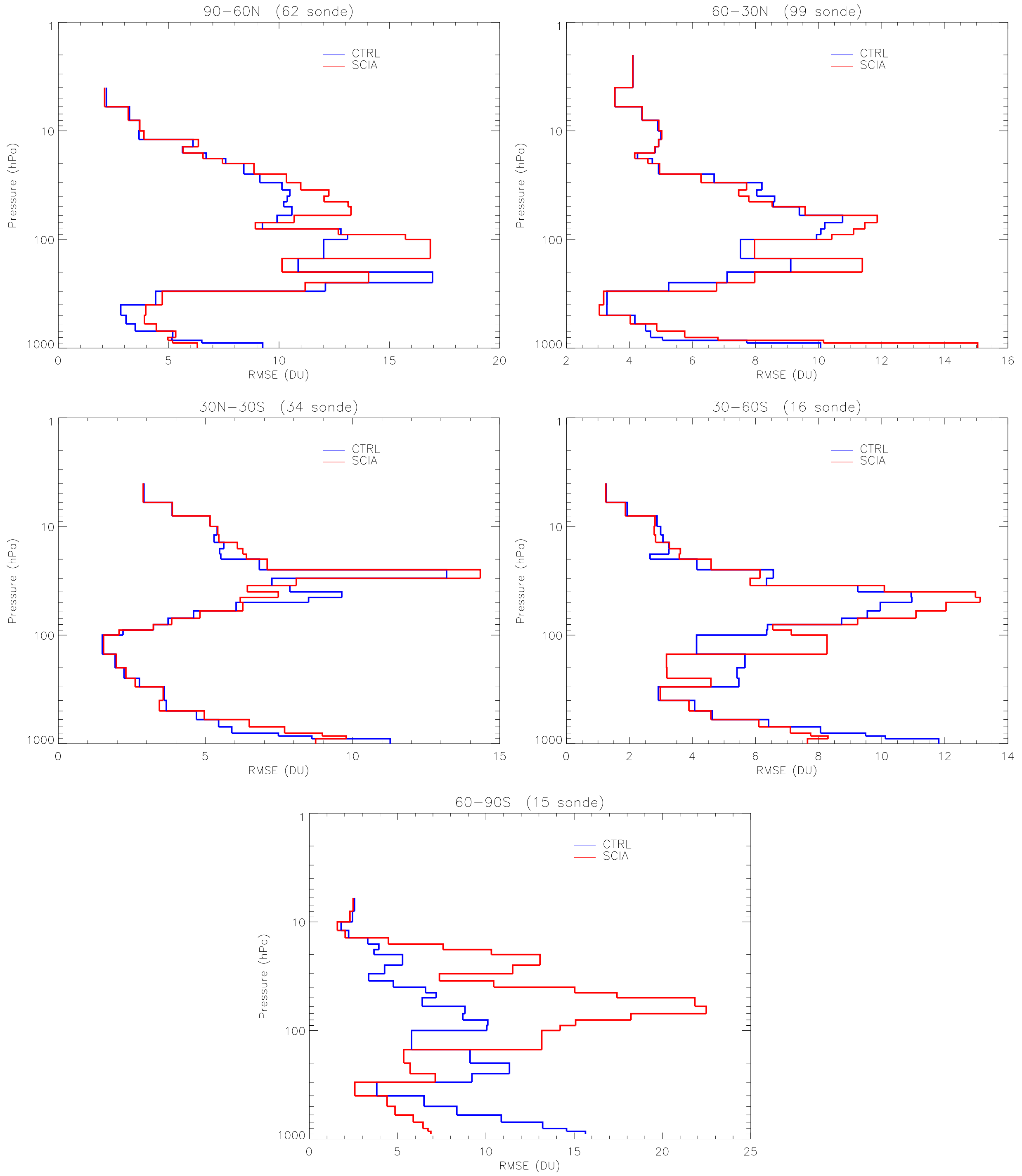
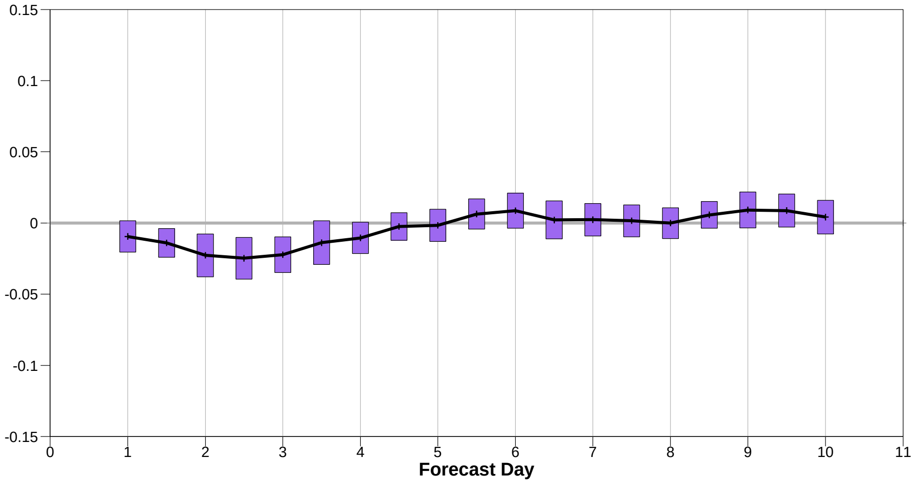
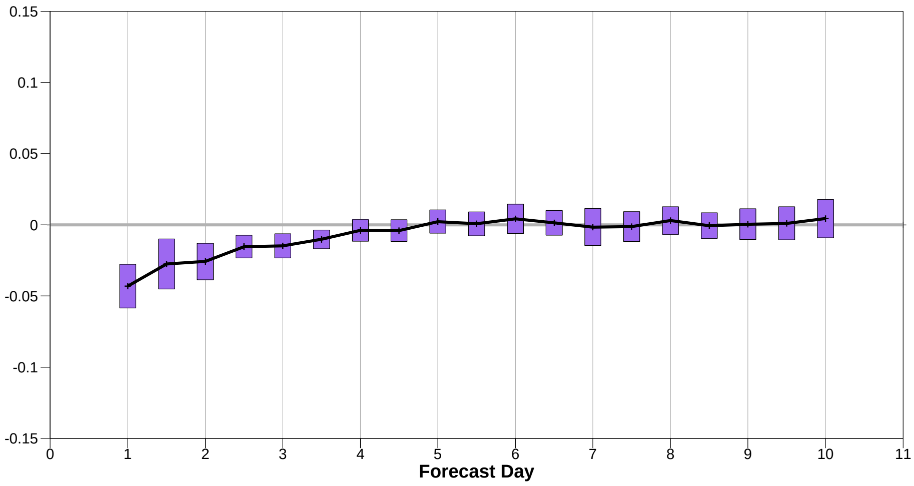


Figure 9: Like in figure 8, but in the comparisons with ozone sondes. Each panel refers to a limited latitudinal band, as stated in the corresponding title. The number of ozone profiles used varied from case to case and it is also reported in each panel's title. Data are in DU.

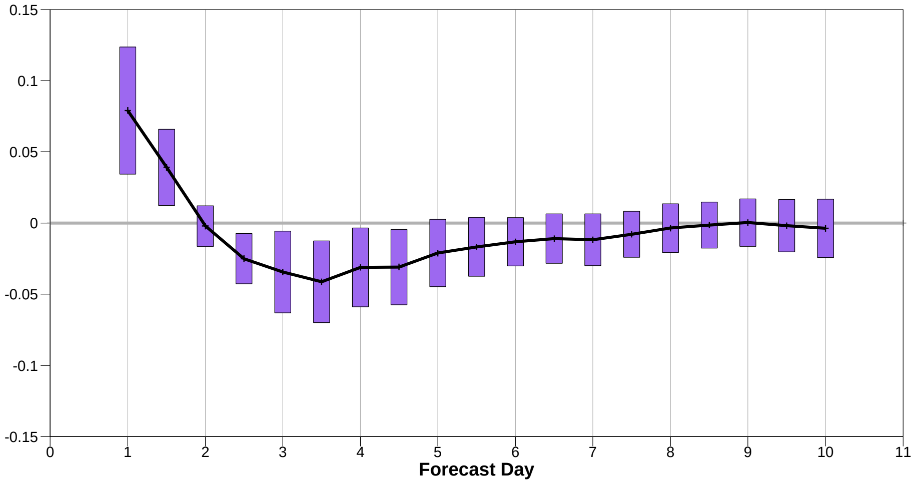


(a)

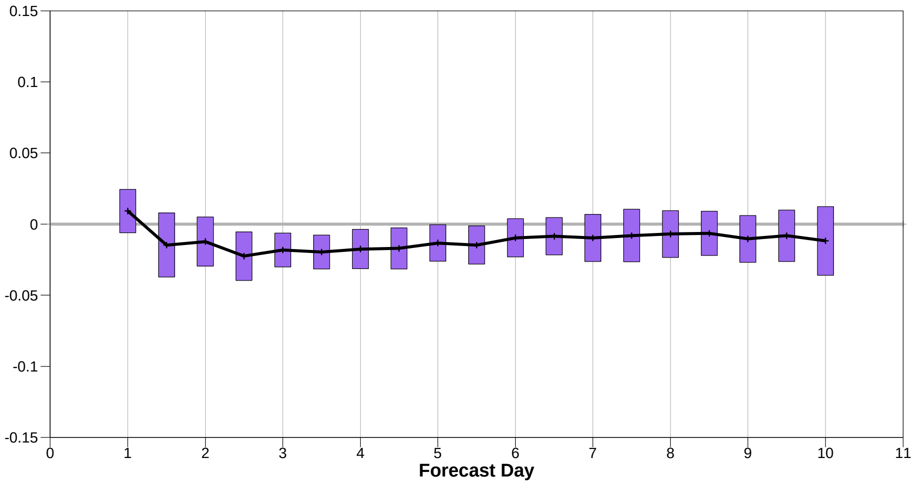


(b)

Figure 10: Control normalized RMS error forecast for the CTRL minus SCIA experiments evaluated in the temperature field at 200hPa (a), and 500hPa (b) as function of the forecast day. The solid line shows the mean RMSE, the bar gives the range of variability around the mean with a confidence level of 95%. Negative values mean that the assimilation of SCIAMACHY increases the RMS error forecast and therefore degrades their quality. These statistics were calculated using a population of 59 members.



(a)



(b)

Figure 11: Like in figure 10, but for the geopotential height.

3.3 Assimilation of NRT TOSOMI SCIAMACHY ozone column retrievals produced by KNMI after the instrument decontamination (with VarBC)

This section discusses the results from a new assimilation study of TOSOMI data performed after the implementation of the VarBC scheme was extented to level 2 products, and in particular to ozone. Two three-month long assimilation experiments covering the period from 1 May to 31 July 2009 were performed at a resolution of T255 on the standard 91 vertical levels. All the radiances assimilated in the operational system were also used in these experiments. Regarding the ozone products, the OMI TCO and the NOAA-17 and NOAA-18 SBUV/2 partial column ozone were actively assimilated in the control experiment (referred to as CTRL). The anomaly in the OMI data was seen to affect only certain pixels, that were filtered out in the assimilation. A parallel study, not discussed here, showed that the assimilation of the not-anomaly-affected OMI pixels was beneficial and could improve the quality of the ozone analyses and produce some small improvements in the forecast scores. A perturbation experiment (also referred to as SCIA in the following plots) was run. This experiment used the same configuration of the CTRL experiment, and only differed from CTRL because of the assimilation of TOSOMI in addition to the OMI and SBUV/2 products. As already mentioned in section 3.2, SCIAMACHY retrievals were pre-thinned to a horizontal resolution of 1°x 1° before the assimilation. The VarBC scheme was applied to both radiances and ozone products. In the latter case, it should be noted that the SBUV/2 partial column ozone were used as anchor to VarBC and therefore they were not bias corrected. This decision followed the results of a previous study that showed that, due to its intrinsic bias, the model ozone could not be taken as a reference to correct the bias in the observations, and that analyses that better compared with independent observations could, instead, be obtained by using the SBUV/2 retrievals as reference.

Figure 12 shows the RMS fit of the ozone analyses from the two new experiments to MLS ozone profiles. The larger the RMSE the worse is the agreement between the MLS ozone profiles and the co-located ozone analyses. With the aid of VarBC, the assimilation of TOSOMI data slightly improves the fit to MLS data particularly in the SH and in the tropics.

Small but statistically significant improvements led by the assimilation of the bias corrected TOSOMI data were also found in the forecast scores. Conversely to the assimilation case without VarBC (discussed in section 3.2) where statistically significant changes where mainly localized in the middle troposphere between 200 and 500hPa and affected the RMSE forecast error but not the anomaly correlation forecasts (ANCF), the results discussed here appear to be more widely distributed in the vertical and have affected both RMSE and ANCF, but mainly in the SH extra-tropics. Only the cases with statistically significant changes are shown. Figure 13 shows ANCF at 200 (panel a) and 100hPa (panel b), and RMSE at 100hPa (panel c) in the temperature field in the extra-tropics in the SH. Positive values mean that the assimilation of SCIAMACHY TCO is improving the forecast scores. The assimilation of TOSOMI data produces small but statistically significant improvements in the temperature ANCF at 100 between days 3 and 4 and also between days 7 and 8 (panel a). During the latter period, improvements were also found in the temperature ANCF at 200 hPa (panel b) and in the temperature RMSE at 100 hPa (panel c) in the SH. Small but statistically significant improvements were also seen in the geopotential height (Z) forecast scores in the extra-tropics in the SH (figure 14). Panels a) and b) show the Z ANCF at four vertical levels (850, 500, 200, and 100 hPa) as stated in the legend; panels c) and d) show the Z RMSE forecast at the same four levels. Positive mean values (i.e. improvement) were found in the ANCF at 850, 500, and 200hPa between days 2 and 4, and at 100hPa between days 4 and 6. The Z RMSE forecast also shows similar signature, particularly at 850 and 500hPa.

These results showed that with VarBC useful information could still be extracted from the TOSOMI data, and that its assimilation was still able to produce small but statistically significant improvements on the the forecast scores and on the quality of the ozone analyses. Following these results, the active assimilation of TOSOMI retrievals restarted in September 2009 when the ozone VarBC scheme became operational.

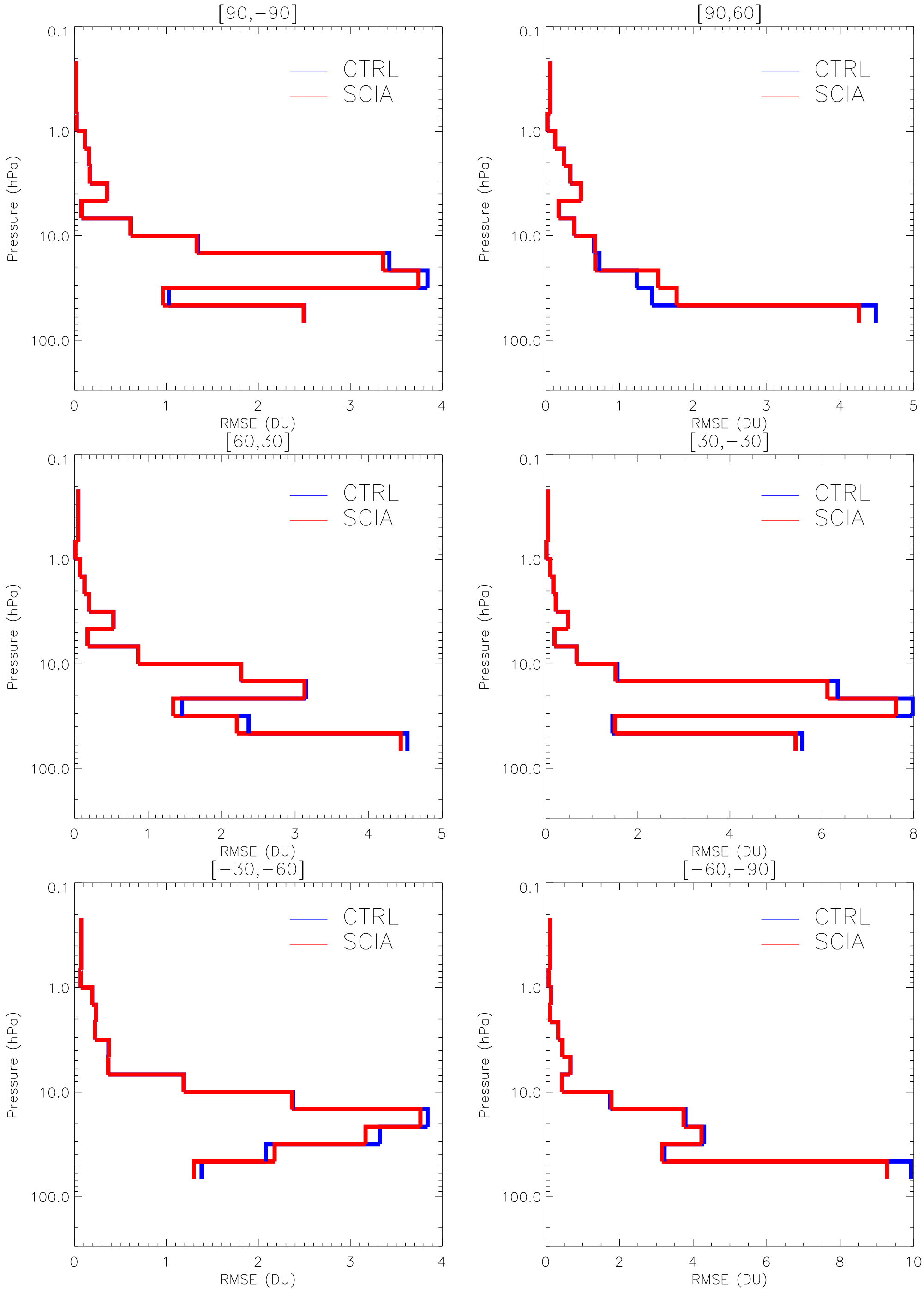


Figure 12: Like in figure 8, but for the new assimilation experiments using VarBC. All ozone values are in DU.

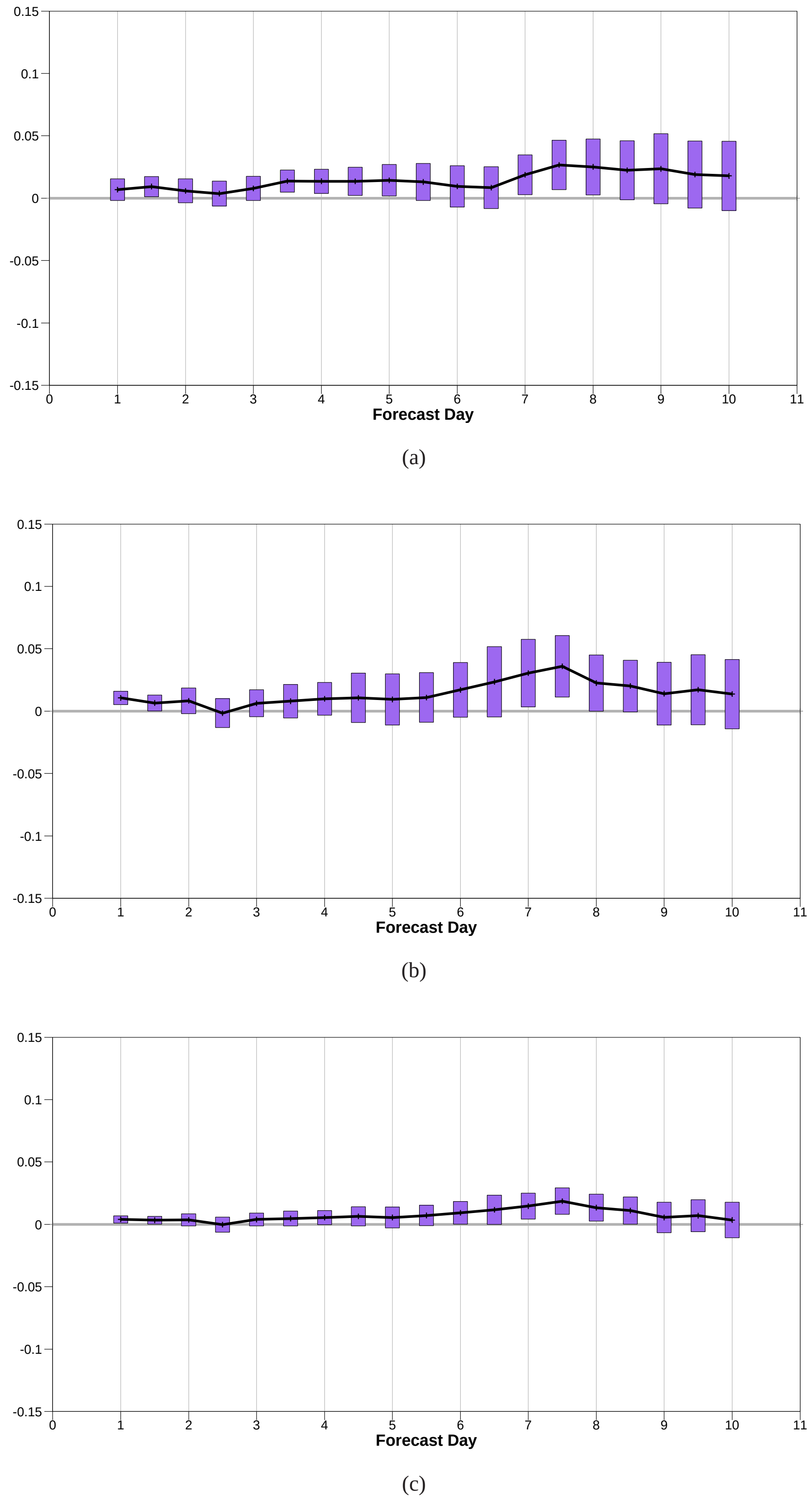
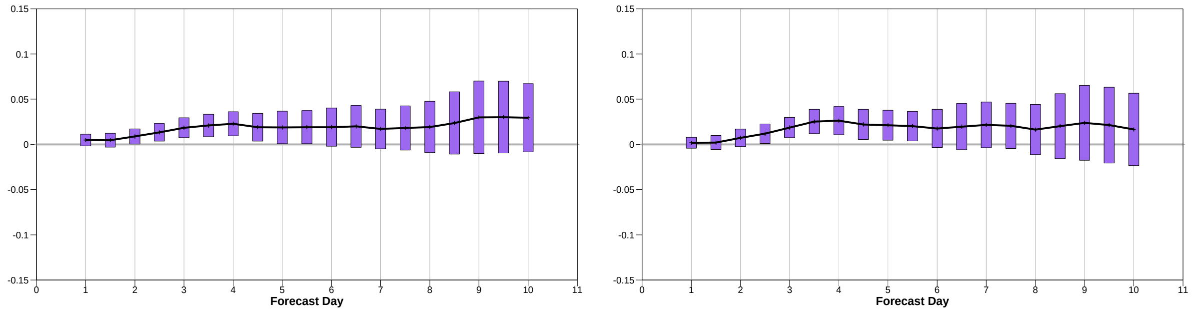
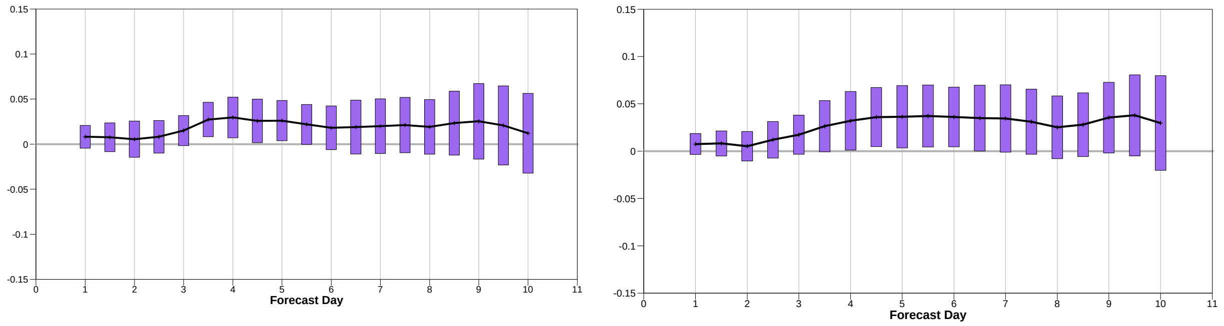


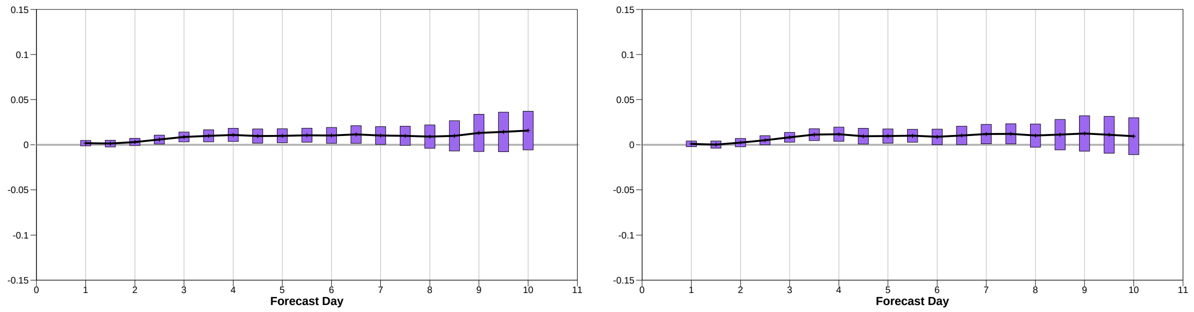
Figure 13: Like in figure 10, but for the new assimilation experiments using VarBC. Panels refer to the ANCF in T at 200 (panel a) and 100hPa (panel b) in the SH, and to the RMSE in T at 100hPa in the SH (c). Positive values mean that the assimilation of SCIAMACHY TCO is improving the forecast scores. These statistics were calculated using a population of 81 members.



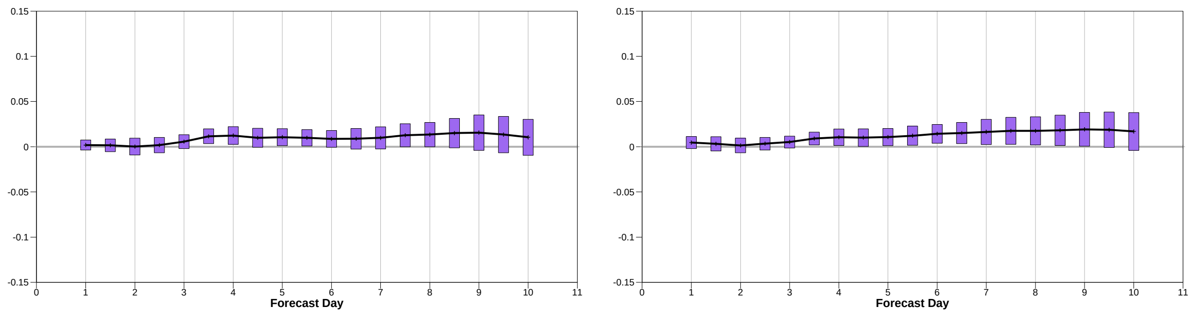
(a)



(b)



(c)



(d)

Figure 14: Like in figure 13, but for the geopotential height in the SH. Panels (a) refer to the ANCF at 850 (left) and 500hPa (right); panels (b) refer to the ANCF at 200 (left) and 100hPa (right). Panels (c) refer to the RMS error forecast (REF) at 850 (left) and 500hPa (right); panels (b) refer to the REF at 200 (left) and 100hPa (right).

3.4 Summary of the NRT SCIAMACHY monitoring and assimilation

The NRT SCIAMACHY ozone columns produced by KNMI (TOSOMI) were available during 2009. The active assimilation of this product was stopped on 18 December 2008 when the SCIAMACHY instrument underwent a decontamination period that was thought to affect the quality of the ozone retrievals (R. Van der A, KNMI, personal communication). Assimilation tests run to assess the impact of assimilating the TOSOMI data retrieved after the instrument decontamination showed potential degradation produced on the ECMWF temperature and geopotential height forecast scores. In addition, also the quality of the ECMWF ozone analyses was found reduced by the assimilation of TOSOMI data with a degraded fit to independent, unassimilated observations (MLS ozone profiles and ozone sondes). This degradation was thought to be related to the bias in the TOSOMI data.

In September 2009, the variational bias correction (VarBC) scheme successfully used to correct the radiance bias was updated to also correct the bias in the level 2 data, particularly in the ozone products. New TOSOMI data assimilation experiments run using the ozone VarBC showed that, after removing the instrumental bias, useful information could still be extracted from SCIAMACHY TCO and that the assimilation of this product could lead to improved temperature and geopotential height forecasts as well as improved ozone analyses.

Following the results from the latest experiments, the operational assimilation of TOSOMI TCO restarted in September 2009 with cycle CY35R3 when the implementation of VarBC was updated to bias correct the retrieval products in addition to radiances.

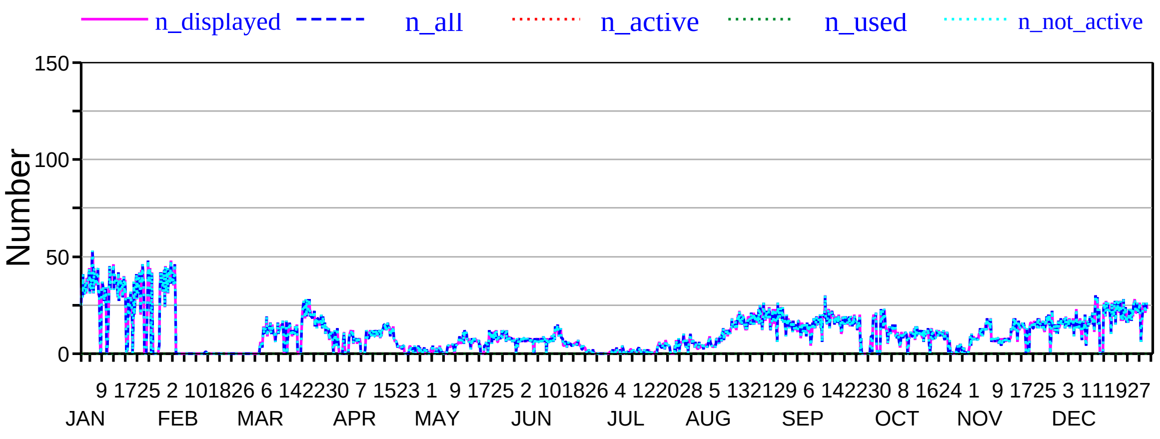
4 Monitoring of GOMOS data

GOMOS makes use of the occultation measurement principle by tracking stars as they set behind the atmosphere. GOMOS has an ultraviolet-visible and a near-infrared spectrometer, covering the wavelength region between 250 and 950 nm. It allows the retrieval of atmospheric trace gas profiles in the altitude range 100-15 km, with an altitude resolution better than 1.7 km. GOMOS gives day- and night-time measurements with about 600 profiles per day. The primary GOMOS target species are O_3, NO_2, NO_3, OClO, H_2O and temperature (fixed to the ECMWF temperature forecasts in v5.00).

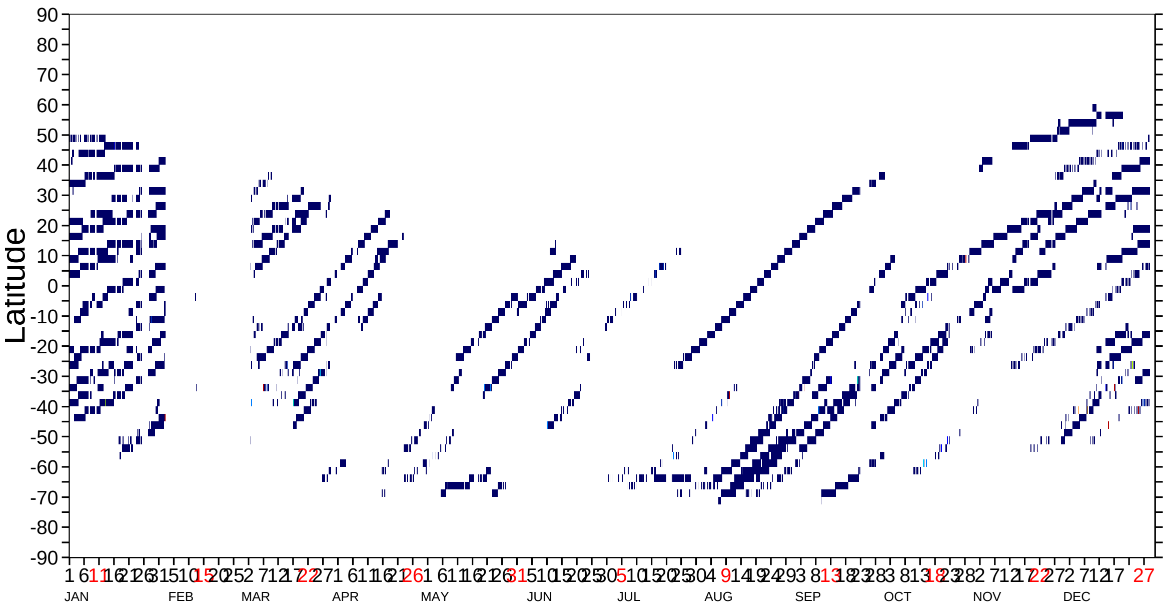
A subset of these retrieved products that is available in NRT (GOM_RR__2P) is routinely and passively monitored at ECMWF. This subset includes temperature, water vapour and ozone profiles.

The GOMOS data were available during most of 2009. However, the instrument suffered of serious anomalies starting from the beginning of February 2009 that mainly affected the pointing system. For that reason, the GOMOS instrument was not operated during February, and no data were therefore available. Because these anomalies affected the pointing system, their main consequence resulted in a reduced amount of data, particularly in the stratosphere, during most of the year. In some cases, the amount af stratospheric data was too low to make the results statistically significant.

Figure 15 shows the time series of the global number of GOMOS ozone observations (top) and of the zonal mean GOMOS temperature (bottom) during 2009, respectively. The plots refer to a mesospheric layer and they are intended to provide a general indication of the daily amount of available data (panel **a**) and their geographical coverage (panel **b**) provided by the instrument during 2009. The panel **a)** of figure 15 shows that, after the anomaly that affected the GOMOS instrument at the beginning of February 2009, the amount of daily data provided in January reduced on average of about 50% or more during the rest of the year. The panel **b)** of figure 15 shows that a large number of observations were discarded in the NH during 2009. This was also noted during 2008 Dragani (2009), and it is believed being a result of the data filtering implemented in the BUFR converter[6] in May 2007 (Dragani, 2008).



(a)



(b)

Figure 15: Time series of the global number of GOMOS observations (panel a) and their latitudinal distribution (panel b) during 2009. The plots refer to the mesospheric level between 0.1 and 0.2 hPa.

[6] The data sampled in bright, twilight or straylight limb conditions are discarded as they are of poor quality and not suited for scientific studies. See the GOMOS quality disclaimer available at `http://envisat.esa.int/dataproducts/availability/disclaimers/` and Meijer et al. (2004) for more information.

4.1 Monitoring of GOMOS temperature data

The quality of the temperature profiles in the BUFR files was generally stable during 2009, and consistent with the temperature data retrieved in 2008 (Dragani, 2008). However, as already anticipated in section 4, at some stratospheric levels the amount of available observations was strongly reduced after the anomaly that affected the GOMOS instrument in February 2009. The results presented below took that circumstance into account by considering the months in which the number of data was statistically significant at most vertical levels.

It should also be noted that the GOMOS temperature was no longer retrieved after the implementation of IFP 5.0 in August 2006. The information provided in the BUFR files was instead derived as the ”Tangent Point Temperature from External Model”. This means that the *temperature profile* is *obtained by the combination of the ECMWF 24 hour temperature forecast in the lower part of the profile up to 1 hPa*[7] *and of the MSIS90 data in the upper part of the profile (smooth transition altitude range around the pressure level 1hPa)* (ESA, 2007).

Figures 16 and 17 show the comparisons between area averaged GOMOS and ECMWF temperature profiles (left panel) and GOMOS temperature departures (right panel) for the periods 1 July to 31 August and 1 November to 31 December 2009, respectively. In both figures, each panel refers to the results averaged over a given latitudinal band. In the July-August figure, the top panels refer to the tropics (30°N-30°S), the middle panels refer to the midlatitudes in the SH (30°-60°S), and the bottom panels refer to the high latitudes in the SH (60°-90°S). There were no data available at latitudes northern than 30°N. In the November-December figure, the top panels refer to the midlatitudes in the NH (30°-60°N), the middle panels refer to the tropics (30°N-30°S), and the bottom panels refer to the middle panels refer to the midlatitudes in the SH (30°-60°S). In the latter case, there were no data available at high latitudes.

In July-August (figure 16), the mean tropical temperature profile in the BUFR files is lower than their model equivalent, with differences of about -0.5% (about -1K) in the stratosphere and up to -3% (about -6K) in the mesosphere. By contrast at mid and high latitudes in the SH, the temperature residuals are within ±1% in the Stratosphere, being typically positive at pressures greater than 10hPa and negative at pressures smaller than 10hPa. Larger departures up to -4% (about -8K) were seen in the mesosphere. The standard deviations of the departures ranged from 1 to 3% at all levels and available latitudinal bands.

In November-December (figure 17), the temperature profiles in the BUFR files are lower than their model equivalent at most levels and all latitudinal bands, with some exceptions near the tropopause and the stratopause. In particular, the first guess and analysis departures were typically up to about -1% (-2 K) in the stratosphere and up to about -4% (-8K) in the mesosphere, as the temperature profiles were relaxed to the MSIS90 data. The standard deviations of the departures were within 1 and 3% at all levels and available latitudinal bands.

The timeseries of the global mean temperature data and their departures also confirm the level of agreement discussed above between the temperature data in the GOMOS files and the ECMWF temperature analyses. An example that refers to the 20 hPa pressure level is displayed in figure 18. The bottom panels in figure 18 show the GOMOS data availability in the mid stratosphere during 2009. As noted above, the amount of observations retrieved at stratospheric levels was much smaller than normal during most of the year (e.g. by comparisons with the amount available in January 2009), when at all available, and that only in December the amount of data nearly reached the levels of that at the beginning of the year.

[7] The ECMWF forecasts and analyses were only available up to 1 hPa.

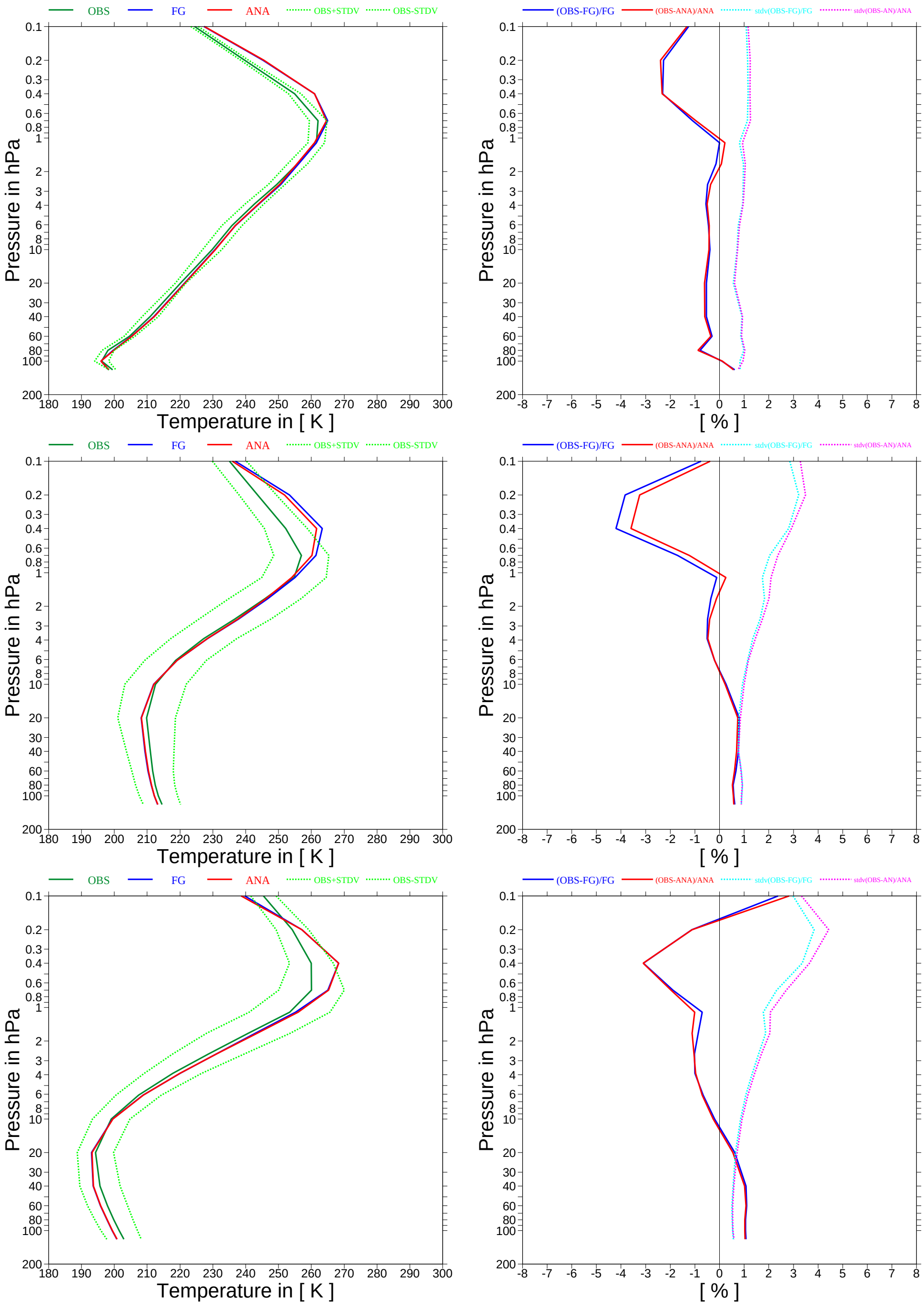


Figure 16: Comparisons between the area averaged temperature extracted from the GOMOS files and the area averaged ECMWF temperature first-guess and analysis. Right panels refer to the profile comparisons, left panels show the relative first-guess and analysis departures. The averaging period is between July and August 2009. The top panels refer to the tropical band 30°N-30°S, the middle panels refer to the midlatitudes in the SH (30°-60°S), and the bottom panels refers to the high latitudes in the SH (60°-90°S). Temperature values are in K, departures are in %.

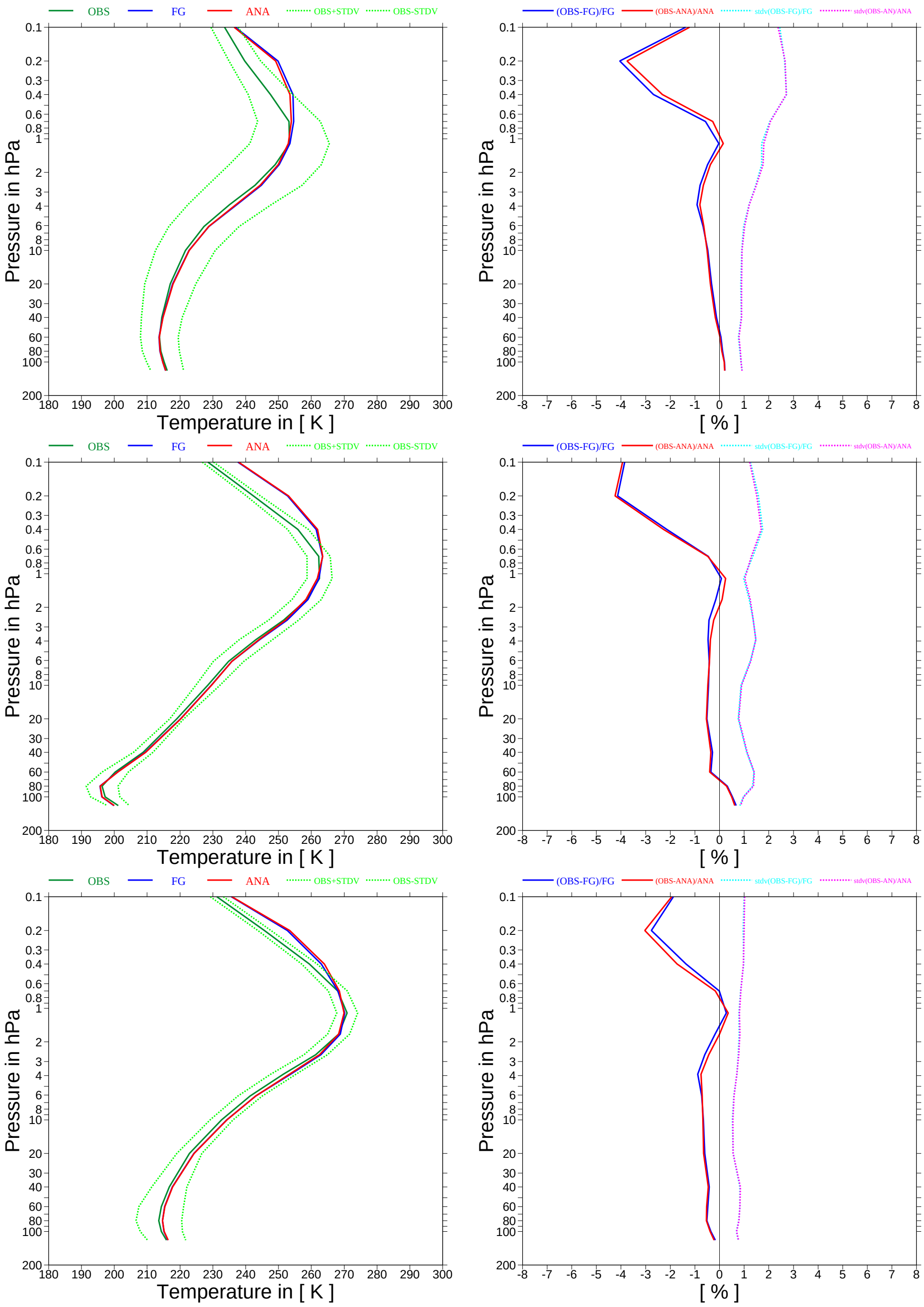


Figure 17: Like in figure 16, but the averaging period is between 1 November and 31 December 2009. The top panels refer to the midlatitudes in the NH (30°-60°N), the middle panels refer to the tropical band 30°N-30°S, and the bottom panels refers to the midlatitudes in the SH (30°-60°S).

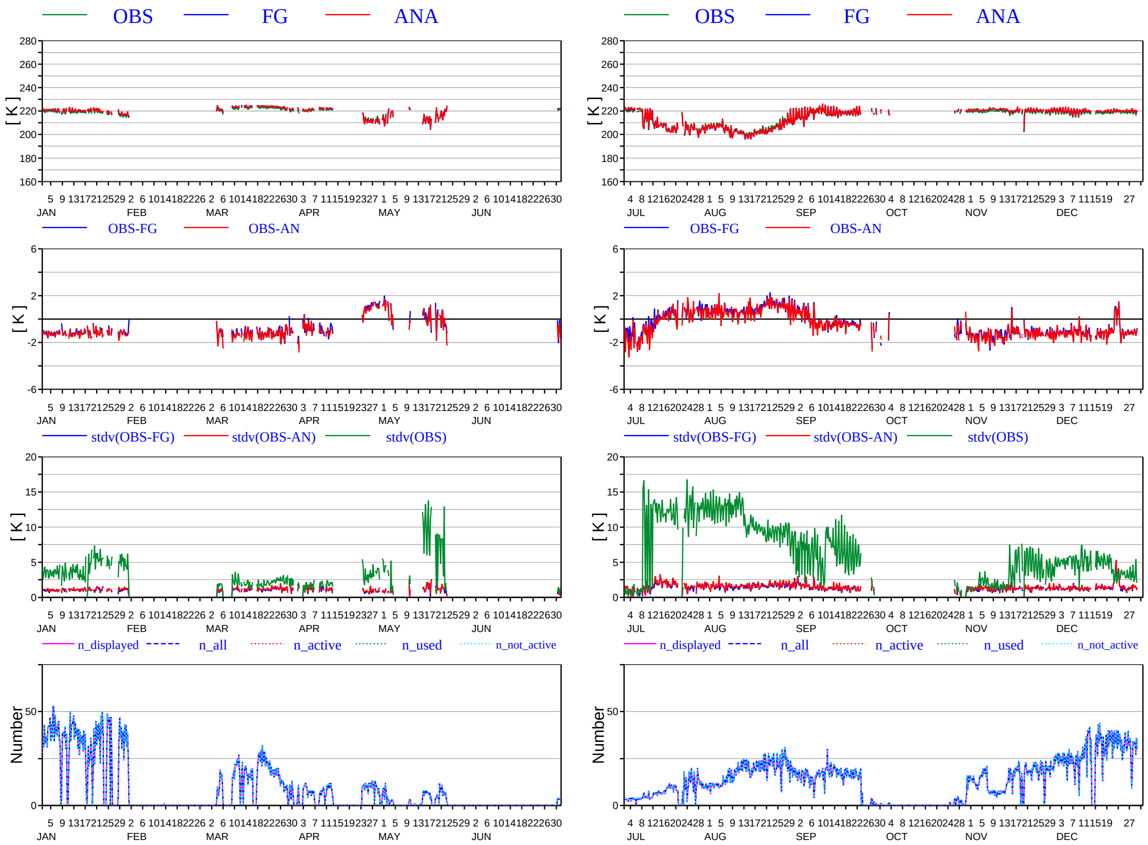
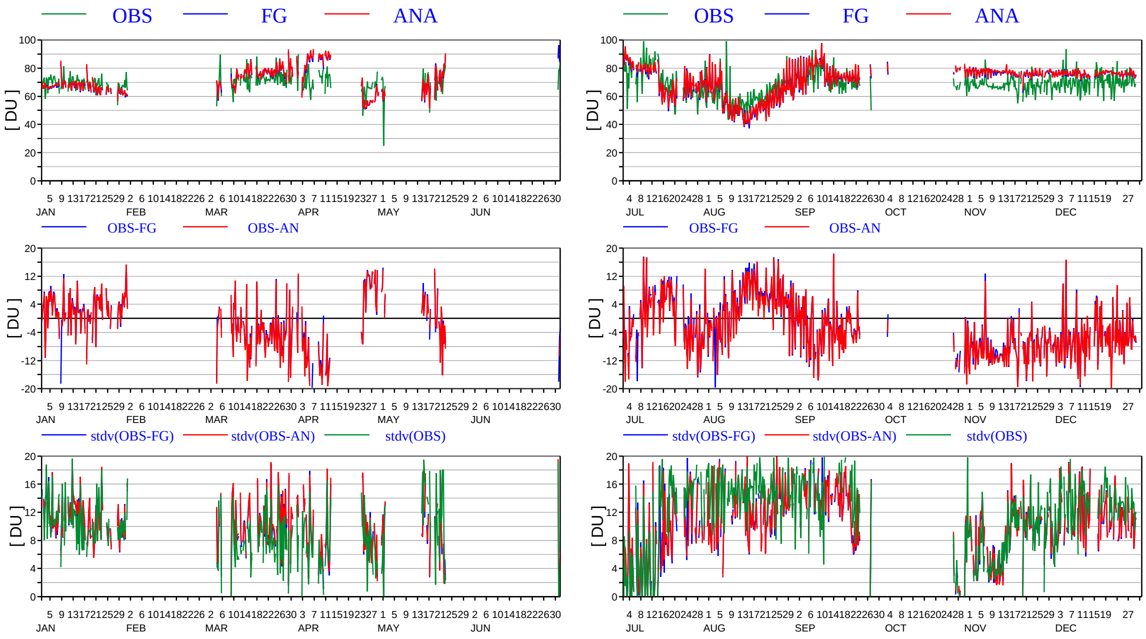


Figure 18: Timeseries of globally averaged data at 20 hPa covering the periods 1 January to 30 June (left panel), and 1 July to 31 December 2009 (right panel). From top to bottom, each figure show a) GOMOS NRT total temperature observations, first-guess and analysis values, b) the first-guess and analysis departures, c) the observation and departure standard deviations, and d) number of mean daily data count. All temperature values are in K.

4.2 Monitoring of GOMOS ozone data

This section discusses the results from the monitoring of the NRT GOMOS Level 2 ozone profiles in 2009. The discussion on the data availability and daily mean amount given in section 4 also applies to the GOMOS ozone retrievals.

Figure 19 shows the 2009 global mean time series of the observations and their model equivalent (top panel), of the first-guess and analysis departures (middle panel), and of their standard deviations (bottom panel) for the vertical layer between 20 and 40 hPa, which corresponds roughly to the layer where ozone mixing ratio peaks. From figure 19, the GOMOS ozone observations exhibit slightly higher ozone values than the ECMWF ozone analyses (about 4DU over the layer) in January (i.e. before the instrumental anomaly), followed by a period of negative observation minus model residuals during spring. At the beginning of the second half of 2009, both the ECMWF ozone first guess and analyses and the GOMOS ozone observations well capture the same ozone variability of the ozone distribution in the mid-stratosphere. However differences within $\pm$12DU were found. Later in the year following a period of limited data availability, particularly in the stratosphere, the first-guess and analysis departures were once again negative with a mean value of about -8DU. Large standard deviations up to 20 DU were found in the data, corresponding to just below 25% of the annual mean ozone value in this layer.



(a) (b)

Figure 19: Timeseries of globally averaged data covering the periods (a) 1 January to 30 June, and (b) 1 July to 31 December 2009 at 20-40 hPa. The top panels of each figure show GOMOS NRT partial column ozone, first-guess and analysis values, the middle panels first-guess and analysis departures and the bottom panels the standard deviations of GOMOS ozone data and of first-guess and analysis departures. All ozone values are in DU.

When averaging over latitudinal bands, the level of agreement just discussed is usually confirmed. Figures 20 and 21 show the area averaged GOMOS ozone profiles (left hand side panels) and GOMOS departures (right hand side panels) for three latitudinal bands and averaged over the period July-August, and November-December 2009, respectively.

In both figures, each panel refers to the results averaged over a given latitudinal band. In figure 20, the top panels refer to the tropics (30°N-30°S), the middle panels refer to the midlatitudes in the SH (30°-60°S), and the bottom panels refer to the high latitudes in the SH (60°-90°S). There were no data available at latitudes northern than 30°N. In figure 21, the top panels refer to the midlatitudes in the NH (30°-60°N), the middle panels refer to the tropics (30°N-30°S), and the bottom panels refer to the middle panels refer to the midlatitudes in the SH (30°-60°S). In the latter case, there were no data available at high latitudes.

In both periods, the ECMWF ozone first-guess and analyses were within the observation one-standard deviation at all levels and available latitudes.

During July-August, the mean tropical ozone profile shows larger values than its model equivalent in the upper stratosphere (between 1 and 6 hPa), and lower values elsewhere, with residuals typically within -10 and +15% at all mesospheric levels and in the stratosphere at pressure levels lower than 40hPa. At mid and high latitudes in the SH, the ozone residuals are typically negative in the layers between 6 and 20hPa and in the lower stratosphere between 40 and 80hPa, and positive elsewhere with fluctuations within -10 +15% at midlatitudes and within -20 and +25% at high latitudes. The standard deviations of the departures were larger than 20% at all levels and available latitudinal bands.

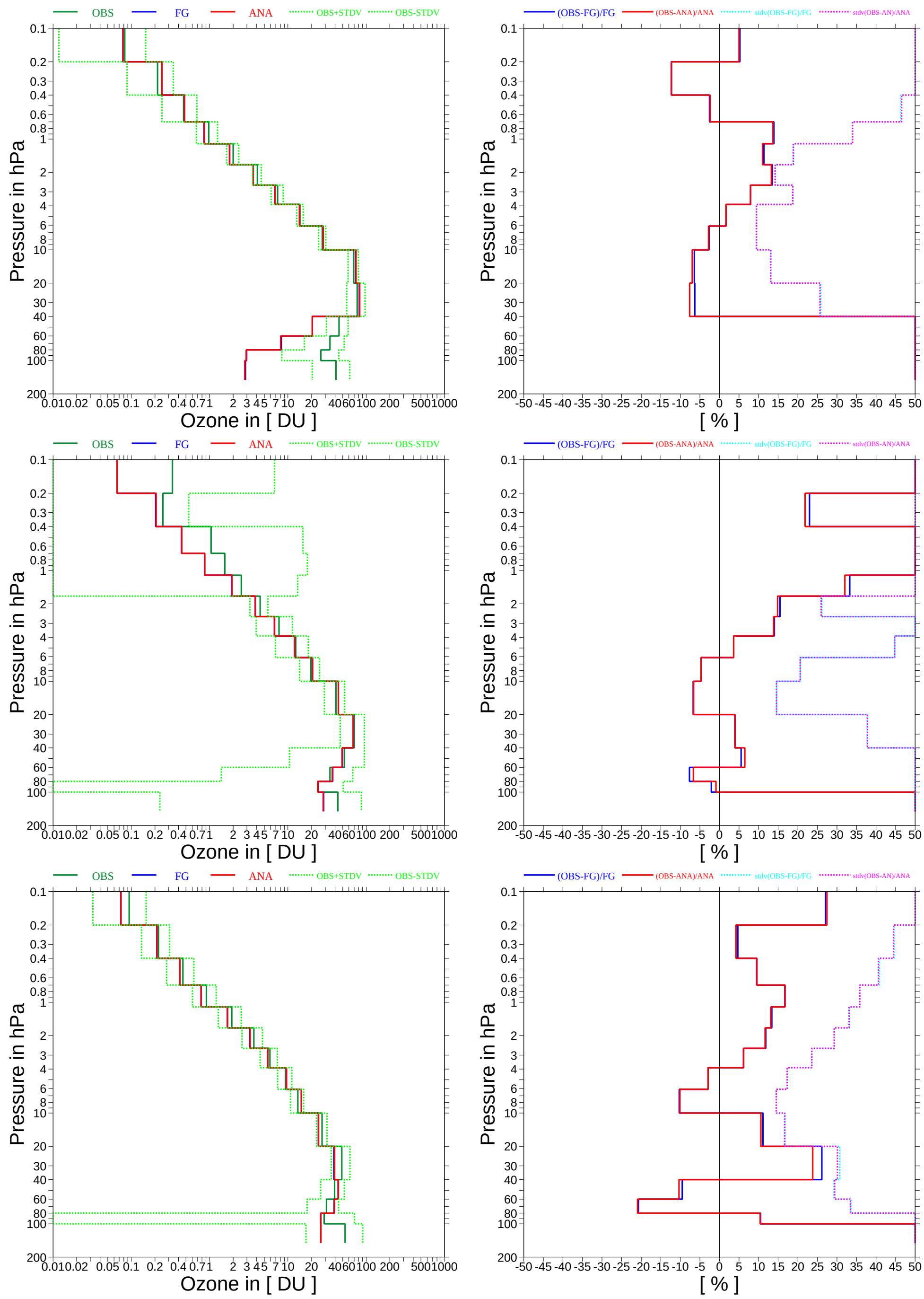


Figure 20: Like in figure 16, but for ozone. Ozone values are in DU, departures are in %.

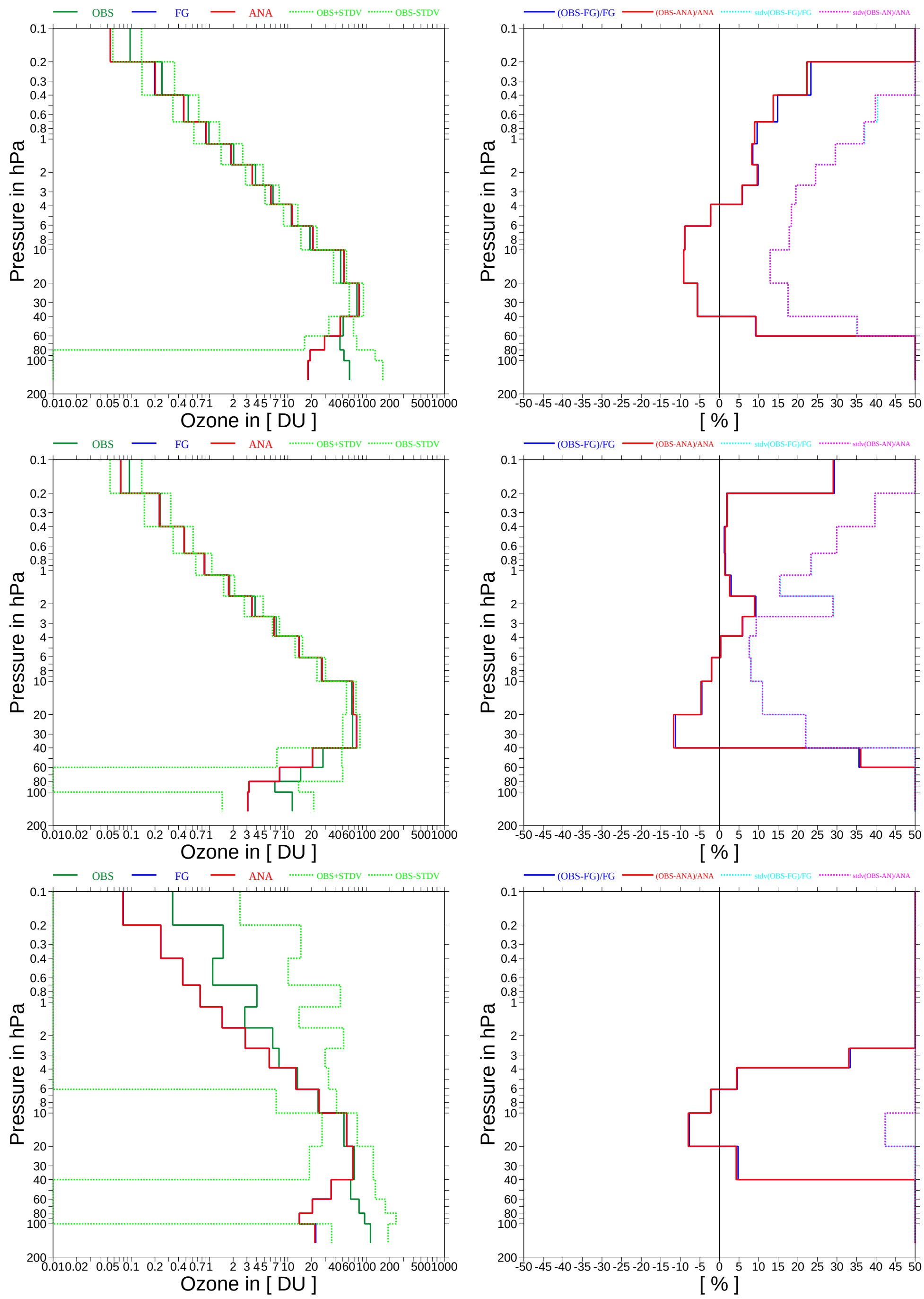
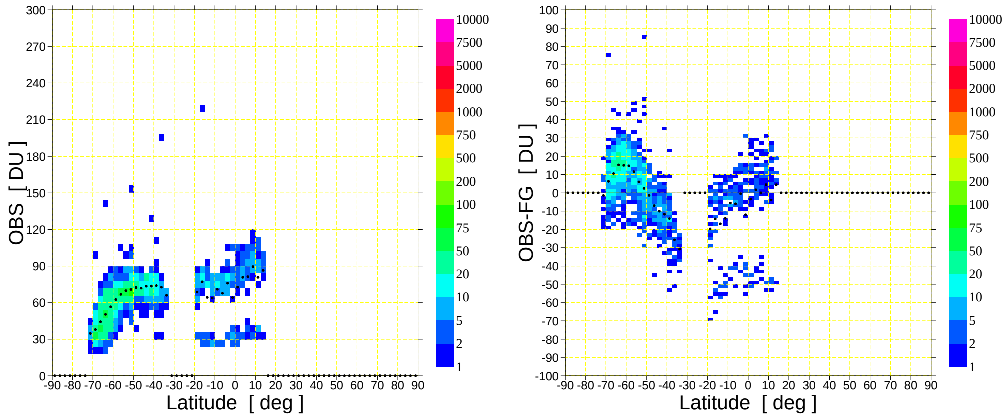


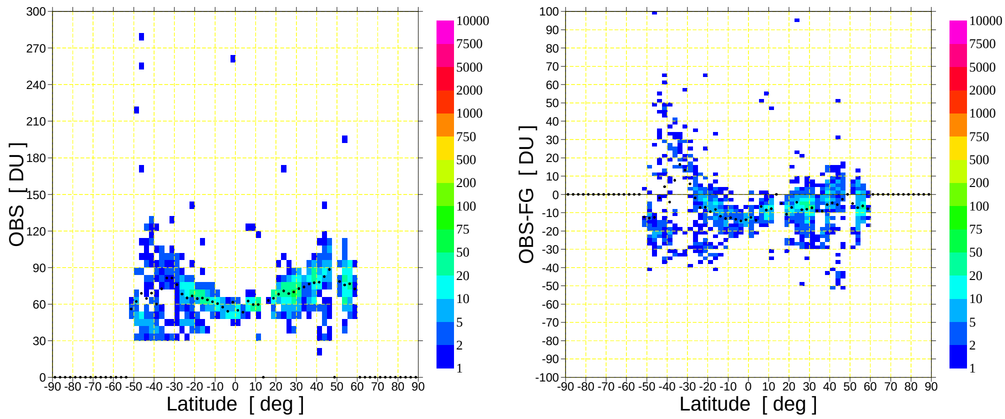
Figure 21: Like in figure 17, but for ozone. Ozone values are in DU, departures are in %.

In November-December (figure 21), the mean GOMOS ozone profile shows lower values than their model equivalent between 6 and 40hPa in the tropics and midlatitudes in the NH, and between 6 and 20hPa in the midlatitudes in the SH, and positive at all other vertical levels. The mean first-guess and analysis departures range within ±10% at most stratospheric levels in the NH and in the tropics. Larger departures (larger than 50%) were found at midlatitudes in the SH both in the lower stratosphere (pressure levels larger than 40hPa) and in the upper stratosphere and mesosphere (pressure levels smaller than 4hPa). The standard deviations of the departures were larger than 10% at levels and available latitudinal bands, with values larger than 50% at all levels at midlatitudes in the SH.

The presence of large noise in the data is also illustrated by the scatter plots of GOMOS ozone data and its first-guess departures. An example valid for the layer 20-40 hPa is given in figure 22. Top panels (a) refer to the period August 2009, while the bottom panels (b) refer to the period December 2009. The panels on the left in figure 22 show the scatter plots of the observations versus latitude, those on the right show the scatter plots of the first-guess departures versus latitude. The relatively large scatter in the observations against the latitudes leads to a large scatter in the first-guess departures as well, with variability within ±30 DU in both cases. A few outliers were also seen in the scatter plots.



(a)



(b)

Figure 22: Scatter plots of NRT GOMOS ozone (left) and of NRT GOMOS ozone first-guess departures (right) in the layer 20-40 hPa plotted against latitude, for the periods August 2009 (panels [a]) and December 2009 (panels [b]). The colours give the number of observations per bin, and the black dots the mean per bin. All ozone values are in DU.

4.3 Monitoring of GOMOS water vapour data

With the restriction discussed above, the NRT GOMOS water vapour data were available in the GOM_RR__2P BUFR files for most of 2009. It should be noted that the amount of water vapour data available at some levels during the year was sometimes too low to make the results statistically significant, particularly in the lower stratosphere.

As discussed in the previous report Dragani (2009), also in 2009 the quality of the water vapour data was poor compared with their ECMWF model equivalent.

Figures 23 and 24 show the comparisons between the monthly mean area averaged GOMOS water vapour profiles (the green lines) with their model equivalent at three latitudinal bands averaged over the periods July-August (l.h.s. panels) and November-December (r.h.s. panels) 2009 (see captions for details). These profile plots show that the GOMOS water vapour values were from one to four orders of magnitude larger than those given by the model at all stratospheric levels. The largest differences were found in the upper stratosphere, where not only did the GOMOS observations exhibit on average values of four order of magnitudes larger than their model equivalent, they also were larger than the mean GOMOS tropospheric observation.

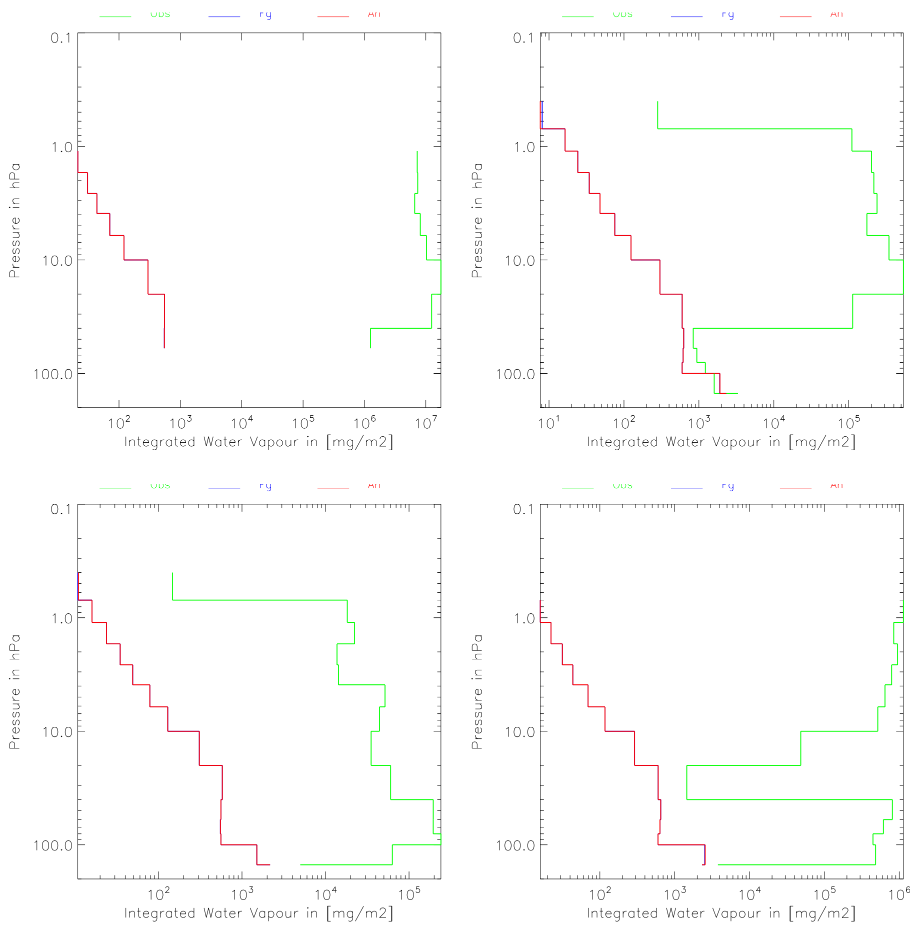


Figure 23: Comparisons between the area averaged GOMOS water vapour profiles and the area averaged ECMWF water vapour first-guess and analysis for July-August 2009 (l.h.s. panels) and November-December 2009 (r.h.s. panels). The July-August plots (l.h.s. panels) were obtained by averaging the data over the tropical band [30°N-30°S] (top panel), and [30°-60°]S (bottom panel). In contrast, the November-December plots (r.h.s. panels) refer to the midlatitudes in the NH ([30°-60°]N) (top panel), and to the tropical band (bottom panel). Water vapour values are in mg/m^2.

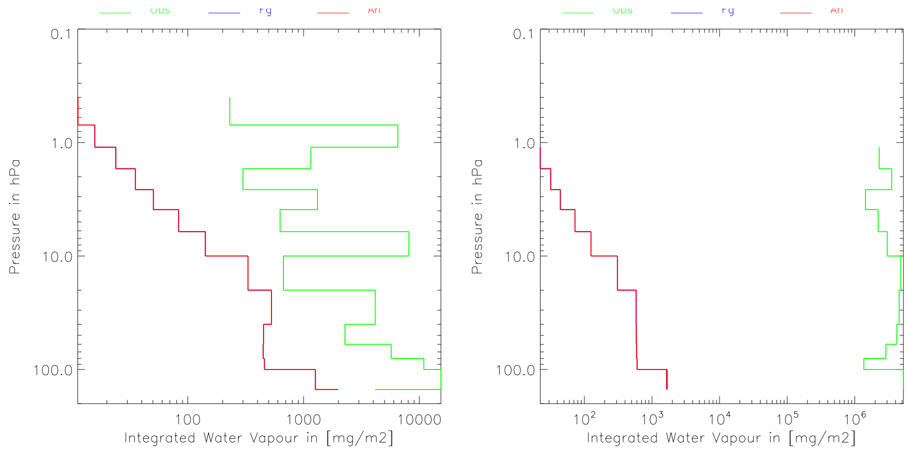


Figure 24: Like in figure 23, but the July-August plot (l.h.s. panel) was obtained by averaging the data over [60°-90°]S latitudinal band. Conversely, the November-December plot (r.h.s. panel) was obtained by averaging the data over the midlatitudes in the SH ([30°-60°]S) latitudinal band.

The poor level of agreement between the GOMOS water vapour profiles and their model equivalent is also shown in the scatter plots presented in figure 25 for the integrated layer between 1 and 100 hPa. The two panels show the scatter plot for August (l.h.s. panel) and December (r.h.s. panel) 2009, respectively.

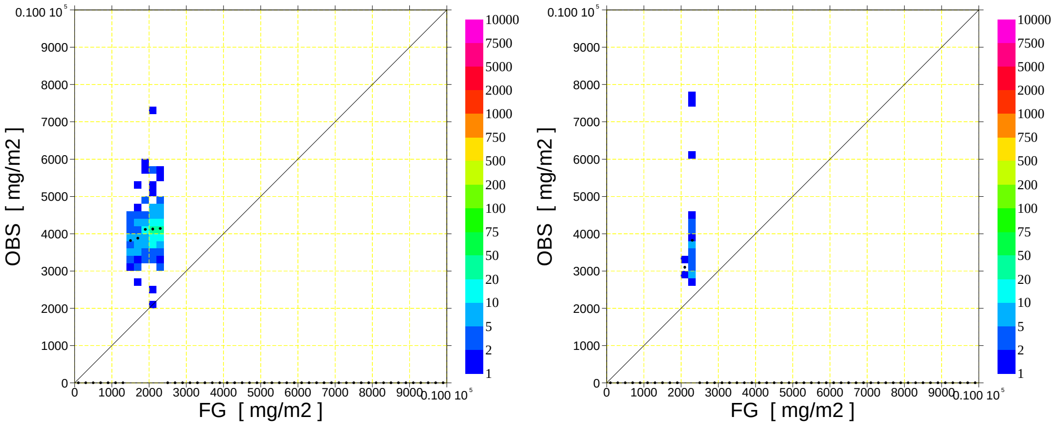


Figure 25: Scatter plots of NRT GOMOS water vapour content against the ECMWF first-guess in the integrated layer 1-100 hPa for the periods August (left), and December 2009 (right). The colours give the number of observations per bin, and the black dots the mean per bin. Values are in mg/m^2.

5 Monitoring of MIPAS data

Owing to instrument problems, NRT Level 2 MIPAS data (MIP_NLE_2P) have not been available since 27 March 2004, so that no monitoring activity of these observations could be performed during 2009. Results from the monitoring statistics covering the period October 2003 - March 2004 were presented by Dethof (2004).

The planned assessment of the MIPAS L2 data retrieved from the low spectral resolution data sampled during the period October-December 2007 will be performed as soon as the data will become available. This depends upon the operational implementation of the new MIPAS processor, which is now planned for 2010.

In addition, research activity to assess the impact of assimilating low spectral resolution MIPAS level 1 radiances on the ECMWF ozone analyses that started during 2008, continued throughout 2009. A similar test was already carried out within the Assimilation of Envisat data (ASSET) project (Bormann and Thépaut, 2006; Bormann et al., 2006), using the full spectral resolution radiances. As the assimilation of limb radiances at ECMWF is not normally performed, updating the assimilation system required several steps and refinements. During 2008, the Integrated Forecasts System (IFS) was updated to allow the assimilation of MIPAS radiances. This required a substantial revision of the radiative transfer model (RTMIPAS), the calculation of a new set of coefficients used in the regression model, which parameterizes the transmittance in RTMIPAS, as well as an accurate investigation of the RTMIPAS performance. This performance was assessed against a line by line radiative transfer model developed at University of Oxford to retrieve MIPAS Level 2 data. In addition, suitable set of microwindows, that will be used in the assimilation experiment, had to be selected from the whole set of MIPAS channels. During 2009, most of the work dealt with the characterization of the bias affecting the level 1 data. Assimilation schemes are all based on the assumption that the data assimilated are unbiased with normally distributed errors. In reality, this is unlikely the case.

ECMWF has successfully been using a variational bias correction (VarBC) scheme for radiances since September 2006. However, there was neither an expertise nor a know-how on how the bias of a limb sounder could or should be characterized in VarBC. Therefore it was decided that as a first attempt, a static bias correction, the so-called γ/δ bias correction scheme (e.g. Watts and McNally, 2004) could be used. This bias correction scheme is based on the fact that most of observed radiance bias and its variation with airmass can be explained by errors arising from the radiative transfer model, and that by applying an adjustment to the channel absorption coefficient most of the bias can be accounted for and removed. Due to the lack of prior knowledge of the MIPAS bias and its structure, the calculation of this adjustment required recursive tuning based on a number of successive three-month long assimilation experiments. Once a suitable γ/δ correction will be identified, the MIPAS radiance assimilation can be finally tested.

6 Conclusions

The ECMWF technical support to ESA for the validation of ozone, temperature and water vapour products retrieved from the three atmospheric instruments on ENVISAT (ESA contract 21519/08/I-OL: Technical support for global validation of Envisat data products) continued, upon data availability, during 2009. Because of instrumental problems which caused the unavailability of the NRT MIPAS (MIP_NLE_2P) product, no monitoring could be performed of these data since 27 March 2004. In addition, the monitoring of the NRT SCIAMACHY (SCI_RV__2P) product could not be performed after May 2006 also due to data unavailability. The TOSOMI product retrieved at KNMI from SCIAMACHY measurements and distributed via the ESA funded PROMOTE consortium is now regarded as the official ESA Level 2 total column ozone retrieved from SCIAMACHY (Minute of the ESA contract progress meeting held at ECMWF on 6 December 2006). This product was available during the entire 2009. Finally, the NRT GOMOS products (GOM_RR__2P) were available during most of 2009. However, the instrument suffered of serious anomalies starting from the beginning of February 2009 that mainly affected the pointing system. For that reason, the GOMOS instrument was not operated during February, and no data were therefore available. Because these anomalies affected the pointing system, their main consequence resulted in a reduced amount of data, particularly in the stratosphere, during most of the year. In some cases, the amount af stratospheric data was too low to make the results statistically significant, particularly for the water vapour.

Based on the data availability, an indication of the operability of the ENVISAT products to ECMWF during 2009 was provided by assessing their timeliness. The timeliness of the TOSOMI products as downloaded by KNMI was 81% as annual average in 2009, that of the GOMOS products was 97.1%. In both cases, these values are slightly higher than those in 2008 (i.e. the data volume delivered on time to be used during 2009 was higher than that delivered in 2008). In particular, the timeliness of GOMOS data is the highest since 2006.

The TOSOMI product was operationally assimilated from 28 September 2004 until 18 December 2008, when SCIAMACHY underwent a decontamination period that was thought to affect the quality of the ozone retrievals (R. Van der A, KNMI, personal communication). Assimilation tests run to assess the impact of assimilating the TOSOMI data retrieved after the instrument decontamination showed potential degradation produced on the ECMWF temperature and geopotential height forecast scores. In addition, also the quality of the ECMWF ozone analyses was found reduced by the assimilation of TOSOMI data with a degraded fit to independent, unassimilated observations. With the operational update of the variational bias correction (VarBC) scheme to correcting the bias in the level 2 data, in addition to that in the radiances, a new assimilation experiment of TOSOMI data was run. The new results showed that, after removing the instrumental bias, useful information could still be extracted from SCIAMACHY TCO and that the assimilation of this product could lead to improved temperature and geopotential height forecasts as well as improved ozone analyses. Following the results from the latest experiments, the operational assimilation of TOSOMI TCO restarted in September 2009 with cycle CY35R3.

The quality of the GOMOS temperature profiles was generally stable during 2009, and consistent with that reported by Dragani (2008, 2009). On average, the GOMOS temperature departures are less than -1% (-2 K) in most of the stratosphere and slightly larger in the mesosphere (up to -4%, about -8K).

The GOMOS ozone monitoring statistics showed that the ECMWF ozone first-guess and analyses were within the observation one-standard deviation at all levels and available latitudes. Two periods were discussed in details: July-August and November-December 2009. The mean first-guess and analysis departures obtained by averaging over the tropics and the midlatitudes were typically found to be within -10 and +15% in most of the stratosphere (at least for pressure values smaller than 40hPa), but larger departures were found in some cases in the lower stratosphere (for pressure values larger than 40hPa) and in the mesosphere. GOMOS observations were available at high latitudes in the SH only during the July-August period, and they showed departures ranging from -20 to +25% at most levels. There were no data available at latitudes northern than 60∘N during 2009. The standard deviations of the departures were larger than 20% at all levels and available latitudinal bands. The data still show quite a large noise, illustrated by the scatter of the ozone data and the corresponding first-guess and analysis departures as function of latitude. One example was discussed for the layer between 20 and 40hPa, that roughly corresponds to the layer where the ozone mixing ratio peaks. That plot also showed the presence of a few outliers.

The quality of the water vapour data was generally poor during 2009 and based on the 2009 data availability consistent with that reported for 2008 (Dragani, 2009). The monitoring statistics showed that the GOMOS water vapour values were typically from one to four orders of magnitude larger than those given by the model at all stratospheric levels and latitudinal bands. The largest differences were found in the upper stratosphere, where not only did the GOMOS observations exhibit values of four order of magnitudes larger than their model equivalent on average, they also were larger than the mean GOMOS tropospheric water vapour value.

It should be noted that the GOMOS data monitored in the present study were selected from the whole set of retrievals that were derived from observations sampled in full dark illumination conditions. The filter for such a selection was proposed by the GOMOS QWG and implemented in May 2007 in the PDS2BUFR converter. However, Dragani (2009) suggested that this filter is still able to retain some of the poor quality data, and that instead a much better agreement between the GOMOS retrievals and the ECMWF analyses could be obtained by selecting the data at the source according to the star identification number. This selection cannot be done once the data are converter into BUFR as the star identification number does not have a corresponding WMO BUFR parameter. Dragani (2009) also showed that by selecting the data at the source the amount of monitored observations was much reduced compared with that obtained by simply applying the filter in the converter. It is adviced that either the GOMOS data are selected at the source according to their star illumination conditions or the implementation of the filter in the PDS2BUFR converter is revised.

7 Acknowledgements

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