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Contract Report to the European Space Agency

Monitoring and Assimilation of SCIAMACHY, GOMOS and MIPAS Retrievals at ECMWF

February 2011

Author: Rossana Dragani

Final 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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European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading, Berkshire, UK

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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 2010 in support to the ESA activities.

The GOMOS and SCIAMACHY data were available throughout the year, the only exception being GOMOS in November 2010 after the 2010 orbit change. Both instruments showed a good timeliness in 2010. About 96.1% of GOMOS and 83% of SCIAMACHY data were delivered on time to be included in the operational experiment. Although not fully operational, the MIPAS Level 2 dissemination has recently restarted. The operational monitoring at ECMWF will resume as soon as all the modifications required to account for these data will be implemented in the operational system.

The NRT TOSOMI TCO was operationally assimilated until 22 October 2010, when ENVISAT was commanded to its new orbit, and then resumed on 16 December 2010, when assimilation experiments confirmed that the quality of the data was still fit for operational use.

The quality of the NRT GOMOS products was generally stable in 2010 and consistent with that reported for previous years. In particular, the temperature first guess and analysis departures were typically negative, and up to -1% (-2K) in the stratosphere, and within -2 and -7% (within -4 and -14K) in the mesosphere. The NRT GOMOS ozone profiles showed a level of agreement with their model equivalent within $\pm$15% in most of the stratosphere (for p$<$40hPa), 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 than their model equivalent. The detailed analysis of the period 29 November - 31 December 2010 has shown an increase in the GOMOS observation noise and scatter, particularly in the ozone product, that could be a consequence of the ENVISAT orbit change. This aspect will be closely monitored in 2011.

1 Executive summary

The Level 2 products from the atmospheric instruments on board of the ENVISAT satellite have been routinely monitored at ECMWF during the three year period from January 2008 to December 2010. The present paper focuses on the monitoring and assimilation activity performed during 2010. The corresponding detailed assessments for 2008 and 2009 have reported in Dragani (2009c) and Dragani (2010b), respectively. The key points from those two reports have briefly been summarised below in the present paper (see sections 4.1 for SCIAMACHY and section 5.1 for GOMOS).

In addition, table 1 provides an excutive summary of the monitoring and assimilation activity performed at ECMWF during the three year period from January 2008 to December 2010 for all the available products. Table 1 is composed of three parts: For each instrument (GOMOS and SCIAMACHY) and year (2008-2010), it focuses 1) on the data availability to ECMWF (in terms of timeliness, long period of data unavailability, and their reasons), 2) on the period when the observations were assimilated at ECMWF (if applicable), and 3) on the level of agreement ("Poor", "Medium", "Good") between each product and their ECMWF equivalent.

It is noted that, although a discussion on the quality of the MIPAS level 2 data is reported in section 6 (where it is shown that all three parameters retrieved from MIPAS measurements - ozone, temperature and water vapour - generally are in good agreement with their model equivalent), we refrain from drawing conclusions on the quality of the MIPAS Level 2 products at this stage, as the available statistics are preliminary results based on one month-worth of data.

	GOMOS			SCIAMACHY		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**
Timeliness	96.4%	97.1%	96.3%	80.7%	81.0%	83.0%
Unavailability	N/A	Feb	27 Oct- 29 Nov	N/A	N/A	N/A
Anomalies	N/A	Pointing sys.	STARSEL[1]	N/A	N/A	N/A
Actively assimilated	No	No	No	01/01-19/12	16/09-31/12	01/01-22/10 16-31/12
Ozone	Medium	Medium	Medium	Good	Good	Good
Temperature	Good	Good	Good	N/A	N/A	N/A
Water Vapour	Poor	Poor	Poor	N/A	N/A	N/A

Table 1: Summary of the key points form the monitoring and assimilation of GOMOS and SCIAMACHY products during the period 2008-2010.[1] STARSEL is the part of the GOMOS software that prevented the instrument operations to be restarted immediately after the 2010 ENVISAT orbit change.

2 Introduction

The present final report summarises the results from the global validation and monitoring of the ENVISAT atmospheric data products performed at ECMWF under the ESA funded project 21519/08/I-OL ("Technical support for global validation of Envisat data products"). 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. Formally, the list of products 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). Project 21519/08/I-OL ran for a period of three years from January 2008 to December 2010, and continued the activity carried out under a number of previous ESA contracts, namely 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, 2009c, 2010b). This paper discusses in detail the results from the monitoring and assimilation of the ENVISAT L2 atmospheric data products during the period January to December 2010. A brief summary of the monitoring and assimilation activity performed between January 2008 and December 2009. The latter period was extensively discussed in Dragani (2009c) and Dragani (2010b).

The ECMWF deterministic model is a global spectral model. It benefits from a current horizontal resolution truncation of T1279, which corresponds to about 16 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. The observation monitoring of all data, including ENVISAT products, is done in the delayed-cut-off analyses (Dethof, 2004; 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 ozone forecast model uses an updated version of the Cariolle and Déqué (1986) scheme (hereafter CD86). In particular, 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. 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 extended forecast radiation scheme, where an ozone climatology (Fortuin and Langematz, 1995) is preferred instead. In addition, it is not possible for ozone observations to modify the wind field in 4D-Var through the adjoint calculations.

Ozone data from a number of satellite instruments are currently assimilated in the ECMWF system. At the time of writing, the ozone data either monitored or assimilated in the ECMWF operational system are those listed in table 2.

Instrument	Satellite	Usage	Data Type
SBUV/2	NOAA-16	Passive	Partial columns
SBUV/2	NOAA-17	Active	Partial columns
SBUV/2	NOAA-18	Active	Partial columns
SBUV/2	NOAA-19	Passive	Partial columns
SCIAMACHY	ENVISAT	Active	Total columns
GOMOS	ENVISAT	Passive	Profiles
OMI	Aura	Active	Total columns
MLS	Aura	Passive	Profiles
GOME-2	MetOp-A	Passive	Total columns
SEVIRI	Met-9	Passive	Total columns

Table 2: List of all the ozone products actively assimilated or passively monitored in the ECMWF operational system.

The NRT ozone retrievals from the SBUV/2 instruments, produced by NOAA and available from NESDIS[1], are retrieved as a 21 level ozone profiles. These data are converted into a six-layer product at ECMWF to reduce the observation error correlation. The NRT SCIAMACHY TCO produced by KNMI[2] and generally referred to as TOSOMI, has been assimilated at ECMWF almost continuously since 28 September 2004. As discussed below in section 3, two interruptions to the TOSOMI data assimilation were recorded during the three-year period (2008-2010) covered by the present contract: 1) from 18 December 2008 to 16 September 2009 (Dragani, 2009b), and 2) from 22 October to 16 December 2010 (Dragani, 2010a). 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 (Dragani, 2009a). 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°. Quality control and first-guess checks are carried out for all assimilated data. With the exception of MLS, the assimilation of all other products has been prevented by their not adequate quality. 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. It is anticipated that the assimilation of several channels in the ozone band from the Infrared Atmospheric Sounding Interferometer (IASI, on board of MetOp-A) and Advanced InfraRed Sounder (AIRS, on board of AQUA) instruments could start in 2011. Total column water vapour (TCWV) data from the MERIS

[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.

instrument aboard ENVISAT have been assimilated since September 2009, with the only exception of the period between 22 October and 16 December 2010 Dragani (2010a). All satellite observations are bias corrected using a variational bias correction (VarBC) scheme (Dee, 2005). This scheme became first operational in September 2006, when it was only used to correct for biases in the radiance data, and only recently (September 2009) was extended to retrieved products and used for ozone (Dragani, 2009d) and TCWV (Bauer, 2009).

During the period January to December 2010, the ECMWF operational model system was upgraded three times to model cycle CY36R1 on 26 January, to model cycle CY36R2 on 22 June, and to model cycle CY36R4 on 9 November 2010. The model cycle CY36R3 included a number of technical changes but it was not operationally implemented. With cycle CY36R1, the horizontal resolution of the deterministic model was increased from the original T799 (25 km grid) to the current T1279 (16 km) that improved the representation of features such as tropical storms, fronts, heavy rainfall and land/sea transitions. Cycle CY36R2 featured the implementation of the Ensemble Data Assimilation that provides the initial-time perturbations for the Ensemble Perturbation System. Several changes were implemented in cycle CY36r4. Many changes and retuning were introduced in the model physics, e.g. a five-species prognostic microphysics scheme, which includes cloud rain water content and cloud ice water content as new model variables. In addition, improvements in the use of satellite observations, particularly all-sky microwave radiances, were also added.

This report is structured as follows: Section 3 discusses the timeliness of ESA and KNMI products to ECMWF during 2010, and compares it with that of the past few years. Section 4 summarizes the results of the monitoring and assimilation of SCIAMACHY total column ozone retrievals; section 5 shows results of the monitoring of GOMOS data. An initial analysis of the monitoring of MIPAS L2 data is discussed in section 6. This monitoring is based on a low resolution, research mode experiment, rather than on the operational system as the latter system needs to be updated and modified to account for the changes in the MIPAS data format. Conclusions are presented in the last section.

3 Operability of ESA and KNMI products during 2010

We discuss the timeliness of the ESA and KNMI products at ECMWF during 2010, in the same way it was produced by Dragani (2008, 2009c, 2010b).

This is done by comparing 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 data - depending on their timely availability - can be assimilated 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 (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 assimilated observations that fall into a given 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 in 2010 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.

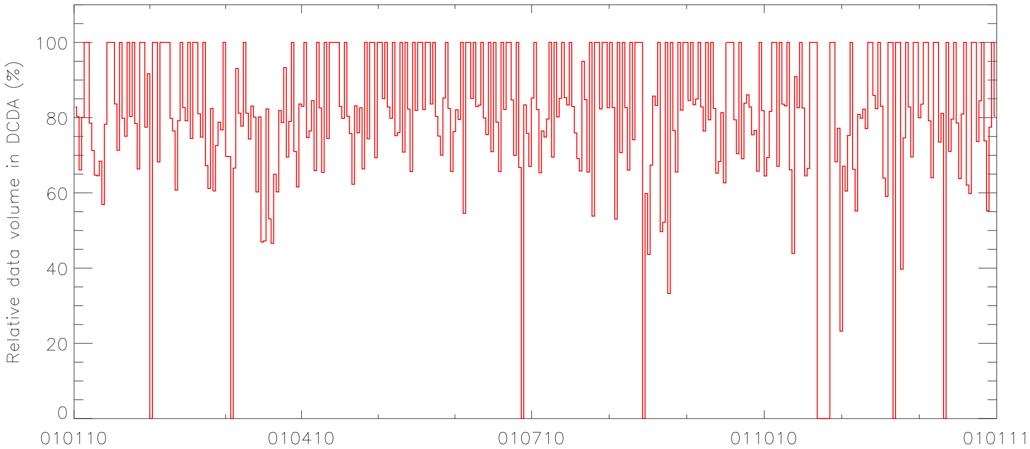


Figure 1: The 2010 time series of the TOSOMI total column ozone daily data volume received in time for the delayed-cut-off relative to the total daily data volume received. Values are in %.

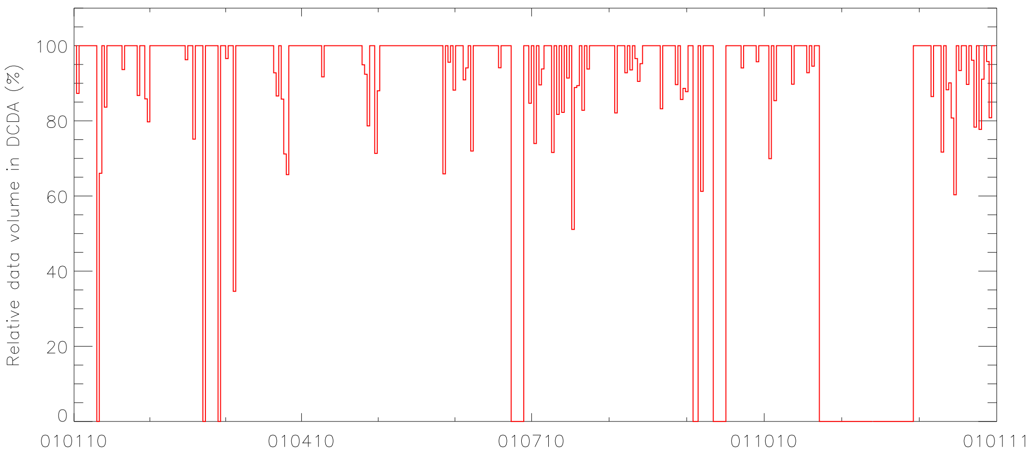


Figure 2: Like in figure 1, but for GOMOS data.

Instrument	2006	2007	2008	2009	2010
GOMOS	96.1%	94.7%	96.4%	97.1%	96.3%
TOSOMI	89.0%	83.1%	80.7%	81.0%	83.0%

Table 3: 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.

Table 3 gives the annual mean percentage of data volume received in time for the delayed-cut-off analyses during 2010, and the corresponding annual mean values since 2006. Annual plots for the operability of ESA and KNMI products for the years from 2006 to 2009 were presented in Dragani (2008, 2009c, 2010b).

Table 3 shows that GOMOS has mantained a high level of operability during 2010, that has generally been higher than 95%. The timeliness of the TOSOMI product has never been as high as that of GOMOS, and in generally the annual mean values have been degrading over the years from 89% in 2006 to 83% in 2010. It should be noted that the operability of TOSOMI in 2010 has slightly increased of 1.3% compared with that of 2008, that had the lowest value since the record began, and of 2% compared to 2009.

4 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). The instrument 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 L2 TCO from the nadir measurements was stopped. The latest results 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 consortium[4] (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. Dethof

[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.

[4] These services are now part of the Monitoring Acmospheric Composition and Climate (MACC) project.

(2004) could show that the assimilation of this product could have a positive impact on the ECMWF ozone analyses, especially in the Antarctic polar vortex region. Based on the se results, the operational assimilation of TOSOMI started on 28 September 2004, when the model was updated to cycle CY28R3, and still performed.

4.1 Summary of the activity during 2008 and 2009

The data were continuously available during the two year period 2008-2009. In 2008, the quality of the data was found stable and consistent with that reported in the previous years e.g. by Dragani (2008). The monitoring statistics showed a good level of agreement between the SCIAMACHY TCO and the ECMWF TCO both in the global mean and area average. In particular, the global mean first-guess and analysis departures for NRT SCIAMACHY TCO were found to be well within ± 5 DU. The generally good quality of the SCIAMACHY TCO was also confirmed by comparisons with independent total column ozone observations retrieved from the OMI and GOME-2 measurements. Results from these comparisons showed that the regions characterized by the largest differences in TCO between OMI and SCIAMACHY were at high latitudes near the end of the orbits.

The assimilation of TOSOMI data 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).

Nearly two-month assimilation experiments were 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. These experiments, that covered the period 8 January - 28 February 2009, were performed at a resolution of T159 on the standard 91 vertical levels from surface up to 0.01hPa. All the data assimilated operationally were also used in these experiments. These data are listed in Appendix A. 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). The OMI data were not assimilated as the instrument at that time suffered by a number of anomalies that affected the data quality. 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. The results were discussed by Dragani (2010b), and summarised below as follows:

- The assimilation of TOSOMI data degraded the fit of the ozone analyses to MLS data at most vertical levels and latitudinal bands. This degradation appeared particularly strong at high latitudes in both hemisphere, but also in the tropical lower stratopshere.
- The fit of the ozone analyses to ozone sonde profiles was also degraded, particularly the degradation at high latitudes.
- The temperature and the geopotential height forecast skills were reduced by the assimilation of TOSOMI. In particular, 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.

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 a new set of assimilation experiments that were run after the implementation of VarBC was extented to level 2 products in general, and ozone in particular (in model cycle CY35R3, September 2009). Using VarBC for L2 products, two additional three-month long assimilation experiments were performed at a resolution of T255 on the standard 91 vertical levels during the period 1 May - 31 July 2009. The OMI TCO and the NOAA-17 and NOAA-18 SBUV/2 partial column ozone were actively assimilated in the new control experiment (referred to as CTRL). Note that the anomaly in the OMI data was seen to affect only certain pixels, that were filtered out in the assimilation (Dragani, 2009a). The TOSOMI TCO were then added in assimilation in the perturbation experiment. The VarBC scheme was applied to both radiances and ozone products (except the SBUV/2 data that were used as anchor to the bias correction). 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[5]. The analysis of the new assimilation experiments showed that, when VarBC was used, the assimilation of TOSOMI data could slightly improve 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 found in the forecast scores, particularly the correlation coefficients of the temperature forecasts anomalies in the upper troposphere in the SH. Small but statistically significant improvements were also seen in the geopotential height (Z) forecast scores at 850, 500, and 200hPa between days 2 and 4, and at 100hPa between days 4 and 6 in the southern extra-tropics. Based on these results, the assimilation of TOSOMI retrievals restarted in September 2009 when the ozone VarBC scheme became operational.

4.2 Monitoring of NRT TOSOMI SCIAMACHY ozone column retrievals produced by KNMI during 2010

The TOSOMI product was assimilated at ECMWF during most of 2010. The operational assimilation was interrupted on 22 October when ENVISAT was manouvred to its new orbit, and then restarted on 16 December 2010, when the results of assimilation experiments showed that the data quality was still suitable for an operational usage.

Figure 3 shows 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 (l.h.s. panels), and July to December 2010 (r.h.s. panels), respectively.

The timeseries in figure 3 show a generally stable behaviour of the data during the whole year. The first-guess and analysis departures (blue and red lines in the mid panels) were well within $\pm$2DU during 2010. A few episodes characterized by larger first-guess and analysis departures were registered during March and April. These large differences are generally associated to episodes of large ozone variations in the data (only partly captured by the first guess) associated with smaller than average standard deviations. When these situations occur, the 4D-Var assimilation scheme is likely to give a large weight to the observations which can lead to large changes in the analyses.

As also reported by Dragani (2008, 2009c, 2010b), 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 smaller in the second half of 2010 than during the first six months. This reduction, although apparently

[5] Dragani (2009d) 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, by using the SBUV/2 retrievals as reference (i.e. anchor to VarBC), the ozone analyses compared better with independent observations.

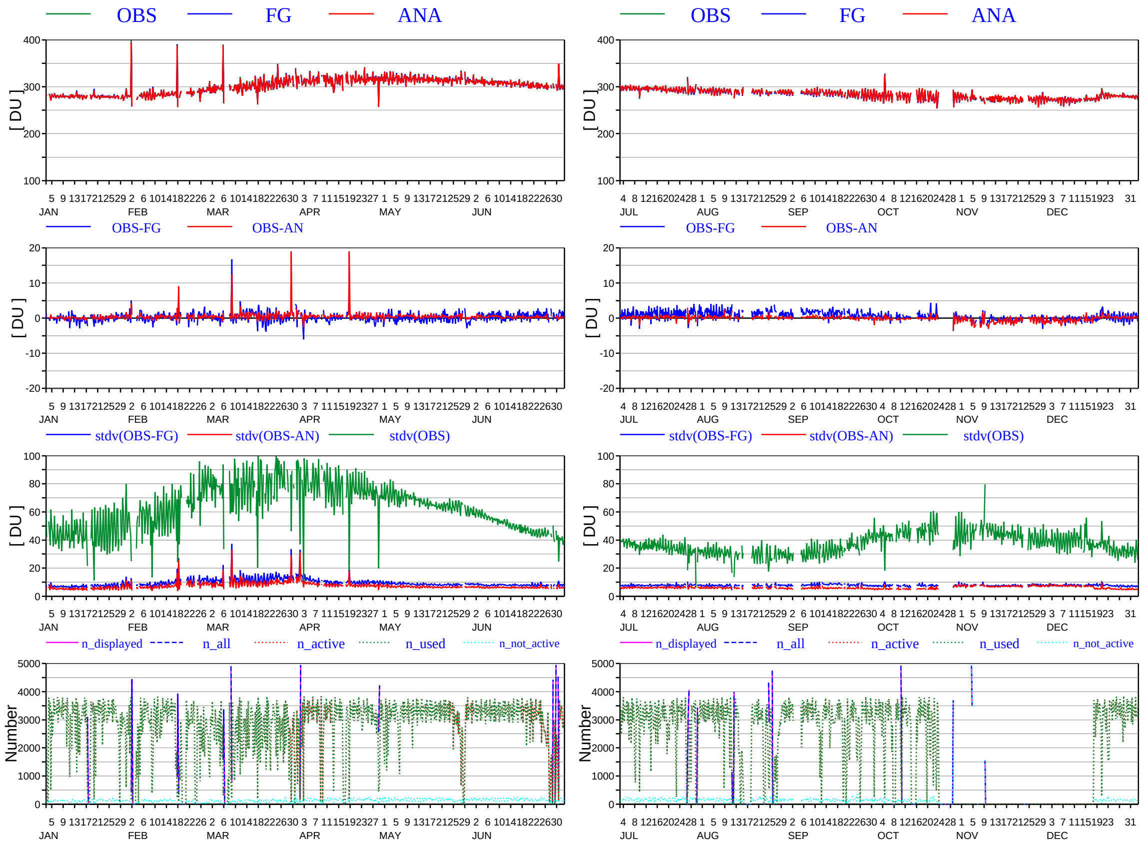


Figure 3: Timeseries of globally averaged data covering the periods 1 January to 30 June (left panel), and 1 July to 31 December 2010 (right panel). The top panels of each figure show TOSOMI SCIAMACHY NRT total ozone observations, first-guess and analysis values, the middle panels first-guess and analysis departures and the bottom panels the standard deviations of SCIAMACHY and of first-guess and analysis departures. All ozone values are in DU.

small (typically 1 to 2 DU), still represents about 10-20% of the annual mean value.

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 4. On average the first-guess departures (top panel in figure 4) 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 4) 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[6] or less.

Comparisons with total column ozone data from other UV instruments also show the generally good quality of these observations. Figure 5, 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 2010. The OMI data used in the comparisons are the NRT total column ozone distributed by NASA. On average, figure 5 shows a good level of agreement between SCIAMACHY and OMI total column ozone, particularly during the first half of 2010. Some differences can be found in the tropics, where SCIAMACHY usually exhibits lower values than OMI throughout the year (differences are normally about -15DU, -5% of the global mean TCO value), and at high latitudes where the OMI ozone values can be about 10% lower than

[6]This is consistent with what was found in the 2006-2009 studies (Dragani, 2006, 2008, 2009c, 2010b).

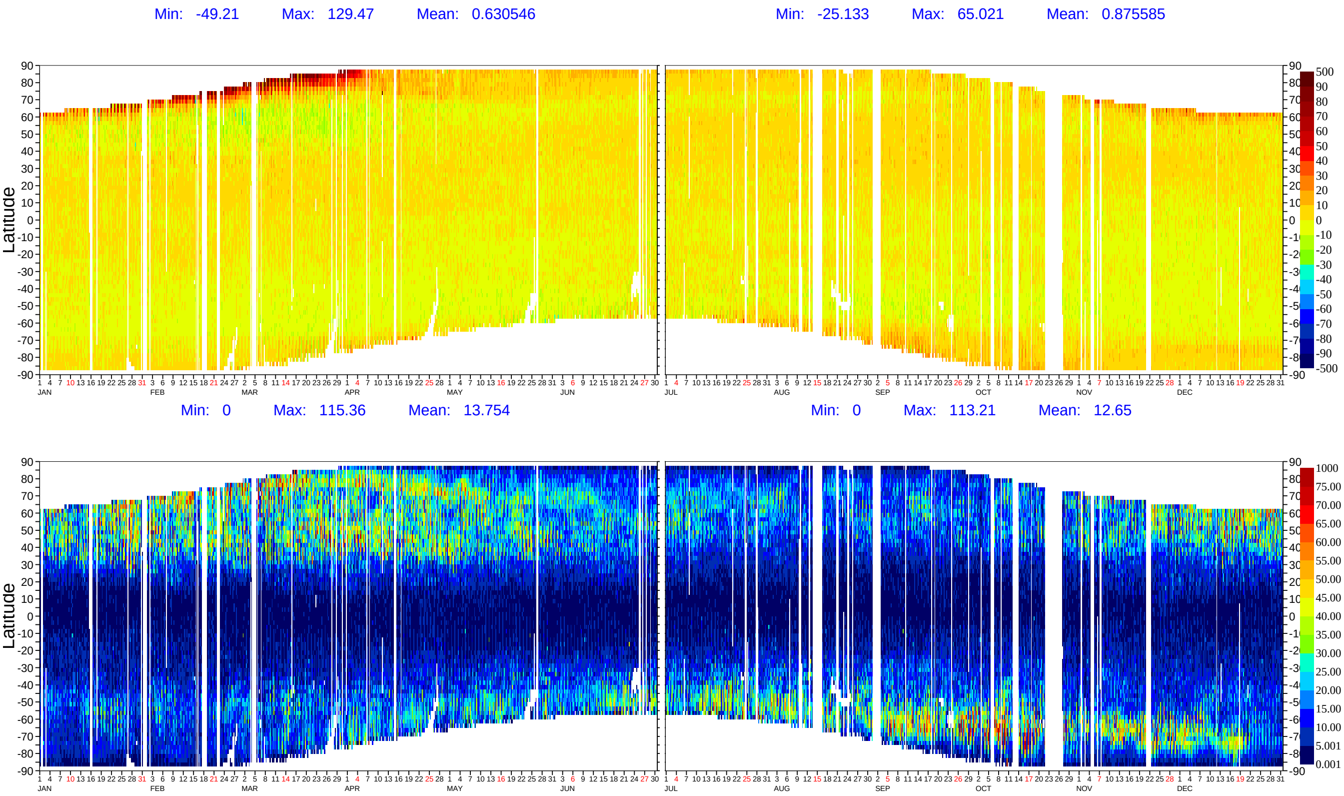


Figure 4: Time series of the zonal mean NRT SCIAMACHY first-guess departures (top panel) and of the zonal mean NRT SCIAMACHY standard deviation (bottom panel) during 2010. All ozone values are in DU.

those of SCIAMACHY. It should be noted that UV nadir sensors like OMI and SCIAMACHY[7] 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 4, 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 (as shown in figure 4.2).

Figure 6 shows the time series of the zonal mean difference between SCIAMACHY TCO and MetOp-A GOME-2 TCO for 2010. 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 10-15DU at most latitudes on average, with the exception of the end of the illuminated part of the orbits in the NH during spring 2010, where the differences were up to 60DU. In contrast to the comparison with OMI TCO, figure 6 shows that SCIAMACHY has on average larger TCO values than GOME-2.

4.3 Summary of the NRT SCIAMACHY monitoring and assimilation

The NRT SCIAMACHY ozone columns produced by KNMI (known as TOSOMI) were generally available during 2010, only a few short interruptions were recorded, the longest being for about four days between 22 and 26 October when the instrument was switched off to allow the ENVISAT orbit change.

The data quality was stable throughout 2010. The TOSOMI data were actively assimilated until 22 October when the assimilation was temporarily interrupted to allow ECMWF to assess the quality of the data after the ENVISAT orbit change. Assimilation experiments performed between November and the beginning of December 2010 showed no sign of degradation due to the change in the ENVISAT orbit. Therefore, the operational

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

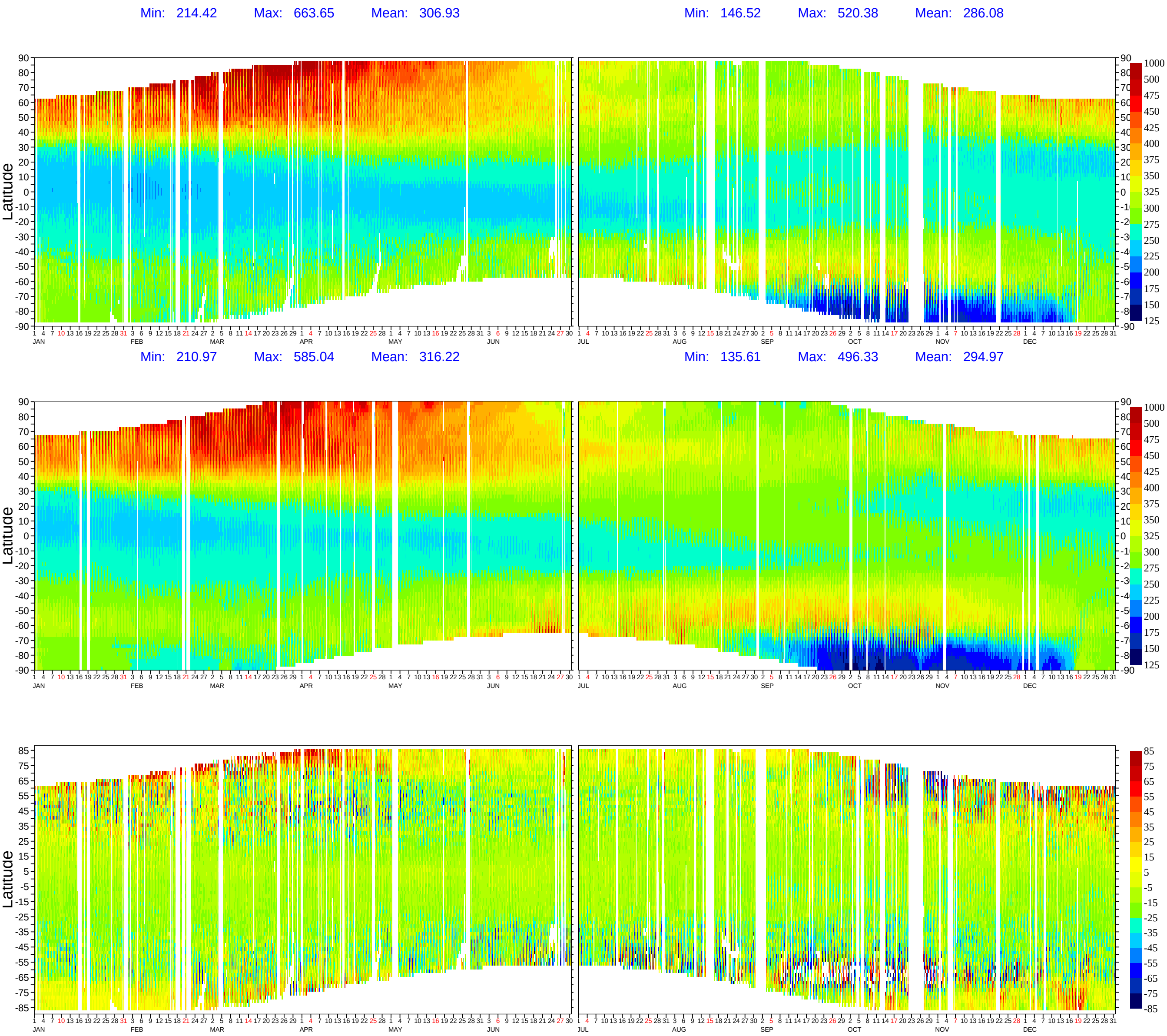


Figure 5: Time series of the zonal mean NRT SCIAMACHY ozone (top panel), OMI total column ozone (middle panel), and their difference (bottom panel) for 2010. All ozone values are in DU.

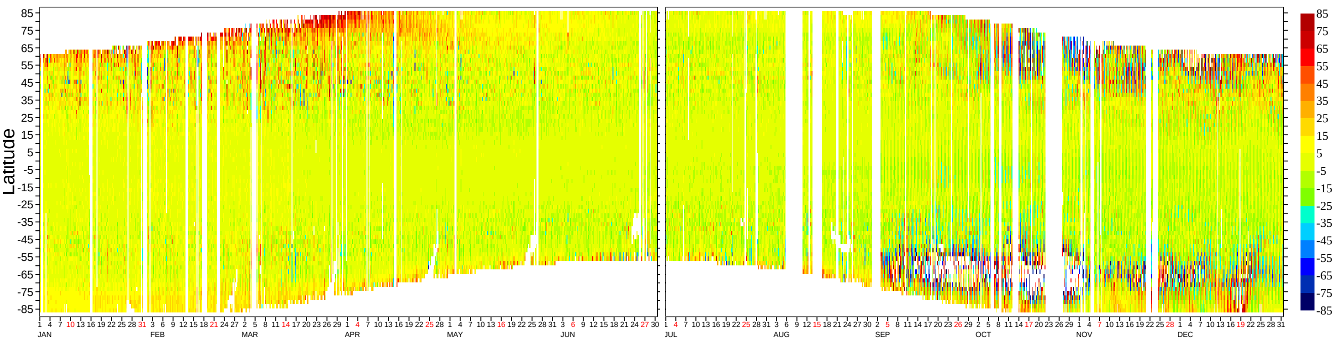


Figure 6: Time series of the zonal mean difference between SCIAMACHY TCO and GOME-2 TCO for 2010. Values are in DU.

assimilation restarted on 16 December 2010.

5 Monitoring of GOMOS data

GOMOS (Bertaux et al., 2010) 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.

Section 5.1 briefly summarizes the results from the monitoring activity performed during 2008 and 2009. Detailed assessment of these two years can be found in Dragani (2009c) and Dragani (2010b). The results from the 2010 monitoring are presented in sections 5.2-5.5.

5.1 Summary of the monitoring of GOMOS data during 2008 and 2009

The GOMOS retrievals were available during most of the two-year period 2008-2009. The only exception was the month of February 2009, when the instrument suffered of serious anomalies that mainly affected the pointing system. For that reason, the GOMOS instrument was not operated. Because these anomalies affected the pointing system, their main consequence resulted in a reduced amount of data, particularly in the stratosphere, during most of 2009. In some cases, the amount af stratospheric data was too low to make the results statistically significant, particularly for the water vapour.

When available, the quality of the GOMOS retrievals was generally stable and consistent with that reported under previous contracts. On average, the GOMOS temperature departures were less than -1% (-2 K) in most of the stratosphere and slightly larger in the mesosphere (normally up to -4%, about -8K between 0.2 and 0.4hPa). The mean first-guess and analysis departures from the NRT GOMOS ozone profiles were within -10 and +20% in most of the stratosphere (for pressure values smaller than 40hPa), but larger departures were found on average in the lower stratosphere (for pressure values larger than 40hPa), and in the mesosphere. The first-guess and analysis departure standard deviations were larger than 15% in the lower stratosphere and larger than 50% in the upper stratosphere and mesosphere. The quality of the water vapour data was generally poor during both 2008 and 2009. The monitoring statistics showed 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 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.

5.2 GOMOS data availability during 2010

The GOMOS data were generally available during 2010, with the only exception of the period between 22 October (when the instrument was switched off before the ENVISAT orbit change) and 29 November when the operational data processing and dissemination restarted.

Figure 7 shows the time series of the global number of GOMOS ozone observations (top) and of the zonal mean

GOMOS temperature (bottom) during 2010, respectively. The plots refer to the layer between 2.6 and 3.9 hPa and they are intended to provide a general indication of the amount of available data per six hour window (panel **a**) and their geographical coverage (panel **b**) during 2010. The data amount, that counted about 40 observations per six hour window during the first three months of 2010, decreased to about 20 profiles per six hour window afterwards, when the GOMOS orbit shifted to cover most of the southern hemisphere. After the ENVISAT orbit change, the GOMOS coverage was shifted to sample the tropics and midlatitudes in both hemispheres. The number of profiles also increased slightly.

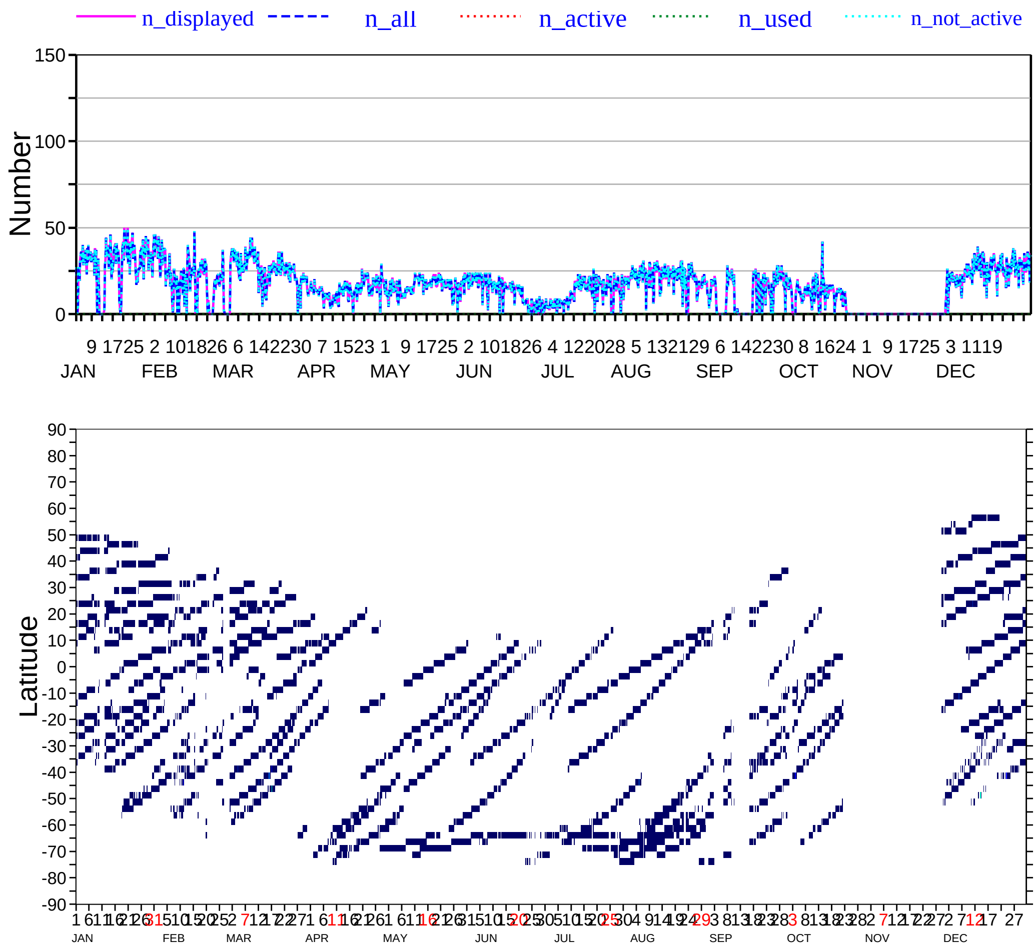


Figure 7: Time series of the global number of GOMOS observations (top panel) and their latitudinal distribution (bottom panel) during 2010. The plots refer to the layer between 2.6 and 3.9 hPa.

5.3 Monitoring of GOMOS temperature data

The quality of the temperature profiles in the BUFR files was generally stable during 2010, and consistent with that reported in 2008 and 2009 (Dragani, 2008, 2009c).

It should also be noted that the GOMOS temperature was no longer retrieved in NRT 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*[8] *and of the MSIS90 data in the upper part of the profile (smooth transition altitude range around the pressure level 1hPa)* (ESA, 2007).

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

Figure 8 shows the timeseries of the global mean temperature data and their departures at the 20 hPa pressure level. The level of agreement is generally better than 1%, with first-guess and analysis departures less than 2 K. Between the end of March and the beginning of April, the level of agreement in the mid stratosphere appears to suddenly improve producing an almost zero global mean residuals. This is only a consequence of the annual latitudinal shift southward of the GOMOS orbit.

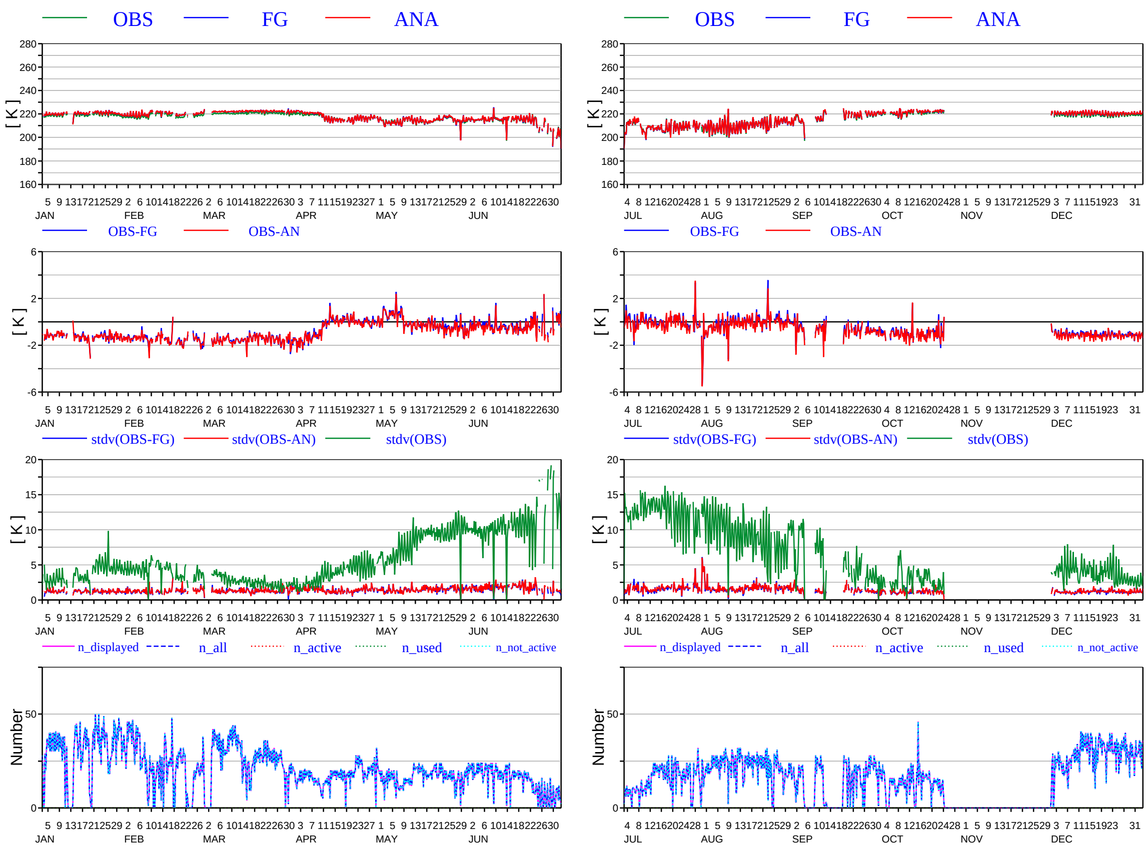


Figure 8: Timeseries of globally averaged data at 20 hPa covering the periods 1 January to 30 June (left panel), and 1 July to 31 December 2010 (right panel). From top to bottom, each figure show a) GOMOS NRT total temperature observations, first-guess and analysis values, b) the first-guess and analysis departures, c) the observation and departure standard deviations, and d) number of mean daily data count. All temperature values are in K.

Figure 9 presents the time series of the first-guess and analysis departures globally averaged (top panel) and averaged over all the available latitudinal bands (refer to the figure captions for details) during the first six months of 2010. Figure 9 shows that there is a generally negative bias (observation values lower than their model equivalent) when GOMOS measurements cover the tropics and the midlatitudes (first part of the year); while the high latitudes in the SH are more characterized by a positive bias that balances the negative one in the tropics, leading to an overall almost zero global mean bias from April.

The comparisons between the area averaged GOMOS and ECMWF temperature profiles confirm the level of agreement discussed above between the temperature data in the GOMOS files and the ECMWF temperature analyses. Two periods are discussed in details: the first period covers the two month period April-May 2010, which is characteristic of the level of agreement between observations and their model equivalent during most of the year before the ENVISAT orbit change (figure 10); the second period was chosen after the ENVISAT orbit change, and runs from 29 November until 31 December 2010 (figure 11). In both figures, each panel refers to the results averaged over a given latitudinal band depending on the data availability. For each period, the comparisons between area averaged GOMOS and ECMWF temperature profiles are presented on the left panels, while their relative departures are shown in the right panels. In the April-May 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 either hemispheres.

In April-May (figure 10), 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 -5% (-10K) in the mesosphere. At midlatitudes in the SH, the temperature residuals show a zero bias over the stratosphere, but large negative differences up to -7% in the mesosphere. The high latitudes in the SH are, instead, characterized by a positive, up to +0.5% bias in the lower stratosphere (for pressure levels larger than 8hPa), and a small negative bias (about -0.3%) in the rest of the stratosphere. The mesospheric residuals at this latitudinal band are also negative and up to -4%. The standard deviations of the departures ranged from 1 to 3% at all levels and available latitudinal bands.

In November-December (figure 11), 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. In particular, the first guess and analysis departures were typically up to about -1% (-2 K) in the stratosphere and within -2 and -4% (within -4 and -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.

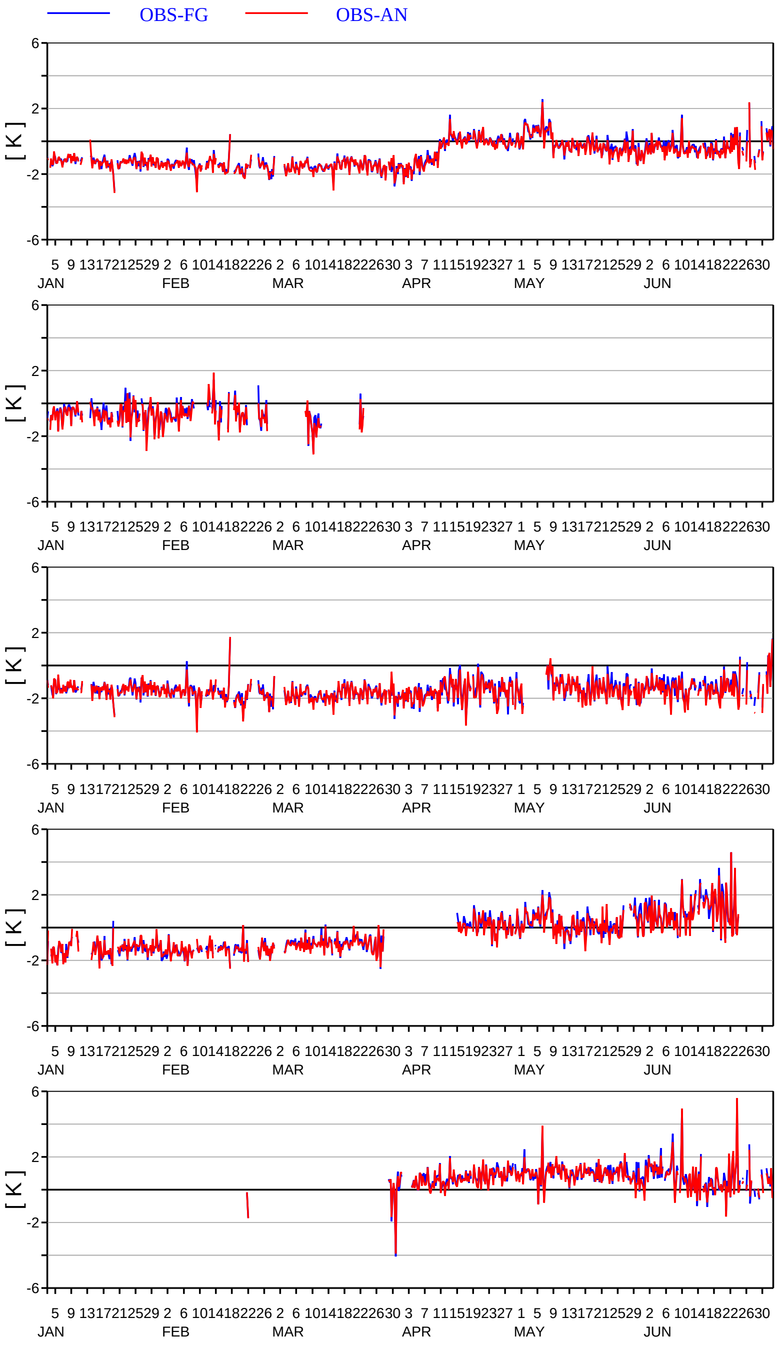


Figure 9: Timeseries of the GOMOS temperature first-guess and analysis departures at 20hPa for the period 1 January - 30 June 2010. From top to bottom, the timeseries are averaged over: all available latitudes (60N-90S), the midlatitudes in the NH (30-60N), the tropics (30S-30N), the midlatitudes in the SH (30-60S), and the high latitudes in the SH (60-90S). All temperature values are in K.

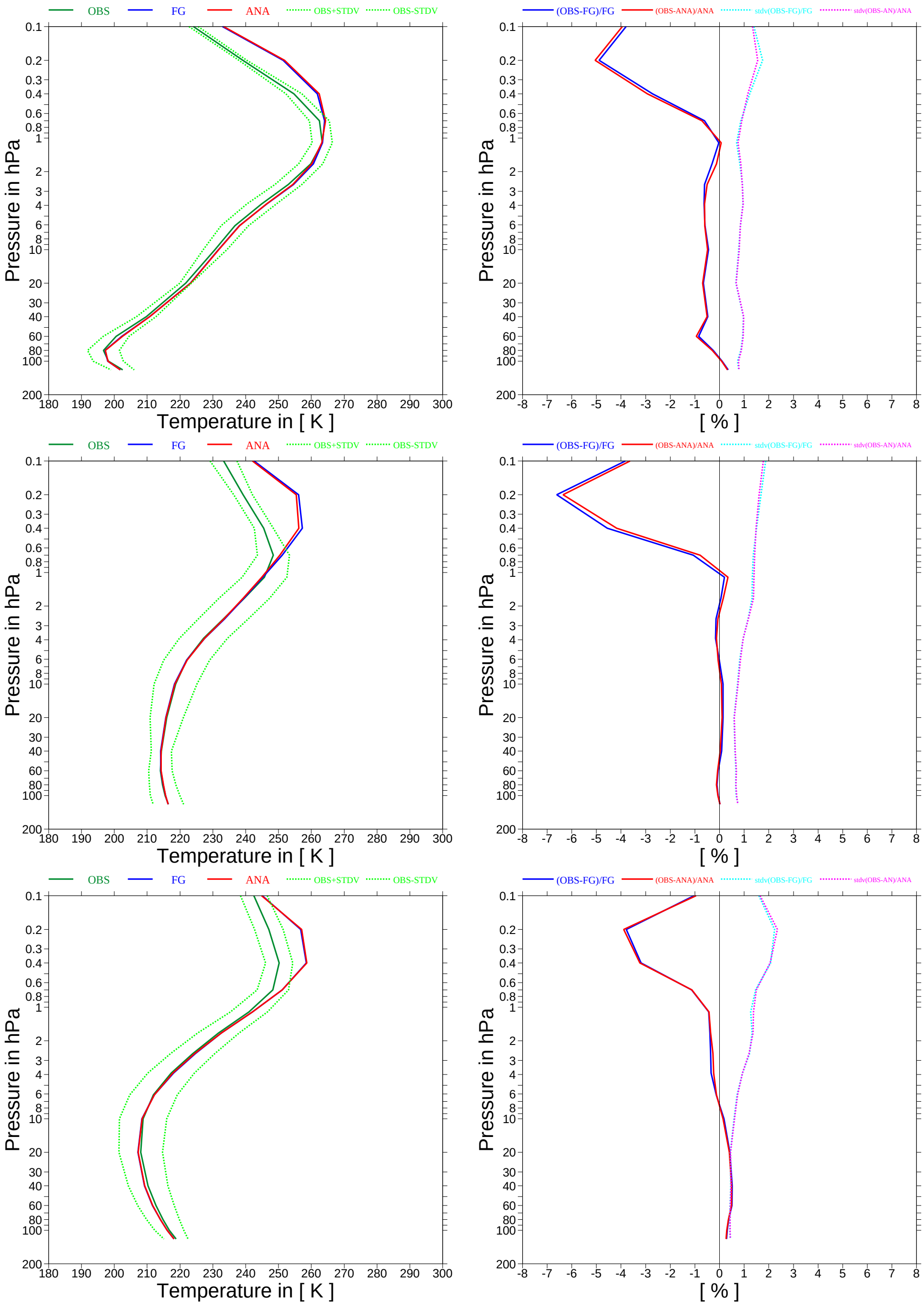


Figure 10: Comparisons between the area averaged temperature extracted from the GOMOS files and the area averaged ECMWF temperature first-guess and analysis. Right panels refer to the profile comparisons, left panels show the relative first-guess and analysis departures. The averaging period is between April and May 2010. 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 %.

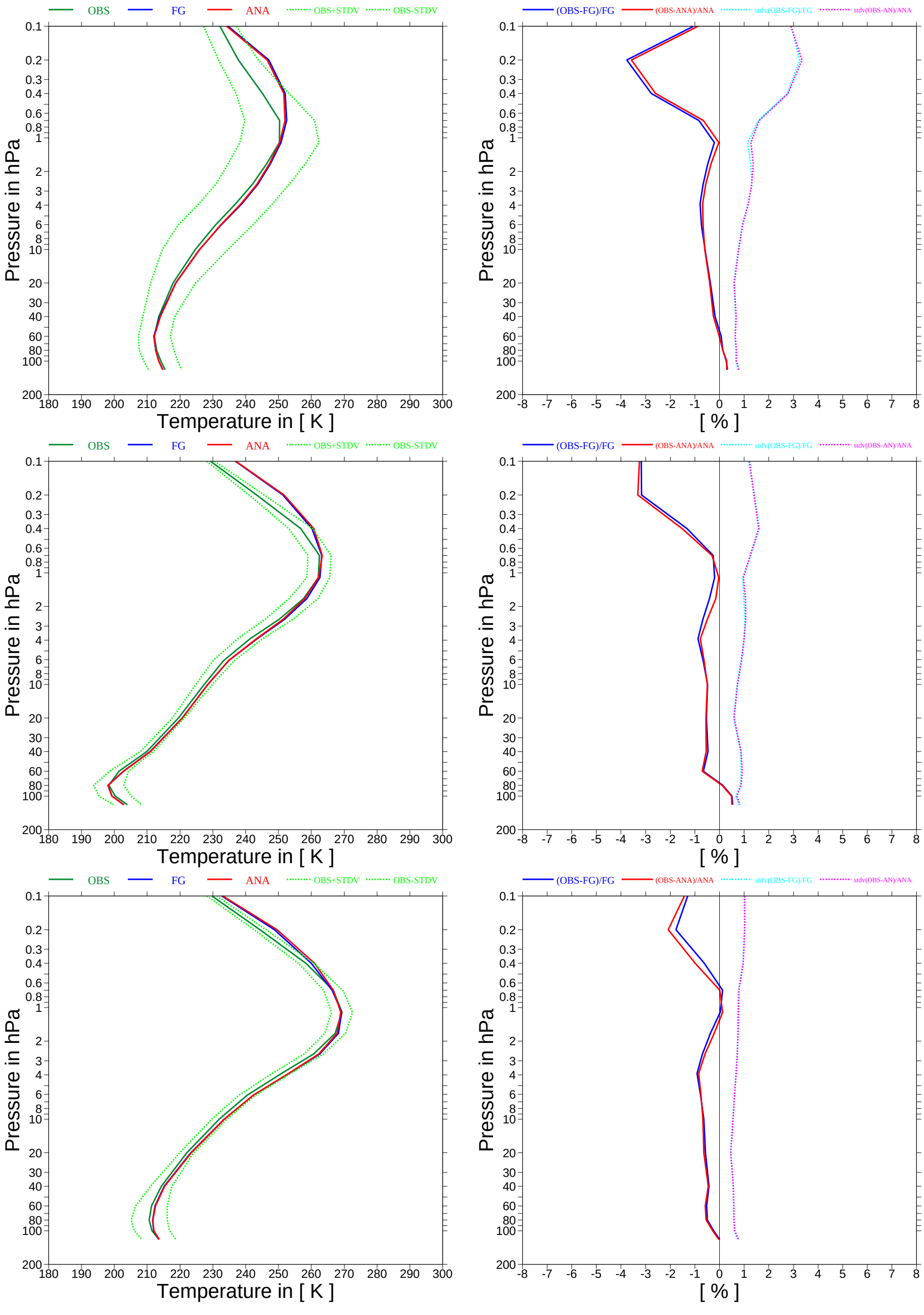
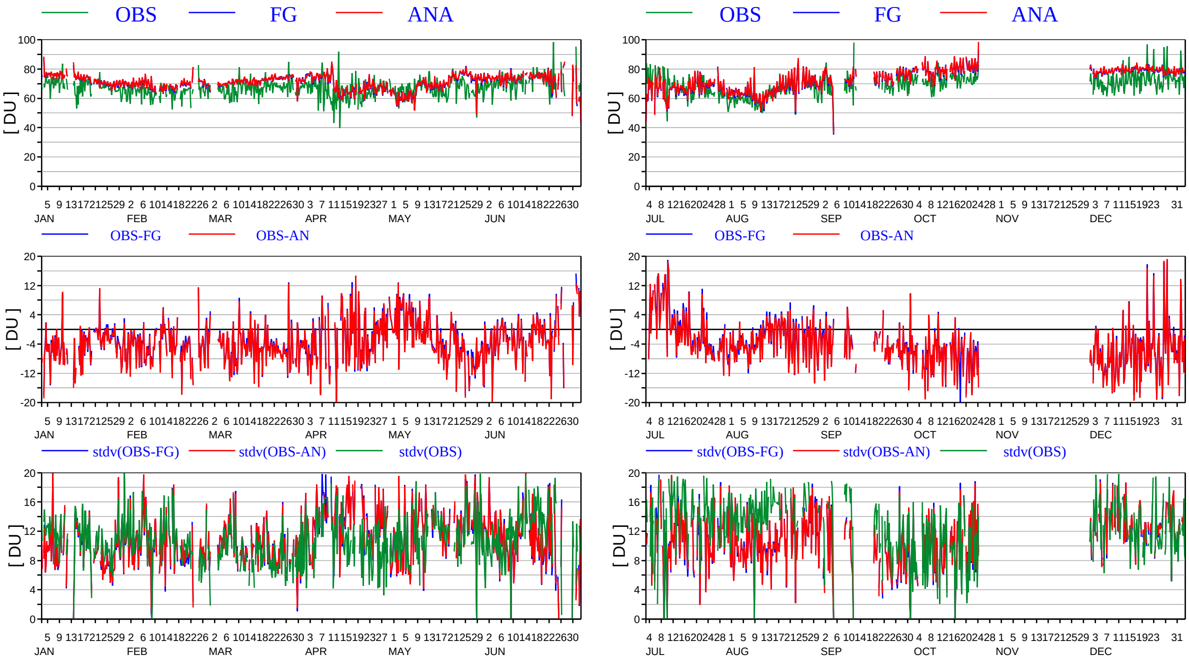


Figure 11: Like in figure 10, but the averaging period is between 29 November and 31 December 2010, so they cover the period of GOMOS availability after the orbit change. The top panels refer to the midlatitudes in the NH (30°-60°N), the middle panels refer to the tropical band 30°N-30°S, and the bottom panels refers to the midlatitudes in the SH (30°-60°S).

5.4 Monitoring of GOMOS ozone data

This section discusses the results from the monitoring of the NRT GOMOS Level 2 ozone profiles in 2010. The discussion on the data availability and daily mean amount given in section 5 also applies to the GOMOS ozone retrievals.

Figure 12 shows the 2010 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 12, the GOMOS ozone observations exhibit slightly lower ozone values than the ECMWF ozone analyses (about 4DU over the layer) during most of the year. When averaging over latitudinal bands (not shown), the level of agreement just discussed is usually confirmed. Large standard deviations of about 15 DU were found in the data, corresponding to just below 20% of the annual mean ozone value in this layer.



(a) (b)

Figure 12: Timeseries of globally averaged data covering the periods (a) 1 January to 30 June, and (b) 1 July to 31 December 2010 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.

Figures 13 and 14 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 April-May, and (29) November-December 2010, respectively.

In both figures, each panel refers to the results averaged over a given latitudinal band. In figure 13, 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 14, 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

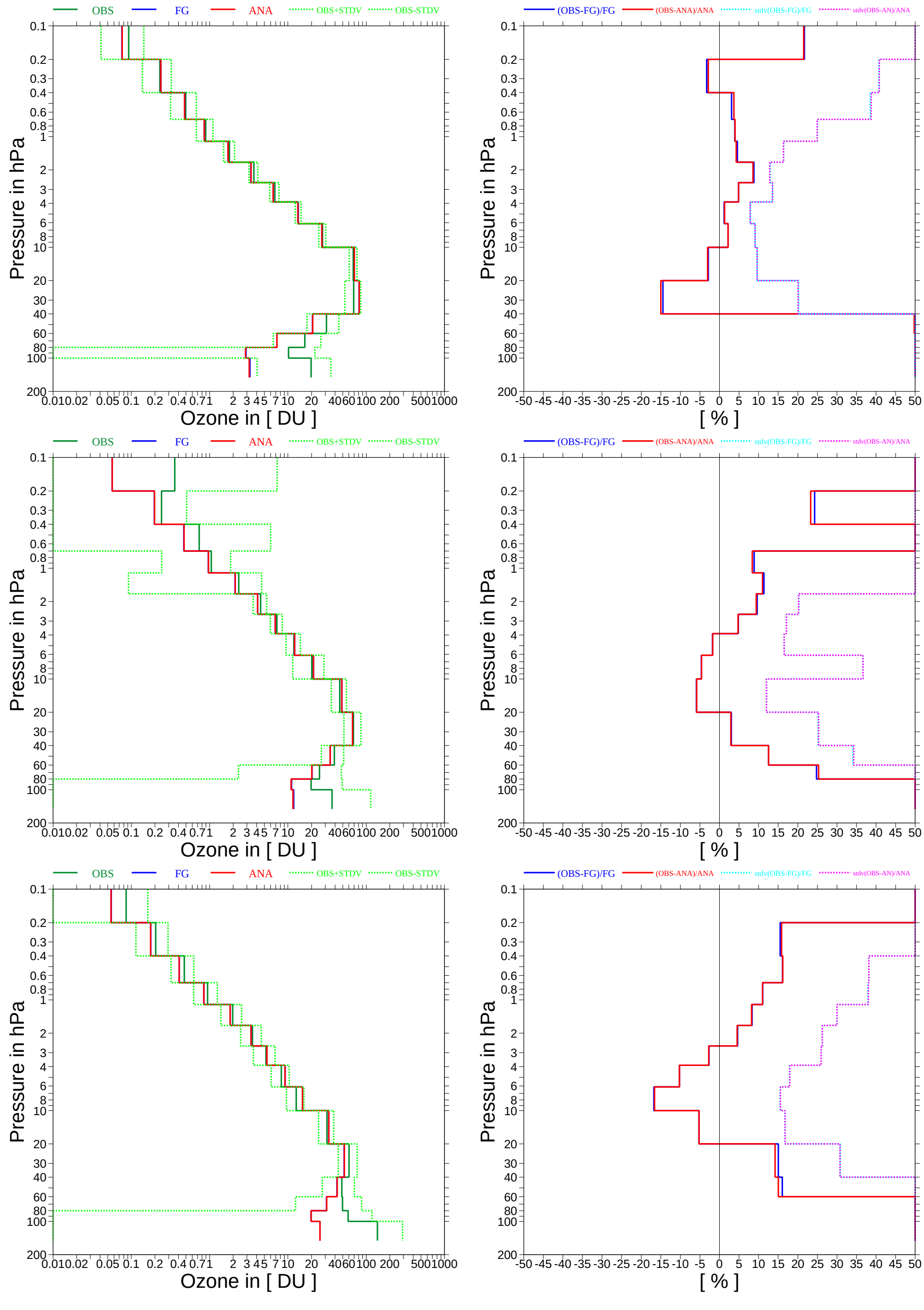


Figure 13: Like in figure 10, but for ozone. Ozone values are in DU, departures are in %.

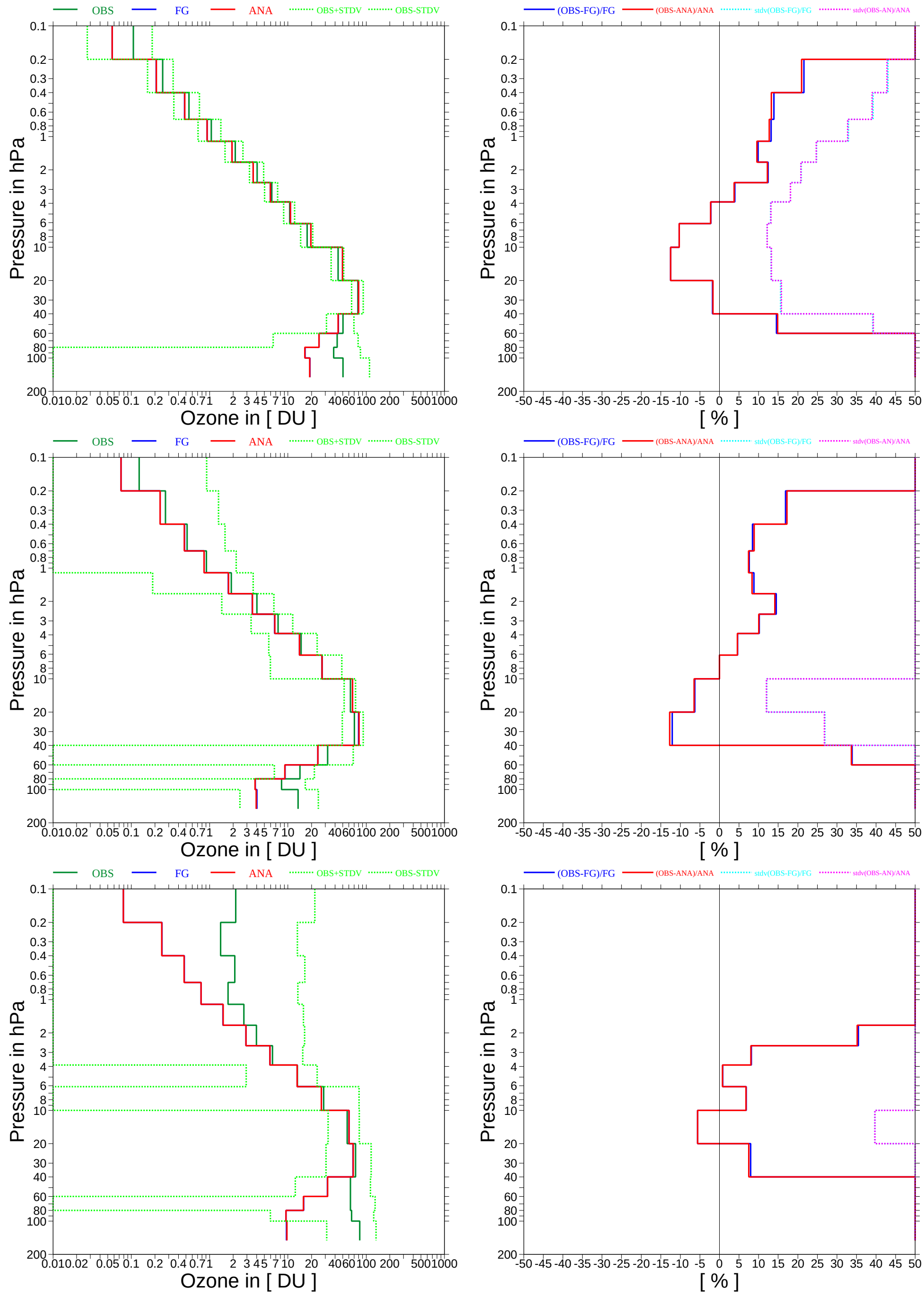


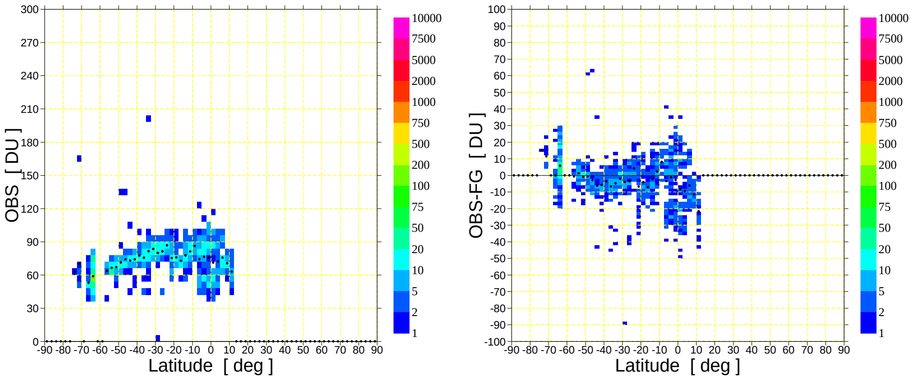
Figure 14: Like in figure 11, but for ozone. Ozone values are in DU, departures are in %.

(green, dottet lines in l.h.s. panels) at all levels and available latitudes.

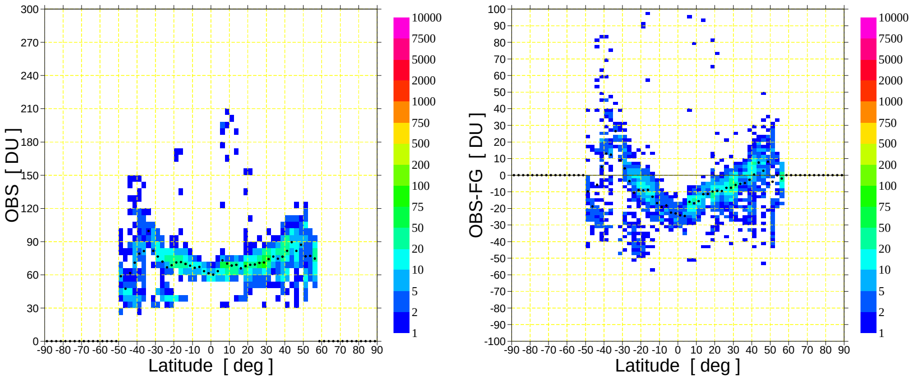
During April-May, the first-guess and analysis departures were typically within ±15% at most levels from the mid stratosphere up to the mesosphere, at all latitudinanal bands. Larger departures (larger than 50%) are normally found in the lower stratosphere. The standard deviations of the departures where normally larger 15% at all levels and available latitudinal bands, and larger than 50% near the tropical stratopause and mesosphere.

After the ENVISAT orbit change, the GOMOS mean ozone profiles calculated over the midlatitudes in the NH and the tropics (top and middl panels in figure 13) show lower values than its model equivalent in the mid stratosphere (between 5 and 40 hPa), and higher values elsewhere, with residuals typically within -10 and +15% at all mesospheric levels and in the stratosphere at pressure levels lower than 40hPa. At high latitudes in the SH, the ozone residuals were typically positive at most vertical levels, and with values larger than 50% in the lower and upper stratosphere, as well as in the mesosphere. The standard deviations of the departures were larger than 15% at all levels and available latitudinal bands, and larger than 50% in places.

The GOMOS ozone data typically showed large scatter. An example for the layer 20-40 hPa is given in figure 15, that show the scatter plots of the observations versus latitude (left) and those of the first-guess departures versus latitude (right) for May 2010 (top panels) and December 2010 (bottom panels).



(a)



(b)

Figure 15: 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 May 2010 (panels [a]) and December 2010 (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.

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 May, and between ±40 DU in December. A few outliers were also seen in the scatter plots, particularly in the December plots. This could point to some level of degradation in the retrievals related to the ENVISAT orbit change. This aspect will be closely monitored during 2011.

5.5 Monitoring of GOMOS water vapour data

The NRT GOMOS water vapour data were available in the GOM_RR__2P BUFR files for most of 2010, the only exception being November 2010 after the ENVISAT orbit change as discussed above. It should be noted that the amount of water vapour data available at some levels during the year was sometimes too low to provide statistically significant results, particularly in the lower stratosphere.

The level of agreement of the water vapour data with their ECMWF model equivalent was generally poor, as noted in previous years (e.g. Dragani, 2009c, 2010b). This is, for example, illustrated by the scatter plots presented in figure 16 for the integrated layer between 1 and 100 hPa. The two panels show the scatter plot for June (l.h.s. panel) and December (r.h.s. panel) 2010, respectively.

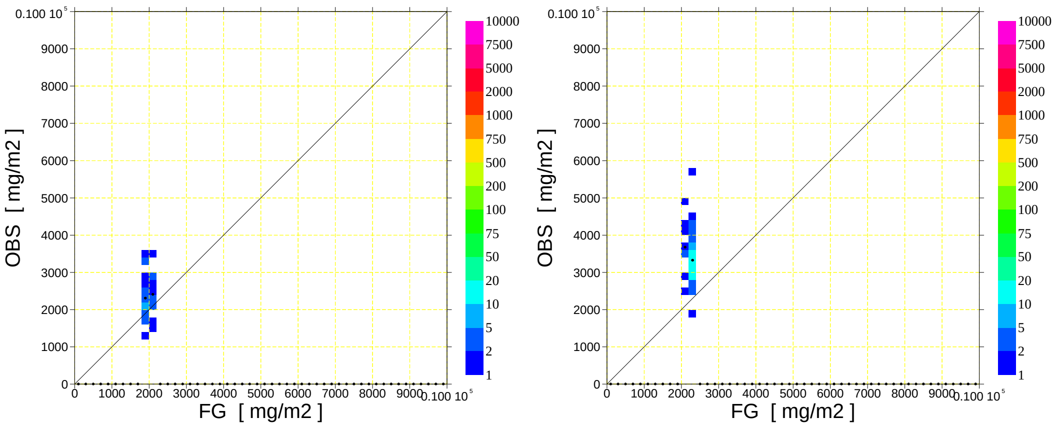


Figure 16: Scatter plots of NRT GOMOS water vapour content against the ECMWF first-guess in the integrated layer 1-100 hPa for the periods June (left), and December 2010 (right). The colours give the number of observations per bin, and the black dots the mean per bin. Values are in mg/m^2.

Figure 17 shows 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 June-July (l.h.s. panels) and (29) November-December (r.h.s. panels) 2010 (see captions for details). These profile plots confirm the poor level of agreement between the GOMOS water vapour data and their model equivalent, and show in particular 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.

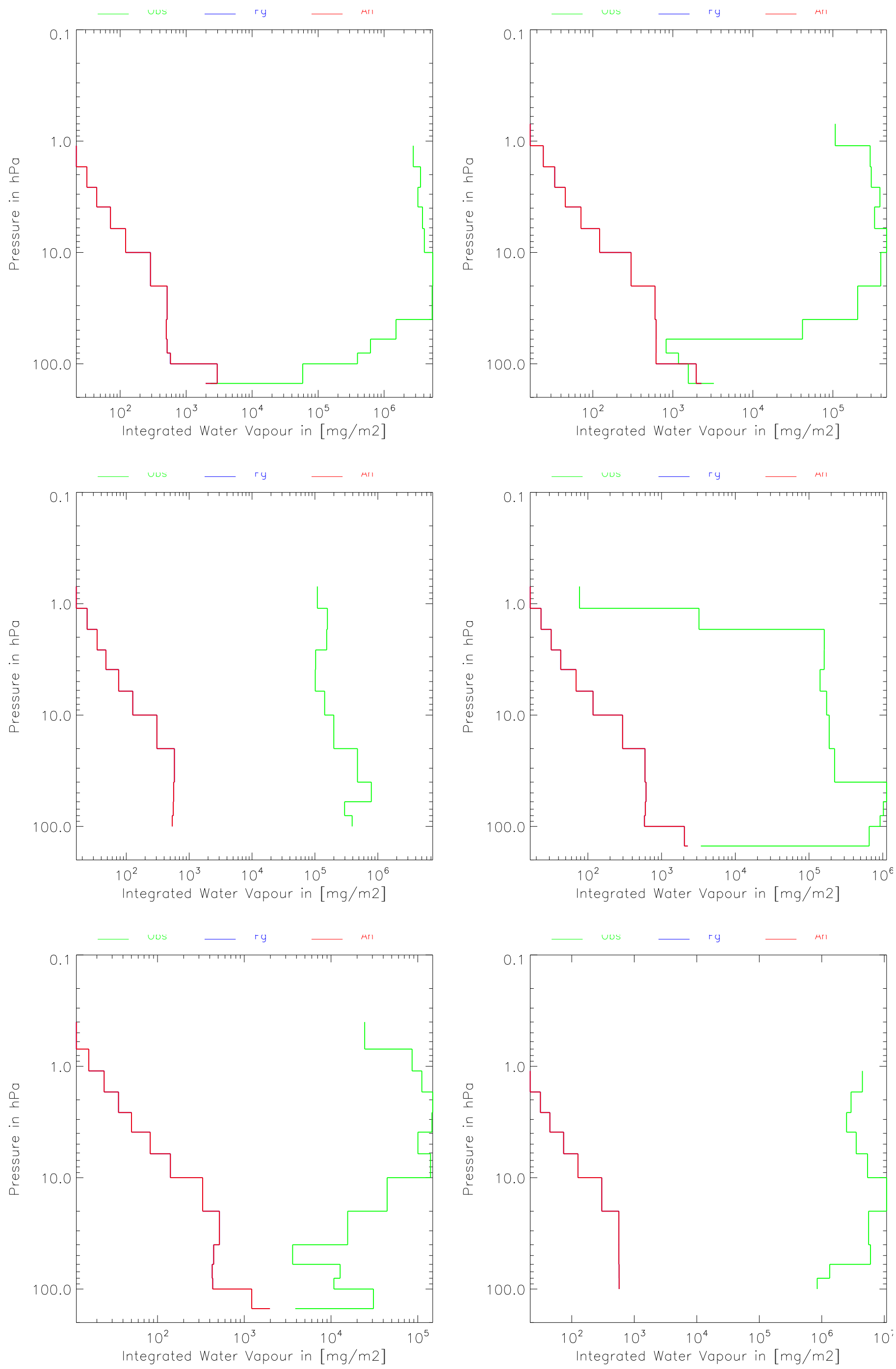


Figure 17: Comparisons between the area averaged GOMOS water vapour profiles and the area averaged ECMWF water vapour first-guess and analysis for June-July 2010 (l.h.s. panels) and 29 November - 31 December 2010 (r.h.s. panels). The June-July plots (l.h.s. panels) were obtained by averaging the data over the tropical band [30°N-30°S] (top panel), the mid ([30°-60°]S) and high ([60°-90°]S) latitudes in the SH (middle and bottom panels, respectively). In contrast, the November-December plots (r.h.s. panels) refer to the midlatitudes in the NH ([30°-60°]N) (top panel), to the tropical band (middle panel), and to the midlatitudes in the SH (bottom panel). Water vapour values are in mg/m^2.

6 Monitoring of MIPAS data

The NRT L2 MIPAS data (MIP_NLE_2P) were actively assimilated at ECMWF from October 2003 until the end of March 2004 (Dethof, 2004), when the instrument had to be switched off due to instrumental problems. After implementing several changes to the instrument characteristics, MIPAS operations gradually restarted in 2005, and by the end of 2007 they reached 100% of the duty cycle. Nonetheless, the NRT L2 data have remained unavailable until very recently. Although at the time of writing there were still some issues to solve in terms of data production[9], most of the MIPAS L2 data are now available on the ESA ftp server in BUFR format. In December 2010, ECMWF restarted the operational data downloading of MIPAS retrievals. All necessary changes and updates are being developed in the ECMWF system so that the operational monitoring and possibly the assimilation of these data can soon restart. This could be delayed in the year, depending on the ECMWF schedule and deadlines to submit modifications to the operational suite. Until the operational monitoring will be fully resumed, the MIPAS L2 data will be monitored in a parallel experiment run in research mode at low resolution.

Figures 18 to 23 refer to a preliminary monitoring of the MIPAS ozone, temperature and water vapour profiles in the above mentioned research experiment valid for one month between 18 December 2010 and 17 January 2011. The plots were obtained by globally averaging all the profiles and as area averaged profiles over five latitudinal bands ([60°-90°]N, [30°-60°]N, [30°S-30°N], [30°-60°]S, [60°-90°]S).

Figures 18 and 19 show a generally good agreement between the MIPAS ozone retrievals and the ECMWF ozone first-guess and analyses. At all latitudes, the MIPAS observations exhibit higher ozone values than their model equivalent, expect in the region between 10 and 30 hPa. The relative ozone departure plots (figure 19) show an agreement within $\pm$20% in most of the stratosphere and in the mesosphere in the tropics and at midlatitudes. Larger mesospheric departures (up to 50%) were found at high latitudes.

The comparisons between the MIPAS temperature retrievals and their model equivalent (figures 20 and 21) also show a good level of agreement in most of the stratosphere and latitudes, with departures typically within $\pm$1% (about $\pm$2K). Larger and generally negative (observations have a cold bias with respect to the model) departures were found in the mesosphere, with values up to 10% (about 20K).

Figures 22 and 23 refer to the mean profile comparisons between the MIPAS water vapour retrievals and their model equivalent. The level of agreement appears good at most levels in the lower stratosphere, with relative departures typically within $\pm$10%. Slightly larger differences were found in the upper troposphere, where the MIPAS data are drier than their model equivalent (up to -50% differences), and in the upper stratosphere and mesosphere, where the water vapour first-guess and analyses are drier than the observations (differences up to +20%).

In addition to the operational monitoring, ESA and ECMWF have agreed in assessing the impact of assimilating the MIPAS L2 data (ozone and water vapour) retrieved from the low spectral resolution data on the ECMWF forecasts and analyses. This assessment will be performed as soon as the modifications for MIPAS data have been fully developed and tested.

The impact of assimilating low spectral resolution MIPAS level 1 radiances on the ECMWF ozone analyses has also been performed. These results, that were presented at the 2010 ESA Living Planet Conference in Bergen, Norway, are summarised in a separate paper (Dragani and Bormann, 2010).

[9]Some inconsistenies were occasionally found in the PDS data files that caused the PDS2BUFR converter to fail. This is believed to happen when the instrument is commanded to switch from the nominal mode to a special one, and back to nominal mode. On average, MIPAS had sequences of four days of nominal mode followed by one day of one of the special mode sampling during 2010.

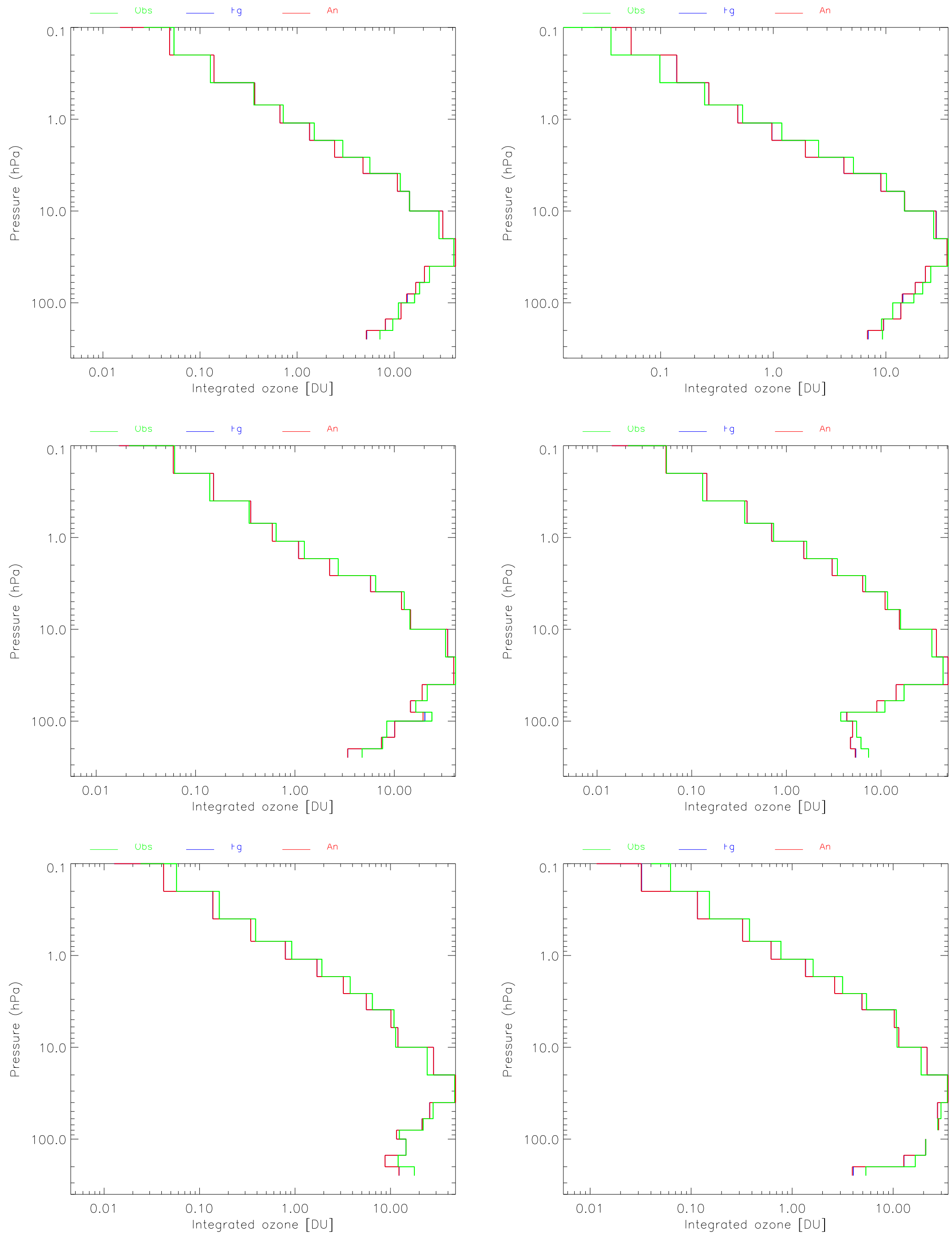


Figure 18: Comparisons between the area averaged MIPAS ozone profile (green) and the area averaged ECMWF ozone first-guess (blue) and analysis (red) for the period 18 December 2010 - 17 January 2011. The panels refer to the global mean profiles (top left panel), and to the mean profiles over the high latitudes ([60°-90°]) in the NH (top right panel), the midlatitudes ([30°-60°]) in the NH (middle left panel), the tropical band [30°N-30°S] (middle right panel), the mid and high latitudes in the SH (bottom left and right panels, respectively). Data are in DU.

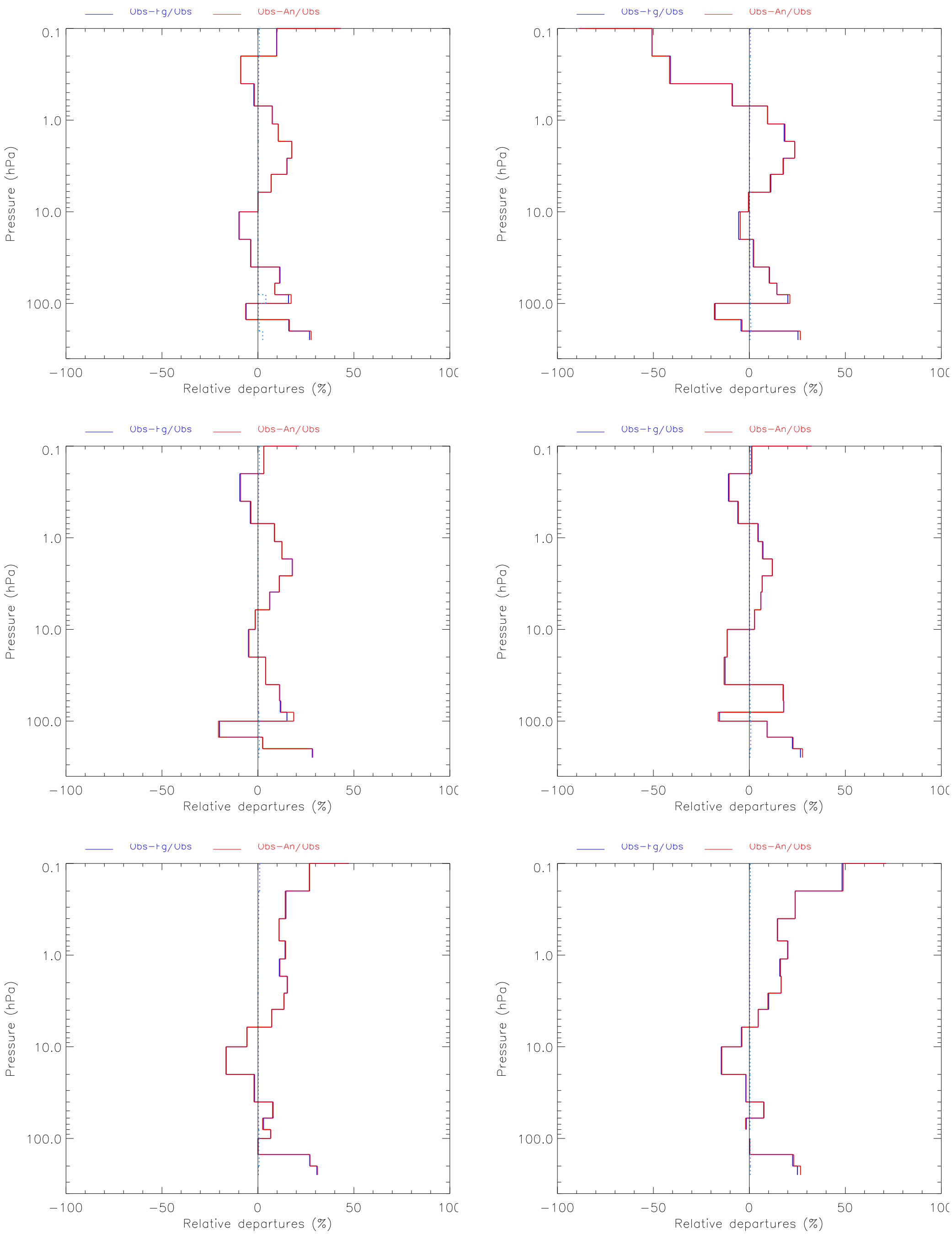


Figure 19: As in figure 18, but for the relative ozone first-guess (blue) and analysis (red) departures. Data are in %.

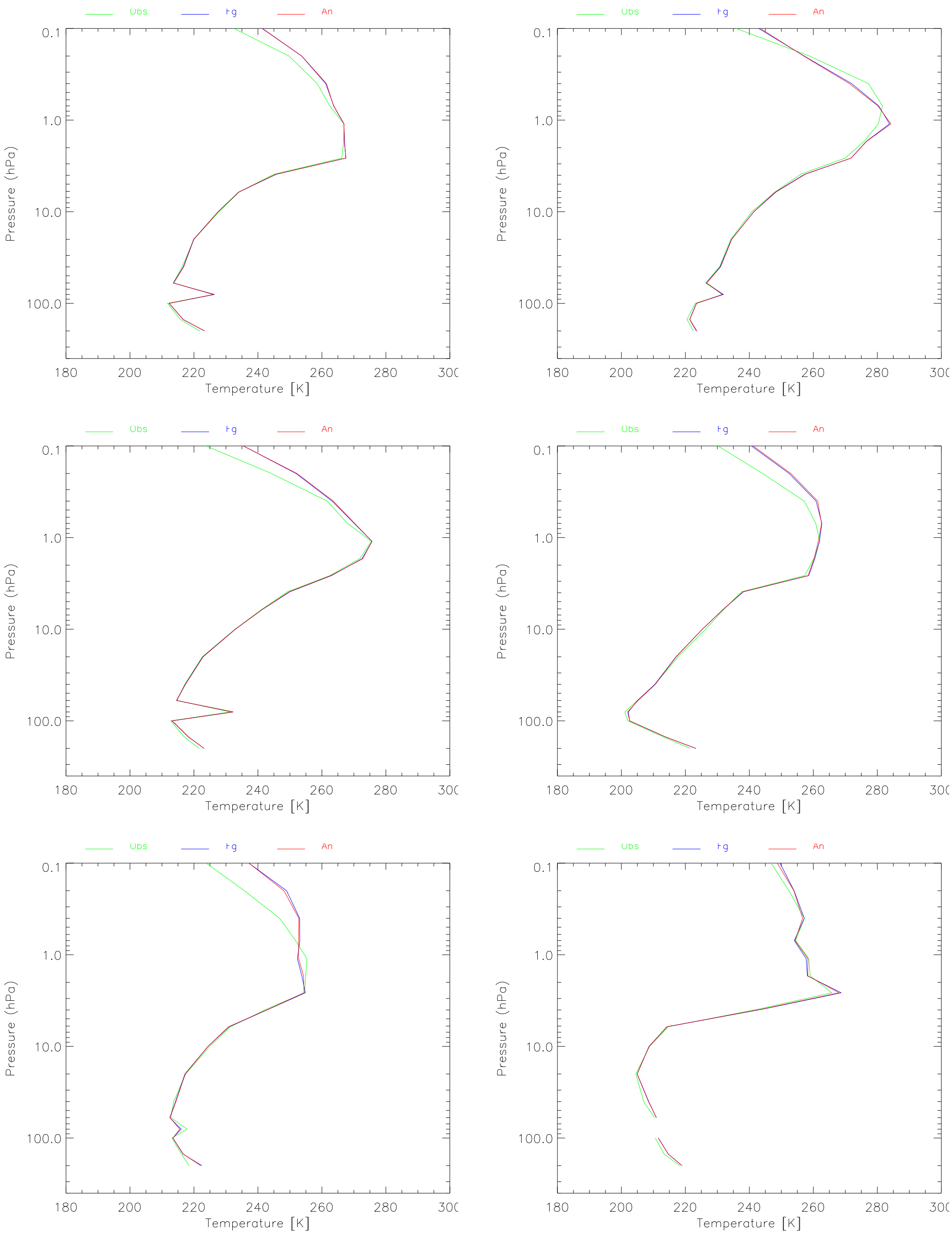


Figure 20: As in figure 18, but for the temperature. Data are in K.

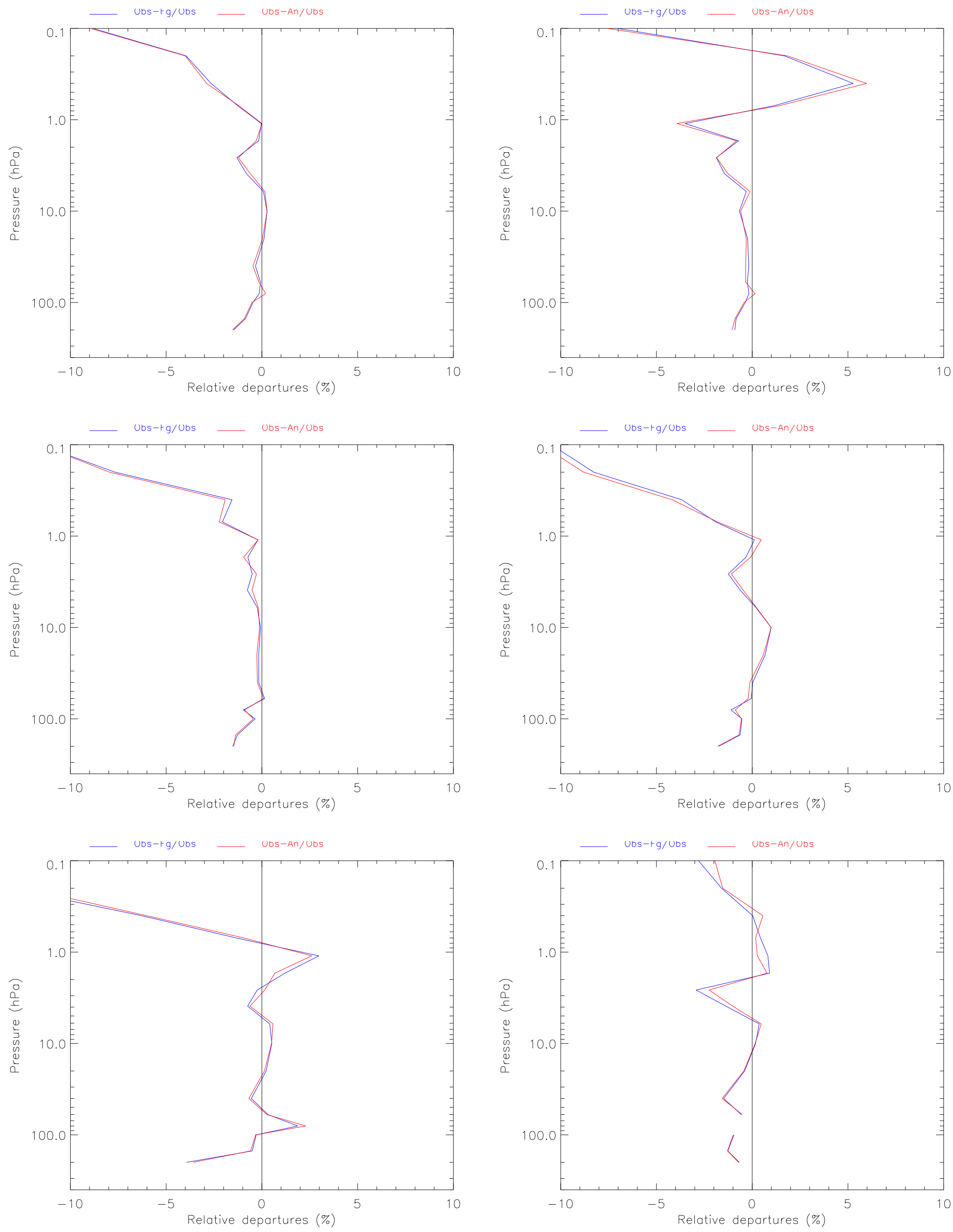


Figure 21: As in figure 20, but for the relative temperature first-guess and analysis departures. Data are in %.

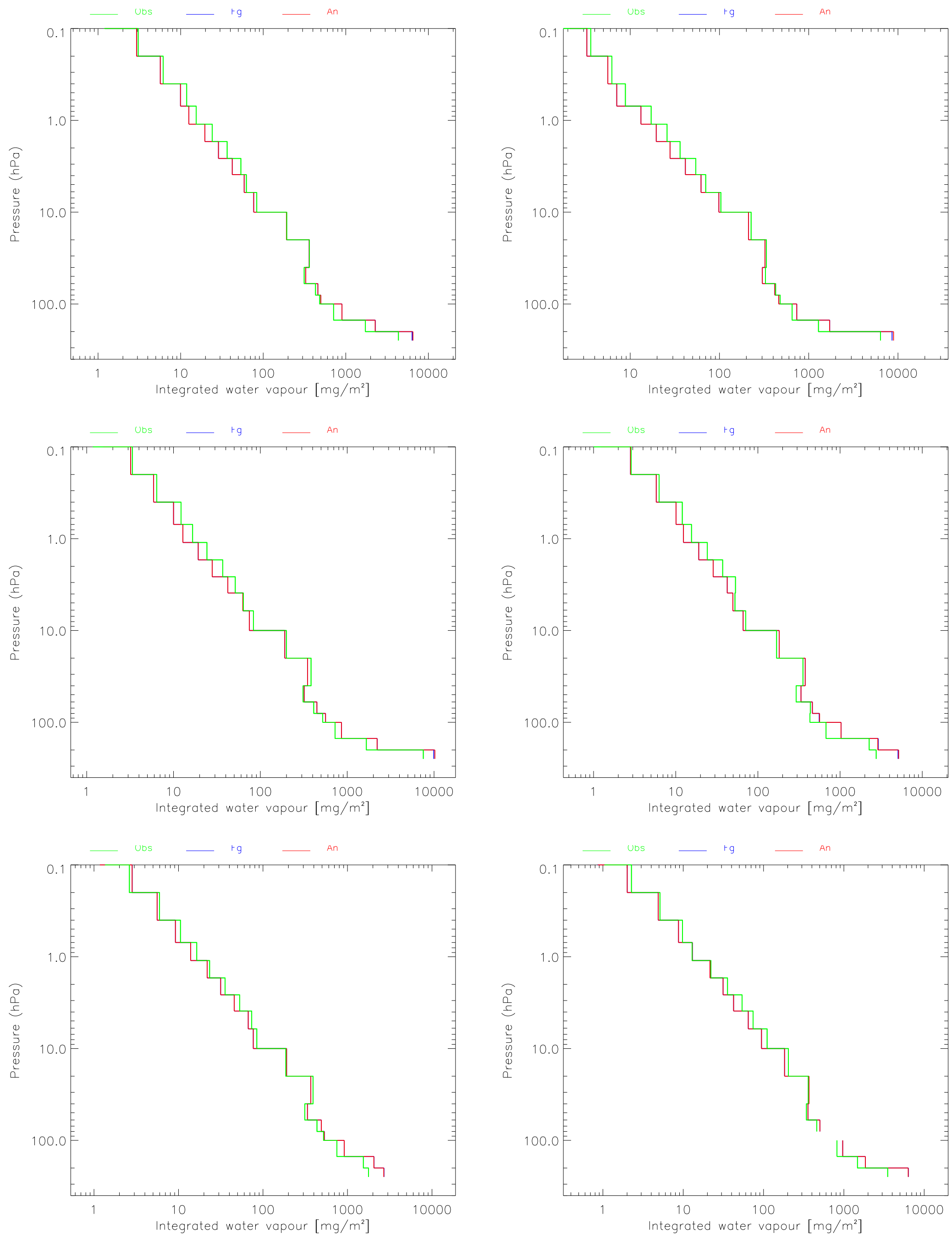


Figure 22: As in figure 18, but for the water vapour. Data are in mg/m^2.

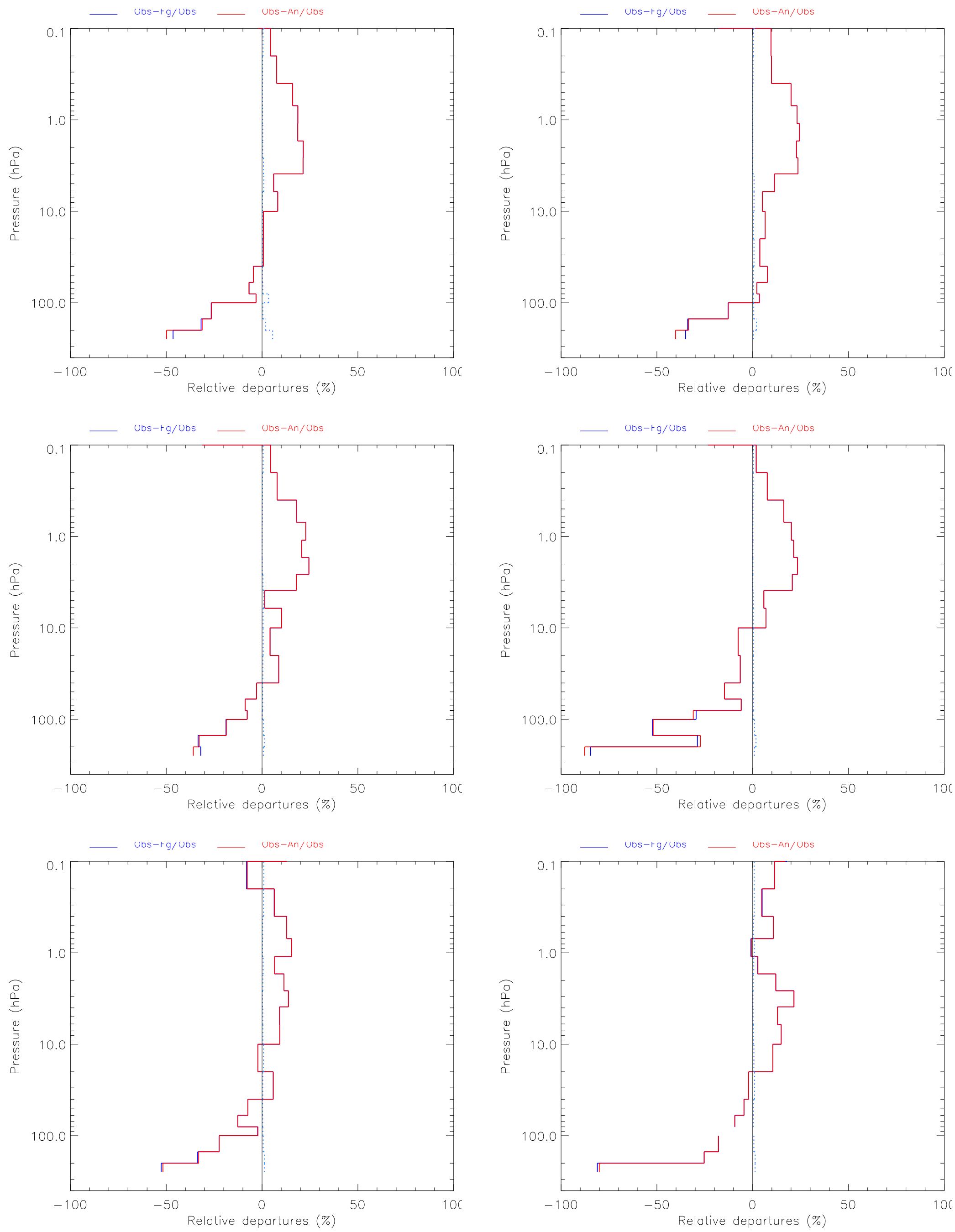


Figure 23: As in figure 19, but for the relative water vapour first-guess and analysis departures. Data are in %.

7 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 during 2010.

Because of instrumental problems, no operational monitoring could be performed of the NRT MIPAS (MIP_NLE_2P) products after 27 March 2004. Although with some issues that still need to be addressed at the time of writing, the MIPAS L2 data have once again become available recently, and ECMWF has restarted the operational download of these products. The operational monitoring could not be restarted immediately as several modifications need to be implemented to the operational suite to account for MIPAS data. Nonetheless, ECMWF will endeavour to provide technical support to ESA by monitoring the MIPAS data in low resolution research experiment. 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 (Minutes of the ESA contract progress meeting held at ECMWF on 6 December 2006). This product was available during the entire 2010. Finally, the NRT GOMOS products (GOM_RR__2P) were available during most of 2010, with the exception of November 2010, due to problems after the 2010 ENVISAT orbit change.

During 2010, the annual mean operability of TOSOMI based on the data timeliness was 83%, that of the GOMOS products was 96.3%. In the case of TOSOMI, we register an increase of 2% with respect to 2009, although the 2010 percentage is still 6% below the 2006 value, which is the highest recorded so far. GOMOS operability continues to be very high, but a reduction of -0.8% was recorded in 2010 compared to that for 2009.

The TOSOMI product was operationally assimilated during most of 2010. On 22 October, when ENVISAT was commanded into its new orbit and most instruments were switched off, the operational assimilation was also temporary suspended. The TOSOMI product was only unavailable for about four days, i.e. during the actual manouvre. However, the operational assimilation remained suspended for about six weeks to allow ECMWF to verify that the quality of the retrievals had not being compromised by the new ENVISAT settings, and that the data were still fit for operational use. Having found the quality of the data during November and December stable and consistent with that before the 2010 orbit change, it was decided to resume the operational assimilation on 16 December 2010.

The quality of the GOMOS temperature profiles was generally stable during 2010, and consistent with that reported by Dragani (2009c, 2010b). On average, the GOMOS temperature departures were less than -1% (-2 K) in most of the stratosphere and larger in the mesosphere (within -2 and -7%, i.e. within -4 and -14K).

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: April-May and (29) November-December 2010. The mean first-guess and analysis departures obtained by averaging over the tropics and the midlatitudes were typically found to be within $\pm$15% in most of the stratosphere (at least for pressure values smaller than 40hPa), but larger departures were normally 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 April-May period, and they showed departures ranging from -20 to +15% at most levels. There were no data available at latitudes northern than 60°N during 2010. The standard deviations of the departures were larger than 10% at all levels and available latitudinal bands. The data still show quite a large noise, particularly after the 2010 orbit change, 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 2010 and consistent with that reported for 2008 and 2009 (Dragani, 2009c, 2010b). 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 (2009c) 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 (2009c) also showed that, by selecting the data at the source according to the star identification number, the amount of monitored observations was much reduced compared with that obtained by simply applying the filter in the converter (about 15% of those monitored operationally and filtered within the PDS2BUFR converter).

A preliminary analysis on the quality of the MIPAS ozone, temperature and water vapour was also made. As modifications to the operational system still need to be implemented to allow the monitoring of the new data format, a low-resolution, research-mode experiment was set-up to provide interim analysis of the MIPAS Level 2 data quality. Based on one month-worth of data, the MIPAS retrievals for all the three parameters (ozone, temperature, and water vapour) generally are in good agreement with their model equivalent. The ozone first-guess and analysis departures are normally within $\pm$20% in most of the stratosphere and in the mesosphere in the tropics and at midlatitudes, although larger mesospheric departures (up to 50%) were found at high latitudes. The stratospheric temperature residuals are normally within $\pm$1% (about $\pm$2K), but negative departures up to -10% (about -20K) were found in most of the mesosphere. Finally, the relative water vapour departures typically within $\pm$10% in the lower stratosphere. Slightly larger differences were found in the upper troposphere, where the MIPAS water vapour data were drier than their model equivalent (up to -50% differences), and in the upper stratosphere and mesosphere, where the water vapour first-guess and analyses were drier than the observations (differences up to +20%).

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A Data usage at ECMWF

At the time of writing, the following data were used at ECMWF:

- Radiances (brightness temperature / level 1):
  - AMSU-A (NOAA-15/18/19, AQUA, MetOp-A).
  - AMSU-B/MHS (NOAA-17/18, MetOp-A).
  - SSM/I (F-13/15), AMSR-E (AQUA).

  - IASI (MetOp-A), AIRS (AQUA).
  - HIRS (MetOp-A).
  - MVIRI (Met-7), SEVIRI (Met-9), GOES-11/12, MTSAT-1R imagers.

- Bending angles (level 1):

  - COSMIC (six satellites), GRAS (MetOp-A).

- Ozone data (level 2):

  - SCIAMACHY TCO (ENVISAT), OMI TCO (Aura).
  - SBUV/2 partial columns (NOAA-17/18)

- Atmospheric Motion Vectors (wind speed / level 2).

  - Meteosat-7/9, GOES-11/12, MTSAT-1R, MODIS (AQUA/TERRA).

- Sea Surface paramaters (wind speed and wave height / level 2):

  - Seawinds (QuikSCAT), ERS-2 scatterometer, ASCAT (MetOp-A).
  - Wave height from RA-2/ASAR (ENVISAT), Jason Altimeters.

- Conventional data:

  - 2m-temperature, dew-point temperature, 10m-wind (ships, weather stations).
  - Temperature, pressure, wind (buoys).
  - Temperature, humidity pressure, wind profiles (radiosondes, dropsondes, commercial ships).
  - Wind profiles (Doppler radars).
  - Temperature, pressure, wind profiles (aircrafts).

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