EVALUATION OF ENVISAT DATA USING A NWP SYSTEM: A VORTEX-CENTRED VIEW

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ABSTRACT/RESUME

We provide first results of work toward the evaluation of Envisat data using the Met Office (UK) Numerical Weather Prediction (NWP) System. The Envisat data to be evaluated is level 2 temperature, ozone and water vapour from MIPAS and GOMOS, and level 2 total column ozone data from SCIAMACHY. Initially, we focus on the evaluation of MIPAS and SCIAMACHY data without assimilation, using a vortex-centred approach and looking at the data along the orbit track. This approach has already been used to evaluate water vapour from the Upper Atmosphere Research Satellite Microwave Limb Sounder (UARS MLS) [1-2]. Early results indicate: (1) MIPAS temperature and ozone data are consistent with the other MIPAS datasets and the meteorology [3], and (2) SCIAMACHY data are consistent with the total ozone analyses (incorporating GOME total column ozone data) provided by KNMI/ESA [4]. The bias between the SCIAMACHY data and KNMI/ESA analyses is ~≤6DU in magnitude, and the standard deviation of the differences is ~20DU. These results agree with an independent evaluation of biases for the GOME fast-delivery service total ozone column data (version 3.0) from BIRA-IASB [5]. Comparison of MIPAS temperature and ozone data against independent data from sondes indicates that the MIPAS temperature data is better characterized than the MIPAS ozone data. It is found that the MIPAS ozone error should include the systematic error, and that MIPAS ozone data has a slightly positive bias against sonde data convolved with the MIPAS averaging kernels. It is also found that MIPAS temperature retrievals sometimes show an unrealistic vertical oscillation. Finally, we discuss the approach to the evaluation of Envisat data using an NWP system [6].

1. INTRODUCTION

The European Space Agency (ESA) Envisat was launched on 28 February 2002 (local time). It is an advanced Earth observing satellite designed to provide measurements of the atmosphere, ocean, land and ice over a five-year period [7]. As the successor to the highly successful ESA ERS-1 and ERS-2 satellites it will provide continuity of measurement with most ERS instruments, thereby extending to more than 10 years the long-term datasets critical for global environmental monitoring, and furthering many operational and commercial applications.

The capabilities of Envisat exceed those of any previous or planned Earth observation satellite. The payload includes three new atmospheric sounding instruments (GOMOS, MIPAS and SCIAMACHY) designed primarily for atmospheric chemistry, including measurements of ozone and water vapour in the stratosphere.

The PIs of accepted proposals relevant to the evaluation of the Envisat atmospheric chemistry programme include the ACVT-Model Assimilation (ACVT-MASI) sub-group. The activities in the ACVT-MASI sub-group will feed into the EU-funded ASSET (ASSimilation of Envisat daTa) project [8]. As part of the ACVT-MASI activities, the Data Assimilation Research Centre (DARC), in collaboration with colleagues across Europe, will evaluate Envisat data using a NWP assimilation system (AOID 1039).

The project AOID 1039 seeks to evaluate level 2 data from GOMOS, MIPAS and SCIAMACHY. Its objective is to assess the error characteristics and biases of the Envisat data. Data assimilation will be used to combine these data with other contemporaneous measurements, and with data from an atmospheric circulation model. The model used will be the NWP system of the Met Office (UK). Details of the approach can be found in [6]. The deliverable from AOID 1039 is an assessment of the error characteristics and biases of the temperature, ozone and water vapour level 2 datasets from GOMOS, MIPAS and SCIAMACHY.

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As a prelude to the assimilation work in AOID 1039, we focus on the evaluation of MIPAS and SCIAMACHY data without assimilation, using a vortex-centred approach and looking at the data along the orbit track [1-2]. (Note that GOMOS data was evaluated very briefly early in the Envisat cal-val phase and a report sent to the GOMOS cal-val team and ESA.)

In section 2 the methodology of the study in AOID 1039 will be outlined. In section 3 we present first results. In section 4 we present preliminary conclusions and identify further work to be done.

2. METHODOLOGY

2.1 Vortex-centred view

The initial evaluation of the Envisat data uses a vortex-centred view of the level 2 data. Since the stratospheric winter flow (NH or SH) is dominated by a strong circumpolar westerly vortex, which organizes strongly the distribution and evolution of passive tracers in the stratosphere (such as water vapour), this approach focuses on the role played by the wintertime stratospheric polar vortex [9]. Orbit tracks from satellite instruments provide this vortex-centred view. This approach has the further advantage that the data is not modified by, e.g., linear interpolation to a fixed grid. Note that the data assimilation approach to be used in AOID 1039 has a number of advantages in comparison to linear (or higher order) interpolation (see [6] for details).

Although we will focus on Envisat observations made during the SH winter/spring of 2002, we will also look at the performance of the Envisat data at other latitudes. In this paper we focus on the following aspects:

(1) self-consistency of the standard MIPAS data (ozone, water vapour, CH_4, N_2O, HNO_3 and NO_2) along orbit track against pressure slices,
(2) comparison of along-orbit/pressure slices of MIPAS data against meteorological data (geopotential height and temperature from the Met Office troposphere-stratosphere analyses),
(3) comparison of along-orbit SCIAMACHY total column ozone data against total column ozone analyses from KNMI/ESA (incorporating GOME total column ozone data),
(4) comparison of MIPAS temperature and ozone data against sonde data (the comparison uses nearest-neighbour MIPAS data),
(5) quantification of the data comparisons.

Procedures (1)-(2) test the self-consistency of the Envisat datasets; procedures (3)-(4) provide an independent evaluation of the datasets; procedure (5) quantifies the evaluation of the datasets.

Results from this evaluation of Envisat will provide information on the quality of the Envisat data. This will be invaluable for the evaluation of the Envisat data using data assimilation.

2.2 Data assimilation

The subsequent evaluation of the Envisat data will use the Met Office (UK) NWP system. Data assimilation ([6] discusses the advantages of this technique) will be used to test the error characteristics and biases of the Envisat data as follows:

(1) Observing System Experiments (OSEs) in which different sets of data are systematically removed from the assimilation,
(2) residual (observations minus analyses) statistics generated by the assimilation system to identify potential biases in the Envisat data,
(3) statistical tests to assess deviations from Gaussian behaviour in the errors of the Envisat data and the assimilated datasets,
(4) statistical tests to test optimality (e.g Best Linear Unbiased Estimate – BLUE) of the analyses,
(5) comparison against independent data (i.e. not used in the assimilation).

Procedures (1)-(4) test the self-consistency of the datasets (observations and analyses) and the model; procedure (5) provides an independent evaluation of the analyses. Procedures (1)-(5) quantify the evaluation of the datasets.

3. RESULTS

3.1 MIPAS data

To illustrate the vortex-centred approach, we first focus on one MIPAS orbit for a particular day (other MIPAS orbits for this day and for other days show similar results). Fig. 1 shows the geopotential height fields (from the Met Office troposphere-stratosphere analyses) at 1hPa, 10hPa and 100hPa on 24th October 2002, as well as a MIPAS orbit cutting through the southern winter stratospheric polar vortex [9] at 10hPa. The synoptic situation shows that the polar vortex has broken down at 1hPa, but that it is still strong at 10hPa and 100hPa. At 10hPa there is a quasi-stationary anticyclone south of Australia. This top-down break of the southern winter polar vortex is the norm [2]. (Note that the southern winter stratosphere experienced an unprecedented major warming in September 2002 reflected in the total column ozone field [10].)

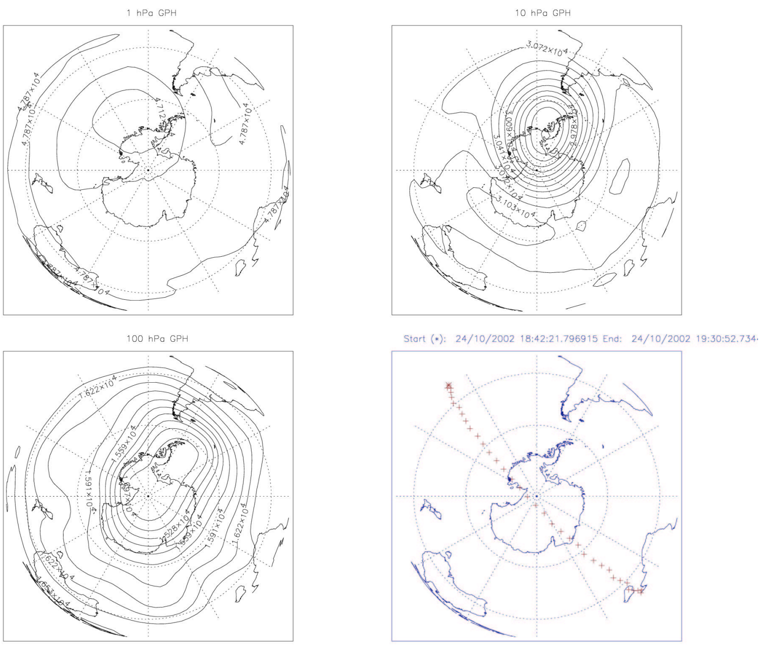

Fig.1. Geopotential height on 24th October 2002 at 1hPa (top LH), 10hPa (top RH) and 100hPa (bottom LH). MIPAS orbit track, starting from star (bottom RH)

Fig. 2 shows the MIPAS ozone and water vapour orbit track against pressure values for the track in Fig. 1. Fig. 2 shows relatively low ozone values and relatively high water vapour values in the lower stratospheric polar vortex. Relatively low ozone values are consistent with ozone loss in the polar vortex due to heterogeneous chemistry processes [11], and relatively high water vapour values are consistent with descent of relatively moist air (water vapour is a stratospheric tracer over the seasonal time-scale) in the wintertime polar vortex [2]. The relatively low water vapour values equatorward of the polar vortex are consistent with stretching and mixing processes occurring in the anticyclone (see Fig. 1), and which help to bring relatively dry air poleward [2]. A source of stratospheric water vapour is methane oxidation, and N_2O (which has no known source in the stratosphere) is photolysed in the stratosphere (both methane and N_2O are stratospheric tracers over the seasonal time-scale). In agreement with this picture of the stratospheric circulation, the analogous slices for methane and N_2O show relatively low values in the lower stratosphere of the polar vortex (not shown).

Fig. 3 shows the MIPAS orbit track/pressure temperature data and co-located (independent from MIPAS data) Met Office temperature analyses for the track in Fig. 1. Fig. 3 shows very good agreement between the MIPAS data and the analyses.

Overall, Figs. 1-3 show that the MIPAS data is self-consistent, agrees well with the meteorology, and agrees well with independent data. Note that this comparison is qualitative. A quantitative comparison of MIPAS data is done later in this sub-section.

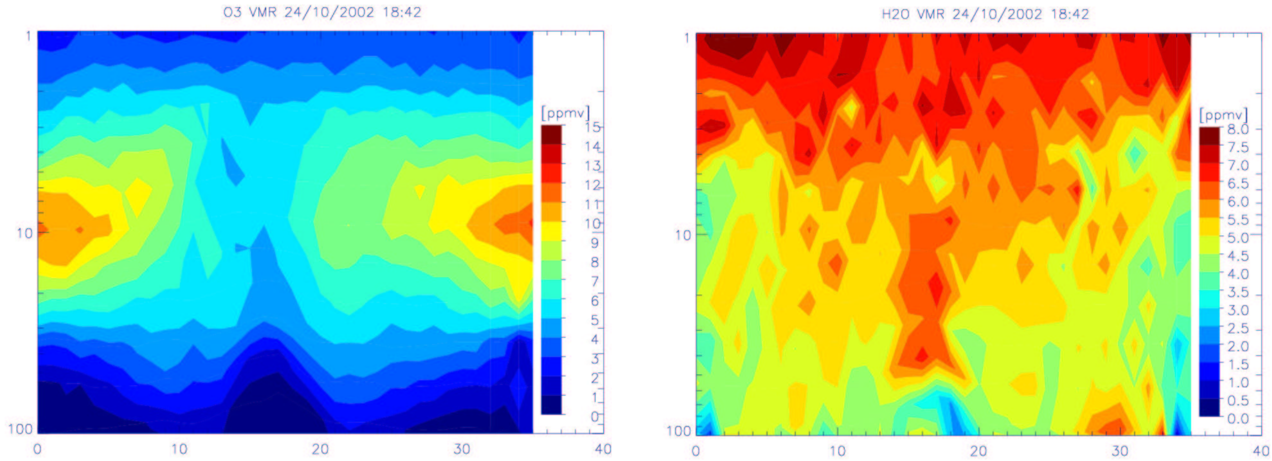

Fig.2. MIPAS data against pressure (hPa) along the orbit track in Fig. 1 (0 is start of track, denoted by a star in Fig. 1): ozone (LH), water vapour (RH)

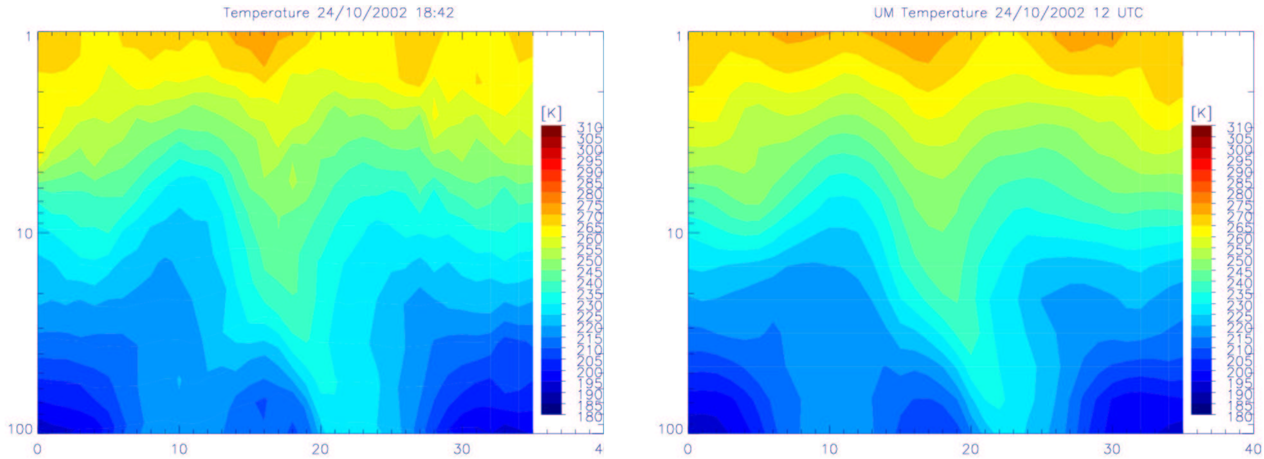

Fig. 3: LH: MIPAS temperature data against pressure (hPa) along the orbit track in Fig. 1 (0 is start of track, denoted by a star in Fig. 1). RH: co-located Met Office temperature analyses along the orbit track of Fig. 1

Figs. 1-3 concern self-consistency tests on the MIPAS data. An important part of the evaluation process is the comparison with independent data. To do this, we compare MIPAS temperature and ozone data with sondes. This has been done for a series of sites spanning the globe (Ny Alesund at 78.9N, 11.9E, to Marambio at 64.3S, 56.7W). The MIPAS data chosen for this comparison are the two nearest-neighbour profiles.

Fig. 4 shows the comparison between MIPAS and sonde data on 27th September 2002 at Marambio. In this paper, the sonde data error is ignored.

Fig. 4 shows very good agreement between the MIPAS and sonde data (similar good agreement is obtained for the comparison with other sondes and for other days). This suggests that the MIPAS data is qualitatively capturing the main features of the stratospheric temperature and ozone fields. There is little or no MIPAS data below 100hPa (note, however, that there is work ongoing to extend the MIPAS data to the upper troposphere).

Figs. 1-4 provide qualitative information on the MIPAS data. To quantify the behaviour of the MIPAS data we perform an analysis of the differences between the MIPAS temperature and ozone data and the sonde data.

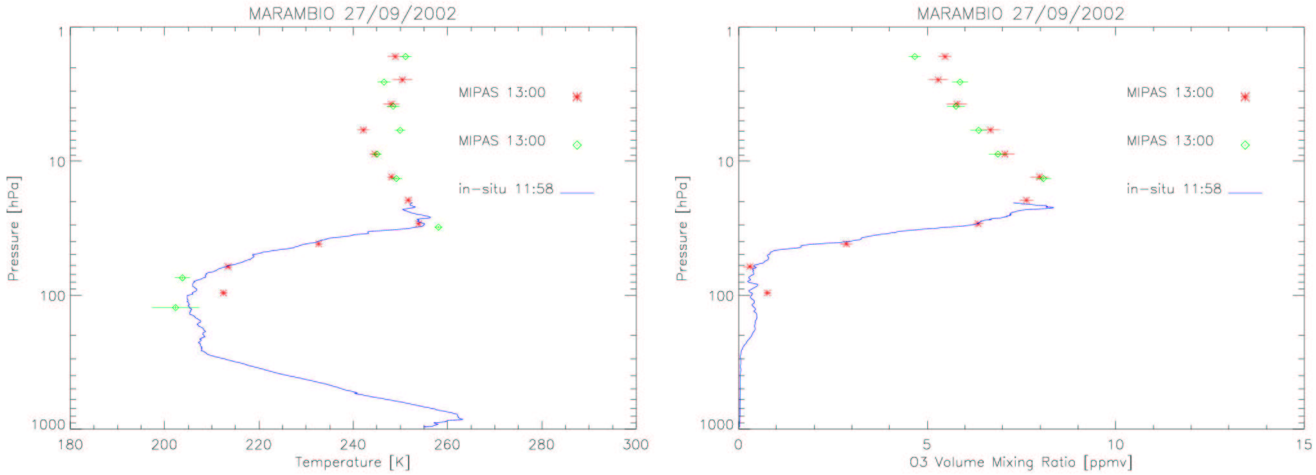

Fig. 4. LH: MIPAS temperature profiles (red and green) against sonde temperature profile (blue). RH: MIPAS ozone profiles (red and green) against sonde ozone profile (blue). Horizontal bars are 1-σ error bars for MIPAS data. Both comparisons are for Marambio on 27th September 2002

For the quantitative comparison of the MIPAS and sonde data we take account of the difference in resolutions by convolving the sonde data with the MIPAS averaging kernels (AKs) [12]. The AKs used for this comparison were transformed from fixed height coordinates to variable pressure coordinates. Fig. 5 shows the comparison between MIPAS temperature data and convolved temperature sonde data from Jokioinen (60.8N, 23.5E) on 18th September 2002.

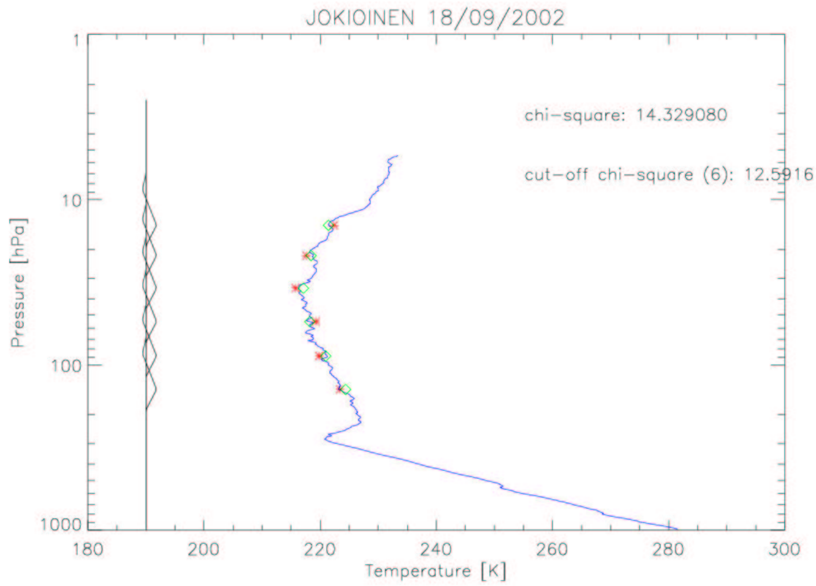

Fig. 5. MIPAS temperature profile (red) against sonde temperature profile (convolved with the MIPAS AK; green) for 18th September 2002 at Jokioinen. The full sonde temperature profile is shown in blue. The MIPAS AKs are shown on the LH of the figure. The result of a chi-squared test gives 14.33. The cut-off chi-squared value (for 6 degrees of freedom) at the 95% confidence limit is 12.59.

Fig. 5 shows that there is very good agreement between the two independent sources of information (MIPAS and sonde). The calculated chi-square value is slightly higher than the cut-off value at the 95% confidence limit. This suggests that the MIPAS temperature random error is not enough to fully characterize the MIPAS error budget. This result is confirmed by other MIPAS/sondes comparisons (not shown).

Fig. 6 shows the difference between MIPAS and sonde (convolved with the MIPAS AK) temperature and ozone data, normalised by the quoted MIPAS 1-σ error, for Ny Alesund. For well-characterized MIPAS data the magnitude of the calculated differences should be less than 1. Fig. 7 shows histograms of the difference between MIPAS and sonde (convolved with the MIPAS AK) temperature and ozone data, normalised by the quoted MIPAS 1-σ error, for a series of stations spanning the globe (e.g. Ny Alesund, Payerne, Marambio, Jokioinen). In Figs. 6 and 7 the statistics are built up over September 2002. In all cases, the MIPAS data used is the nearest neighbour profile, with the constraint that its distance from the sonde location must be less than or equal to 500 km.

Figs. 6 and 7 suggest the following:

- The MIPAS temperature data is better characterized than the MIPAS ozone data.
- The quoted MIPAS 1-σ temperature and ozone data errors follow closely a Gaussian distribution.
- The quoted 1-σ errors for MIPAS ozone are too small. This further suggests that the quoted errors should include an estimate of the systematic error (currently, level 2 products only include the random component).
- The MIPAS ozone data has a slight positive bias against the convolved sonde data (i.e. the MIPAS ozone data values are larger).
- The statistics for MIPAS temperature have outliers which appear to be due to unrealistic vertical oscillations in the temperature retrievals.

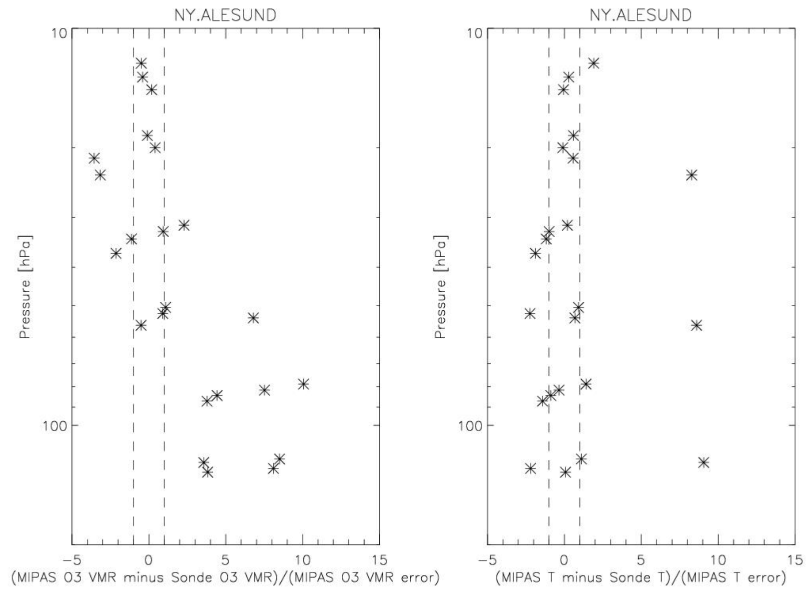

Fig. 6. MIPAS minus convolved sonde data divided by the MIPAS 1-σ error against pressure (200hPa to 10hPa) for Ny Alesund. Statistics are accumulated for September 2002. LH: Temperature. RH: Ozone. The vertical dashed lines indicate where this ratio is ±1.

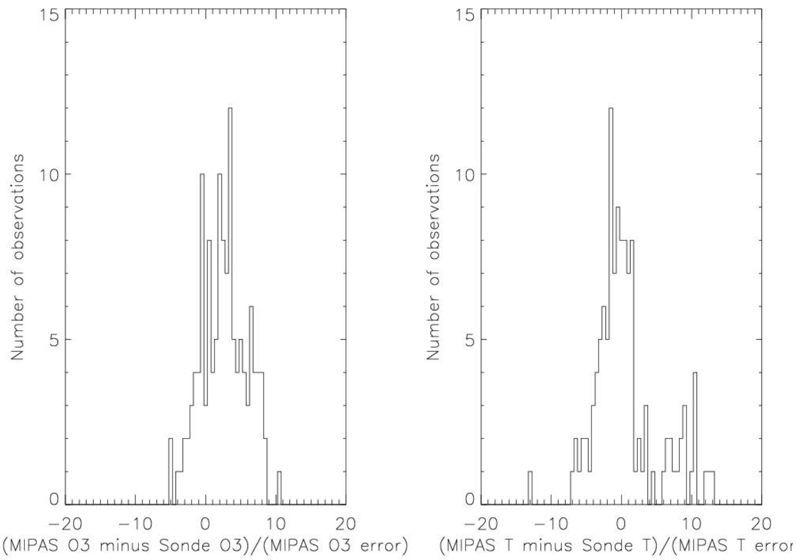

Fig. 7. Histogram of the MIPAS minus convolved sonde data divided by the MIPAS 1-σ error against number of observations falling within each bin. Statistics are accumulated over pressure levels between 200hPa and 10hPa, September 2002 and a series of stations spanning the globe.

3.2 <u>SCIAMACHY data</u>

We now focus on total ozone column data along the SCIAMACHY footprint. Fig. 8 shows the comparison between SCIAMACHY total column ozone data and the KNMI/ESA total column ozone analyses on 25th September 2002.

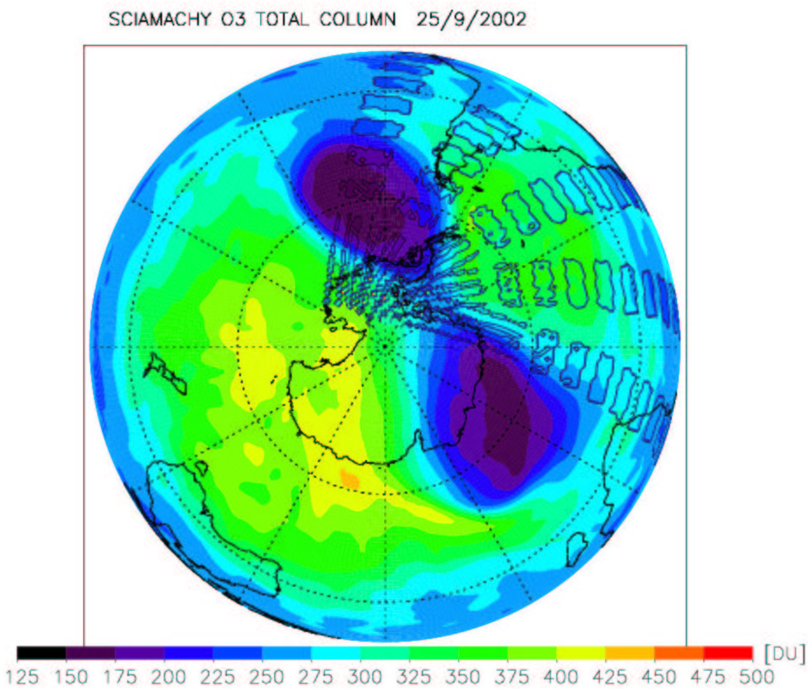

Fig. 8. SCIAMACHY total ozone column data (footprint) superimposed on the KNMI/ESA total ozone column analyses on 25th September 2002. The colour scale applies to both datasets

Fig. 8 shows good agreement between the SCIAMACHY and KNMI/ESA total column ozone (similar good agreement is found for other days). In particular, SCIAMACHY captures the large range of variation in the total column ozone values and, furthermore, captures elements of the split in the ozone hole observed in September [10].

To perform a quantitative analysis of the SCIAMACHY data, we calculate the histogram of the SCIAMACHY minus KNMI/ESA analysis differences for a number of days. Fig. 9 shows the histogram for 25th September 2002. The SCIAMACHY data considered spans the globe.

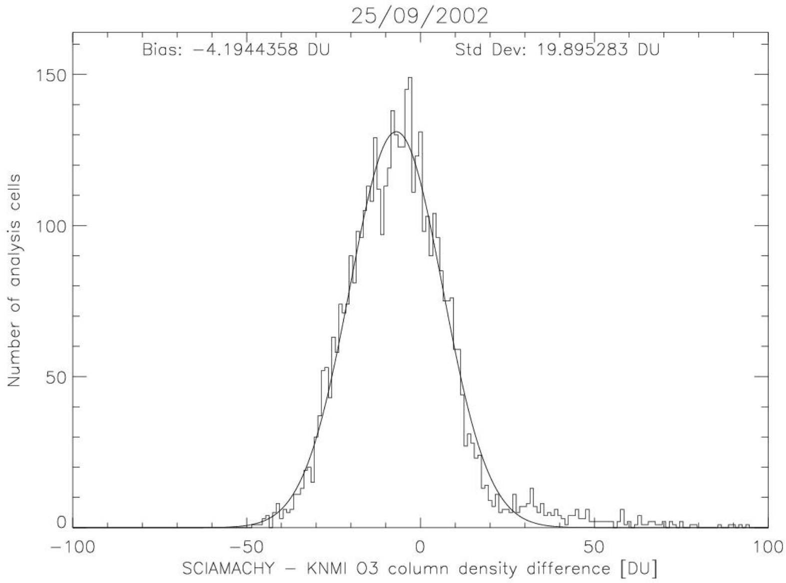

Fig. 9. Histogram of SCIAMACHY minus KNMI/ESA total column ozone differences for 25th September 2002

Fig. 9 and comparisons for other days (not shown) show that the bias between the SCIAMACHY total column ozone data and the KNMI/ESA total column ozone analyses is ~≤6DU (Dobson Units) in magnitude, and that the standard deviation of the differences is ~20DU. These results agree with an independent evaluation of the biases for GOME fast-delivery service total ozone data (version 3.0) from BIRA-IASB [5]. Fig. 9 also provides evidence that the SCIAMACHY total ozone column errors follow closely a Gaussian distribution.

3.3 <u>Data assimilation</u>

At the time of writing this report, 6 hours of MIPAS ozone data have been assimilated (together with all available operational data) into a troposphere-stratosphere version of the Met Office NWP system [13]. The Met Office three-dimensional variational (3d-var) scheme is described in [14]. The treatment of the ozone background error covariance matrices is discussed in [6] and [15]. This assimilation experiment is now being evaluated.

4. CONCLUSIONS

Envisat data from GOMOS, MIPAS and SCIAMACHY has been evaluated qualitatively (using a vortex-centred approach) and quantitatively (using the MIPAS AKs, and comparing the Envisat data against independent data). This work provides information on the quality of the Envisat data and is invaluable for the evaluation of the Envisat data using data assimilation (AOID 1039). The conclusions below are based on: (1) the qualitative comparison using the vortex-centred approach for the SH winter/spring, (2) quantitative comparisons between Envisat data and independent data across a wide range of latitudes.

4.1 <u>MIPAS data</u>

First results suggest the following:

- There is consistency between the MIPAS data and the meteorological data
- Temperature and ozone comparison with independent data (sondes convolved with AKs) suggest:

- The MIPAS temperature data is better characterized than the MIPAS ozone data
- Unrealistic vertical oscillations in the MIPAS temperature retrieval
- MIPAS ozone errors are too small, and systematic errors must be included to fully characterize the error budget
- MIPAS ozone data has a slightly positive bias against sonde data convolved with the MIPAS AKs
- MIPAS temperature and ozone errors are close to Gaussian

4.2 SCIAMACHY data

First results suggest the following:

- SCIAMACHY total column ozone data agrees well with the GOME analyses (note that GOME biases are not removed in this work)
- The magnitude of the bias between SCIAMACHY and the GOME analyses is ~≤ 6DU (bias can be positive or negative)
- The standard deviation of the differences between SCIAMACHY and the GOME analyses is ~ 20DU
- SCIAMACHY total column ozone errors are close to Gaussian
- Reported results are consistent with independent analyses on the GOME fast-delivery service total ozone data (version 3.0) from BIRA-IASB

4.3 Data assimilation

Very preliminary results indicate that the Met Office NWP system is ready to use for the evaluation of GOMOS, MIPAS and SCIAMACHY data. Over the next months (and years) GOMOS, MIPAS and SCIAMACHY data will be assimilated into the Met Office assimilation system. Initially, the focus will be on level 2 MIPAS ozone and SCIAMACHY total column ozone data. Later on, level 2 MIPAS water vapour data will be assimilated. Level 2 MIPAS temperature data will be assimilated together with the ozone and water vapour data. Data assimilation will be used to evaluate the data (following the approach of [6]) and provide quality 4-dimensional analyses of ozone and water vapour for use by the scientific community. This work will feed into the ASSET project.

5. REFERENCES

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6. ACKNOWLEDGMENTS

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