

INTEGRATED CHARACTERISATION OF ENVISAT OZONE PROFILE DATA USING GROUND-BASED NETWORK DATA

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ABSTRACT

We report an integrated validation study of ozone profile data measured by the three Envisat ozone profilers, Global Ozone Monitoring by Occultation of Stars (GOMOS), Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), and Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY). The study is based on pseudo-global comparisons with correlative data collected by the Atmospheric Chemistry Validation Team for Envisat (ACVT-GBMCD). The study concludes to a reasonable quality and consistency of Envisat profiles when adequate data selection (e.g. dark limb GOMOS data only) and vertical ranges are envisaged. Global structures, seasonal variations and pointing errors are further investigated.

1. INTRODUCTION

The atmospheric chemistry payload of ESA's environmental satellite ENVISAT includes three instruments monitoring the vertical distribution of atmospheric ozone on the global scale: Global Ozone Monitoring by Occultation of Stars (GOMOS), Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), and Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY). Although operating from the same orbiting platform, the three instruments rely on substantially different observation techniques and geometries, leading to different perceptions of the vertical profile of ozone.

Since the successful launch of Envisat in March 2002, the ground-based subgroup of the Atmospheric Chemistry Validation Team for Envisat (ACVT-GBMCD) has collected correlative measurements of the ozone profile at a list of ground-based stations performing network operation in the framework of the Network for the Detection of Stratospheric Change (NDSC), WMO's Global Atmospheric Watch programme (GAW) and NASA's Southern Hemisphere ADditional OZonesonde programme (SHADOZ). Correlative profile measurements have been acquired from the Arctic to the Antarctic by ozonesonde, lidar, and millimeter wave radiometer. This extensive database allows validation studies of Envisat ozone pro-

file data from pole to pole and from the ground up to the lower mesosphere.

2. CORRELATIVE MEASUREMENTS

The three types of ground-based validation instrument (ozonesonde, lidar and microwave radiometer) are based on complementary techniques. When operated at nearby stations, these three complementary measurement techniques allow to obtain correlative ozone profile on a complete altitude range from ground up to 70 km.

Electrochemical cells ozonesondes (O3S) are launched more or less regularly on board of small meteorological balloons at a variety of stations from pole to pole. They measure the number of ozone molecules in a known volume from the ground up to burst point, occurring typically around 30 km. Ozone distribution is recorded at a typical vertical resolution of 100-150 m. Pressure and temperature data are also recorded onboard the same balloon [Johnson et al., 2002].

Light Detection And Ranging, lidar, (LID) measurements are typically made at night and under cloud free conditions. Differential absorption laser beam techniques provide ozone profile with an altitude resolution, of 300-3km depending on the altitude, from the troposphere (10-15km) up to about 50 km.

Microwave radiometers (MWR) provide ozone height distribution night and day. Profiles are retrieved from the spectrum of an emission line of ozone. A vertical resolution of 8 - 12 km is achieved from 20-25 to about 70 km [Calisesi, 2003], [Tsou et al., 2000].

3. METHODOLOGY

To be concise, we will first shown typical results obtained at the NDSC/Alpine station (O3S data from Payerne, Switzerland, 46°N (MCH), LID data from Hohenpeißenberg, Germany, 48°N (DWD) and MWR data from Payerne (MCH)) and then illustrate global features detected by our analysis.

The comparison of different data sets brings along several important issues to address in order to ensure meaningful

comparisons : e.g., differences in space and time resolution, differences in vertical resolution, atmospheric variability, and respective error budgets. A full description of the adopted methodology falls beyond the scope of this paper. The main criteria for MIPAS are as follows, for GOMOS and SCIAMACHY they are mostly the same, otherwise they are stated in the text.

Coincidence criteria of 500 km in space for all three ground-based instruments data, 12 hours in time for O3S and LID data and 36 minutes in time for MWR data have been defined.

The different correlative instrument features require the use of different vertical smoothing techniques. E.g., to adapt the high resolution of O3S and LID measurements to the lower resolution of MIPAS, O3S and LID data are convert by degradation to partial columns centered on MIPAS data points and with a width close to the MIPAS resolution.

The MWR resolution is less than that of MIPAS. Here, MWR averaging kernels and a priori states are used to smooth MIPAS profiles to the lowest resolution using Rodgers and Connor [2003] first approximation method :

$$x_l = x_a + A(x_h - x_a) \quad (1)$$

where x_a is the MWR a-priori profile and A the MWR averaging kernel matrix. x_h is set for the MIPAS high resolution profile and x_l for the MIPAS profile smoothed to the MWR low resolution.

Three different modes of control of ozone in the stratosphere can be distinguished:

- 15-22 km : Dynamical control.
- 22-32 km : Coupling between dynamical and photochemical control.
- 32-45 km : Photochemical control (although in winter the deployment of planetary waves introduces some dynamical control into this layer).

The extreme two layers are relatively thick. Definition of thinner layers in which the ozone profile does not have abrupt variation is needed. According to the criteria, three pressure bands were chosen, each one corresponding to a level where one of the three ground-based instrument data offers the best quality:

- MWR : 2.8-1.4 hPa (~40-45 km)
- LID : 11.2-5.6 hPa (~30-35 km)
- O3S : 63-22 hPa (~18-22 km)

4. MIPAS

MIPAS ozone profiles processed with software version 4.61 (off line) were compared with data from three different ground-based techniques.

4.1 Height Features

As there is still an error in tangent altitude registration, MIPAS profiles have been studied versus pressure.

Fig.1 shows statistical values of comparisons of MIPAS ozone profiles at the NDSC/Alpine station for year 2002. MIPAS profiles agree well with the correlative data. In the range of 18 km to 50km, differences are within 10%. Below 18 km they increase. Above 50 km the standard deviation of the differences increases, indicating the poorer quality of the MIPAS data. Results for year 2003 are similar.

In order to make a global study of the comparison of MIPAS ozone profile with correlative data, results have been separated into 6 latitude bands : (i) Northern High latitudes (NH) from 90°N to 60°N; (ii) Northern Mid latitudes (NM) from 60°N to 30°N; (iii) Northern Low latitudes (NL) from 30°N to 0°; (iv) Southern Low latitudes (SL) from 0° to 30°S; (v) Southern Mid latitudes (SM) from 30°S to 60°S; and (vi) Southern High latitudes (SH) from 60°S to 90°S.

Several correlative instruments have been selected for each latitude band. They are shown in Table 1.

Table 1. Selected instruments, classified into 6 latitude bands, used to made global study of the satellite differences from pole to pole

	O3S	LID	MWR
NH	Ny-Ålesund	Andøya	Ny-Ålesund
NM	Payerne	Hohenpeißenberg	Payerne
NL		Mauna Loa	Mauna Loa
SL	Fiji		
SM	Lauder	Lauder	Lauder
SH	Marambio		

Table 2 gives a summary of height feature results obtained for the 6 latitude bands.

Table 2. MIPAS 4.61 ozone profile mean differences [%] with data from selected ground-based instruments

Alt.[km]	NH	NM	NL	SL	SM	SH
>50	>20	>10	>15		>15	
40-50	10-15	10	10		10	
25-40	10	7	10		10	
18-25	10	10	10	10-15	10	10
<18	>20	>20	>20	>20	>20	>15

Average differences according to height are similar at all latitudes. In the range of 18 to 50km the MIPAS profiles agree well with ground, differences are in the order of 10%. Below and above they increase up to 20%. No meridian variation appears.

4.2 Meridian Structures

MIPAS ozone profiles have been compared with correlative profiles from each available station of the NDSC and SHADOZ networks. Mean relative differences and

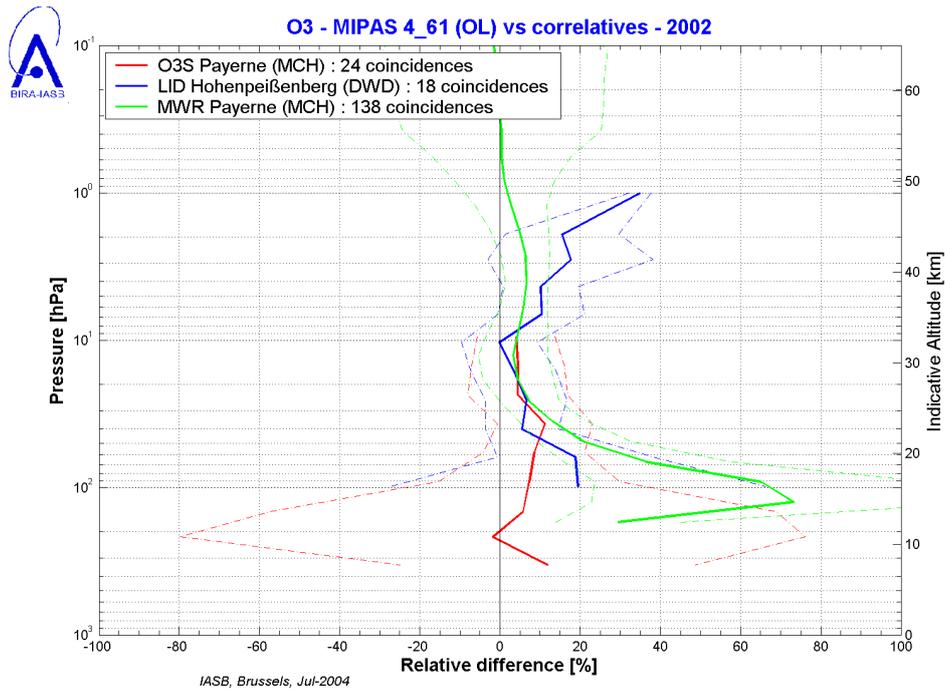


Fig. 1. Percentage relative difference (plain) and standard deviation (dashed) between MIPAS 4.61 ozone profiles in 2002 and coincident correlative data from selected instruments at the NDSC/Alpine station, as a function of height. [MIPAS-corr./corr.]

standard deviations on the 63-22 hPa pressure band are shown on Fig.2 as a function of latitude.

Differences are from 0% to 10% at each station. As in previous section, no significant meridian variation appears.

4.3 Temporal Variations

In order to show seasonal variation of the MIPAS profiles, we have plotted time series of the mean differences on the defined pressure bands. Data have been low pass filtered to highlight seasonality. Global mean and its standard deviation are also calculated. Results of year 2003 for Payerne O3S, Hohenpeißenberg LID and Payerne MWR are shown on Fig.3.

Mean differences show a 10% temporal variability. The data did not allow us to detect any seasonal variation.

4.4 MIPAS Conclusion

Ozone profiles on pressure scale show a good agreement when compared to ground based O3S, LID and MWR. O3S and LID profiles were degraded to partial columns in order to reduce their high resolution to that of MIPAS. To compare with the MWR, the MIPAS ozone profiles were degraded to the MWR vertical resolution and convoluted with the a-priori MWR retrieval information using the MWR averaging kernels. Differences are within 10% from 18 to 40 km in altitude. Below and above this altitude range differences increase. A 10% time variability

of the differences is observed. There is no marked seasonal variation. These results are similar at all latitudes and no significant meridian variation is observed.

5. GOMOS

All GOMOS ozone profiles used in this paper have been computed with the prototype processor version 6.0a. The GOMOS retrieved profile is strongly affected by the brightness of the limb in which the star occults [Lambert et al., 2003b], [Soebijanta et al., 2003], [Meyer et al., 2003]. As bright limb occultations give poor results, only dark limb occultations have been selected for all comparisons shown here. This represents about 45% of the coincident profiles, depending on the station.

The coincidence criteria are 500 km in space for all three instrument data, 12 hours in time for O3S and LID data and 36 minutes in time for MWR data.

Neither averaging kernels nor a priori states were released for GOMOS. As GOMOS profiles have a high resolution, O3S, LID and GOMOS profiles were directly interpolated on the same altitude grid in order to be compared. With the MWR data, MWR averaging kernels were used to degrade high resolution profiles from GOMOS to the lowest resolution of MWR using Rodgers method (eq.1).

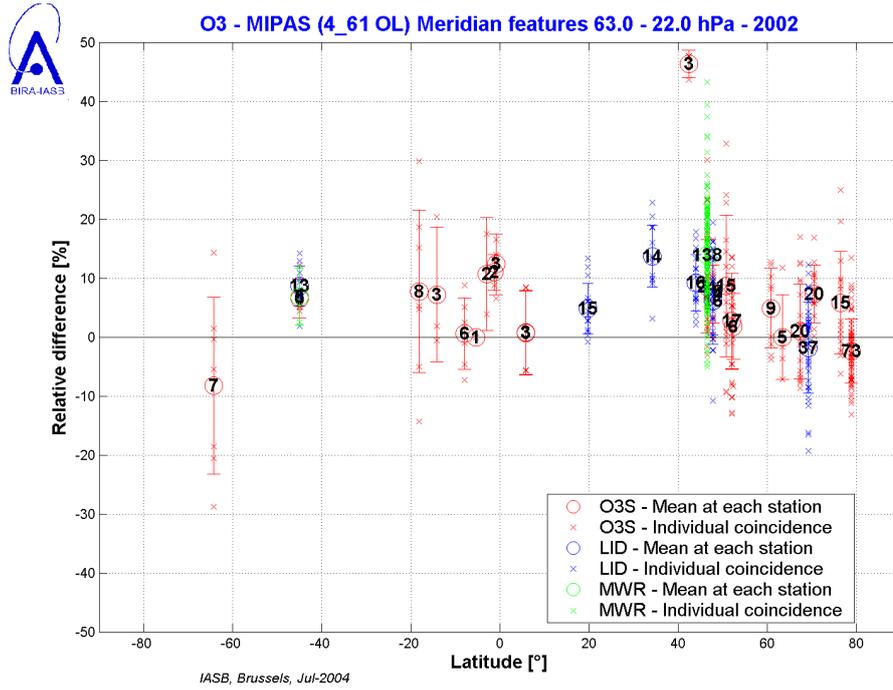


Fig. 2. Mean relative differences and standard deviation, on the 63-22 hPa pressure band, between MIPAS 4.61 ozone profiles in 2002 and coincident correlative data. Calculated for each available instrument and plotted altogether according to the latitude. The numbers displayed on each circle represent the number of coincidences available. [MIPAS-corr./corr.]

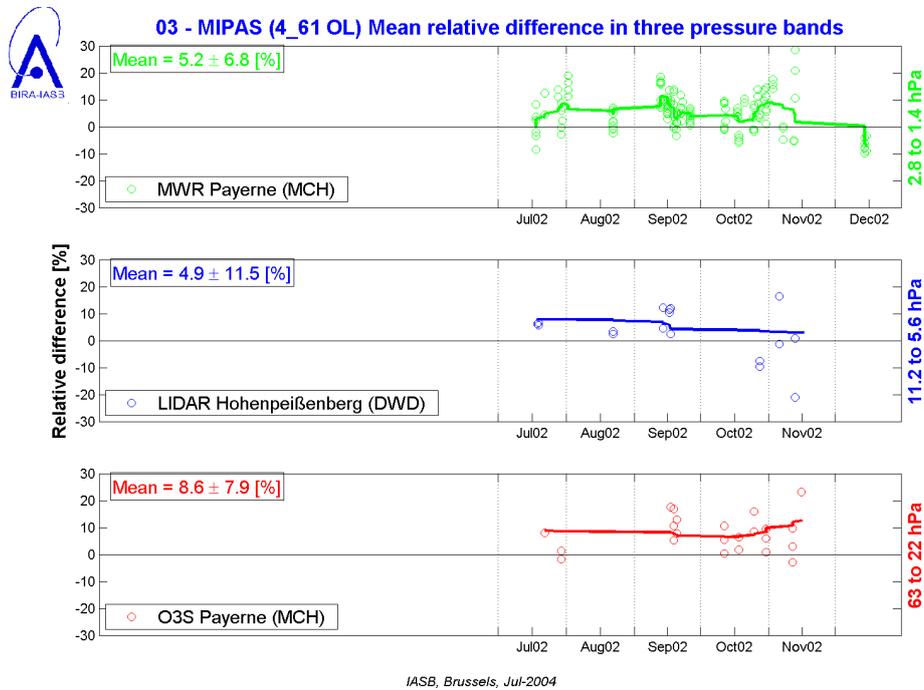


Fig. 3. Time-series on different pressure bands of MIPAS ozone profile percentage relative difference with correlative measurements at the NDSC/Alpine station for year 2002 [MIPAS-corr./corr.].

5.1 Height Features

As for MIPAS, we first show statistics of the comparisons of GOMOS dark limb profiles obtained at the NDSC/Alpine station in Fig.4 and then summarise global features.

GOMOS ozone profiles show a good agreement with the correlative data. In the altitude range of 20 to 50 km differences are within 5-10%. Above and below they increase.

Results at other locations are summarised in Table 3. The selected instruments from the ground stations, classified in 6 latitude bands from pole to pole, are the same as for MIPAS (see Table 1).

Table 3. GOMOS 6.0a dark limb ozone profile differences [%] to data from selected ground-based instruments

Alt.[km]	NH	NM	NL	SL	SM	SH
>50	>20	>15	>15		7	
40-50	>20	5	10		5	
20-40	10	5	5		5	
15-20	15	10	15		15	
<15	>20	>20	>20		>20	

For southern low latitudes and southern high latitudes not enough coincidences were found to draw reliable statistics.

GOMOS ozone profiles show a good agreement with the ground-based, for latitudes from 60°N to 60°S. In the 20-40km altitude range, differences are within 5-10%. However, at northern high latitude agreement is poorer with 15-20% differences.

5.2 Meridian Structures

To have a global view of the dependence in latitude of GOMOS profiles, relative differences in the low stratosphere, their mean and standard deviation were calculated for each instrument, at each ground station. They are plotted altogether as a function of latitude in Fig.5.

Below 60° of latitude, GOMOS ozone profiles agree well with the ground-based data. Differences are in the order of 5-10% in the 20-25 km altitude layer. At northern high latitudes results seem to be worse and differences increase. Here a meridian structure appears, contrarily as with MIPAS.

5.3 Temporal Variations

As for MIPAS, we have plotted time series of the mean differences on an altitude band in order to study seasonality. Chosen altitude bands according to the criteria develop at section 3. are :

- MWR : 40-45 km
- LID : 30-35 km

- O3S : 18-22 km

Time series of the differences between GOMOS and the O3S of Payerne, LID at Hohenpeißenberg and MWR at Payerne, for year 2002, are presented on Fig.6.

No seasonal component appears. A 5% agreement is observed. That is in line with height features results at mid latitudes.

5.4 Occultation Angle

GOMOS is looking at stars rising or setting behind the atmosphere. A feature which might influence the profiles quality could be the angle in which GOMOS see the star occults. If the star occults quasi parallel to the horizon, scintillation due to atmosphere turbulence influence the ozone profile quality. In order to study this feature, differences in an altitude band have been plotted according to the occultation angle. A 90° angle is set for vertical occultation and 0° angle for quasi horizontal occultation. Comparisons have been performed with O3S as they offers the best quality in the lower part of the profile, where the scintillation effect may be significant. Results for O3S coincident profile located between 50°N and 50°S of latitude, during year 2002, are shown on Fig.7.

The data set did not allow us to detect any marked structure. Differences are spread around the zero axe independently of the occultation angle. Other cases have been studied by separating the results by latitude bands and on other altitude layers (not shown). No characteristic dependence was observed in any case.

5.5 GOMOS Conclusion

GOMOS ozone profile acquired by dark limb occultation agree well with the correlative data. Differences are within 5% in the altitude range of 20-50 km. Below and above this range they increase. For high northern latitudes, the agreement is poorer. Dependence of the profile quality from the occultation angle with ENVISAT orbit plane have been study. No critical effect of this parameter was observed.

6. SCIAMACHY

Preliminary limb ozone profiles from SCIAMACHY have been retrieved at University of Bremen. This product is here compared to ground-based O3S, LID and MWR in the same way as for MIPAS and GOMOS. The data set provided comprises ozone profile from July 2002 to December 2002. Retrievals were performed from 15 km to 40 km from SCIAMACHY Level 0 limb data.

Due to the lower spatial resolution of the SCIAMACHY limb sounding and the poorer number of coincidences available, the coincidence criteria is reduced to 1000 km in space for all three correlative instruments, 12 hours in time for O3S and LID data and 36 minutes in time for MWR data.

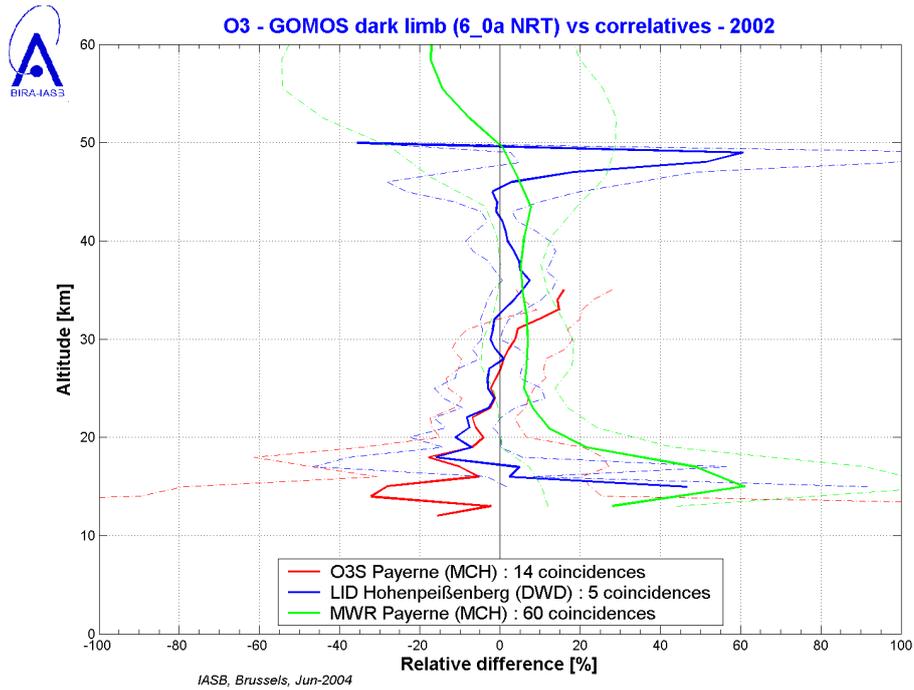


Fig. 4. Percentage relative difference (plain) and standard deviation (dashed) between GOMOS 6.0a dark limb ozone profiles in 2002 and coincident correlative data from selected instruments at the NDSC/Alpine station, as a function of altitude [GOMOS-corr./corr.]

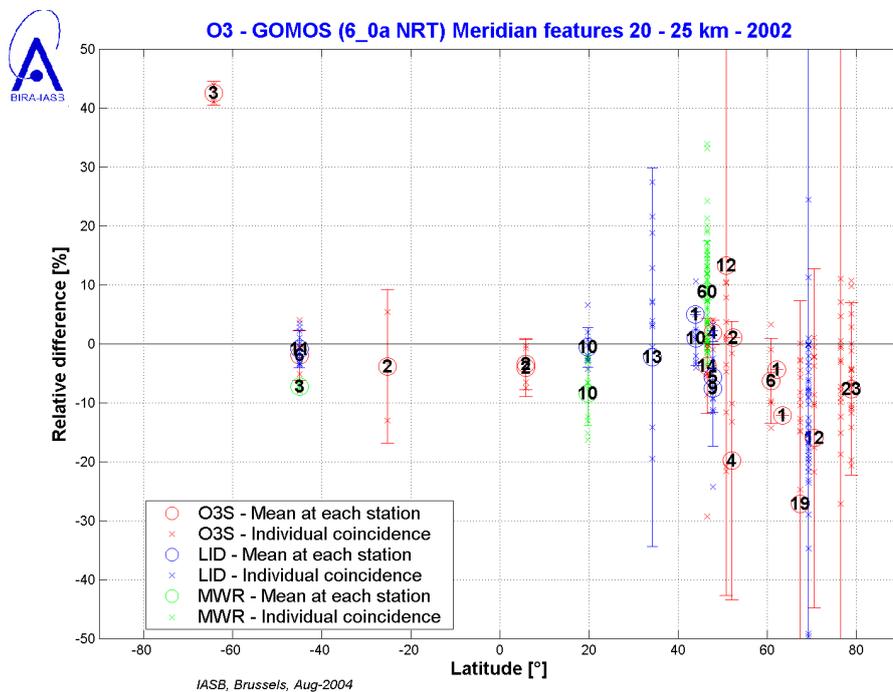


Fig. 5. Mean relative difference and standard deviation, on the 20-25 km altitude band, between GOMOS 6.0a dark limb ozone profile in 2002 and coincident correlative data. Calculated for each available instrument and plotted according to latitude. The numbers displayed on each circle represent the number of coincidences available. [GOMOS-corr./corr.]

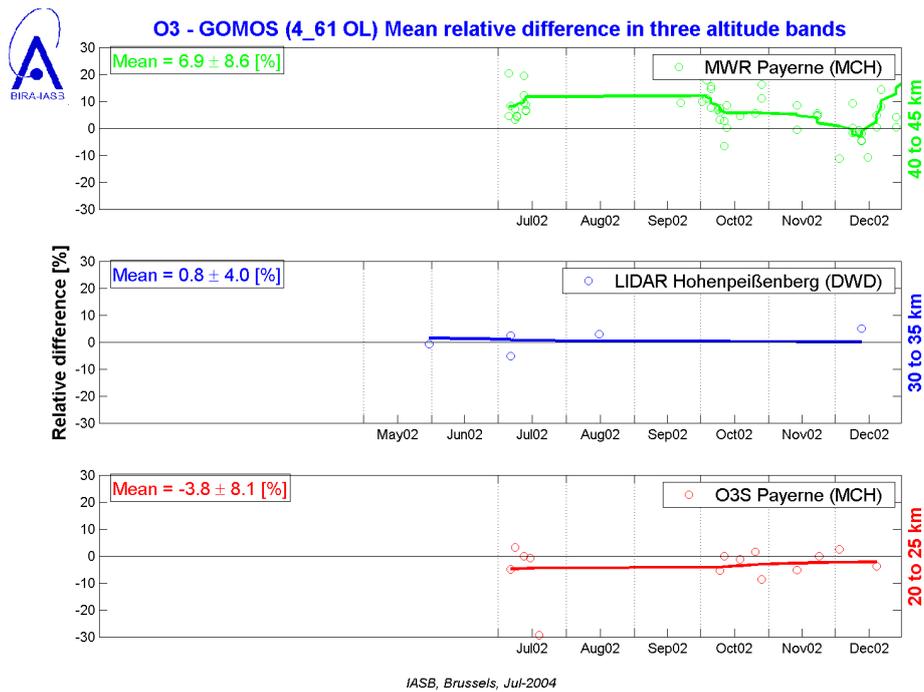


Fig. 6. Time series, on altitude band, of GOMOS dark limb ozone profile percentage relative differences with correlative measurements at the NDSC/Alpine station for year 2002 [GOMOS-corr./corr.].

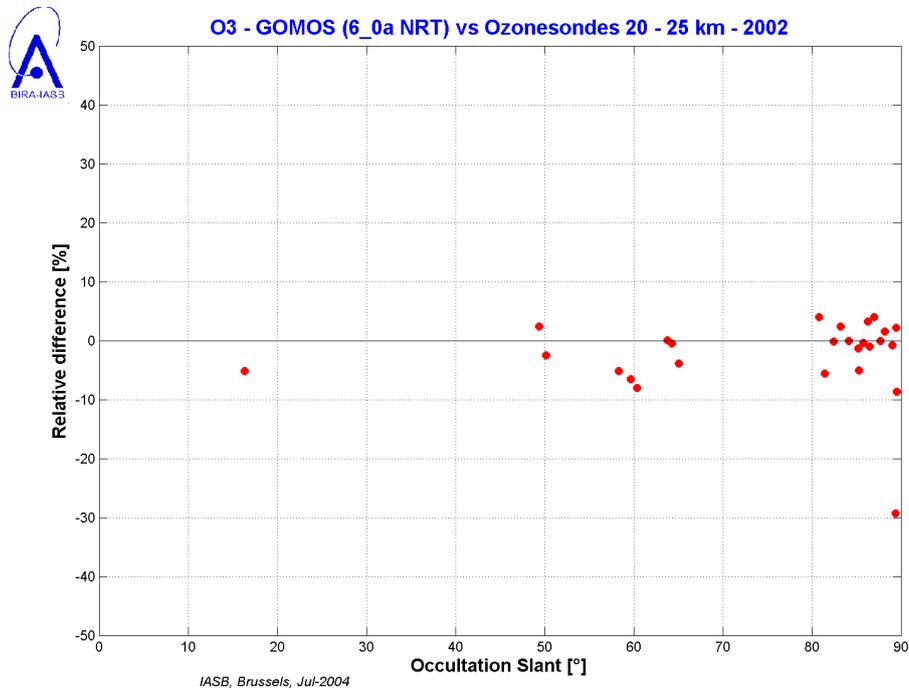


Fig. 7. Percentage relative differences between GOMOS dark limb profiles in 2002 and all ozonesonde data located between 50°N and 50°S on the 20-25 km altitude band according to occultation angle.

As neither averaging kernels nor a priori states were provided for SCIAMACHY, the comparison method was to degrade O3S and LID profiles to partial columns to reduce their high resolutions to that of SCIAMACHY. MWR ozone profile were directly interpolated on the SCIAMACHY altitude grid to compare the profiles.

6.1 Height Features

Differences of the SCIAMACHY ozone profiles to Payerne O3S, Hohenpeißenberg LID and Payerne MWR coincident data are shown in Fig.8, as a function of altitude.

As SCIAMACHY profiles are retrieved from 15 km to 40 km, differences outside this altitude range are due to the a-priori contribution and are not to be considered at all.

From 18 km to 40 km differences to the three instruments show a slope from -35% to +35%. This is a characteristic feature of an altitude shift of the profiles. That will be further investigated at section 6.3. According to general structure of ozone profile an offset in altitude will raise that SCIAMACHY overestimates ozone concentration above 25 km and underestimates it below. At all latitudes, height features plots show a slope and differences in 15 and 40 km altitude range are from -30% to 30% and more due to the altitude shifts.

6.2 Temporal Variations

As for MIPAS and GOMOS, the time dependence of the profiles has been investigated. Time series of the differences are computed on three altitude bands. These altitude bands have been chosen according to criteria developed in section 3. and adapted to SCIAMACHY altitude range of retrieval (15-40 km), each one corresponding to one of the three correlative instruments :

- MWR : 35-40 km
- LID : 30-35 km
- O3S : 18-22 km

Results are shown in Fig.9

A general offset depending of the altitude band is observed, due to the altitude shift. A small seasonal increase seems to appear in the lower stratosphere but due to the interference of the altitude shift, we can not observed independent features. This should be confirmed by further study.

6.3 Altitude shift

A problem exists with the accuracy of the limb pointing information in the Level 0 (and then in Level 1) data sets [von Savigny et al., 2003]. The pointing errors were found to be caused by an incorrect knowledge of the satellite position.

In order to analyse in detail this altitude shift we have computed mean profiles of the coincident data from SCIAMACHY and from the selected correlative instruments. These mean profiles allow us to calculate the correlation function of the two profiles. The abscissa of the maximum giving the altitude shift.

$$Corr(f, g)(x) = \int f(y)g(x + y)dy \quad (2)$$

Calculated altitude shifts from the three instruments of the NDSC/Alpine station are presented in Table 4. Similar values are obtained from the different instruments leading to a mean shift of 1.5 km at this location.

Table 4. Altitude shifts between SCIAMACHY ozone limb profiles and correlative data from selected instruments of the NDSC/Alpine station.

Correlatives	Altitude shift [km]
O3S Payerne	1.5
LID Hohenpeißenberg	1.7
MWR Payerne	1.4

6.4 Longitudinal Structures

SCIAMACHY limb pointing is updated twice a day, always roughly at the same geographical locations : (i) around 60° - 70°W between approximately 20°N and the equator, i.e., the Caribbean and/or the northern part of South America; and (ii) around 100°E and 45°S, i.e., south-west of Australia. Just after this sudden update of the on-board orbit model, the limb pointing appears to be accurate and then deviate slowly from the nominal pointing.

Mean altitude shifts, at all NDSC stations located between 50°S and 50°N of latitude, have been calculated. In order to show the slow deviation of the pointing error, these data are plotted according to longitude. Results are presented in Fig.10.

Fig.10 show the sudden updates of the on-board orbit model. It take place each time Envisat fly over Caribbean at 60° - 70°W of longitude. Just after the updates, the altitude shift is reduce to 1.5 km and then increases slowly up to 3 km. These results are in agreement with what is expected from the level 0 pointing error. The Australian update of the orbit model is here not viewable as no coincident profiles were found at these longitudes. This pointing error will be corrected in further retrieval.

6.5 SCIAMACHY conclusion

Preliminary ozone limb profiles from University of Bremen were compared to ground-based correlative data. As there is an pointing error in level 0 data, ozone profiles show an altitude shift of 1.5 km to 3 km. The on-board orbit-model is updated at 60° - 70°W of longitude. Just after this update the shift is reduced. Then the pointing error slowly increase and large discrepancies between the SCIAMACHY profiles and correlative data are observed.

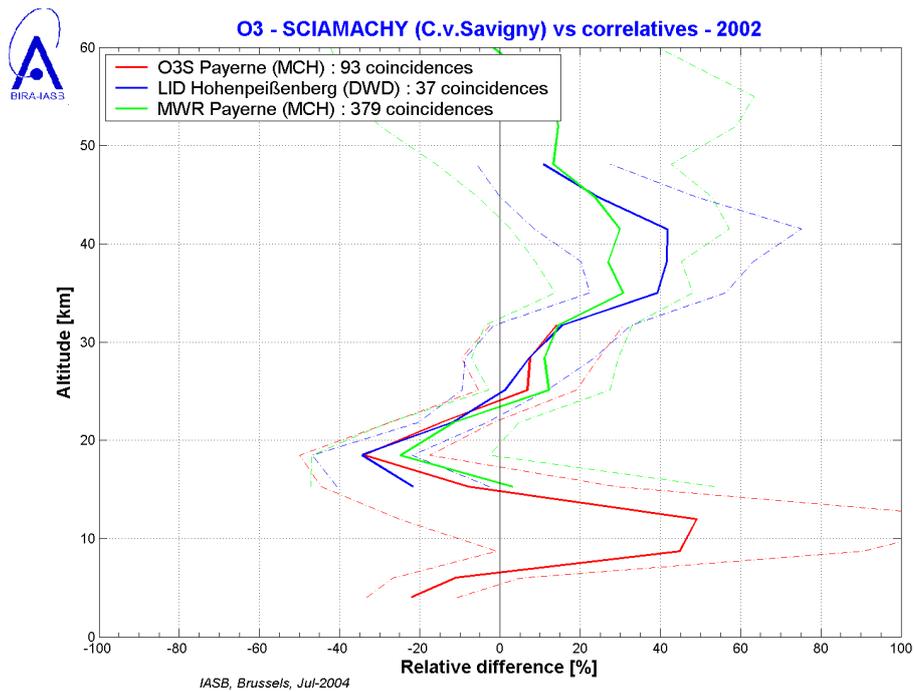


Fig. 8. Percentage relative differences (plain) and standard deviation (dashed) between SCIAMACHY limb ozone profiles in 2002 and coincident correlative data from selected instruments at the NDSC/Alpine station. [SCIA-corr./corr.]

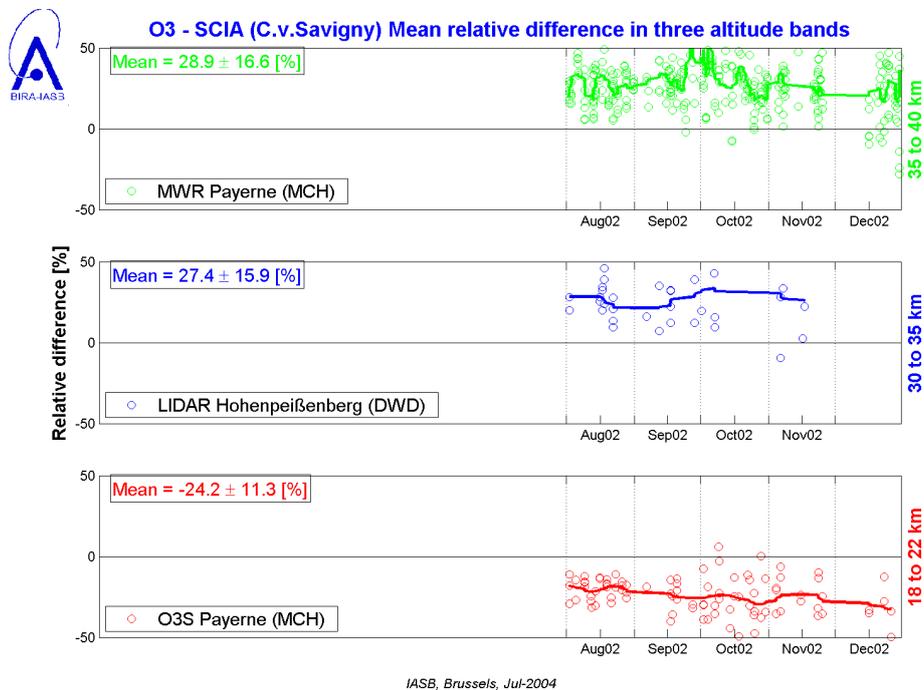


Fig. 9. Time-series, on altitude band, of SCIAMACHY limb ozone profile percentage relative difference with correlative measurement at NDSC/Alpine station for year 2002 [SCIA-corr./corr.].

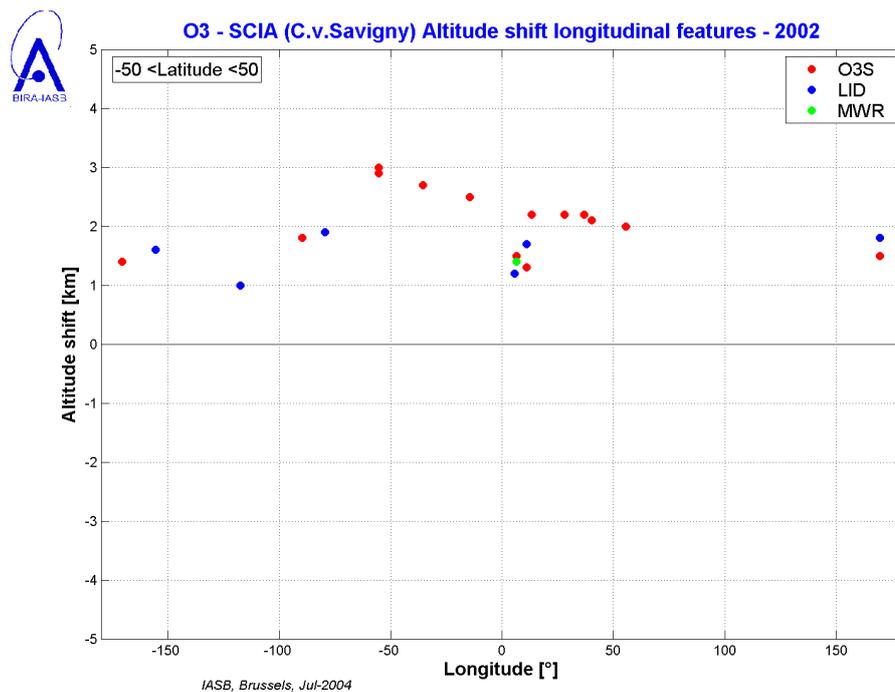


Fig. 10. Mean altitude shifts between SCIAMACHY limb ozone profiles in 2002 and coincident correlative data plotted according to longitude.

7. CONCLUSION

Different and independent techniques have been used to validate data measured by the three Envisat ozone profilers, GOMOS, MIPAS and SCIAMACHY. Correlative profiles recorded by O3S, LID and MWR located from pole to pole have been collected by the ACVT-GBMCD working group, allowing pseudo-global comparisons. The study has highlighted and quantified height features of the profiles, as well as global structures, seasonal variations and pointing errors. Validation conclude to a reasonable quality and consistency of Envisat profiles when adequate data selection and vertical ranges are envisaged.

MIPAS ozone profiles on pressure scale shown a good agreement with ground based O3S, LID and MWR. Differences within 10% are observed in the 18 to 40 km altitude range, below and above this range they increase. Time structures were also investigated, a 10% natural variability of the differences is observed, no seasonal component was detected. These results are similar at all latitudes, there is no marked meridian variation.

GOMOS ozone profiles are strongly affected by the brightness of the limb through which the star occults. Bright limb situations give poor results. When selecting only dark limb occultations, ozone profiles agree well with the correlative data. At mid and low latitudes, differences are within 5-10% in the altitude range of 20-50 km. Below and above this range they increase. For high northern latitudes, the agreement is poorer. When investi-

gating time structures, a 5-10% agreement was observed, in line with height features results. Dependence of the profiles quality on the occultation angle with ENVISAT orbit plane have been studied. No critical effect of this parameter was found.

SCIAMACHY limb ozone profiles have been retrieved at University of Bremen. Validation of this scientific product was performed and ozone limb profile compared to ground-based correlative data. As there is an pointing error in level 0 data, ozone profiles show an altitude shift from 1.5 km to 3 km. The on-board orbit-model is updated each time Envisat fly over Caribbean and over Australia. Altitude shifts between the SCIAMACHY profiles and correlative data were calculated at several locations. The Caribbean update is viewable on longitudinal structures of the differences. Just after this update the altitude shift is reduced. Then the pointing error slowly increase leading to large discrepancies between the SCIAMACHY and correlative data as well in height features as in time series. There were not enough coincident profiles to observe the effect of the Australian update.

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