Global validation of ENVISAT ozone profiles using lidar measurements

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Abstract:
Satellite sensors provide global measurements of ozone concentration which can be used to study the effects of the implementation of the Montreal Protocol. However, a key issue in deriving long-term ozone trends from successive satellite instruments is inter-comparability. Ground-based measurements offer continuous time series but only at few locations. The combination of ground-based measurements with satellite data is therefore an effective means to evaluate satellite instrument inter-comparability.
In this study we present validation results of ozone profiles from three atmospheric sensors onboard ENVISAT by comparison with lidar measurements. Results for SCIAMACHY ozone profiles (version 3.01) show a reasonable agreement with ground-based measurements (0 - -20%). MIPAS full resolution (version 4.61) datasets have a good agreement with lidar (0 - 10%), whereas a small positive bias (up to 20%) was

found for MIPAS reduced resolution prototype data. GOMOS dark limb data (version 5.00) agree very well (0 ± 5%) with the correlative data, but underestimate the ozone concentration at the Polar Regions.

Keywords: GOMOS; MIPAS; SCIAMACHY; lidar; ozone; validation

1 Introduction

In order to assess the effectivity of the measures taken in the framework of the Montreal Protocol, accurate and reliable measurements of atmospheric properties such as ozone and temperature are essential. In addition, coordinated in-situ measurements provide and have provided a valuable contribution to our understanding of stratospheric processes. For instance, studies with ozone sondes have shown that ozone loss is not only related to enhanced chlorine levels, but it also has a strong dependence on stratospheric temperature (Schulz et al., 2000, Schulz et al., 2001). Lidar measurements have, for example, been used to characterise polar stratospheric clouds (Massoli et al., 2006) and to study geographic differences in observed stratospheric temperature and waves (Blum et al., 2004). Nevertheless, ground-based and balloon-borne measurements are only available at a few locations.

Satellite instruments are in this respect an excellent source of information as they can provide cost effective and timely global coverage. However, one of the key issues when using different satellite instruments to derive long-term ozone trends is the degree to which the measurements of these instruments properly correlate. This is especially of concern when no simultaneous measurements are available due to coverage gaps in successive missions. A second major issue is the trade-off between the geographic coverage (i.e. temporal and spatial resolutions) and the obtained accuracy for satellite retrievals (Meijer et al., 2004).

The establishment of a long-term time series of ground-based measurements with known quality and the comparison with satellite measurements is therefore a prerequisite to assess the quality of satellite data and to ensure both a good performance of individual sensors as well as an appropriate combination of multi-sensor datasets. Ground-based and balloon-borne measurements have already proven to be essential in the validation of various models (Reid et al., 1998) and satellite retrievals (Cortesi et al., 2007, Jiang et al., 2007, Meijer et al., 2003, Ridolfi et al., 2007, Witte et al., 2008).

In this study we evaluate the ozone profiles derived from the measurements of the three atmospheric instruments onboard ENVISAT: SCIAMACHY, MIPAS and GOMOS. More precisely, four ozone profile products derived from measurements by these instruments are compared with ground-based lidar measurements.

2 Datasets and methodology

In this study we have investigated the differences between lidar and satellite-based measurements of stratospheric ozone. The lidar measurements of stratospheric ozone were taken at eleven sites (see Table 1) ranging from Lauder, New Zealand (-45.04 ºS) to Eureka, Canada (80.05 ºN). All of these lidar systems are DIfferential Absorption Lidars (DIAL) which make use of two wavelengths. Since the absorption by ozone is wavelength dependent, comparison of the return signals allows the derivation of the ozone concentration as a function of altitude.

Insert table 1 about here

The validation approach followed in this study is similar to that of Meijer et al. (2004). Both satellite and lidar data were first interpolated using a linear spline to a common altitude grid and then compared in a quality assessment. The selected datasets were subsequently compared in terms of mean, median and standard deviation of the differences for various subsets, such as the geographical region, measurement conditions and collocation criteria. Here, a lower confidence altitude limit was set for all lidar data to 18 km and the upper altitude limit was set to 45 km.

One prototype and three operational ESA satellite products from three atmospheric sensors have been compared with lidar:

- SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) level 2 processor version 3.01. SCIAMACHY observes the solar radiation transmitted or reflected by the atmosphere during sunrise and sunset from 240 to 2380 nm. From these observations, vertical columns and profiles are retrieved for various atmospheric constituents. See Bovensmann et al (1999) for an overview of the measurement techniques of this instrument
- Michelson Interferometer for Passive Atmosphere Sounding (MIPAS) full resolution (FR) level 2 processor version 4.61. MIPAS provides profiles of temperature and atmospheric constituents from limb-viewing midinfrared emission measurements by a high resolution Fourier transform spectrometer. The high resolution observations cover the upper troposphere/lower stratosphere (UTLS) to the mesosphere. Fischer et al. (2008) provides a more detailed description of this sensor
- MIPAS reduced resolution (RR) prototype data
- Global Ozone Monitoring by Occultation of Stars (GOMOS) processor version 5.00. GOMOS utilises the stellar occultation technique to detect atmospheric trace gasses (with a focus on ozone), as well as temperature. The transmitted radiation of the star setting in the atmosphere is analysed by spectrometers covering the UV-visible (250 nm to 675 nm, 756 nm to 773 nm) and near infrared bands (926 nm to 952 nm) with a spectral resolution of 1.2 and 0.2 nm, respectively. Geophysical variables are retrieved over the altitude range from 15 to 100 km with an approximate height resolution of 1.7 km. See Kyrölä et al (2004) for a review of this sensor

Over 12 000 collocations (maximum of 800 km and 20 hours difference between measurements) of SCIAMACHY profiles with lidar were found for the period 2002-2007. The upper altitude limit for the comparison interval is restricted to 40 km as recommended in the SCIAMACHY data disclaimer.

The MIPAS instrument encountered an anomaly in March 2004. It was able to continue measurements in January 2005, but with a reduced spectral resolution. There are therefore two different MIPAS products available. For the comparison with operational MIPAS FR version 4.61 data, the collocations were restricted to a maximum of 10 hours and a maximum distance of 400 km (> 600 collocations). The reduced resolution data are not operationally produced and only a very limited dataset was available for verification activities. The collocation criteria have therefore been extended to a maximum of 20 hours and a distance of 500 km (only 28 collocations).

For GOMOS processor version 5.00, a maximum time lapse of 20 hours and a maximum distance of 800 km were chosen. The solar zenith angle was further restricted to 108° or larger to ensure that only star occultations in dark limb conditions are considered. The maximum error that was allowed for both the GOMOS data as well as the lidar data was set to 30%. More than 1600 collocations fulfilled these criteria. The analysis results for these collocated datasets are shown in section 3.

3 Results

3.1 SCIAMACHY processor version 3.01

Figure 1 displays the comparison results for SCIAMACHY processor version 3.01. The left panel shows the mean ozone number densities of the lidar (thick blue line) and SCIAMACHY (thick red line) measurements together with the standard deviations (thin lines) as a function of altitude. It is clear that SCIAMACHY is underestimating the ozone concentrations. We can quantify the underestimation using the middle panel which shows the mean and median of the differences with respect to lidar. The underestimation of ozone is ranging between about 5% at the bottom of the profile (18 km) increasing to 25% at an altitude of 40 km. These results supported the SCIAMACHY processor development and the verification of the new prototype has shown significant improvements. This new dataset will be available beginning of 2009.

Insert Figure 1 about here

3.2 MIPAS FR processor version 4.61 and RR prototype data

In Figure 2 we present the comparison results for the completed MIPAS full spectral resolution dataset based on processor version 4.61. Differences with lidar are varying between 0 to 5% over the range 18-40 km with MIPAS overestimating the ozone concentrations. For MIPAS reduced resolution data processed with the prototype processor the differences are larger (up to 20%), but the available dataset is very limited (the number of collocations is less than 30). This product has a higher vertical resolution and it is anticipated that the operational processor version 5.00 will become available in the second half of 2008, thus increasing the size of the dataset for comparison soon.

Insert Figure 2 about here

3.3 GOMOS processor version 5.00

Figure 3 presents the validation results for GOMOS operational processor version 5.00. The three panels show the Polar Regions, mid-latitudes and tropics (from left to right respectively). We can observe that the GOMOS version 5.00 dataset has an excellent agreement with lidar in the mid-latitudes over the compared range (18-45 km). In the tropics, where the ozone maximum can be generally found at higher altitudes, we see the effects of decreasing signals when continuing to descent below the ozone maximum: GOMOS increasingly deviates from the lidar signals. For the mid-latitudes we can expect a similar behaviour at altitudes below the analysed minimum (18 km). In the Polar Regions GOMOS shows a constant underestimation of the ozone concentration, ranging from -5% at 18 km to 5-10% at 40 km and then rapidly increasing to about 30% at 45 km. We can see that some outlier profiles exist from the deviation between the mean and median profiles. Straylight may be playing a role in the origin of the differences between GOMOS and lidar.

Insert Figure 3 about here

4 Conclusions

In this study we have presented the validation results of the ozone profiles delivered by ESA from three atmospheric sensors onboard ENVISAT: GOMOS, MIPAS and SCIAMACHY. Intercomparisons with lidar measurements have been performed at 11 stations worldwide belonging to the Network for the Detection of Atmospheric Composition Change (NDACC). We have compared these collocated profiles and analyzed the results for dependence on several geophysical (e.g., latitude) and instrument observational (e.g., GOMOS star characteristics) parameters and looked at the instruments' performance in time.
The SCIAMACHY ozone profiles (version 3.01) have been more precisely corrected for the altitude shift present in previous data versions and showed a reasonable agreement with lidar. Ozone profile validation results showed a good agreement of MIPAS (version 4.61) full resolution and a small positive bias was found for MIPAS reduced resolution data throughout the stratosphere ranging from 0 to 20%. Nevertheless,

individual comparisons showed a very good agreement in the high vertical structures in the profiles. GOMOS data (version 5.00) from measurements in dark limb conditions agreed very well with the correlative data and no significant systematic errors are observed, except for the northern Polar Regions where GOMOS seems to slightly underestimate the ozone number densities.

The continuous monitoring of the quality of satellite-based products through validation with long-term ground-based measurements provides the means to instrument intercomparison and algorithm development. Despite data gaps in between satellite missions, the ozone layer can be globally monitored in a consistent way ensuring that the trends in ozone will be properly identified.

Acknowledgements

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Table 1. Overview of used lidar sites

Site	Latitude (º)	Longitude (º)
Alomar	69.3	16.0
Eureka	80.1	-86.4
Hohenpeissenberg	47.8	11.0
La Reunion	-20.8	55.5
Lauder	-45.0	169.7
Mauna Loa	19.5	-155.6
Ny Ålesund	78.9	11.9
Observatoire Haute Provence	43.9	5.7
Rio Gallegos	-51.6	-69.3
Table Mountain	34.4	-117.7
Tsukuba	36.1	140.1

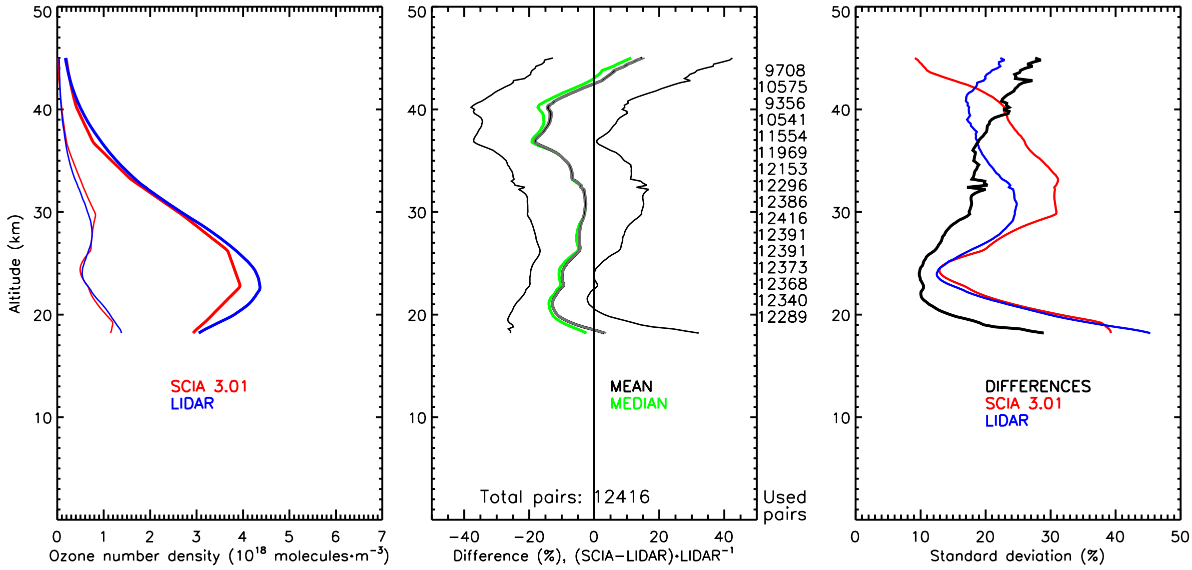

Figure 1. Validation results for SCIAMACHY operational processor version 3.01 in comparison with lidar measurements. Left panel: Mean SCIAMACHY (thick red line) and mean lidar (thick blue lines) ozone concentrations with their respective standard deviations (thin lines) as a function of altitude. Middle panel: Mean (thick black line) plus/minus one standard deviation (thin black lines) of all individual difference profiles from the mean difference profile and mean difference plus/minus two standard errors (thin grey lines) and median (green line) percentage difference (SCIAMACHY minus lidar divided by lidar) as a function of altitude. On the right side of the middle panel is listed the number of collocations for each altitude. The right panel shows the standard deviations of SCIAMACHY (red), lidar (blue) and the standard deviation of the differences between SCIAMACHY and lidar (black line) as a function of altitude.

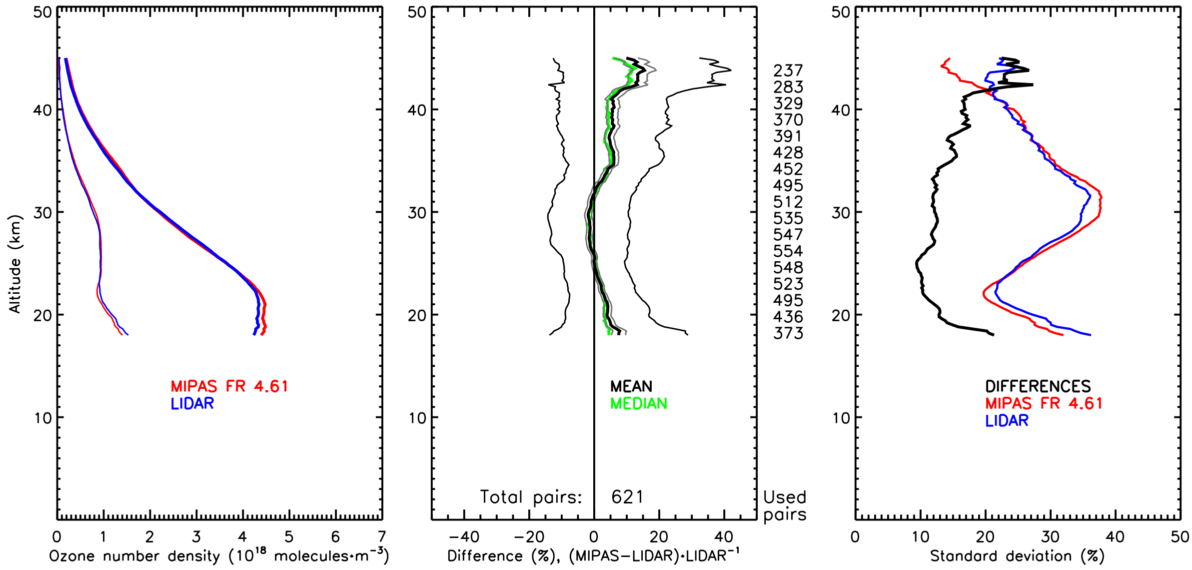

Figure 2. Validation results for MIPAS FR processor version 4.61 in comparison with lidar measurements. Same as Figure 1 except for MIPAS FR version 4.61.

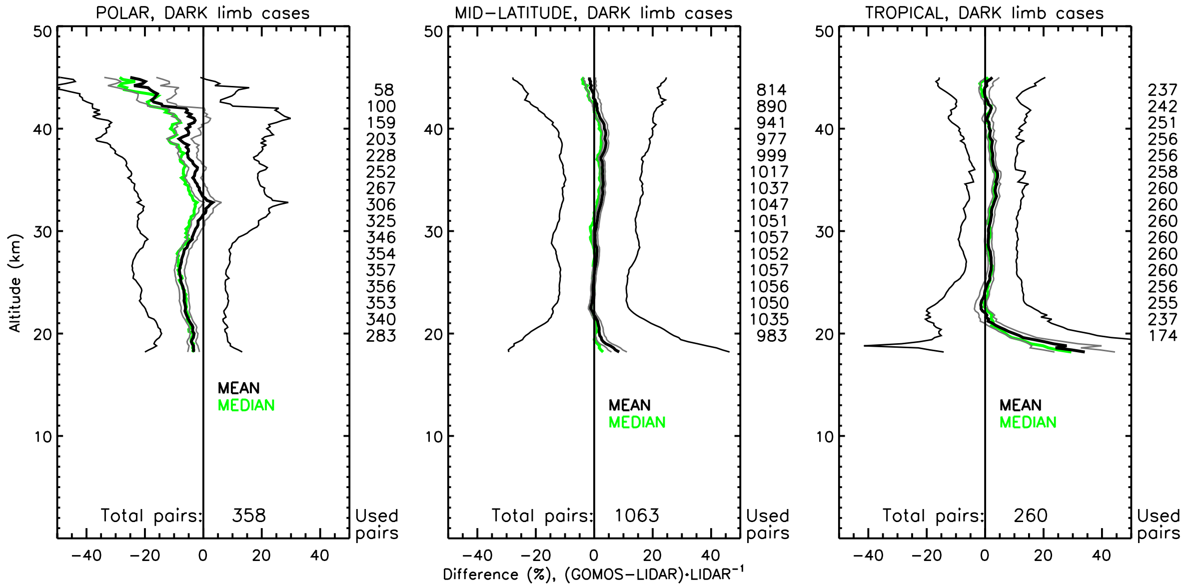

Figure 3. Validation results for GOMOS IPF 5.00 ozone profiles in comparison with lidar measurements. Mean (thick black lines) plus/minus one standard deviation (thin black lines), mean plus/minus two standard errors (thin grey lines) and median (thick green lines) of the percentage differences between GOMOS and lidar ozone concentrations as a function of altitude. On the right side of each panel is listed the number of collocations for each altitude. Left panel: Polar Regions. Middle panel: Mid-latitudes. Right panel: Tropics.