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LONG-TERM MULTI-MISSION VALIDATION OF OZONE AND TEMPERATURE PROFILES BY THE VALIDATION WITH LIDAR (VALID) PROJECT

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ABSTRACT

The Satellite validation with lidar (VALID) project supports the long-term multi-mission validation of atmospheric chemistry and physics instruments with ground-based lidars. VALID involves lidar stations around the world measuring stratospheric ozone and temperature profiles, and tropospheric aerosol and cloud properties. Currently around ten thousand lidar profiles have been made available for validation purposes in VALID and its predecessor EQUAL (ENVISAT quality assessment with lidar).

The satellite data under investigation here are the ozone and temperature profiles delivered by the MIPAS (Michelson interferometer for passive atmospheric sounding) and SCIAMACHY (Scanning imaging absorption spectrometer for atmospheric chartography) instruments as new algorithms have become available recently.

We have collocated the satellite profiles with the lidar measurements and analysed the comparison results for dependence on several geophysical and instrument

observational parameters. Results for the delta validation are presented for SCIAMACHY level 2 version 5.01 and for MIPAS level 2 version ORM (optimised retrieval model) 5.0x. For the SCIAMACHY validation, additional ozone sonde and microwave radiometer data have been included to enlarge the validation dataset.

The consistent underestimation of the ozone concentrations by SCIAMACHY seen in version 3.01 is now removed. In the mid-latitudes, SCIAMACHY version 5.01 matches the validation instruments within 5% up to 38 km altitude. The cloud free data are more positively biased. In the polar regions, there is a variable bias ranging from -10% to +7% in the altitude range 15 to 35 km, increasing above (its magnitude depending on validation instrument). The cloud free data have a more enhanced negative bias. In the tropics, there is positive bias in SCIAMACHY v5.01 (5 to 23%) and the cloud free data appear to have a more positive bias (few percent). The large deviation at low altitudes could be due to sub-visual cirrus and will be further investigated in the future. Finally, with respect to the observation

direction (corresponding to the scan angle), Eastern orientated profiles overall have a more negative bias than Western profiles

For the MIPAS version 5.0x data, the ozone profiles match the lidar data very well over a large part of the compared altitudes. Deviations are seen at the bottom of the profiles starting with a positive bias when going down below the ozone maxima reaching up to +5%. In the tropics this bias changes sign when reaching the lower most altitudes and gets to -10%. At the highest altitudes there is a positive bias in the tropics (max. 2%) and in the mid-latitudes (max. 5%), whereas in the polar region there is an increasing underestimation from an altitude of 35 km (close to 0%) towards the top at 45 km (nearly 15%).

The temperature data are mostly within 1 to 2 K from the lidar data. Looking at the different altitude axis, we cannot say that using the engineering altitudes gives a better performance than when using the corrected altitude axis. In fact, the comparison improves when introducing a shift of +500 m for the MIPAS data in the polar region and mid-latitudes (larger shift needed for the tropics). This is not seen in the ozone data and thus needs further study.

1. INTRODUCTION

Validation of satellite retrieved products is important to monitor the evolution of instrument performance and to assist algorithm development. For ozone and temperature data, this can be done very well with self-calibrating lidars over a given altitude range (18 to 45 km for ozone and, depending on the lidar setup, from 15 to 70 km for temperature). In this extended abstract we have summarised the results of the delta validation for the two new level 2 processing algorithms for SCIAMACHY (v5.01) and MIPAS (v5.0x).

2. METHODOLOGY AND DATA

In the following sections we will describe the used datasets and the applied validation strategies.

2.1. Satellite retrieved data

2.1.1. MIPAS ozone and temperature profiles

The analysed ozone and temperature data fall in the time period January 2005 to November 2009, therefore all MIPAS data are in the optimised resolution.

The MIPAS data were processed with the Level 2 scientific prototype algorithm (ORM) which is fully aligned with the upcoming operational Level 2 processor (IPF 5.0x). The measurements were taken with a reduced spectral resolution with respect to the original specification (0.0625 cm⁻¹ instead of 0.025 cm⁻¹), but with a finer vertical sampling. The upgrades of this version allow solving the ill-conditioning of the

retrieval induced by the increased vertical sampling by means of a regularization approach.

The following upgrades are included with respect to the previous MIPAS IPF 4 version: 1) A-posteriori regularization is applied to the main target parameters (temperature, O₃, HNO₃, CH₄, N₂O and NO₂) except for pressure and H₂O profiles. The regularization approach is the one described in [1]. 2) The vertical averaging kernel matrices (AKMs) of the regularized profiles are provided in the new level 2 products. The condition number of the matrix that has been inverted in the retrieval is also provided. The condition number provides information if the matrix is nearly singular and if its inversion can cause instabilities in the results. In this study we did not take the condition number into account, but we did convolve the lidar ozone profiles with the averaging kernels of the collocated MIPAS profiles.

2.1.2. SCIAMACHY ozone profiles

The SCIAMACHY level 2 validation dataset for version 5.01 (processed with the operational Level 1 processor version 7.03) covers around 1900 selected orbits identified by the validation teams for the complete mission until 2010. Besides general adjustments to the ozone retrieval algorithm, limb cloud flagging and aerosols are introduced in the new version. Additional products such as limb BrO profiles and H₂O total columns have also become available. Here we shall focus on the validation of the ozone profiles and investigate whether the presence of clouds (i.e. suite of cloud flags totalling 0 (no clouds) or more (clouds - regardless of what type- at some altitudes or failed retrieval)) affect the ozone retrieval.

2.2. Lidar data

Tab. 1 gives an overview of the lidar stations participating in this validation study.

Table 1. Lidar sites providing ozone and temperature data

| Site name | Latitude | Longitude | O ₃ | T |
|-----------------------------|----------|-----------|----------------|---|
| Alomar | 69.3 | 16.0 | + | + |
| Dumont d'Urville | | | + | + |
| Esrangle | 67.9 | 21.1 | | + |
| Eureka | 80.1 | -86.4 | + | + |
| Hohenpeissenberg | 47.8 | 11.0 | + | + |
| La Reunion | -20.8 | 55.5 | + | + |
| Lauder | -45.0 | 169.7 | + | |
| Mauna Loa | 19.54 | -155.6 | + | + |
| Ny Alesund | 78.9 | 11.9 | + | + |
| Observatoire Haute Provence | 43.9 | 5.7 | + | + |
| Río Gallegos | -51.6 | -69.3 | + | |
| Table Mountain | 34.4 | -117.7 | + | + |
| Tsukuba | 36.1 | 140.1 | + | + |

The lidar data have been restricted to the altitude range 18 to 45 km for ozone data and, depending on the lidar setup, from 15 to 70 km for temperature data. For the latter comparison, we have also included temperature profiles from ozone sondes and radio sondes up to an altitude of 30 km.

2.3. Methodology

Collocations were sought with a maximum distance of 800 km (300 km) between measurements and a 20 hour (5 hour) difference in time for ozone (temperature) measurements. Only data at altitudes flagged to have a valid retrieval were taken into account. The data were subsequently splined to a common altitude grid and statistics on the differences were calculated for different subsets based on classification by a specific parameter. No averaging kernels have been applied for the SCIAMACHY data.

3. RESULTS

3.1. MIPAS ozone and temperature profiles

A total of 2063 data pairs were available for the ozone validation study and about 260 data pairs were found for the temperature comparison.

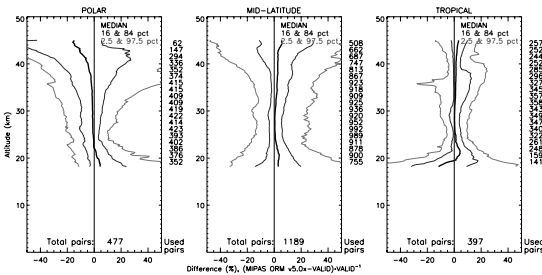


Figure 1. Validation results for MIPAS ORM v5.01 ozone profiles for different latitude regions: tropics (right), mid-latitudes (middle) and polar regions (left). Each panel shows the 2.5, 16, 50 (=median), 84 and 97.5 percentiles of the difference (relative to the lidar profiles) as a function of altitude.

On the right axis the number of used collocated pairs is shown and at the bottom the total number of available pairs.

Fig. 1 shows the validation results for the ozone profiles obtained from the MIPAS ORM v5.01 data. Compared to the convolved lidar data, differences are within a few percent. Specifically, in the polar region the difference is about zero in the altitude region 20 km to 35 km. Above 35 km the underestimation (overestimation) by MIPAS (or the lidar) is increasing to 15% at 45 km. In the mid-latitudes the fit is very good, with a small positive bias (0 to 5%) in the MIPAS data. In the tropics there is a perfect match from 25 km upwards to about 40 km. MIPAS is slightly overestimating (5%) at the top. Below the ozone maximum MIPAS appears to be

overestimating ozone in most cases. This is also seen in comparison to balloon sonde data (not shown).

Furthermore, a few outlier profiles can be identified from the percentile plots. These are found at higher altitudes (mid-latitudes and polar regions) and at the bottom of the profiles (everywhere, but especially in the tropics).

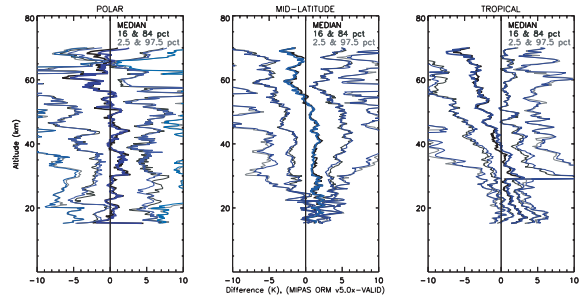


Figure 2. Temperature validation results for all lidar collocations for the polar (left panel), mid-latitude (middle panel) and tropical (right panel) regions. Shown are data on the nominal engineering altitude (black) and the corrected altitude axis (blue). Data show the difference in K with respect to the lidar as a function of altitude. Note that the number of collocations is not equal but comparable for the two datasets.

The temperature comparison shows that the bias is within the -6 K to +2 K extremes, mostly within 1 to 2 K from the lidar. An altitude offset of 500 m or larger (towards the equator) is visible, but its origin needs to be further investigated as the shift is not observed in the ozone data. Note that the number of collocations is rather low, especially for the polar regions. With the ORM processor, the information on the tangent altitudes is derived from the ENVISAT platform attitude information which is known to be insufficiently accurate. The operational processor will be retrieving the altitudes from ECMWF data, which should remove the problem.

3.2. SCIAMACHY ozone profiles

In this study we have split the ozone data into two categories using the cloud flags: “cloud free” whenever all four flags were equal to zero and “cloudy” whenever there is a non-zero flag. 8843 matches with balloon soundings (smoothed to 2 km), 3675 matches with lidar profiles and 3553 matches with microwave radiometer profiles were identified matching the collocation criteria for the cloudy data. Most of these collocated pairs are found in the mid-latitude region. A total of 860 pairs were found for the cloud-free cases, also with the majority (630 cases) of the collocations in the mid-latitudes.

Fig. 3 shows the comparison to the ozone sondes, microwave radiometer and lidar data for both cases. The

top panel shows that there is a variable bias in the polar region ranging from -10% to +7% in the altitude range 15 to 35 km, increasing above (magnitude depending on validation instrument). The cloud free data have a more enhanced negative bias. Various high outliers are observed.

In the mid-latitudes (Fig. 3b) SCIAMACHY v5.01 matches validation instruments within 5% up to 38 km altitude. The cloud free data are more positively biased. A positive bias is seen in the tropics (Fig. 3c) for the SCIAMACHY v5.01 cloudy data (5 to 23%) and the cloud free data appear to have a more positive bias (few percent). It has been suggested that the deviations in the tropics at the lowest compared altitudes may be due to sub-visual cirrus clouds [2]. Sub-visual cirrus clouds are defined as having an optical depth of 0.03 or smaller in the visual portion of the spectrum. These clouds are most often found in the tropics due to the very low temperature in the upper troposphere and high water vapour concentrations. They mostly occur in the upper two kilometres below the tropopause but can be thicker, extend a various hundreds of kilometres and persist up to days [3-5].

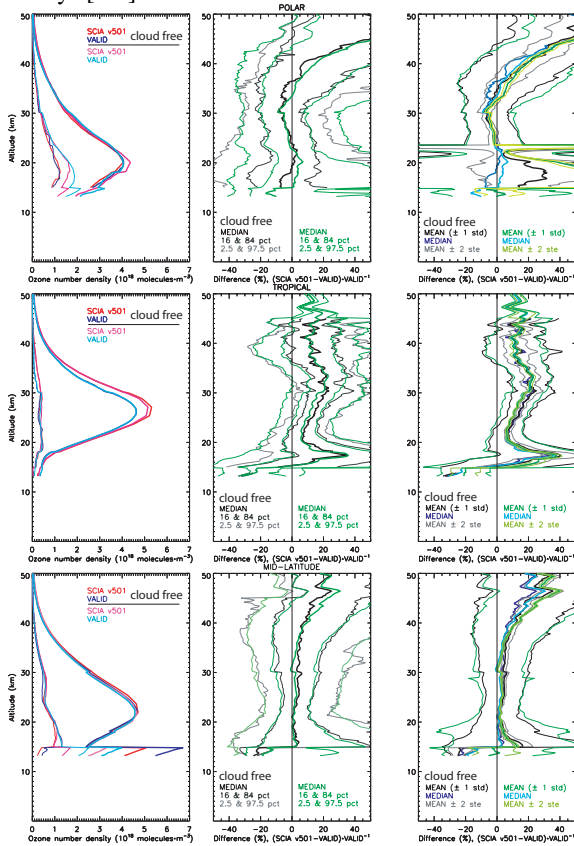


Figure 3. Validation results for SCIAMACHY ozone profiles showing the three main latitude regions: polar (top), mid-latitudes (middle) and the tropics (bottom). The left panels show the mean ozone number densities

for validation instruments in blue and for SCIAMACHY in red together with standard deviations (thin lines) as a function of altitude. Lighter colours correspond to data with a non-zero cloud flags. Middle panels: relative differences (percentiles as in Fig. 1) with cloud free data in black and cloudy data in green. Right panels: mean difference profiles (green for cloudy and black for non-cloudy data) plus/minus 1 standard deviation (thin lines with same colours) and 2 standard errors (grey for cloudy and light green for non-cloudy data) together with the median differences (blue tones).

Fig. 4 is showing the results when we group the data by viewing orientation. Four classes are available: West, central West, central East and East. It can be seen that with respect to the observation direction, profiles orientated towards the East (red and orange lines) overall have a more negative bias than Western profiles (green and blue lines). This scan angle dependence is also observed in the sensor degradation [6].

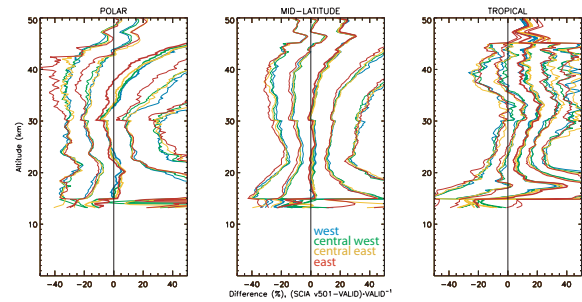


Figure 4. Validation results for SCIAMACHY ozone profiles showing the three main latitude regions: polar (left), mid-latitudes (middle) and the tropics (right). Eastern oriented data are plotted in red, central East in orange, central West in green and Western oriented data in blue.

4. CONCLUSIONS

Validation of satellite retrieved products is important to monitor the evolution of instrument performance and to assist algorithm development. For ozone and temperature data, this can be done very well with self-calibrating lidars over a given altitude range (18 to 45 km for ozone and, depending on the lidar setup, from 15 to 70 km for temperature). Here we have presented some results of the delta validation for the two new level 2 processing algorithms for SCIAMACHY (v5.01) and MIPAS (ORM v5.0x).

For the MIPAS dataset, the analysed ozone and temperature data fall in the time period January 2005 to November 2009, therefore all data are in the optimised resolution. A-posteriori regularization is applied to the main target parameters and vertical averaging kernel matrices (AKMs) of the regularized profiles are provided. The lidar ozone profiles have been convolved with the averaging kernels of the collocated MIPAS

ozone profiles. Differences were found to be within a few percent. Specifically, in the polar region: above 20 km to 35 km the difference is about zero; above 35 km the underestimation (overestimation) by MIPAS (or the lidar) is increasing to 15% at 45 km. In the mid-latitudes: the fit is very good, with a small positive bias (0 to 5%) in the MIPAS data. In the tropics: from 25 km upwards to about 40 km there is a perfect match and MIPAS is slightly overestimating (5%) at the top. Below the ozone maximum MIPAS appears to be overestimating ozone in most cases. Similar results are obtained in comparison to balloon sonde data.

The temperature comparison showed that the bias is within -6 K to +2 K and mostly within 1 to 2 K from the lidar. An altitude offset of 500 m or larger (towards the equator) is visible, but its origin needs to be further investigated as the shift is not observed in the ozone data. With the operational processor the altitude information will be derived from the ECMWF pressure to altitude grid, which may resolve this issue.

For the SCIAMACHY level 2 validation dataset (version 5.01) we focussed on the validation of the ozone profiles considering whether the presence of clouds affect the ozone retrieval. Additional data from microwave radiometers and balloon sondes were used for the validation and no averaging kernels were applied.

The underestimation seen in most of the data for the previous version (3.01) is now gone. In the mid-latitudes, the version 5.01 data match the lidar profiles within 5 percent. In the polar region there is a variable bias (-10% to +7%), increasing at higher altitudes with the magnitude depending on the used validation instrument. In the tropics there is a positive bias, especially at lower altitudes. This may be due to sub-visual cirrus and is to be further investigated. Cloud free data result in a more positive bias for the tropics and mid-latitudes and a more negative bias for the polar region. However, the cloud free (all four cloud flags equal to zero) data comprise a small part of the total dataset. Finally, comparing the different viewing directions, it was found that Eastern profiles have a more negative bias than profiles observed in the Western direction. A dependence on the scan angle is also seen for the sensor degradation. An issue with the altitude registration as also seen for MIPAS may also influence this.

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