SCIAMACHY validation using the AMAXDOAS instrument

Klaus-Peter Heue(1), Steffen Beirle(1) Marco Bruns(2), John P. Burrows(2), Ulrich Platt(1), Irene Pundt(1), Andreas Richter(2), Thomas Wagner(1) and Ping Wang(2)

(1) Institut für Umweltphysik, Universität Heidelberg, INF229, D-69120 Heidelberg, Germany,
Email: Klaus-Peter.Heue@iup.uni-heidelberg.de
(2) Institut für Umweltphysik, Universität Bremen, Otto-Hahn-Allee 1, D-28359 Bremen, Germany,
Email: Andreas.Richter@iup.physik.uni-bremen.de

ABSTRACT

The AMAXDOAS-instrument is a special designed Multi Axis DOAS instrument for airborne measurements. From the four different viewing angles the AMAXDOAS the traces gas columns of NO_2, O_3, BrO and OClO below and above the aircraft can be derived. Two spectrometers are used for the wavelength region between 300nm and 550nm.
Here we present AMAXDOAS NO_2 - measurements from early spring 2003 in Europe and compare the results to different SCIAMACHY retrievals. A quantitative validation of tropospheric columns is shown, and a first qualitative comparison to total columns is presented.
A comparison between the two SCIAMACHY algorithms is not part of this project and will be done elsewhere.

1. INTRODUCTION

SCIAMACHY on ENVISAT measures the sunlight reflected from the earth or scattered in the atmosphere. From the spectra to retrieve vertical columns of many trace gases such as O_3,OClO BrO, SO_2, NO_2, CO, CO_2, CH_4, H_2O, N_2O. [1,2,3,4] can be retrieved.
In the troposphere NO_2 is produced by both anthropogenic and natural sources, such as biomass burning or lightning. Many sources emit NO which is rapidly oxidized to NO_2. During daytime NO_2 is photolysed leading to O_3 production, normally the sum NO + NO_2 is referred to as NO_x.
In Europe the high variations in the NO_2 concentrations provide good conditions for the validation of satellite instruments like SCIAMACHY with a high spatial resolution (30 x 60 km^2).
The AMAXDOAS instrument is laid out to separate the stratospheric and tropospheric column of several traces gases like BrO, NO_2, and O_3 [5]. As the conversion of slant to vertical columns is known to be one of the major uncertainties [6], with the AMAXDOAS an instrument was built to validate slant columns as well.
In September 2002 and February – March 2003 it was installed on the DLR-Falcon during two SCIAMACHY-validation campaigns. Together with the AMAXDOAS an Ozone lidar (OLEX) and a microwave radiometer (AZUR) were installed on the Falcon. In about 40 flights the airplane flew from the Arctic to the Tropics. All these flights were coordinated with SCIAMACHY overpasses. [7]

2. DESCRIPTION OF THE INSTRUMENTS

2.1 The AMAXDOAS instrument

The AMAXDOAS instrument consists of two spectrometers (300-440nm and 400-550nm) connected to small telescopes outside of the aeroplane via quartz fibres. Here four telescopes were used with different elevation angles, nadir and zenith and plus and minus 2° relative to the horizon.[8] The telescopes have an aperture of 0.2° and a diameter of 1cm. The scattered sunlight observed by the telescopes and spectrally analysed by the spectrometers is simultaneously detected by two CCD cameras for all viewing directions.
Due to the small field of view of the telescope the horizontal resolution along the flight track of the AMAXDOAS is mainly given by integration time (30sec) and the speed of the aeroplane (800km/h) resulting in 6.6 km.
Flying in 11 km altitude in the mid latitude we can assume the zenith viewing telescope to observe the stratosphere and the nadir viewing to observe the troposphere. It is obvious that, the nadir viewing data are influenced by the stratospheric absorptions as well.

2.2 The AMAXDOAS data analysis

The AMAXDOAS data were analysed using the DOAS technique [9] with the WINDOAS software [10] of BIRA/IASB. For the NO_2 the fitting window 420 to 444 nm was used. The cross sections of NO_2, O_3, H_2O a polynomial of third degree and a ring spectrum were included in the fit. A first order intensity offset was allowed as well.
As reference spectrum a measured spectrum observed under cloudless conditions in a clean air region, like

over mountains was used. To minimize instrumental effects the reference spectrum was taken with the same telescope.
In Fig.1 a typical NO_2 fit from a flight from Basel (CH) to Tozeur (Tunisia) on 19 February 2003 is shown. The NO_2 cross section can clearly be recognized. The flight will be discussed in detail later on.

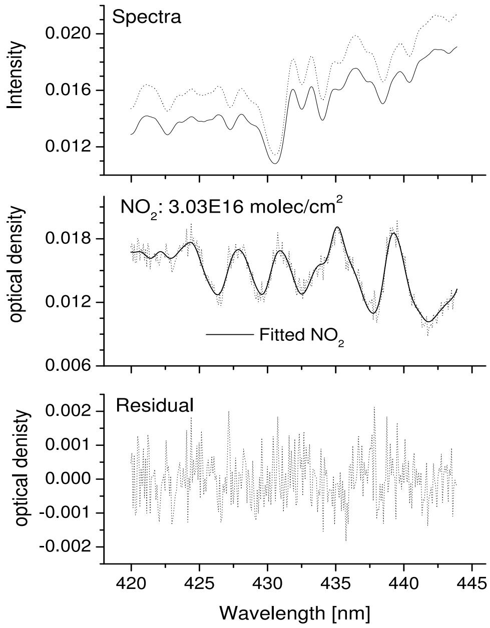

Fig. 1. DOAS-fit for NO_2 of a Nadir spectrum. The spectrum was taken 19 Feb. 2003 at 8:14:30 close to Zürich. The reference was taken 30min later over the Alps.

To retrieve tropospheric column densities a polynomial was fitted to the minima of the nadir viewing telescope and subtracted afterwards, to exclude the stratospheric influence in the nadir data, Fig.2. The result is called

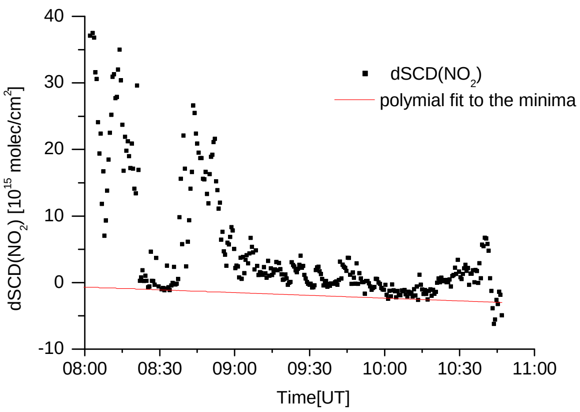

Fig. 2. Differential slant column densities of NO_2 and a polynomial fitted to the minima. The polynomial is subtracted afterwards to retrieve the tropospheric SCD.

tropospheric slant column density (TSCD) and might well be compared to similar SCIAMACHY data. After the division of the TSCD with the Air Mass Factor (AMF) the tropospheric vertical column density (TVCD) is achieved.
To obtain total column densities the column density of the reference spectrum is needed, therefore a Langley plot was used if possible or the vertical column observed by an independent instrument, e.g. GOME, was used for that single point.

2.3 The SCIAMACHY instrument

The SCIAMACHY instrument is a 8 channel spectrometer covering the wavelength region from the UV (2240nm) to near infrared (2380nm). The resolution depends on the channels and varies between 0.22nm and 1.48nm. The NO_2 analysis is done in wavelength region observed by channel 3, here the resolution is 0.44nm.
Measurements are alternately performed in the limb and Nadir mode, changing within two minutes. With this method the total and the stratospheric column can be observed independently. At the beginning and the end of each orbit a solar and lunar occultation measurement are performed. The horizontal resolution is 30 x 60 km^2. Global coverage is achieved every 6 days.[1]

2.4 The SCIAMACHY data analysis

The SCIAMACHY data results presented here were analysed independently in Bremen and Heidelberg. Operational SCIAMACHY products will soon be available from DLR and ESA, but currently verification of these products is still ongoing.
Therefore a detailed description of the used algorithms is not useful at this point, but some main features will be given in the according section.
Details on retrieval algorithm from Bremen can be found in [11]. The tropospheric column densities for 19 Feb. 2003 were analysed in Bremen.
For the algorithm used in Heidelberg refer to [2]. In section 4.2 a comparison of the total column densities from 10 March 2003 is discussed.

3. VALIDATION OF TROPOSPHERIC NO_2 – COLUMNS (BREMEN)

An excellent agreement between the SCIAMACHY and AMAXDOAS was found for both TSCD and TVCD and is discussed in detail in [12]. Here only an overview over this work is given.

3.1 Retrieval of tropospheric columns

For the retrieval of the tropospheric columns a stratospheric correction of the data was made. Similar to the established approaches used for GOME data a clean air background form the Pacific Ocean was subtracted to gain TSCDs. [12] As in the case of AMAXDOAS the TSCDs can be converted to TVCDs by the division with the tropospheric AMF.

The idea of subtracting a clean air background used for the AMAXDOAS data is obviously very similar to the one used for the GOME and SCIAMACHY data.

The tropospheric AMFs for both instruments were calculated assuming the same conditions such as aerosol extinction profile, albedo, and NO_2-profile.

3.2 The flight chosen for the comparison

For the comparison of the SCIAMACHY and AMAXDOAS tropospheric columns the flight from

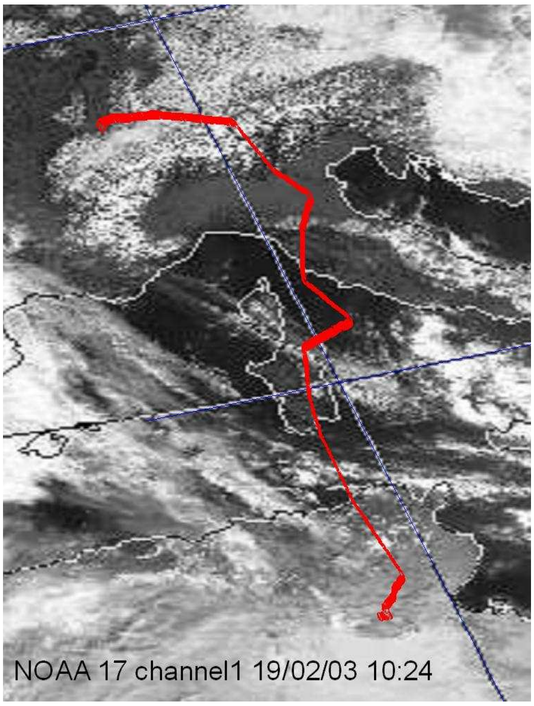

Fig. 3. NOAA-17 Satellite image [14] of southern Europe and the Mediterranean of 19/02/2003 showing the clouds along the flight track.

Basel to Tozeur was chosen. The flight track crossed the clean air region of the Alps and the Po-Valley, one of the most polluted areas in Europe. The weather conditions on this day had been ideal for a comparison with SCIAMACHY, there were no clouds in the regions of interest. The flight track and the cloud situation can be seen in Fig. 3.

3.3 Validation results

As the approaches for the stratospheric corrections were similar for both instruments a comparison for both TSCD and TVCD will be shown here.

Fig. 4 shows the vertical column density measured by both instruments over northern Italy and the Mediterranean and northern Africa. Both Instruments measured the same general distribution concerning the clean air in the Alps, and the high polluted Po-Valley, also the Apennine mountains can be realised in both datasets. Unfortunately the north of the Swiss midlands

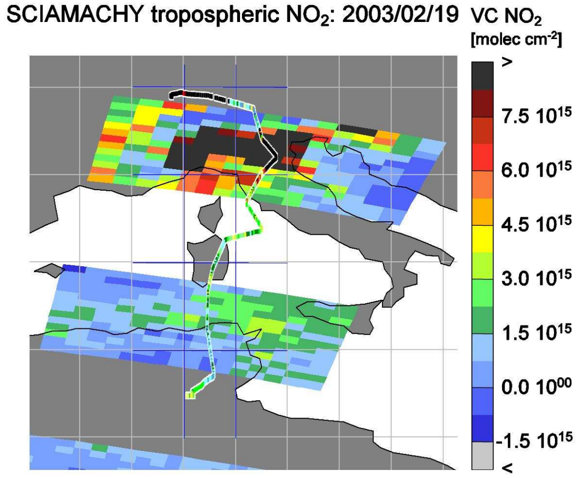

Fig. 4. SCIAMACHY and AMAXDOAS tropospheric vertical column, plotted in the same colour scale.

is not covered by SCIAMACHY on this day, because also here AMAXDOAS detected high column densities. South of Sardegna both instruments detect only moderate NO_2 columns ($0\text{-}3*10^{15}$ molec/cm^2).

For a more detailed comparison the SCIAMACHY data were horizontally scaled down to a smaller grid with resolution comparable to those from AMAXDOAS. Then for the AMAXDOAS data covered by the pixel a corresponding SCIAMACHY data point was found.

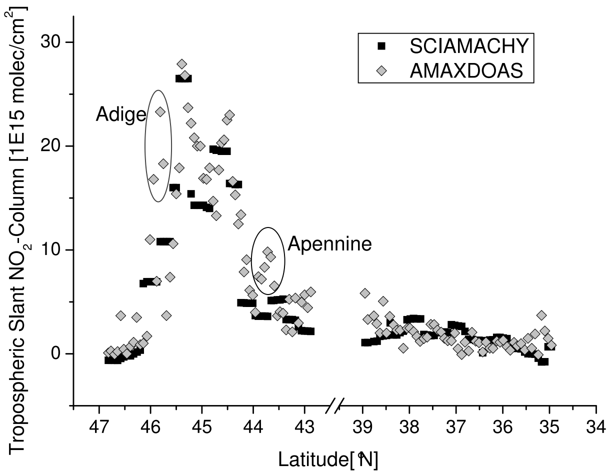

Fig. 5. TSCD plotted as a function of Latitude. The outliers in the data can be attributed to local emissions in the mountains. In the southern alps the emission of the highway to Austria and Germany following the Adige river can be seen.

In Fig. 5 the tropospheric slant NO_2 – columns are plotted for both instruments as a function of latitude. In general the agreement is very good, there are some outliers, especially over the mountains edge, were SCIAMACHY is mainly influenced by the snow capped mountains and AMAXDOAS is able to detect local pollution in the valley, due to the better resolution.

4. VALIDATION OF TOTAL VERTICAL NO_2 – COLUMNS (HEIDELBERG)

For AMAXDOAS the retrieval of total columns is not as straight forward as the retrieval of the tropospheric columns. The main problem is the unknown vertical column in the reference spectrum. For the flight shown here, the vertical column measured by GOME was used for the reference.

4.1 SCIAMACHY data analysis for the total columns.

The SCIAMACHY slant columns were retrieved as described in [2], but for the total vertical column of course no stratospheric correction was applied and the slant columns were divided by a stratospheric AMF.

4.2 Description of the measurement flight

For the comparison with the total vertical columns retrieved in Heidelberg, a different flight was chosen. The flight from 10 March 2003 from Oberpfaffenhofen (south west of München) to Kiruna (northern Sweden), was chosen.

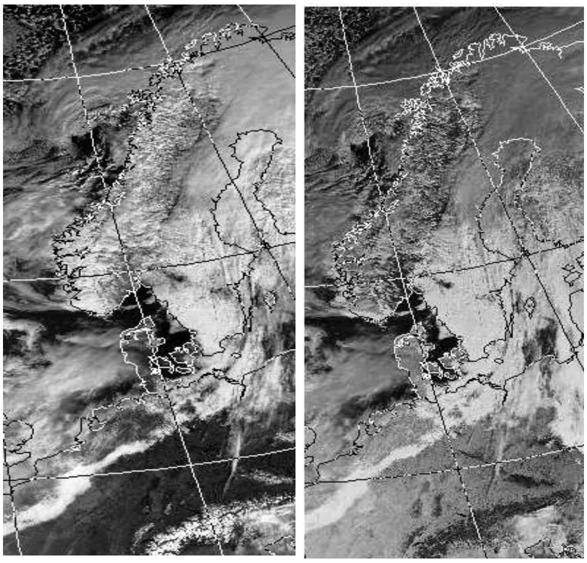

Fig. 6. Cloud distribution [14] in the region of interest on 10 March 2003. Channel 1 (vis) left panel, Channel 3 (near IR) right panel, in Scandinavia not only cloud but also snow can be observed

The cloud distribution shown in Fig. 6 illustrates a small band of thick clouds across Germany and Belgium. The image was taken at 9:56, just a few minutes after SCIAMACHY passed Germany. Over Scandinavia only thin clouds are observed. The cloudy situation observed on this day is not ideal for both instruments, but a comparison is possible anyhow, especially as the influence of clouds on both instruments is similar.

4.3 Comparison with AMAXDOAS

The total vertical NO_2 columns for both SCIAMACHY and AMAXDOAS are shown Fig. 7 for 10 March 2003. The general agreement is very good, a strong enhancement is observed over the Ruhrgebiet and compared to the North a slight enhancement is observed over northern Germany and southern Scandinavia. SCIAMACHY slightly underestimates the local NO_2 concentration in the Ruhrgebiet compared to AMAXDOAS. This might be due to the different horizontal resolution, or to temporal changes in the concentration and cloud coverage. The thick clouds observed in Fig 6. are reported in the AMAXDOAS log at the time when the Falcon passed over the Ruhrgebiet. Both measurements were take within 45 min, SCIAMACHY passed Germany at 9:50 whereas the aeroplane started in Oberpfaffenhofen at 9:45 and overflew the Ruhrgebiet between 10:30 and 10:37.

The main uncertainty however is the conversion of slant columns to vertical columns. Due to different viewing

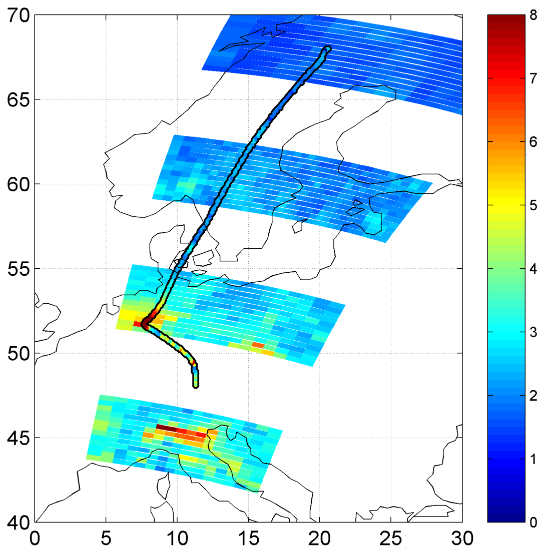

Fig. 7. Vertical NO_2 – columns observed by SCIAMACHY and AMAXDOAS on 10 March 2003.

geometry concerning the stratosphere a direct comparison of the total slant column is not possible.

Although similar settings for the AMF-calculations were used, there are still some possible errors. Whereas SCIAMACHY observes the stratosphere from 800km altitude, the flight altitude of the aeroplane was 11km.

So the scattered or reflected light detected by SCIAMACHY crossed the stratosphere twice, and only once until it reaches the AMAXDOAS. Therefore AMAXDOAS is less sensitive to the stratosphere.
The influence of clouds for satellite or air borne instruments is still under investigation. For the AMAXDOAS the variety of possible influences depending on the position of the absorber is discussed in [15].

5. CONCLUSIONS AND OUTLOOK

The overall agreement between SCIAMACHY and AMAXDOAS is very good. A detailed comparison of the tropospheric vertical and slant columns demonstrated the strength of the validation of SCIAMACHY without the uncertainties of the AMF calculations.
The comparison with the total vertical columns, showed larger deviations. This is possibly caused by the different sensibility to tropospheric variation when the stratosphere is considered as well.
A more quantitative validation of the SCIAMACHY NO_2 retrieval in Heidelberg will be made in the near future.

ACKNOWLEDGEMENTS

The authors would like to thank, the DLR-Flight operations for the support during the integration of the instrument and throughout the whole campaigns. Many thanks to our former group members Rütger T. Rollenbeck and Frédéric Finocchi who have contributed much to the success of the AMAXDOAS project and to the workshop of the Institut für Umweltphysik in Heidelberg for their support during the planning of the instrument and constructing various parts of it.
For the financial support we would like to thank the Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR) under contracts 50 EE 0023 and 50 EE 0024 and the German Bundesministerium für Bildung und Forschung (BMBF) for its funding of this work through project 07 ATC-03 (Afo 2000-C)

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