THE AMAX-DOAS INSTRUMENT AND ITS APPLICATION FOR SCIAMACHY VALIDATION

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ABSTRACT

We present a novel spectroscopic instrument operated on aircrafts which will yield profile information for several atmospheric trace gases. The AMAX-DOAS (Airborne Multi-AXis Differential Optical Absorption Spectroscopy) instrument consists of two spectrometers (covering the UV and visible spectral range), each connected to 10 telescopes. Five of which are pointed upwards (i.e. into the stratosphere, when the aircraft operates at its normal cruising altitude at about tropopause level) under different angles while the other 5 telescopes are pointed downwards to the troposphere. Thus, it is possible to separate the tropospheric and stratospheric trace gas columns for a significant number of the observed species (e.g. O_3, NO_2, OClO, BrO, H_2O, SO_2, and HCHO). For some of the atmospheric trace gases (most probably for O_3 and NO_2) it will even be possible to resolve the atmospheric profiles at moderate vertical resolution. The selection of trace gases and the separation of the troposphere and stratosphere makes this instrument ideally suited for the validation of SCIAMACHY on ENVISAT. Together with Lidar- and Microwave instruments the AMAX-DOAS instruments aboard the DLR Falcon will be used during two major campaigns ranging from the Seychelles to Greenland in 2002 for SCIAMACHY validation. The first test flight of the system was performed in May 2001 and another one is scheduled for December 2001.

1. INTRODUCTION

The SCIAMACHY instrument aboard the European research satellite ENVISAT will for the first time provide stratospheric and tropospheric profiles of many atmospheric trace parameters (temperature pressure and density) and constituents (gases and aerosols) on a global scale for the first time [1, 2, 3]. The expected quantity and quality of the SCIAMACHY data exceeds those of previous space borne instruments making the requirements for the validation of its data products significantly more demanding than those of previous instruments. This is in large part due to the vertically resolved information on the atmospheric trace gas concentrations obtained from combined nadir, limb, and occultation observations.

For the validation of vertical trace gas profiles measured by SCIAMACHY several balloon flights are planned. These yield data sets of relatively high vertically resolved trace gas concentrations. For ozone and water vapour H_2O, vertical profiles are also provided by ozone sondes, Microwave and LIDAR-observations as well. For most of the target species of SCIAMACHY (like NO_2, BrO, OClO, SO_2), the DOAS and FTS instruments aboard the large balloons provide an essential mean of validation [4, 5]. However, a most important restriction on the validation by large balloon soundings is their limited number and thus their limited spatial and temporal coverage.

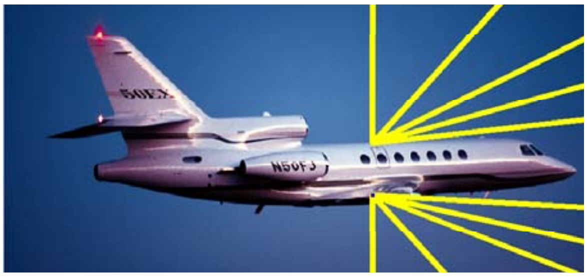

Fig. 1. Viewing geometry of the AMAX-DOAS instruments on board the Falcon aircraft. In addition to zenith and nadir direction several telescopes are mounted with smaller elevation angles.

The intention of the AMAX-DOAS observations is to close the gap by providing longitudinal and latitudinal cross sections of validation data for several atmospheric trace gases using DOAS instruments [6] on board the Falcon aircraft. These measurements build on the successful work carried out with airborne DOAS aboard the NASA DC-8 [7] and the German Airforce Transall [8, 9] during EASOE (European Arctic

stratospheric Ozone Experiment 1992). Compared to these early experiments in particular the novel viewing geometry (Multi-axis) now allows measurements in several directions above and below the aircraft (see Fig. 1 and 2). In order to match the space limitations of the Falcon aircraft the system was updated, adapted and optimised.
To derive information on the vertical profiles of the measured species the novel viewing geometry measures light from several different directions below and above the aircraft. This set of (up to 10) different atmospheric absorption paths allows the vertical column densities at least above and below the aircraft to be retrieved; i.e. at an flight altitude corresponding to the tropopause height separation of stratospheric and the tropospheric trace gas columns is possible (Fig. 2). This separation is of obvious importance for the validation of SCIAMACHY measurements.

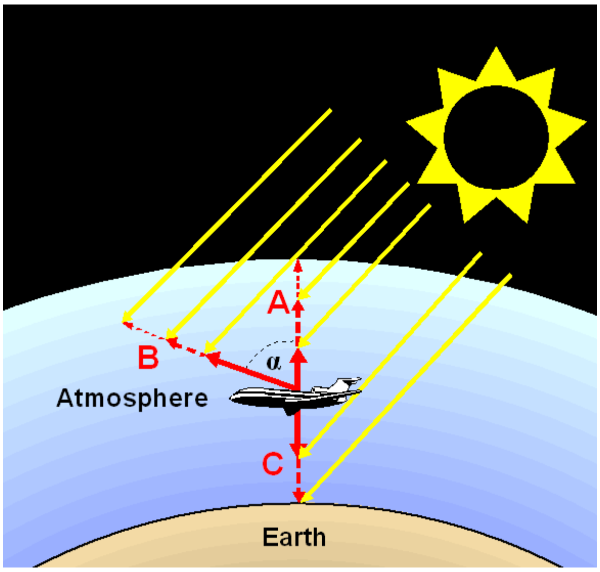

Fig. 2. The light measured under different viewing angles (α) contains different atmospheric absorption signals. The zenith looking telescope (**A**) is essentially only sensitive to the atmosphere above the aircraft; the nadir looking telescope (**C**) is sensitive to the atmosphere above <u>and</u> below the aircraft. Assuming that the aircraft operates at tropopause height it is thus possible to extract the tropospheric absorption signal from the difference between both viewing directions. In addition, from observations under different elevation angles (e.g. **A and B**) additional height information about the atmospheric trace gas profiles can be derived.

For some of the atmospheric trace gases (most probably for O_3 and NO_2) it will even be possible from the aircraft DOAS observations to resolve the atmospheric trace gas profiles at moderate vertical resolution (Fig. 2). The DOAS data thus constitute an unique data set for the validation of SCIAMACHY, which complements the stratospheric and mesospheric profiles obtained from the two other instruments on board the FALCON (OLEX-LIDAR: Aerosol and Ozone profiles; ASUR Microwave detector: Ozone-, ClO-, H_2O-profiles).
The SCIAMACHY validation flights comprise one short duration engineering test flight after the instrument package has been built into the Falcon (this flight was performed in May 2001) and some flights for the investigation of specific atmospheric conditions (e.g. SO_2 emissions in late winter smog above eastern Europe during the heating period) as well as two large campaigns of about 50 flight hours each. During these campaigns extended longitudinal and latitudinal cross sections for the SCIAMACHY validation will be generated.

2. INSTRUMENT AND DATA ANALYSIS

In order to cover the entire UV/vis spectral range at optimised spectral resolution (0.5 - 1 nm FWHM) [6], two separate DOAS instruments one for the UV (≈300 to 400 nm) and one for the visible (≈400 to 700 nm) are employed. Some trace gases show characteristic absorption structures only in the UV (e.g. BrO, SO_2, HCHO) or in the visible spectral range (e.g. H_2O, IO). Several species (e.g. O_3, NO_2, OClO, O_4) can be measured in both spectral ranges. In order to meet the high requirements on the quality of the AMAX-DOAS trace gas retrieval (relatively small differences of the trace gas absorptions corresponding to the different viewing directions are to be resolved), it is therefore essential to use an optimal instrument design suitable for the different resolutions and low stray-light levels required for the different wavelength regions.

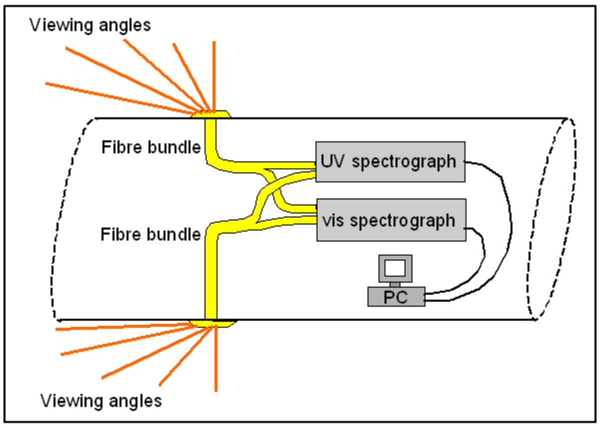

Fig. 3. Scheme of the viewing angles above and below the aircraft's altitude and of the instrumental set-up inside the aircraft.

From the telescopes mounted the light will be transmitted to the entrance slits of the instruments using glass fibre bundles (see Figures 1 and 3). The viewing geometry requires both viewing angles below and above the flight altitude. Two fibre bundles are used transmitting the light from the upper and lower entrance optics (clusters of telescopes). At the instrument's end the fibre bundles are split to supply both instruments.

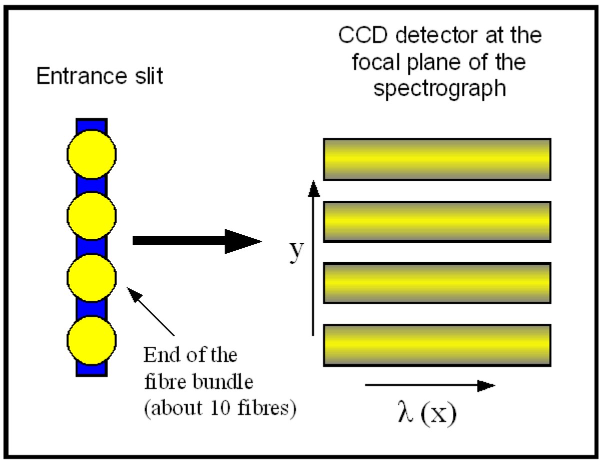

Fig. 4. Orientation of the spectra of the measured light from different viewing angles on the CCD array. The dispersion direction is labelled 'x', thus for each fibre ending at the entrance slit a complete and separate spectrum is generated on the CCD.

To separate the spectra of the light observed from the different viewing angles two-dimensional CCD arrays are needed as detectors [10]. The light is dispersed in λ (x)-direction (Fig. 4) and the different spectra for the light from different fibres are separated in y-direction (with each spectrum covering ≈10 to 20 lines of the CCD array). Thus it is possible to measure the different spectra simultaneously using essentially the same instrumental transmission function. The measurements are automatically controlled by a PC, which also stores the data.

For the evaluation of the measured spectra the DOAS method is applied [6]. The trace gas absorptions in the measured spectra are analysed using the same wavelength ranges and fitting parameters as applied for the data analysis of SCIAMACHY. This will reduce systematic differences between both data sets. For a variety of trace gases (like O_3, NO_2, and BrO) commonly agreed, optimised parameters for the DOAS algorithms already exist (see e.g. [11]). For much of the remaining species (e.g. IO, OClO, HCHO, SO_2) the sensitivity of the results to the variation of the analysis parameters has to be investigated. The information about the vertical profiles of the measured trace gases from the aircraft measurements is obtained from an inversion of the measured absorptions for different viewing angles. To convert this information into height profiles (in the simplest case the separation of the stratospheric and tropospheric column density) radiative transport modelling has to be applied [12, 13, 14].

3. SENSITIVITY STUDIES

To assess the suitability of the AMAX-DOAS observations for the determination of profile information of atmospheric trace gases two fundamental aspects have to be investigated:

First, the sensitivity of measurements for the different viewing directions with respect to trace gases located in layers at different distances below and above the aircraft has to be investigated. The stronger the sensitivity differences for the various viewing directions, the more information on the vertical trace gas distribution can be derived.

Second, the dependence of the sensitivity on the solar zenith angle (SZA) has to be investigated.

Usually the sensitivity of DOAS measurements using extraterrestrial light sources (e.g. the sun) is expressed as air mass factor (AMF). The AMF is defined as the ratio of the slant column density (SCD, the trace gas concentration integrated along the light path) and the vertical column density (VCD, the vertically integrated trace gas concentration). For simple viewing geometries (e.g. direct light observations) the AMF represents the geometrical elongation of the SCD compared to the VCD; for more complex viewing geometries (e.g. scattered light observations) the AMF is usually derived from atmospheric transport modelling [12, 13, 14]. The sensitivity studies presented in this work were calculated using the radiative transfer model SCIATRAN [13].

3.1 <u>Different Viewing Directions</u>

In order to investigate the sensitivity of the different viewing directions towards different altitudes we calculated AMFs for assumed thin (1 km) trace gas layers located at different altitudes. The results are expressed as differences to the respective AMFs for zenith (Fig. 5) and nadir (Fig. 6) viewing direction.

We find that the AMF differences are large for atmospheric layers close (within about ±5 km) to the altitude of the aircraft, and therefore expect that we can extract information about the trace gas concentration profile for these layers. For atmospheric layers further away from the flight altitude, however, no significant profile information can be expected. Nevertheless, still total column data above and below the aircraft will be obtained.

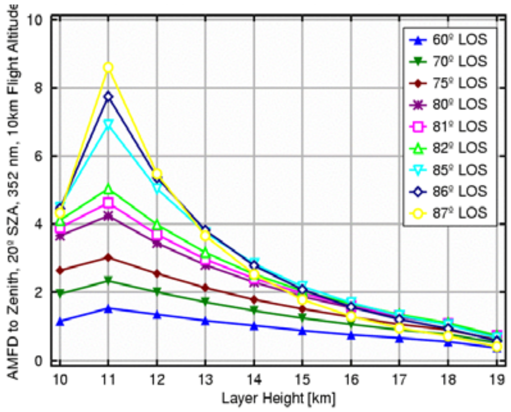

Fig. 5. Airmass factor differences with respect to zenith viewing direction for different upwards looking viewing directions (observation angles see Fig. 2). The calculations were performed for a flight altitude of 10 km, a wavelength of 352 nm, a SZA of 20° and 1 km layers at different altitudes.

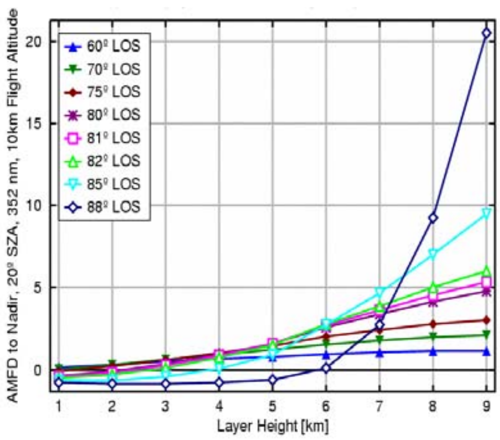

Fig. 6. Airmass factor differences with respect to nadir viewing direction as in Fig. 5 but for different downward looking viewing directions.

3.2 Different Solar Zenith Angles

In general AMFs depend on the SZA: towards large SZA, the AMF usually increase, since the absorption path through the atmosphere increases. In Fig. 7 and 8 the AMFs for upward and downward looking directions are displayed. In contrast to Fig. 5 and 6 now the SZA is varied and the angle of the viewing direction is kept constant (20°). It is obvious that the AMF differences (with respect to zenith or nadir) are nearly independent on SZA (for SZA < 70°). For large SZA the AMF differences increase. This is an important result, since it allows us to apply a similar retrieval algorithm for varying SZA values during one flight.

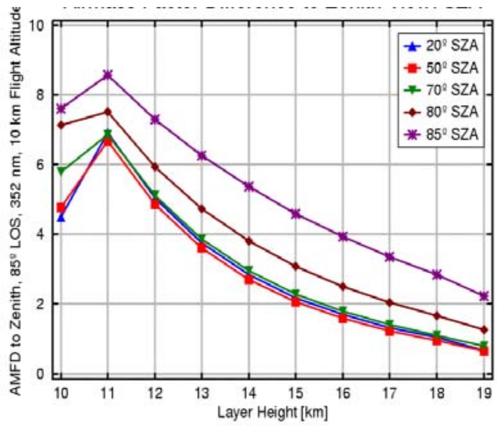

Fig. 7. Airmass factor differences with respect to zenith viewing direction for an elevation of the viewing direction of 5°, but varying SZA. The calculations were performed for a flight altitude of 10 km, a wavelength of 352 nm and 1 km layers at different altitudes.

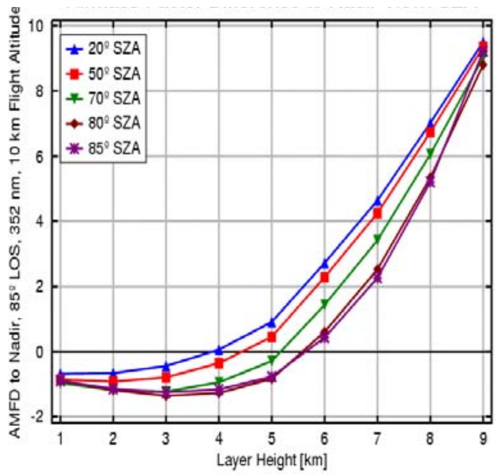

Fig. 8. Airmass factor differences with respect to nadir viewing direction as in Fig. 7 but for an elevation of the viewing direction of -5°, but varying SZA. The calculations were performed for a flight altitude of 10 km, a wavelength of 352 nm and 1 km layers at different altitudes.

4. CONCLUSIONS

The novel AMAX-DOAS instrument (Airborne Multi-AXis Differential Optical Absorption Spectroscopy) is operated on aircrafts and will yield tropospheric and stratospheric column densities for many atmospheric trace gases (e.g. O_3, NO_2, OClO, BrO, H_2O, SO_2, and HCHO). For some of the atmospheric trace gases (most probably for O_3 and NO_2) it will be possible to resolve the atmospheric profiles at moderate vertical resolution. The height resolution will be best for the layers directly above and below the flight altitude. The selection of trace gases and the separation of the troposphere and stratosphere makes this instrument well suited for the validation of SCIAMACHY on ENVISAT. Together with Lidar- and Microwave instruments the AMAX-DOAS instruments aboard the DLR Falcon will be used during two major campaigns in 2002. They are planned to range from Greenland to the Seychelles and thus yield extended longitudinal and latitudinal cross sections for the SCIAMACHY validation. The first test flight was in May 2001 and another one is scheduled for December 2001.

5. ACKNOWLEDGEMENTS

The financial support of the Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Deutsche Raumfahrt-Agentur, Bonn (formerly DARA) and the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF), contract numbers 50 EE 0023 and 50 EE 0024, are gratefully acknowledged. We also want to thank the DLR Oberpfaffenhofen, Germany for the support of the Falcon flights.

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