

GREENHOUSE GASES FROM SCIAMACHY/ENVISAT NADIR OBSERVATIONS: CO₂ AND CH₄ DURING 2003-2005

Michael Buchwitz, Oliver Schneising, Maximilian Reuter, Heinrich Bovensmann,
John P. Burrows

Institute of Environmental Physics (IUP), University of Bremen,
Otto Hahn Allee 1, 28334 Bremen, Germany

Abstract

Carbon dioxide (CO₂) and methane (CH₄) are the two most important anthropogenic greenhouse gases. SCIAMACHY on ENVISAT is the first and currently only satellite instrument whose measurements are sensitive to CO₂ and CH₄ concentration changes at all atmospheric altitude levels down to the Earth's surface where the greenhouse gas source/sink signals are largest. At the IUP of the University of Bremen the scientific retrieval algorithm WFM-DOAS (WFMD) has been developed to extract the greenhouse gas information from the SCIAMACHY nadir spectra. Here three years of greenhouse gas data (2003-2005) are presented which have been retrieved using the latest version of the retrieval algorithm (WFMDv1.0). The data sets are core input data for the Climate Study Support Service of ESA's GSE atmosphere project PROMOTE led by DLR. For methane an accuracy has been achieved which permits the use of the data for inverse modeling of regional methane surface fluxes - an ongoing activity within the EU FP6 KOPERNIKUS/GMES project GEMS. For CO₂ inverse modeling has not yet been attempted. The further improvement of the CO₂ retrieval algorithm, especially the reduction of errors due to (subvisual cirrus) clouds and aerosols, is an ongoing research activity at IUP. Here a short overview about the data sets is given. For details we refer to the corresponding publications in the (peer-reviewed) literature.

INTRODUCTION

The SCIAMACHY instrument (Burrows et al., 1995, Bovensmann et al., 1999) is part of the atmospheric chemistry payload of the European environmental satellite ENVISAT, which has been launched on 1 March 2002. SCIAMACHY observes the Earth's atmosphere in various viewing geometries (nadir, limb, and solar and lunar occultation). The SCIAMACHY near-infrared/shortwave-infrared (NIR/SWIR) nadir spectra of reflected and backscattered solar radiation enable the retrieval of total columns of carbon dioxide (CO₂), methane (CH₄) and oxygen (O₂) which can be converted into column-averaged dry air mole fractions, or molar mixing ratios, denoted XCO₂ (in ppm) and XCH₄ (in ppb). The SCIAMACHY NIR/SWIR nadir measurements have nearly equal sensitivity to greenhouse gas concentration changes at all atmospheric altitude levels down to the Earth's surface (Buchwitz et al., 2005). High sensitivity to concentration changes close to the Earth's surface is a pre-requisite to get information on regional greenhouse gas surface fluxes (emissions), which is one of the main scientific objectives of the SCIAMACHY greenhouse gas retrievals. To extract the greenhouse gas information from the SCIAMACHY spectra the WFM-DOAS retrieval algorithm has been proposed (Buchwitz et al., 2000) and further developed after launch. Significant progress has been made over the last years from the initial retrievals (Buchwitz et al., 2005) to the latest results presented here. In the following we give a short overview of the existing CO₂ and CH₄ data sets as retrieved from SCIAMACHY using WFM-DOAS version 1.0 (Buchwitz et al., 2007, Schneising et al., 2008a, 2008b).

CARBON DIOXIDE (CO₂)

Carbon dioxide column-averaged dry air mole fractions (or molar mixing ratios), XCO₂, are retrieved from a small spectral fitting window (1558-1594 nm) located in SCIAMACHY channel 6. O₂ from channel 4 (fitting window: 755-775 nm) is used as a proxy for the light path and the O₂ column is used to estimate the air column needed to compute XCO₂. The latest version of the retrieval algorithm is WFM-DOAS version 1.0 (WFMDv1.0) which is described in detail in Schneising et al., 2008a. In the following we show and discuss some results obtained with WFMDv1.0.

It is well known from highly accurate and precise CO₂ surface observations that CO₂ is currently rising by on average about 2 ppm/year (0.5%/year) mainly due to the burning of fossil fuels (IPCC, 2007). This can be clearly observed by SCIAMACHY as shown in Fig. 1 demonstrating that SCIAMACHY can obtain information on atmospheric CO₂ on the 1 ppm level. As can also be seen, the CO₂ increase over the northern hemisphere is superimposed by a much stronger variation, namely the CO₂ seasonal cycle, which is mainly caused by uptake and release of CO₂ by the terrestrial biosphere (photosynthesis, respiration, decay). A detailed discussion of the observed CO₂ annual increase and the retrieved seasonal cycle is given in Buchwitz et al., 2007, and Schneising et al., 2008a.

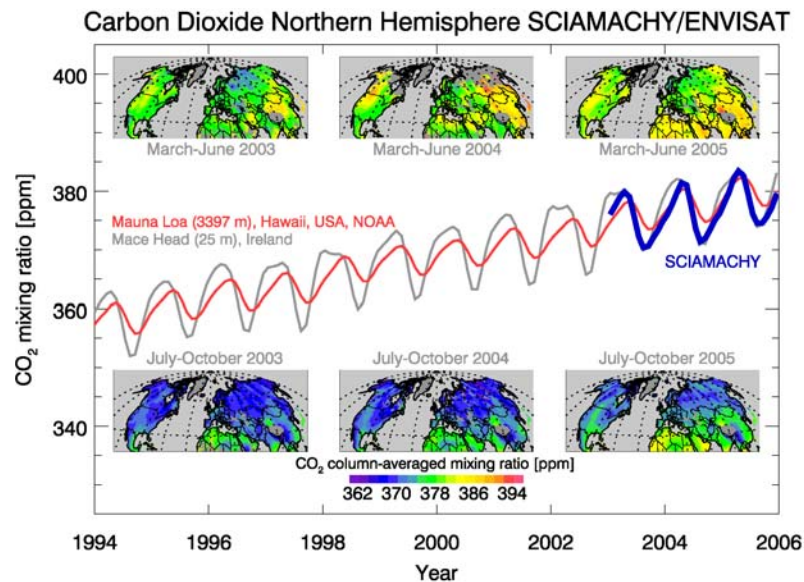


Figure 1: CO₂ annual increase and seasonal cycle as retrieved from SCIAMACHY (blue curve and maps) over the northern hemisphere compared to NOAA/ESRL surface CO₂ measurements based on weekly flask sampling. See Buchwitz et al., 2007, and Schneising et al., 2008a, and references given therein, for details.

Over the southern hemisphere the annual CO₂ increase can also be clearly observed by SCIAMACHY (Schneising et al., 2008a). The amplitude of the CO₂ seasonal cycle in the southern hemisphere is known to be significantly weaker compared to the northern hemisphere. Recent studies indicate that the seasonal cycle as retrieved from SCIAMACHY over the southern hemisphere seems to be significantly disturbed by interferences with sub-visual cirrus clouds (Schneising et al., 2008a). This aspect needs further study and may require further significant improvements of the retrieval algorithm. Activities in this direction are currently ongoing at IUP.

Figure 2 illustrates how the XCO₂ is obtained from the retrieved CO₂ and O₂ columns. Shown are only those data obtained during 2005 for which the WFMDv1.0 quality flag indicates a successful retrieval (see Schneising et al., 2008a). Accepted are only measurements over land (this may be relaxed in future versions of the CO₂ retrieval algorithm). As can be seen, the CO₂ and the O₂ columns are highly correlated because both gases are well-mixed and the spatial variation of their columns is mainly determined by surface pressure (surface elevation) variations. Mountains can therefore be clearly identified in both, the CO₂ (top left) and the O₂ (top right) columns. The O₂ column is converted into a dry air column by dividing the O₂ column by the well-known mixing ratio of atmospheric O₂. The division of the retrieved CO₂ column by the dry air column (for each observed ground-pixel individually) yields the column-averaged dry air mole fraction of CO₂, denoted XCO₂, which is shown in the bottom panel of Fig. 2.

In order to assess the quality of the retrieved XCO₂ comparisons have been made with ground-based Fourier Transform Spectroscopy (FTS) XCO₂ retrievals and global model data (Schneising et al., 2008a). As an example, Figure 3 shows a comparison of the SCIAMACHY year 2005 XCO₂ average (also shown in Fig. 2) with the output of NOAA's CO₂ assimilation system CarbonTracker (Peters et al., 2007). As can be seen from a comparison of the top left panel with the top right panel, a large

difference exists between the (true) CarbonTracker yearly average (top left) and the average obtained by sampling the output of CarbonTracker only if SCIAMACHY data are available. This is due to the relatively sparse sampling of the SCIAMACHY data because of cloud cover, too low sun elevation, etc. As can be seen from Fig. 3 the SCIAMACHY and the CarbonTracker XCO₂ show similar spatial pattern (e.g., low values at mid and high northern hemispheric latitudes, high values in the tropics). As can also be seen, the SCIAMACHY XCO₂ is significantly more variable compared to CarbonTracker. For a detailed discussion of this we refer to Schneising et al., 2008a.

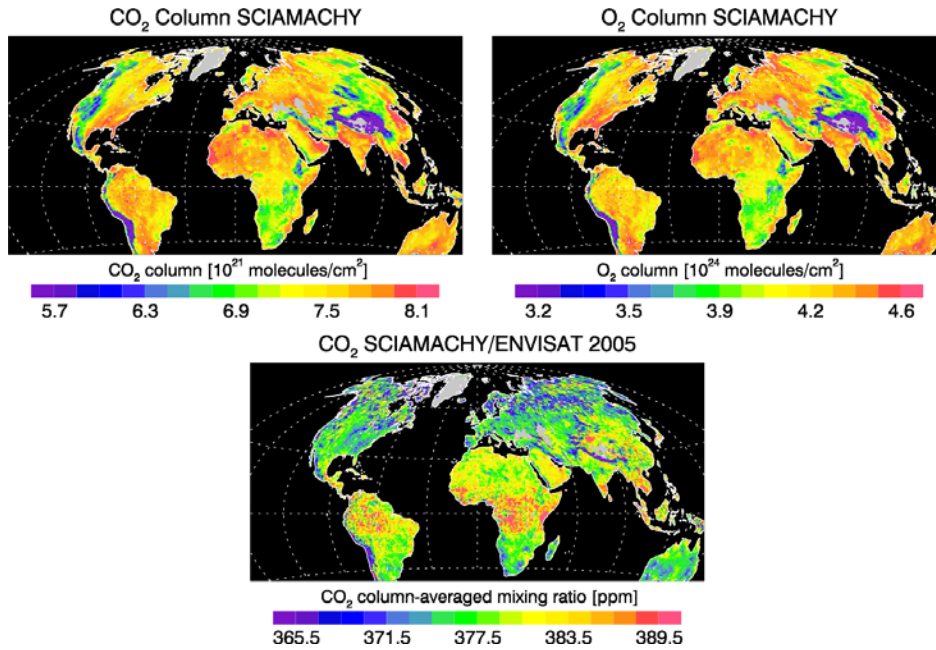


Figure 2: Top left: Vertical column of CO₂ as retrieved from SCIAMACHY channel 6 using WFMDv1.0 for the year 2005. Top right: O₂ column retrieved from channel 4. Bottom: CO₂ column-averaged dry air molar mixing ratio (in ppm).

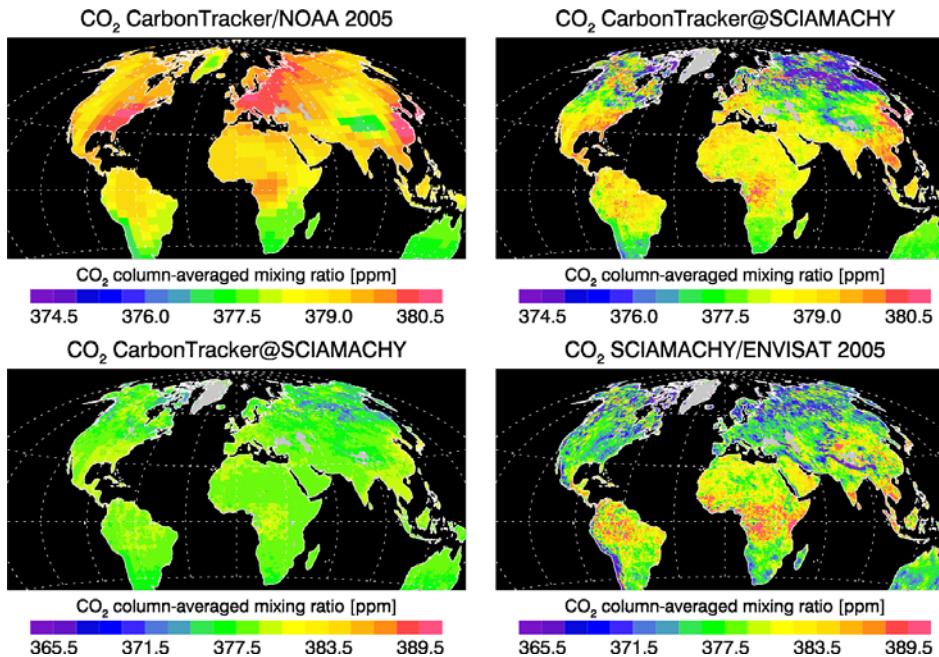


Figure 3: Column-averaged mixing ratios of CO₂ over land for the year 2005: CarbonTracker (top left), CarbonTracker sampled as SCIAMACHY (top right and bottom left; note that the only difference is the scale of the color bar), SCIAMACHY (bottom right; identical with bottom panel of Fig. 2).

Figure 4 shows a three-year average of the retrieved XCO₂ over central Europe. As can be seen the SCIAMACHY XCO₂ is highest over the “Rhine-Main area” which is the region in central Europe where population density and anthropogenic CO₂ emissions are highest. Fig. 4 indicates that SCIAMACHY has the potential to detect regionally elevated CO₂ due to anthropogenic CO₂ emissions. For a detailed discussion of this we refer to Schneising et al., 2008a.

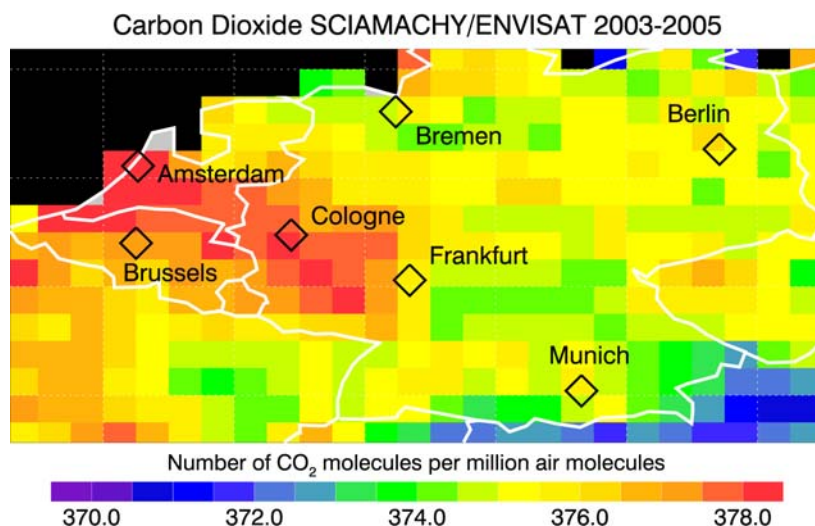


Figure 4: Column-averaged mixing ratio of CO₂ (in ppm) as retrieved from SCIAMACHY over Europe (average 2003-2005). See Schneising et al., 2008a, for a detailed discussion.

METHANE (CH₄)

Methane column-averaged dry-air mole fractions, XCH₄, are retrieved from a small spectral fitting window (1630-1671 nm) located in SCIAMACHY channel 6. CO₂ from channel 6 (fitting window: 1558-1594 nm) is used as a proxy for the light path and the CO₂ column is used to estimate the dry air column needed to compute XCH₄. The latest version of the retrieval algorithm is WFM-DOAS version 1.0 (WFMDv1.0). Here we show some examples. For details we refer to Schneising et al., 2008b.

Figure 5 shows a three-year-average of the retrieved methane. Major source regions of methane can be clearly identified such as Siberian wetlands, China (e.g., wetlands, rice) and the tropics (e.g., wetlands). Especially the elevated methane retrieved from SCIAMACHY over the tropics is an area of intensive research. For example it has been recently shown how critical spectroscopic input parameters are, especially the parameters for water vapor (Frankenberg et al., 2008). Using updated spectroscopic input parameters the SCIAMACHY 2003-2005 has been reprocessed at IUP using WFMDv1.1. The analysis of this data set is currently ongoing at IUP. Preliminary results confirm the finding of Frankenberg et al., 2008, of a potential overestimation of the tropical methane for retrievals based on HITRAN 2004 (Rothman et al., 2005) water vapor line parameters such as WFMDv1.0. This important aspect will be discussed in the final revised version Schneising et al., 2008b. Preliminary results also show that outside the tropics the sensitivity to the spectroscopic input data is much smaller due to less interference with water vapor compared to the humid tropics.

Figures 6 and 7 show more details of the retrieved methane focusing on two interesting methane source regions. Fig. 6 shows northern hemispheric methane for two time periods. As can be seen methane is higher during the second half of the year over certain regions when significant amounts of methane are released from the (warm and humid) Siberian and Canadian wetland areas. Also China and India are major source regions of methane with a significant seasonal dependence as shown in Fig. 7.

Methane SCIAMACHY/ENVISAT 2003-2005

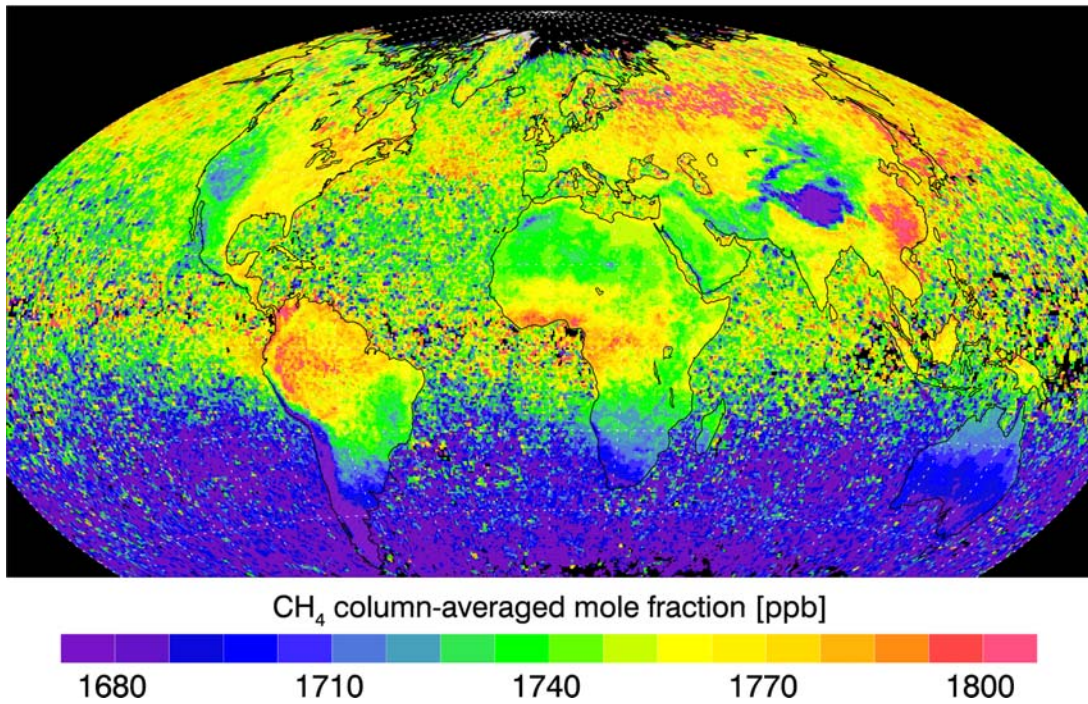


Figure 5: Methane as retrieved from SCIAMACHY. All data during 2003-2005 have been averaged (0.5°x0.5° grid) for which the WFMDv1.0 quality flag indicates a successful retrieval (see Schneising et al., 2008b, for details).

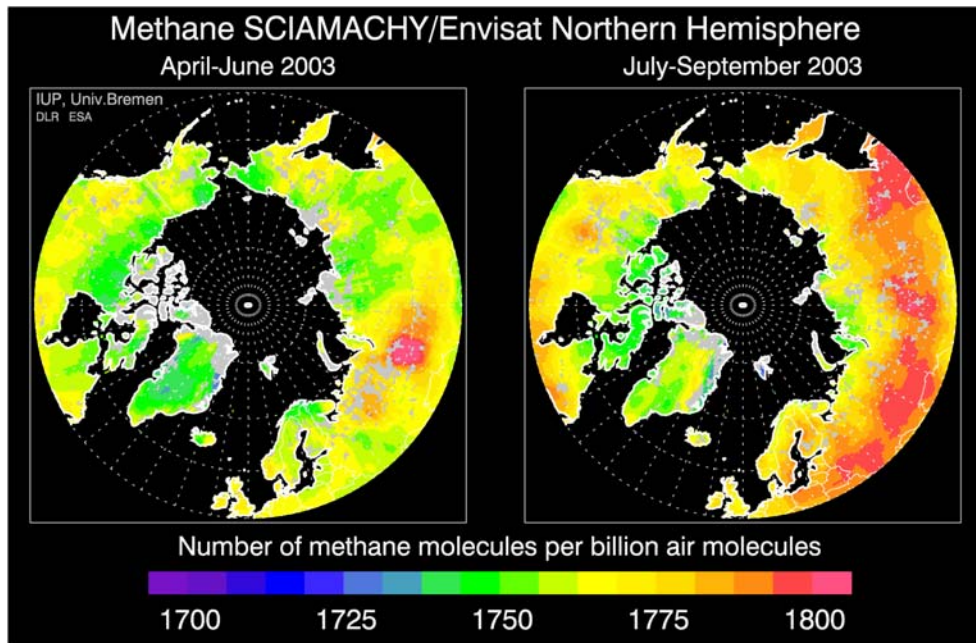


Figure 6: Methane over the northern hemisphere as retrieved from SCIAMACHY using WFMDv1.0 (Schneising et al., 2008b). Left: April-June 2003, right: July-September 2003. Shown are only the data over land.

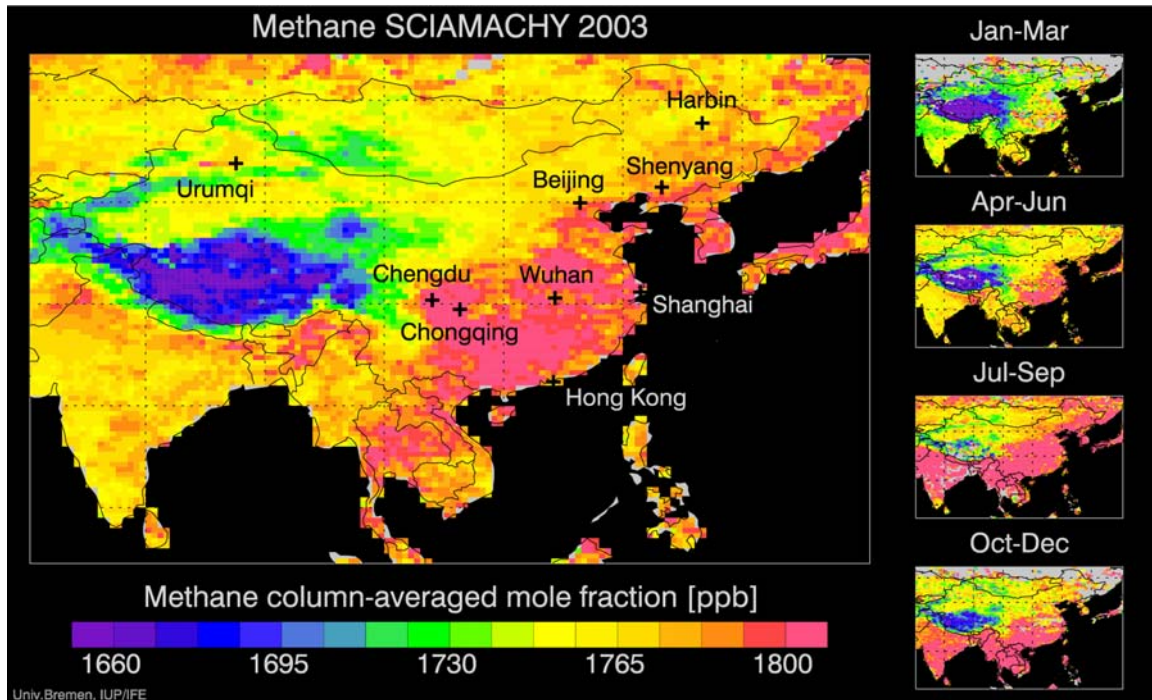


Figure 7: Methane over China and India as retrieved from SCIAMACHY for 2003 using WFMDv1.0 (Schneising et al., 2008b). Shown are only the data over land.

SUMMARY AND OUTLOOK

Concerning the retrieval of greenhouse gas information from the SCIAMACHY nadir spectra significant progress has been made in terms of quantity (number of data processed and analyzed) and quality from the initial retrievals (Buchwitz et al., 2005) to the latest results (Buchwitz et al., 2007; Schneising et al., 2008a, 2008b).

For methane a data quality has been reached which permits inverse modeling of regional methane surface fluxes (an activity currently ongoing at EC-JRC within EU FP6 GEMS). Nevertheless, further improvements are still possible and not all problems have been solved yet. For example it has been recently shown how critical spectroscopic input data are for accurate methane retrieval (Frankenberg et al., 2008; unpublished WFMDv1.1 retrievals).

For CO₂ especially errors due to clouds and aerosols need to be further reduced (Schneising et al., 2008a). This is also an activity currently ongoing at IUP, University of Bremen.

Furthermore all data after 2005 still have to be processed and analyzed.

ACKNOWLEDGEMENTS

We thank ESA and DLR for providing us with the SCIAMACHY operational Level 1 data products. This work was funded by: DLR-Bonn (grants 50EE0727 and 50EE0507), ESA (GSE PROMOTE), EU FP6 AMFIC and the University and the State of Bremen. We acknowledge exchange of information within EU FP6 Network of Excellence ACCENT.

REFERENCES

- Bovensmann, H., Burrows, J. P., Buchwitz, M., et al. (1999) SCIAMACHY - Mission objectives and measurement modes, *J. Atmos. Sci.*, **56**, 2, 127-150
- Buchwitz, M., Rozanov, V. V., Burrows, J. P. (2000) A near infrared optimized DOAS method for the fast global retrieval of atmospheric CH₄, CO, CO₂, H₂O, and N₂O total column amounts from SCIAMACHY/ENVISAT-1 nadir radiances, *J. Geophys. Res.*, **105**, 15231-15246
- Buchwitz, M., de Beek, R., Burrows, J. P., et al. (2005) Atmospheric methane and carbon dioxide from SCIAMACHY satellite data: Initial comparison with chemistry and transport models, *Atmos. Chem. Phys.*, **5**, 941-962
- Buchwitz, M., Schneising, O., Burrows, J. P., et al. (2007) First direct observation of the atmospheric CO₂ year-to-year increase from space, *Atmos. Chem. Phys.*, **7**, 4249-4256
- Burrows, J. P., Hölzle, E., Goede, A. P. H., Visser H., Fricke, W. (1995) SCIAMACHY - Scanning Imaging Absorption Spectrometer for Atmospheric Chartography, *Acta Astronautica*, **35**(7), 445-451
- Frankenberg, C., Bergamaschi, P., Butz, A., et al. (2008), Tropical methane emissions: A revised view from SCIAMACHY onboard ENVISAT, *Geophys. Res. Lett.*, **35**, L15881, 2008.
- IPCC (2007), Solomon, S., Qin, D., Manning, M., et al. (2007) *Climate change 2007: The physical science basis, Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge University Press, Cambridge (UK), New York (USA), pp 996
- Peters, W., Jacobson, A. R., Sweeney, C., et al. (2007) An atmospheric perspective on North American carbon dioxide exchange: CarbonTracker, *Proceedings of the National Academy of Sciences (PNAS) of the United States of America*, 27 November 2007, **104**(48), 18925-18930
- Rothman, L. S., Jacquemart, D., Barbe, A., et al. (2005) The HITRAN 2004 molecular spectroscopic database, *J. Quant. Spectrosc. Radiat. Transfer*, **96**, 139-204
- Schneising, O., Buchwitz, M., Burrows, J. P., et al. (2008a), Three years of greenhouse gas column-averaged dry air mole fractions retrieved from satellite - Part 1: Carbon dioxide, *Atmos. Chem. Phys.*, **8**, 3827-3853
- Schneising, O., Buchwitz, M., Burrows, J. P., et al. (2008b), Three years of greenhouse gas column-averaged dry air mole fractions retrieved from satellite - Part 2: Methane, *Atmos. Chem. Phys. Discuss.*, **8**, 8273-8326