Methane, carbon monoxide and carbon dioxide retrieved from SCIAMACHY by WFM-DOAS

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Summary

The three major "carbon gases" carbon monoxide (CO), methane (CH_4) and carbon dioxide (CO_2) are important atmospheric constituents affecting air quality and climate. Vertical columns of all three gases can be measured by inverting the spectral near-infrared nadir observations of the SCIAMACHY spectrometer onboard the European environmental satellite ENVISAT. We have developed a scientific retrieval algorithm called WFM-DOAS to accomplish this task. Our main data products are (i) the CO vertical column (in molecules/cm^2), (ii) the dry-air column averaged mixing ratio of methane XCH_4 (in ppbv), (iii) and the dry-air column averaged mixing ratio of carbon dioxide XCO_2 (in ppmv). The column averaged mixing ratios are derived by normalizing the retrieved greenhouse gas columns by the simultaneously measured air column. The SCIAMACHY near-infrared nadir observations are nearly equally sensitive to concentration changes at all altitude levels including the boundary layer and therefore enable the detection of surface source regions of carbon monoxide, methane, and CO_2. Our primary goal is to achieve a data quality high enough to detect and quantify the surface sources and sinks of these carbon gases. In order to determine which quality the latest version of the data products have, they must be compared with independent measurements (e.g., ground based FTS, and other satellites such as MOPITT), comparable data products derived from SCIAMACHY but using different retrieval methods, and global models. This requires co-operation between various research institutes as established by ACCENT/Troposat-2.

Introduction

SCIAMACHY (*Bovensmann et al., 1999*) is a spectrometer that measures reflected, scattered and transmitted solar radiation in the spectral region 214-2380 nm at moderate spectral resolution (0.2-1.6 nm). On the Earth's day side SCIAMACHY mainly performs a sequence of alternating nadir and limb observations. The horizontal resolution of the nadir measurements depends on orbital position and spectral interval but is typically 60 km (e.g., for methane and CO_2) or 120 km (e.g., for CO) across track times 30 km along track. A large number of (primarily) atmospheric data products are derived from the SCIAMACHY spectra (see, e.g., *Bovensmann et al., 1999*) including the three carbon gases discussed in this paper.

Carbon monoxide contributes to air pollution because it is toxic in large concentrations, acts as a pre-cursor to tropospheric ozone and - because CO is the leading sink of the hydroxyl radical (OH) - largely determines the self-cleansing efficiency of the troposphere. CO is highly variable in time and space and detailed monitoring of its spatial pattern and time evolution is therefore important. Carbon dioxide and methane are the two most important anthropogenic greenhouse gases and contribute to global climate change. A prerequisite to predict future climate change resulting from emissions of carbon dioxide and methane is a good understanding of their (surface) sources and sinks. Information on CO_2 and methane sources and sinks on the global scale are currently derived from a highly precise but rather sparse (~100) network of ground stations (e.g., NOAA/CMDL). Satellite measurements have the potential to overcome the limitations of the surface network and help to obtain a better understanding of the methane and CO_2 sources and sinks. For the near future dedicated satellite missions are planned to globally measure carbon dioxide and methane accurate and precise enough to obtain information on their surface sources and sinks, e.g., OCO (USA) and GOSAT (Japan), both being primarily passive near-infrared nadir missions. SCIAMACHY is not a dedicated carbon mission but due to its near-infrared nadir observation capability is the first satellite instrument being highly sensitive to methane, CO_2, and CO boundary layer concentration changes as demonstrated by its averaging kernels for CO (*Buchwitz et al., 2004*), methane (*Buchwitz et al., 2005a*) and CO_2 (*Buchwitz et al., 2005a*). Therefore, SCIAMACHY plays a pioneering role in this new area of satellite remote sensing.

Here we give a short overview about the latest versions of our retrieval algorithms and the data products generated with them.

Retrieval algorithm and its validation

The retrieval of a long-lived and therefore relatively well-mixed gas such as methane is extremely challenging as only small variations on top of a large background are of relevance in order to obtain information on its surface sources. Therefore, the retrieval algorithm has to be very accurate. Furthermore, the algorithm also has to be very fast to process huge amounts of data. We have developed the Weighting Function Modified Differential Optical Absorption Spectroscopy (WFM-DOAS) retrieval algorithm to accomplish this task (*Buchwitz et al., 2000, 2004, 2005a, 2005b, 2005c*). WFM-DOAS is an unconstrained linear-least squares method based on scaling (or shifting) pre-selected vertical profiles. The fit parameters for the trace gases are directly the desired vertical columns. The logarithm of a linearised radiative transfer model plus a low-order polynomial is fitted to the logarithm of the ratio of a measured nadir radiance and solar irradiance spectrum, i.e., observed sun-normalized radiance. The WFM-DOAS reference spectra are the logarithm of the sun-normalized radiance and its derivatives computed with a radiative transfer model. In order to avoid time-consuming on-line radiative transfer simulations, a fast look-up table scheme has been implemented.

The latest version of our data products are version 0.5 for CO and methane and version 0.4 for CO_2. Details concerning our version 0.4x data products are given in (*Buchwitz et al., 2004, 2005a, 2005b*). Details concerning our new version 0.5 data products are given in *Buchwitz et al., 2005c.* The validation of our data products with independent ground based (FTS) vertical column measurements is an ongoing activity. Available studies (*Dils et al., 2005, Sussmann et al., 2005a, 2005b, Warneke et al., 2005*) report on the validation of previous versions of our data products (e.g., methane v0.4/0.41 and CO v0.4) and/or on a comparison of a small sub-set of the data as for CO_2 (*Warneke et al., 2005, Dils et al., 2005*). A detailed comparison of our new version 0.5 methane and CO data products (*Buchwitz et al., 2005c*) has not yet been performed but is planned for the near future.

Results

So far we have processed all available SCIAMACHY spectra of the year 2003. Fig. 1 shows year 2003 averages of our latest data products. Because of the low reflectivity of water (oceans, great lakes) in the near-infrared the quality of the measurements over water is typically reduced and only measurements over land are shown here. The estimated measurement errors for CO (~10-50%) and methane (~1-3%) are small enough such that at least moderate to strong source regions can be clearly identified. The XCO_2 measurements are more difficult to interpret because the measurement error due to, e.g., aerosol and albedo variability (see also *Houweling et al., 2005*), is currently on the order of the weak source/sink signal to be detected (< 1.5%). Our future work will aim at reducing the sensitivity to these and other error sources. Figure 2 shows more details focusing on China. Because for January

2003 only a few orbits were available and no data for November and December (for ground processing related reasons) the tri-monthly averaged data (panels on the right hand side) cover the time period February to October using an untypical grouping of the months not reflecting the standard definition of seasons. For a detailed discussion see *Buchwitz et al., 2005c*.

ACCENT SCIAMACHY CO Intercomparison Workshop

Several groups have developed retrieval algorithms for the retrieval of CO columns from the SCIAMACHY spectra. Here we have focussed on the University of Bremen WFM-DOAS algorithm (*Buchwitz et al., 2004, 2005c*). Other groups have, however, implemented somewhat different retrieval methods, e.g., IMAP-DOAS (*Frankenberg et al. 2005a, 2005b, 2005c*) and IMLM (*Gloudemans et al., 2005*). Because CO retrieval from SCIAMACHY is a challenging task it has been decided to compare the data products of the various groups. For this purpose an ACCENT sponsored workshop was held on April 14, 2005, at SRON, the Netherlands. A first comparison based on earlier versions of the three retrieval algorithms has been presented by *Gloudemans et al., 2004.* At the ACCENT workshop a much more detailed comparison has been performed focusing on a single reference orbit (Fig. 3). Results of the workshop are shown in Fig. 4 where the results of the different retrieval algorithms are compared. Quantitatively, there is good agreement. All retrieval algorithms detect the CO plume around -20 deg latitude caused by biomass burning which is also visible in the MOPITT data. Quantitatively, however, there are substantial differences between the various algorithms (up to a factor of 2). It has been identified that a large number of differences exist between the various approaches. It was not possible to determine which of the algorithm differences contribute to what extent to the observed differences of the CO columns. More studies are needed before any firm conclusion can be drawn. However, the fact that the three algorithms show a similar variability in the retrieved CO columns indicates that promising CO products can be expected from all three of them.

Conclusions and outlook

We have shown that encouraging "carbon gas" data products can be derived from the SCIAMACHY nadir observations. A full validation of these data products has not yet been performed. Our future work will focus on establishing in detail the quality of these data products. Our goal is to achieve a quality high enough to get quantitative information on surface sources and sinks of all three carbon gases. So far we have only processed the SCIAMACHY year 2003 spectra. More data will be processed in the near future. Information about the latest status, papers and poster, a collection of images, and information how to obtain our data products is given on our SCIAMACHY/WFM-DOAS web page: http://www.iup.physik.uni-bremen.de/sciamachy/NIR_NADIR_WFM_DOAS/index.html

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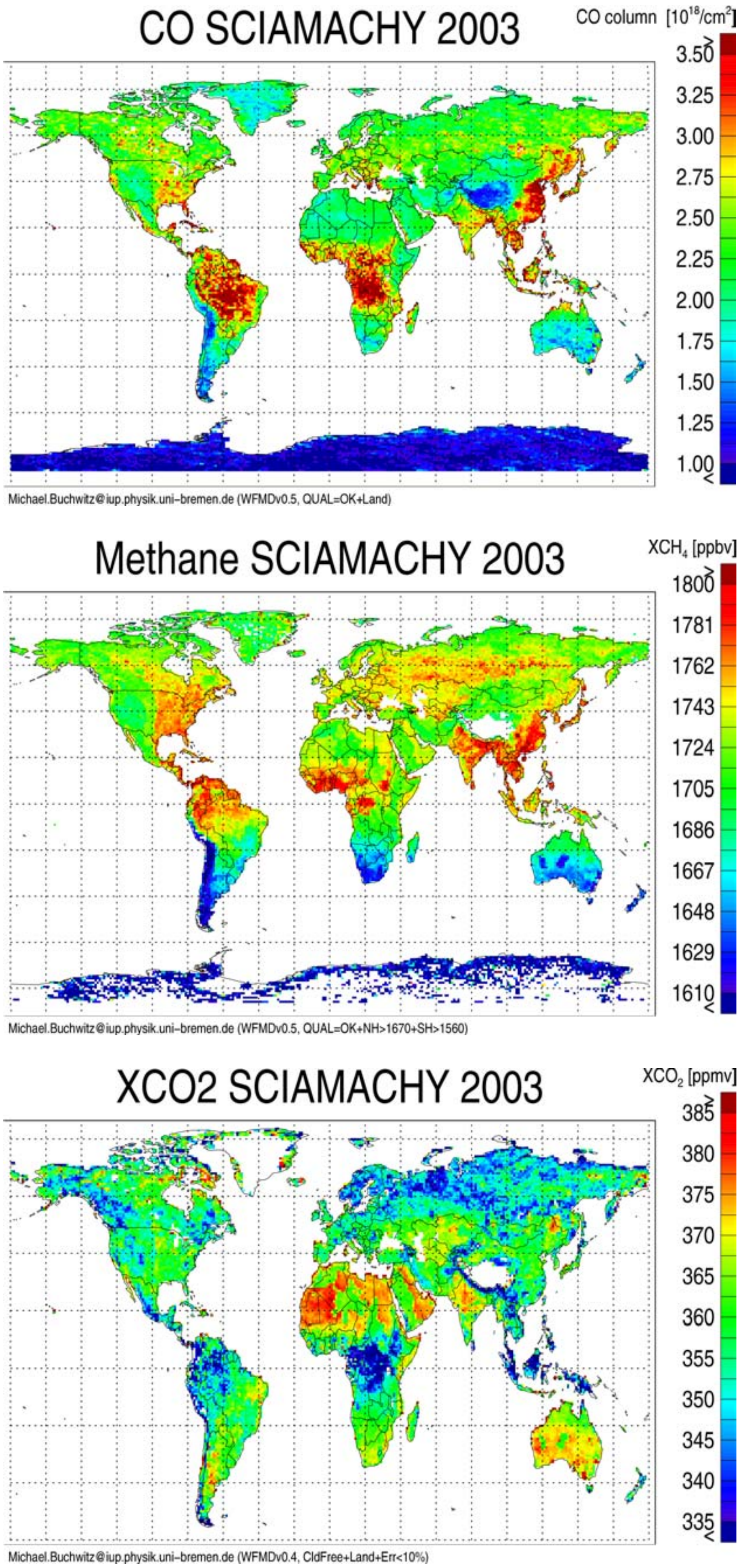

Fig. 1: Year 2003 averages of three major carbon gases measured by SCIAMACHY: Top: CO vertical columns (version 0.5), middle: methane mixing ratios (v0.5), bottom: CO_2 mixing ratios (v0.4).

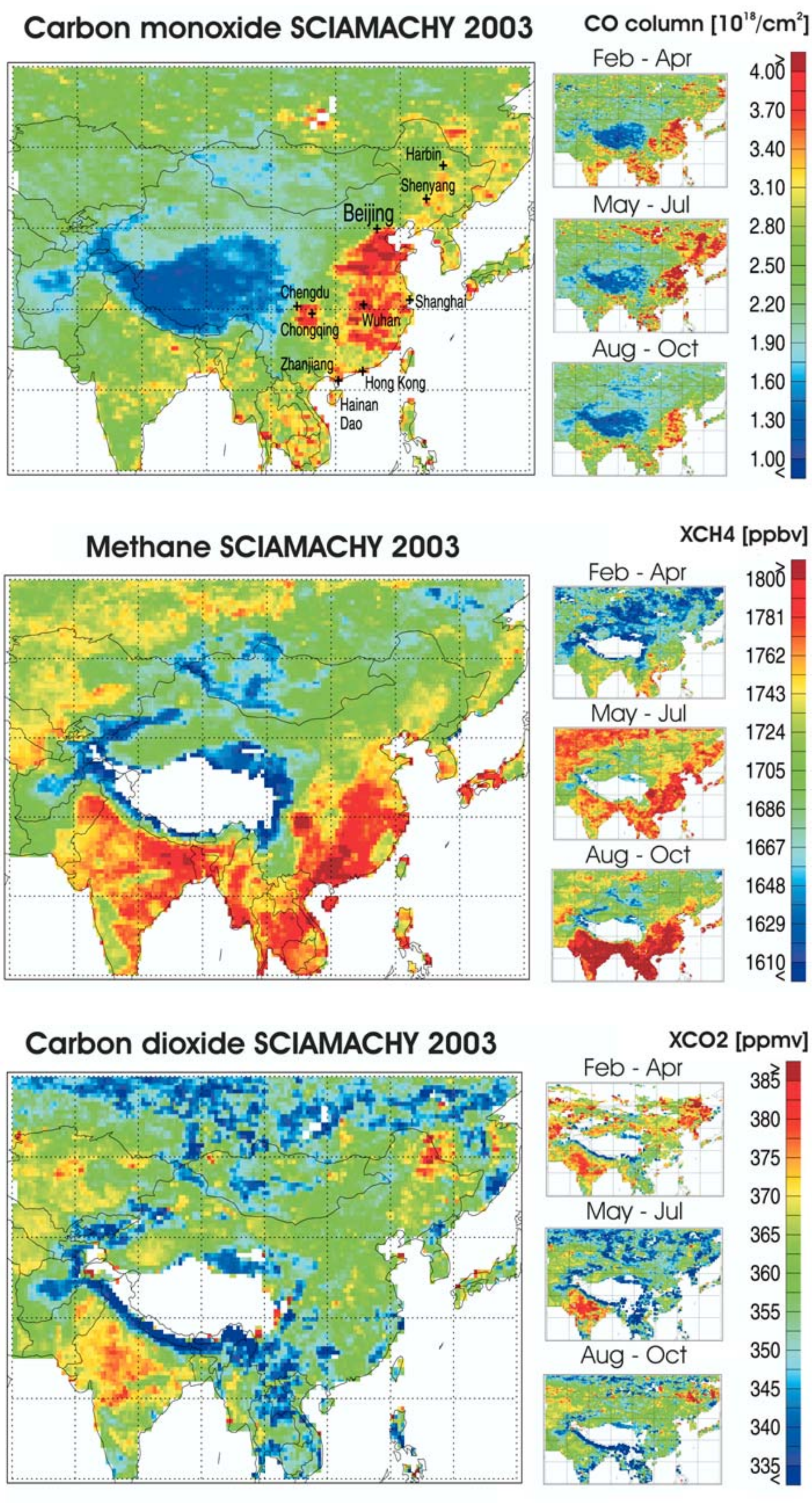

Fig. 2: Carbon monoxide, methane and CO_2 over China as measured by SCIAMACHY. The left panels show the year 2003 averages. The panels on the right hand side show tri-monthly averages for the year 2003. The latitude range covered is 10 ^{o}N-60 ^{o}N and the longitude range is 60 ^{o}E-140 ^{o}E.

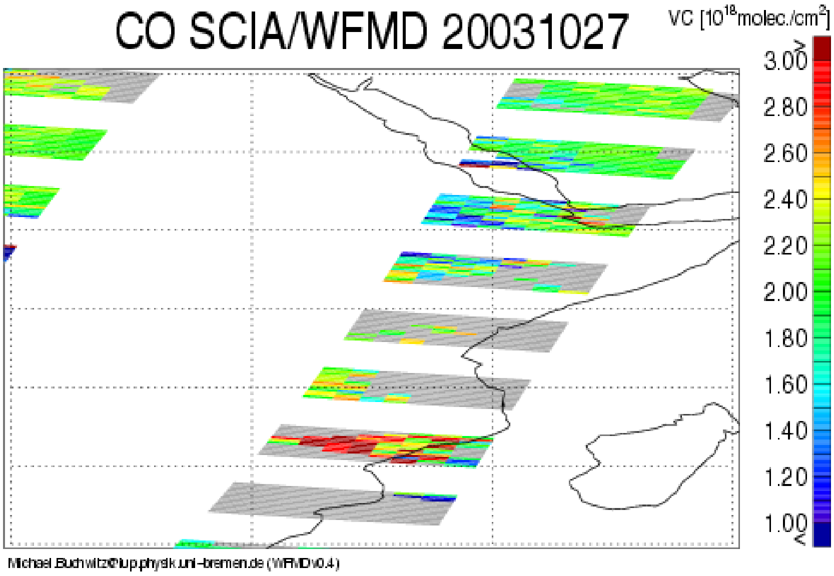

Fig. 3: SCIAMACHY reference orbit 8663 over eastern Africa from October 27, 2003, used for the comparison of the various SCIAMACHY CO retrieval algorithms (Fig. from: Buchwitz et al., 2004). Grey denotes cloud contaminated ground pixels. The regular gaps along the orbit are due to the limb observations.

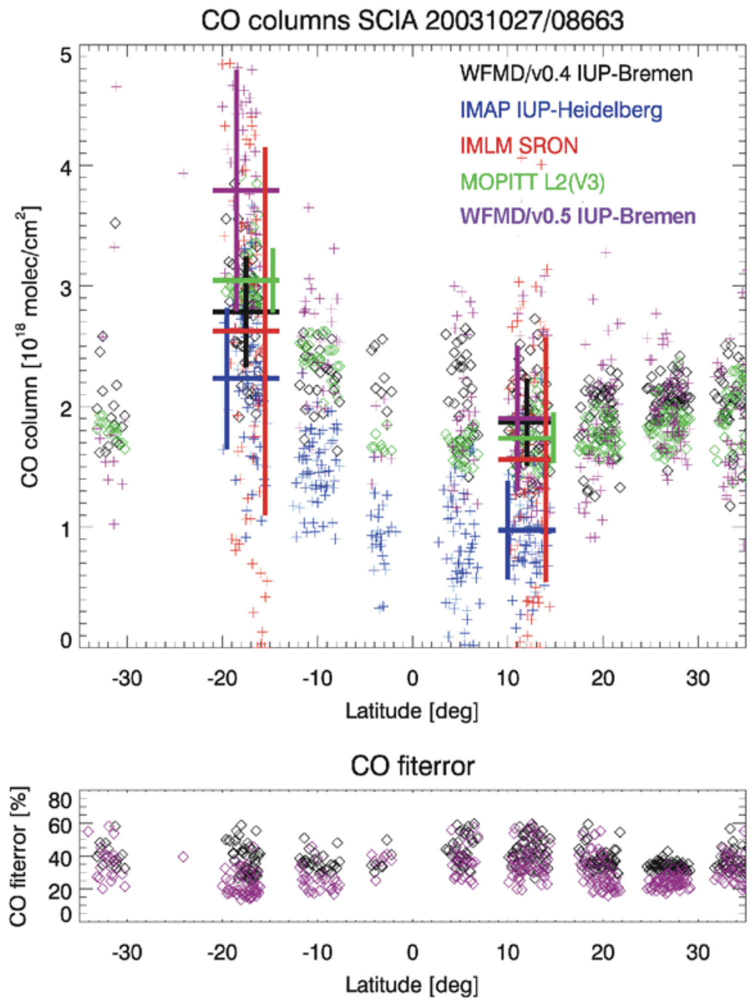

Fig. 4:Top panel: Vertical columns of carbon monoxide as retrieved from SCIAMACHY orbit 8663 from October 27, 2003 (see Fig. 3) using different retrieval algorithms. For comparison the operational Lv2V3 data product from MOPITT (Deeter et al., 2003) is shown in green. The bottom panel shows the fit error for two versions of the WFM-DOAS algorithm (black: v0.4 (Buchwitz et al., 2004), violet: v0.5 (Buchwitz et al., 2005c)).