Validation of SCIAMACHY AMC-DOAS water vapour columns

S. Noël, M. Buchwitz, H. Bovensmann, J. P. Burrows

▶ **To cite this version:**

S. Noël, M. Buchwitz, H. Bovensmann, J. P. Burrows. Validation of SCIAMACHY AMC-DOAS water vapour columns. Atmospheric Chemistry and Physics, 2005, 5 (7), pp.1835-1841. hal-00295698

HAL Id: hal-00295698
https://hal.science/hal-00295698

Submitted on 18 Jun 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Atmos. Chem. Phys., 5, 1835–1841, 2005
www.atmos-chem-phys.org/acp/5/1835/
SRef-ID: 1680-7324/acp/2005-5-1835
European Geosciences Union

Atmospheric Chemistry and Physics

Validation of SCIAMACHY AMC-DOAS water vapour columns

S. Noël, M. Buchwitz, H. Bovensmann, and J. P. Burrows

Institute of Environmental Physics/Remote Sensing, University of Bremen, Germany

Received: 25 January 2005 – Published in Atmos. Chem. Phys. Discuss.: 1 April 2005
Revised: 8 June 2005 – Accepted: 29 June 2005 – Published: 22 July 2005

Abstract. A first validation of water vapour total column amounts derived from measurements of the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) in the visible spectral region has been performed. For this purpose, SCIAMACHY water vapour data have been determined for the year 2003 using an extended version of the Differential Optical Absorption Spectroscopy (DOAS) method, called Air Mass Corrected (AMC-DOAS). The SCIAMACHY results are compared with corresponding water vapour measurements by the Special Sensor Microwave Imager (SSM/I) and with model data from the European Centre for Medium-Range Weather Forecasts (ECMWF).

In confirmation of previous results it could be shown that SCIAMACHY derived water vapour columns are typically slightly lower than both SSM/I and ECMWF data, especially over ocean areas. However, these deviations are much smaller than the observed scatter of the data which is caused by the different temporal and spatial sampling and resolution of the data sets. For example, the overall difference with ECMWF data is only $-0.05\,\mathrm{g/cm^2}$ whereas the typical scatter is in the order of $0.5\,\mathrm{g/cm^2}$. Both values show almost no variation over the year.

In addition, first monthly means of SCIAMACHY water vapour data have been computed. The quality of these monthly means is currently limited by the availability of calibrated SCIAMACHY spectra. Nevertheless, first comparisons with ECMWF data show that SCIAMACHY (and similar instruments) are able to provide a new independent global water vapour data set.

Correspondence to: S. Noël
(stefan.noel@iup.physik.uni-bremen.de)

1 Introduction

It is well known that water vapour is one of the most important atmospheric constituents. Most of the atmospheric water vapour is located in the troposphere close to the surface of the Earth. Weather and climate are essentially influenced by the variation of water vapour concentrations. Especially, water vapour is the major greenhouse gas. Therefore, the global distribution of water vapour is a relevant input quantity for global atmospheric models aiming to predict weather or climate.

However, global water vapour distributions are difficult to be obtained. Currently, there are several sources for global water vapour data, all of them having their specific advantages and limitations. In-situ measurements by radio sondes probably provide data with the highest accuracy and the best vertical resolution; however, these measurements only cover a small horizontal area, and the distribution of radio sonde stations over the Earth is rather inhomogeneous. Especially over the oceans and in the southern hemisphere large regions are not covered by radio sonde data.

Remote sensing data from satellite based instruments provide the possibility to fill these gaps, but they are typically limited in vertical and temporal resolution. Water vapour can be measured from space by various techniques. Most commonly used are microwave (MW) sensors like the Special Sensor Microwave Imager (SSM/I) which are able to provide total water vapour columns at a high spatial (horizontal) resolution (Bauer and Schluessel, 1993). However, the MW retrieval is usually constrained to ocean areas.

Instruments operating at other spectral regions like in the near infrared (NIR) – such as e.g. the Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua/Terra (Gao and Kaufman, 2003) and the Medium Resolution Imaging Spectrometer (MERIS) on ENVISAT (Li et al., 2003) – can derive total water vapour columns also over land.

© 2005 Author(s). This work is licensed under a Creative Commons License.

Unfortunately, in contrast to MW sensors, NIR sensors can not see through clouds which also limits the retrieval.

Another recently developed method for the retrieval of water vapour distributions is the utilisation of data from the Global Positioning System (GPS) satellites (see e.g. Dai et al., 2002).

In addition, several investigations have shown that also measurements performed by the Global Ozone Monitoring Experiment (GOME, see e.g. Burrows et al., 1999) and the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY, see e.g. Bovensmann et al., 1999) in the visible spectral region may be used to derive global water vapour concentrations (Noël et al., 1999, 2002, 2004; Casadio et al., 2000; Maurellis et al., 2000; Lang et al., 2003; Wagner et al., 2003; Buchwitz et al., 2004).

The GOME instrument was started on the second European Remote Sensing Satellite (ERS-2) in 1995 and is still operating (although at somewhat degraded performance and coverage). SCIAMACHY is an extended version of GOME and part of the atmospheric chemistry payload of the European Environmental Satellite ENVISAT which was launched in March 2002. The combination of GOME and SCIAMACHY data already now covers a time span of 9–10 years which may extend even further, depending on the life time of SCIAMACHY (or ENVISAT). In addition, the GOME-2 instruments on the series of operational meteorological satellites Metop (the first one to be launched by the end of 2005) will continue this data set. Therefore, an analysis of these GOME-type instrument data can lead to an additional, independent global water vapour climatology (see also Lang and Lawrence, 2004).

The current paper presents recent results of the so-called "Air Mass Corrected Differential Optical Absorption Spectroscopy" (AMC-DOAS) method which has been applied to SCIAMACHY nadir measurements in the spectral region at about 700 nm. Noël et al. (2004) already showed that it is possible to derive good water vapour total columns from SCIAMACHY measurements using the AMC-DOAS method. However, these results were based on only a small amount of analysed data (some days of measurements). In addition, in the context of the SCIAMACHY/ENVISAT validation program, some first intercomparisons of AMC-DOAS water vapour columns with radio sonde data and ATOVS (Advanced TIROS (Television Infrared Observation Satellite Program) Operational Vertical Sounder) satellite measurements have been performed for a dedicated validation data set (see Timmermans et al., 2004, for details). In the current paper we will extend the validation of the AMC-DOAS water vapour results to a longer period of time, namely the whole year 2003. Furthermore, we will present the first global monthly mean water vapour data from SCIAMACHY.

2 The AMC-DOAS retrieval method

The AMC-DOAS retrieval method has been extensively discussed in Noël et al. (2004). Therefore, only a small summary of the algorithm will be given here.

Similar to the well-known DOAS (Differential Optical Absorption Spectroscopy) approach the AMC-DOAS method derives information about the amount of an atmospheric species from differential absorption structures in sun-normalised radiances. The AMC-DOAS method does not require absolutely calibrated radiances and irradiances, as long as the differential structures are not affected by calibration issues. The method is numerically fast and therefore well suited for operational data processing. The main differences between AMC-DOAS and standard DOAS are as follows:

1. In standard DOAS, which is only applicable in the optically thin case, the absorption depth in the differential spectra is proportional to the absorber amount. Water vapour has highly structured absorption features (saturated and non-saturated lines) which are not resolved by GOME or SCIAMACHY. Therefore, the relation between absorption depth and absorber amount becomes non-linear, which is considered by the AMC-DOAS method.

2. The AMC-DOAS method includes an Air Mass Factor (AMF) correction derived from O_2 absorption features in the same spectral region as the water vapour absorption. This is why the fitting window for the AMC-DOAS water vapour retrieval has been selected to be 688 nm to 700 nm, where both water vapour and molecular oxygen show absorptions of similar strength.

The main purpose of the AMF correction factor is to correct the retrieved water vapour column, but beside this the AMF correction factor can be used as an inherent quality check for the retrieved data. The AMC-DOAS retrieval assumes a cloud-free tropical background atmosphere and does not consider different surface elevations. If the derived AMF correction is too large, this is an indication that these assumptions are not valid (most likely because the observed scene is too cloudy or contains a high mountain area).

Therefore, as in previous studies, only results with an AMF correction factor larger than 0.8 have been taken into account. Currently, the AMC-DOAS retrieval is limited to solar zenith angles (SZAs) below 88°.

Note that in the present study – in contrast to Noël et al. (2004) – no additional scaling factor has been applied to the retrieved columns to better match correlative data. This was no longer necessary after using an updated (narrower) SCIAMACHY slit function of full width at half maximum (FWHM) 0.4 nm. The new slit function width was motivated by the recent analysis of in-flight measurements which revealed differences to the on-ground determined slit functions (Ahlers, 2004). Furthermore, the new slit function leads to

smaller residuals of the AMC-DOAS retrieval which also supports this choice. As a consequence, the AMC-DOAS results do not rely on any other measurement data, e.g. calibration factors derived from comparisons with ground based radio sonde measurements as it is the case for e.g. SSM/I data. The retrieved water vapour columns therefore provide a completely independent data set.

3 Data bases

In the present paper, SCIAMACHY water vapour data are compared with SSM/I measurements and model data from the European Centre for Medium-Range Weather Forecasts (ECMWF).

The SCIAMACHY water vapour data have been derived by applying the AMC-DOAS retrieval method to all available SCIAMACHY nadir data for the year 2003. Because there is no complete consolidated set of SCIAMACHY calibrated spectra (Level 1 data) available yet, the analysis is based on a combination of both consolidated and unconsolidated near-real-time (NRT) data. Even after inclusion of the NRT data there are still larger data gaps, especially in November 2003. In this sense the results presented in the next section are still of preliminary nature.

To avoid a potential influence of the known insufficient radiometric calibration of the current Level 1 data (Skupin et al., 2002, 2003) on the retrieval results, always the same (specially calibrated) solar reference spectrum (provided by J. Frerick, ESA) has been used in the retrieval.

The SSM/I data used in the comparison have been taken from the Daily Gridded Integrated Water Vapour Product provided by the Global Hydrology Resource Center (GHRC) at the Global Hydrology and Climate Center, Huntsville, Alabama. We took only data for the descending orbit part of the DMSP F-14 satellite, because its dayside equatorial crossing time of about 08:00 LT is close to the ENVISAT dayside equatorial crossing time of 10:00 LT. Because SSM/I is a MW sensor, only data over ocean are available.

The ECMWF water vapour columns have been calculated using assimilated meteorological fields (geopotential height, temperature, pressure, and specific humidity) from the operational daily analysis data. These data are provided on a $1.5° \times 1.5°$ spatial grid at 60 altitude levels every 6 h. The 6-h values have been combined and integrated over height to derive the total vertical water vapour column. Afterwards, daily averages of the columns have been computed for each grid point. Note that the ECMWF data are not completely independent from SSM/I data because SSM/I results have been assimilated into the ECMWF model.

For the inter-comparison all SCIAMACHY and ECMWF data have been (re-)gridded to the spatial resolution of the SSM/I data which is $0.5° \times 0.5°$.

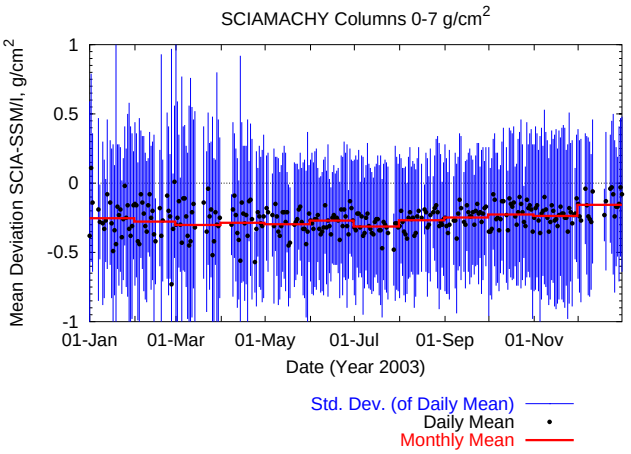

Fig. 1. Global mean and standard deviation of the difference between collocated SCIAMACHY and SSM/I water vapour columns for the year 2003.

4 Results

In this section, two types of results will be presented. First, we will show a time series of (globally averaged) deviations between SCIAMACHY total water vapour columns and SSM/I and ECMWF data for the year 2003. Then we will compare global maps of monthly mean water vapour results based on SCIAMACHY and ECMWF data.

4.1 Time series

The time series data have been generated in the following way:

1. Determine collocations of (daily gridded) SCIAMACHY water vapour total columns between 0 and 7 g/cm^2 (which is about the total range of columns) and correlative data.

2. Compute the absolute differences SCIAMACHY–SSM/I and SCIAMACHY–ECMWF for this collocated data set.

3. Compute the weighted daily means and standard deviations by averaging over all collocated grid points. The weights are chosen to be the cosine of the geographic latitude. The reason for these weights is that the input data are on an equidistant latitude/longitude grid which is not representative for the surface area of the Earth. Therefore, without proper weights, high latitude columns would contribute too much to the global mean.

4. The global monthly means are then derived by averaging the daily means over one month.

The results of this procedure are shown in Figs. 1 and 2. The black circles mark the daily means, the blue vertical lines

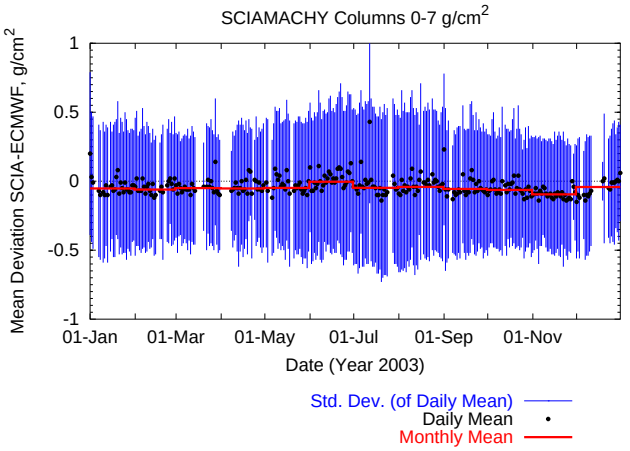

Fig. 2. Global mean and standard deviation of the difference between collocated SCIAMACHY and ECMWF water vapour columns for the year 2003.

are the corresponding daily standard deviations, and the red line denotes the monthly mean.

As can be seen from these figures, the standard deviation of the data is in both the comparisons with SSM/I and ECMWF quite high (about 0.5 g/cm^2, maybe somewhat higher for SSM/I data). This magnitude of scatter has been observed before (see e.g. Noël et al., 2004; Lang and Lawrence, 2004). It can be mainly attributed to the large temporal and spatial variability of atmospheric water vapour.

The scatter of the daily mean values is significantly smaller. For the comparison with SSM/I data it is about 0.1–0.2 g/cm^2, and even less ($\sim$0.1 g/cm^2) for the comparison with ECMWF.

The monthly averages are quite constant over the year 2003. The SCIAMACHY water vapour columns are in the order of 0.2 g/cm^2 lower than the corresponding SSM/I results whereas the typical deviation between SCIAMACHY and ECMWF data is only -0.05 g/cm^2 which is one magnitude lower than the observed daily scatter. Thus, the SCIAMACHY data agree very well with ECMWF data throughout the year.

4.2 Monthly means

Monthly means of SCIAMACHY and ECMWF data have been computed by averaging all available data for a specific month at each grid point. No special weighting is necessary, because only data of the same geolocation are averaged.

Figure 3 shows the resulting means of SCIAMACHY total water vapour column data for the months January, April, July and October 2003, corresponding to different seasons.

The overall picture of the SCIAMACHY monthly means seems quite reasonable. The SCIAMACHY results are quite similar to the corresponding water vapour monthly means derived from ECMWF data displayed in Fig. 4. There is high humidity in the tropics, low humidity at higher latitudes. The movement of the inner tropical convergence zone (ITCZ) with season is clearly visible from the shift of high water vapour columns in the tropics.

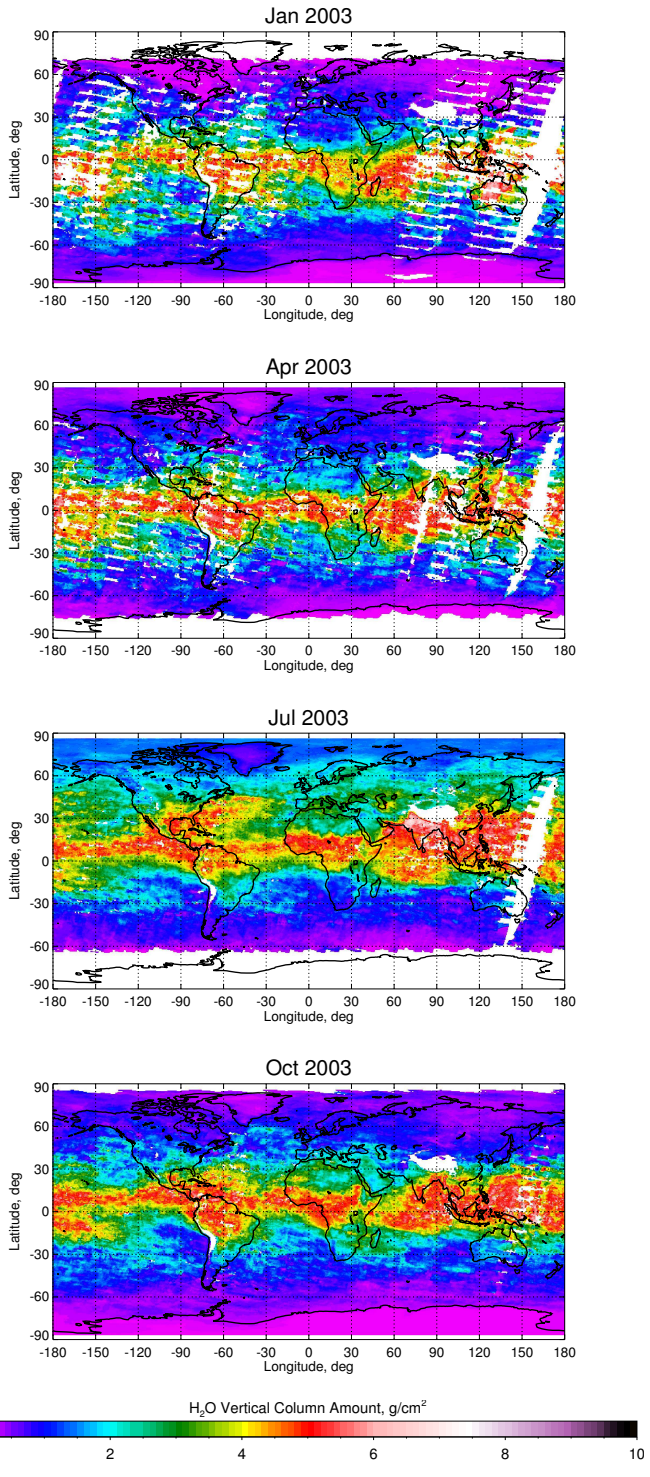

Fig. 3. Monthly means of SCIAMACHY total water vapour columns for the year 2003.

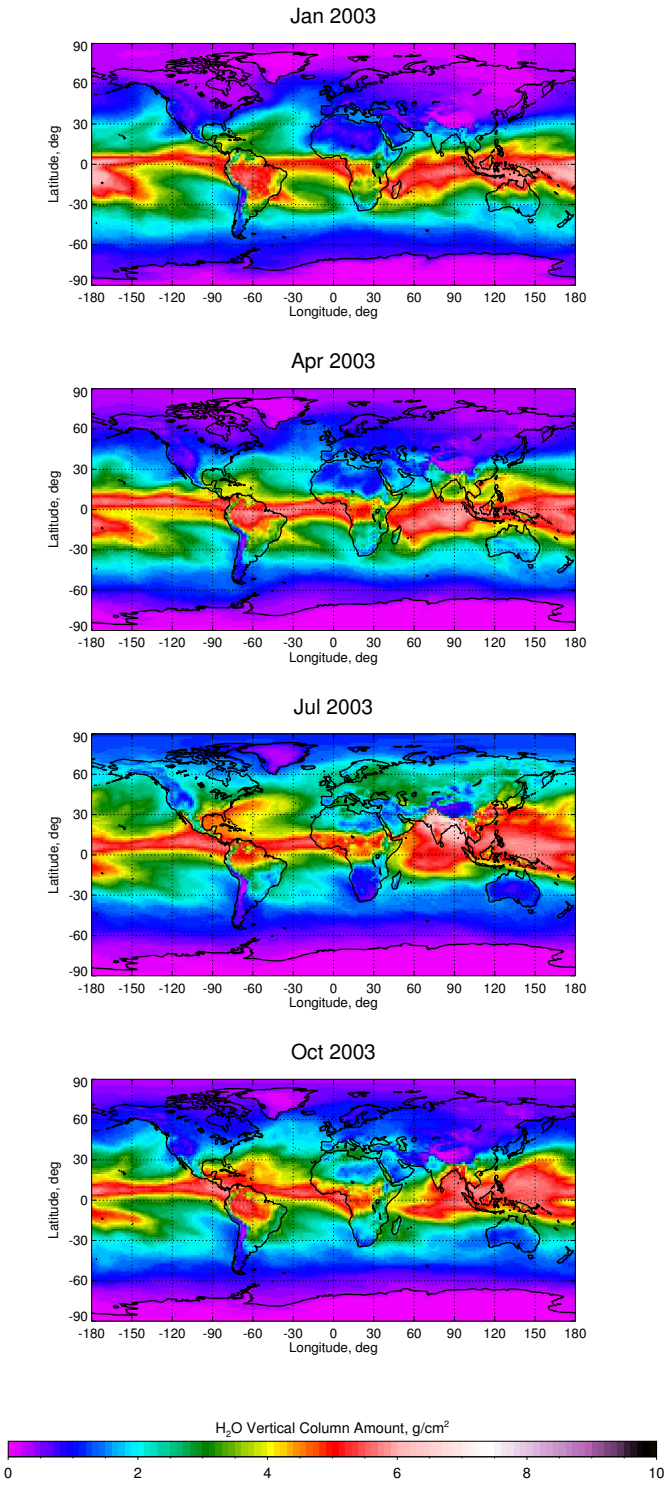

Fig. 4. Monthly means of ECMWF total water vapour columns for the year 2003.

For some regions there are no SCIAMACHY water vapour data available (white areas in Fig. 3). Except for those northern or southern regions, where there are no SCIAMACHY data because of a too high solar zenith angle, these gaps are mainly caused by the incomplete SCIAMACHY Level 1 data set; this is especially evident in November 2003 (not shown) where no data over the Atlantic ocean are available. However, there are also some regions where there are no SCIAMACHY water vapour data for the whole year, like over the Himalaya and the Andes. These gaps are not caused by missing Level 1 data but they correspond to regions which are regularly masked out by the AMC-DOAS quality check. This is expected, because the background atmosphere of high mountain areas is extremely different from the one assumed in the retrieval. In fact, this shows that the AMC-DOAS quality check is working correctly, which adds confidence to the SCIAMACHY AMC-DOAS water vapour data product.

There are also some differences between SCIAMACHY and ECMWF data. For example, in summer 2003 the humidity over the Sahara desert is much higher in SCIAMACHY data than expected from the ECMWF model data. This can be seen more clearly in Fig. 5, where the absolute differences between SCIAMACHY and ECMWF water vapour monthly means are plotted. Noting that any deviation below the typical scatter of the water vapour data of 0.5 g/cm^2 (i.e. the green areas on the plots) can be considered as a good agreement, the difference plots show in general quite encouraging results.

Looking a bit more into the details of Fig. 5 reveals that the agreement between SCIAMACHY and ECMWF data over land seems to be somewhat better than over ocean. Ocean areas are quite noisy in the difference plots. The SCIAMACHY data over ocean tend to be lower than the corresponding ECMWF monthly means. This is in line with the results of the comparison with SSM/I data in the previous subsection. Over the continents, the agreement between both data sets is quite good except for some specific regions at certain times where SCIAMACHY columns are higher than the ECMWF values. This over-estimation of the water vapour content by SCIAMACHY (or the under-estimation by the ECMWF model) seems to occur preferably over desert regions like the above mentioned southern Sahara during summer and western parts of North America. This may indicate an influence of the surface albedo. In addition, the different surface elevation which is is not considered by the AMC-DOAS retrieval may play a role. On the other hand, problems of the ECMWF model data at these regions can also not be excluded, because it is unclear how many real measurements (e.g. radio sonde data) went into the model at these locations.

Furthermore, the different temporal and spatial coverage of SCIAMACHY and ECMWF data may play a role here. As long as there are still large amounts of SCIAMACHY Level 1 data missing no final conclusion on the quality of a monthly mean product can be drawn.

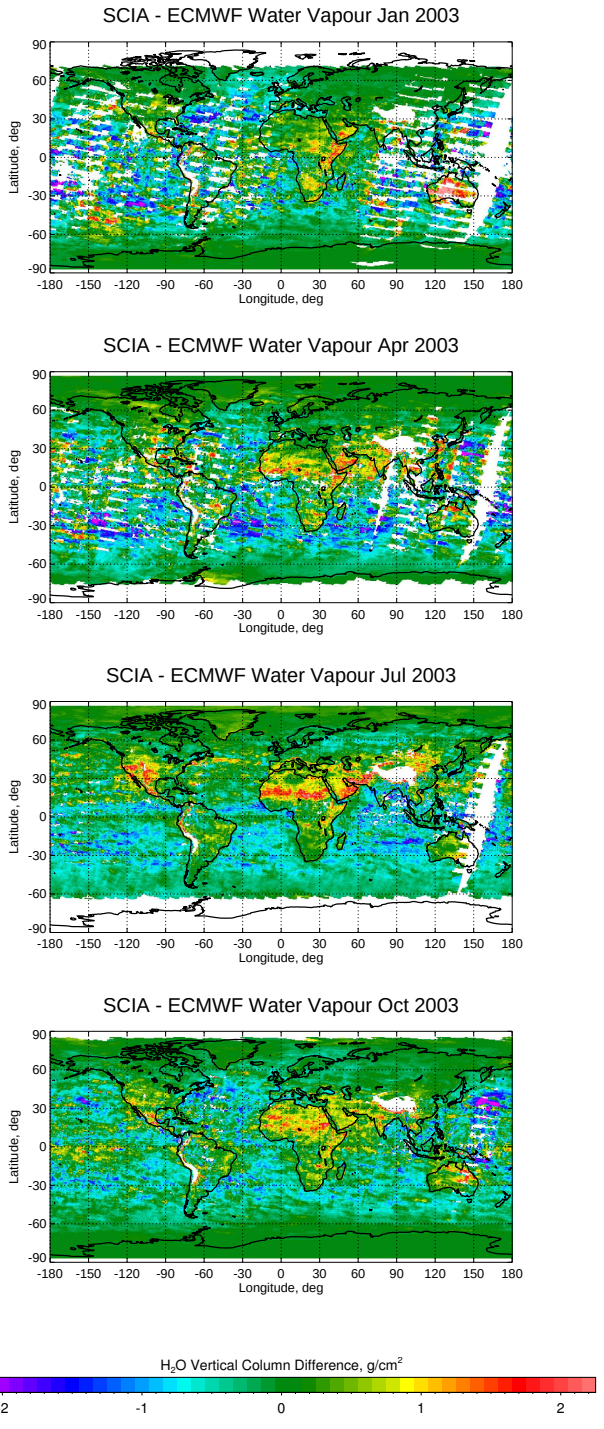

Fig. 5. Difference between SCIAMACHY and ECMWF monthly means of total water vapour columns for the year 2003.

5 Summary and conclusions

A first preliminary validation of SCIAMACHY water vapour columns derived by the AMC-DOAS method has been performed. The interpretation of the results of this effort is somewhat limited by the amount of currently available SCIAMACHY calibrated spectra. Comparisons with SSM/I and ECMWF data for the year 2003 show in general a good agreement. A high scatter of about 0.5 g/cm^2 is visible throughout the year. This scatter is mainly caused by atmospheric variability which in general makes a validation of water vapour columns more difficult.

The global mean SCIAMACHY AMC-DOAS water vapour columns tend to be lower than the correlative data. The agreement of SCIAMACHY results with ECMWF data is somewhat better than with SSM/I data which confirms previous findings which were based on a smaller data set.

As a first step towards a SCIAMACHY (or GOME-type) water vapour climatology reasonable global maps of monthly mean water vapour columns could be derived. Comparisons with corresponding ECMWF monthly means showed in general a good agreement, although there are some discrepancies especially over ocean and desert areas which require further investigation.

Acknowledgements. SCIAMACHY is a national contribution to the ESA ENVISAT project, funded by Germany, The Netherlands, and Belgium.

SCIAMACHY data have been provided by ESA. SSM/I data have been provided by the Global Hydrology Resource Center (GHRC) at the Global Hydrology and Climate Center, Huntsville, Alabama. We thank the European Center for Medium Range Weather Forecasting (ECMWF) for providing us with analysed meteorological fields.

This work has been funded by the BMBF via GSF/PT-UKF, by DLR-Bonn, and by the University of Bremen.

This work is part of and facilitated by IGBP-IGAC and the EU ACCENT Network of Excellence.

Edited by: P. C. Simon

References

Ahlers, B.: Slit function comparison with level 0 data, Tech. Rep. TPD-SCIA-PhE-TN-014, TPD/TNO, 2004.

Bauer, P. and Schluessel, P.: Rainfall, total water, ice water, and water vapor over sea from polarized microwave simulations and Special Sensor Microwave/Imager data, J. Geophys. Res., 98, 20 737–20 759, 1993.

Bovensmann, H., Burrows, J. P., Buchwitz, M., Frerick, J., Noël, S., Rozanov, V. V., Chance, K. V., and Goede, A. H. P.: SCIAMACHY – Mission Objectives and Measurement Modes, J. Atmos. Sci., 56, 127–150, 1999.

Buchwitz, M., Noël, S., Bramstedt, K., Rozanov, V. V., Bovensmann, H., Tsvetkova, S., and Burrows, J. P.: Retrieval of trace gas vertical columns from SCIAMACHY/ENVISAT near-infrared nadir spectra: First preliminary results, Adv. Space Res., 34, 809–814, 2004.

Burrows, J. P., Weber, M., Buchwitz, M., Rozanov, V., Ladstätter-Weißenmayer, A., Richter, A., de Beek, R., Hoogen, R., Bramstedt, K., Eichmann, K.-U., Eisinger, M., and Perner, D.: The Global Ozone Monitoring Experiment (GOME): Mission Concept and First Scientific Results, J. Atmos. Sci., 56, 151–175, 1999.

Casadio, S., Zehner, C., Pisacane, G., and Putz, E.: Empirical retrieval of the atmospheric air mass factor (ERA) for the measurement of water vapour vertical contenet using GOME data, Geophys. Res. Lett., 27, 1483–1486, 2000.

Dai, A., Wang, J., Ware, R. H., and Hove, T. V.: Diurnal variation in water vapor over North America and its implications for sampling errors in radiosonde humidity, J. Geophys. Res., 107, doi:10.1029/2001JD000642, 2002.

Gao, B.-C. and Kaufman, Y. J.: Water vapor retrievals using Moderate Resolution Imaging Spectroradiometer (MODIS) near-infrared channels, J. Geophys. Res., 108, 4389, doi:10.1029/2002JD003023, 2003.

Lang, R. and Lawrence, M. G.: Evaluation of the hydrological cycle of MATCH driven by NCEP reanalysis data: comparison with GOME water vapor field measurements, Atmos. Chem. Phys., 5, 887–908, 2005,
SRef-ID: 1680-7324/acp/2005-5-887.

Lang, R., Williams, J. E., van der Zande, W. J., and Maurellis, A. N.: Application of the Spectral Structure Parameterization technique: retrieval of total water vapor columns from GOME, Atmos. Chem. Phys., 3, 145–160, 2003,
SRef-ID: 1680-7324/acp/2003-3-145.

Li, Z., Muller, J.-P., Cross, P., Albert, P., Hewison, T., Watson, R., Fischer, J., and Bennartz, R.: Validation of MERIS Near IR Water Vapour Retrievals Using MWR and GPS Measurements, in Proceedings of the MERIS User Workshop 10–13 November 2003 ESA-ESRIN, Frascati, Italy, http://envisat.esa.int/workshops/meris03/proceedings.html, 2003.

Maurellis, A. N., Lang, R., van der Zande, W. J., Aben, I., and Ubachs, W.: Precipitable Water Vapor Column Retrieval from GOME Data, Geophys. Res. Lett., 27, 903–906, 2000.

Noël, S., Buchwitz, M., Bovensmann, H., Hoogen, R., and Burrows, J. P.: Atmospheric Water Vapor Amounts Retrieved from GOME Satellite Data, Geophys. Res. Lett., 26, 1841–1844, 1999.

Noël, S., Buchwitz, M., Bovensmann, H., and Burrows, J. P.: Retrieval of total water vapour column amounts from GOME/ERS-2 data, Adv. Space Res., 29, 1697–1702, 2002.

Noël, S., Buchwitz, M., and Burrows, J. P.: First retrieval of global water vapour column amounts from SCIAMACHY measurements, Atmos. Chem. Phys., 4, 111–125, 2004,
SRef-ID: 1680-7324/acp/2004-4-111.

Skupin, J., Noël, S., Wuttke, M. W., Bovensmann, H., and Burrows, J. P.: Calibration of SCIAMACHY in-flight measured irradiances and radiances – First results of level 1 validation, in Proc. ENVISAT Validation Workshop, ESRIN/Frascati, SP-531, ESA Publications Divison, 2002.

Skupin, J., Noël, S., Wuttke, M. W., Bovensmann, H., Burrows, J. P., Hoogeveen, R., Kleipool, Q., and Lichtenberg, G.: In-flight calibration of the SCIAMACHY solar irradiance spectrum, Adv. Space Res., 32, 2129–2134, 2003.

Timmermans, R. M. A., Lang, R., Noël, S., Kois, B., and Kyro, E.: SCIAMACHY H2O column validation by the Atmospheric Chemistry Validation Team, in Proc. Second Workshop on the Atmospheric Chemistry Validation of ENVISAT (ACVE-2), Frascati, Italy, 3–7 May, 2004, ESA SP-562, 2004.

Wagner, T., Heland, J., Zöger, M., and Platt, U.: A fast H_2O total column density product from GOME – Validation with in-situ aircraft measurements, Atmos. Chem. Phys., 3, 651–663, 2003,
SRef-ID: 1680-7324/acp/2003-3-651.