GOME AND SCIAMACHY GLOBAL WATER VAPOUR COLUMNS

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ABSTRACT

Global water vapour total column amounts have been derived from measurements of the Global Ozone Monitoring Experiment (GOME) on ERS-2 and the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) on-board the European environmental satellite ENVISAT. For this purpose, the Air Mass Corrected Differential Optical Absorption Spectroscopy (AMC-DOAS) approach has been applied to GOME and SCIAMACHY nadir measurements in the spectral region around 700 nm.

A possible combination of the GOME and SCIAMACHY data would be the first step to a new long-term water vapour climatology as the combined GOME and SCIAMACHY time series covers already now more than 10 years. A further extension by future SCIAMACHY data and additional measurements from the GOME-2 instruments on the Metop satellites can be expected.

In this paper a first intercomparison between GOME and SCIAMACHY AMC-DOAS water vapour columns is presented which supports that a combination of GOME and SCIAMACHY water vapour data is possible.

As an example for a first climatological application, the combined GOME/SCIAMACHY data set is then used to derive preliminary water vapour trends over Europe within the last decade. Although the significance of the derived small positive trend is currently unclear, the results are supported by a good correlation between water vapour anomalies and corresponding surface temperature data.

1. INTRODUCTION

Several previous investigations have shown that measurements of the Global Ozone Monitoring Experiment (GOME, see e.g. [1]) on ERS-2 and the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY, see e.g. [2]) on ENVISAT in the visible spectral region can be used to derive global water vapour concentrations (see e.g. [3, 4, 5, 6, 7, 8, 9, 10]).

One of the retrieval methods used in this context is the so-called 'Air Mass Corrected Differential Optical Absorption Spectroscopy' (AMC-DOAS) method which has been applied to GOME and SCIAMACHY nadir measurements in the spectral region at about 700 nm (see [3, 4] for details). The AMC-DOAS method does not rely on additional external information, like radio sonde data. The derived water vapour columns therefore provide a completely independent data set.

GOME and SCIAMACHY water vapour total column data are available over both ocean and land, but only measurements on the day side and under (almost) cloud free conditions can be used. The GOME and SCIAMACHY results do not rely on any other measurement data, e.g. calibration factors derived from radio sonde data. The combination of GOME and SCIAMACHY data currently covers a time span of over 10 years which may extend even further, depending on the life time of SCIAMACHY. In addition, the GOME-2 instruments on the series of operational meteorological satellites Metop (the first one to be launched 2006) will extend this data set. Therefore, a combination of the results for these GOME-type instruments can lead to an additional, completely independent global water vapour data set suitable for climatological studies.

This paper presents a first intercomparison between GOME and SCIAMACHY water vapour data retrieved using the AMC-DOAS method. Furthermore, as an example for an application of the combined GOME/SCIAMACHY data set, preliminary water vapour trends over Europe within the last decade are estimated.

2. THE GOME AND SCIAMACHY GLOBAL WATER VAPOUR DATA SET

Currently, water vapour data have been derived using the AMC-DOAS method based on the complete GOME Level 1 data set from June 1995 until December 2004. Due to an on-board tape recorder failure GOME can not provide any longer global measurements data after June 2003. Since this time the GOME coverage is typically limited to the Northern Atlantic region.

ENVISAT has been launched in March 2002, and SCIAMACHY provides regular measurement data since August 2002, although final flight settings have been achieved in December 2003 for the first time. The AMC-DOAS water vapour

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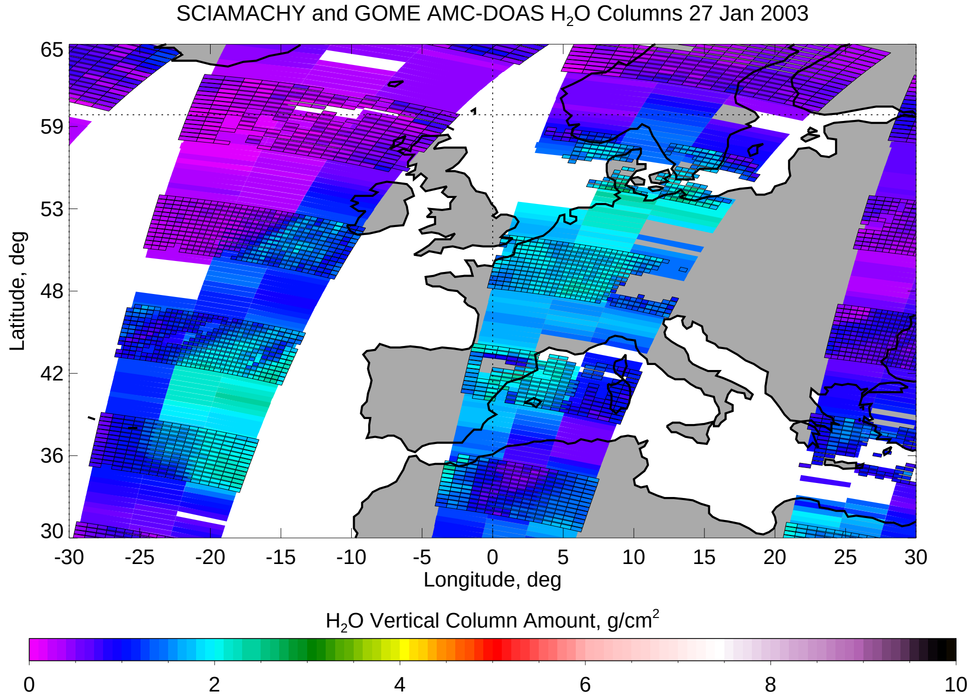

Figure 1. GOME and SCIAMACHY water vapour columns over Europe on 27 January 2003. The smaller SCIAMACHY ground pixels are indicated by boxes.

data set for SCIAMACHY used in this study has been derived from all available (unconsolidated) near real time (NRT) Level 1 data since January 2003, completed by some consolidated data sets from 2003 (because only few NRT data were available for this year). It has to be mentioned that the SCIAMACHY water vapour data set especially for the first years is not yet complete. A reprocessing of the SCIAMACHY water vapour data based on consolidated reprocessed Level 1 files is under preparation. In this sense the SCIAMACHY results presented in this paper can be considered as preliminary.

Especially for SCIAMACHY, an extensive validation of the AMC-DOAS water vapour columns has been performed (see e.g. [11, 5]), showing that the SCIAMACHY AMC-DOAS water vapour data compare well with correlative data from e.g. the Special Sensor Microwave Imager (SSM/I) [12] and model results from the European Centre for Medium-range Weather Forecasts (ECMWF).

3. INTERCOMPARISON BETWEEN GOME AND SCIAMACHY WATER VAPOUR DATA

Because of the limited availability of SCIAMACHY Level 1b files in the year 2002 and the reduced global coverage of GOME after June 2003 we restrict the intercomparison between the water vapour results of the two instruments to the year 2003. This is also the year for which most intercomparisons with SSM/I and ECMWF water vapour data have been performed [5].

Intercomparisons between GOME and SCIAMACHY are facilitated by the fact that the orbits of ERS-2 and ENVISAT are almost identical. Both are sun-fixed polar orbits which only differ in the local time of the ascending note crossing (10:30 for ERS-2 and 10:00 for ENVISAT). However, the spatial resolution of SCIAMACHY measurements is typically 30 km$\times$60 km compared to about 40 km$\times$320 km for GOME. On the other hand, the SCIAMACHY nadir swath contains regular gaps because SCIAMACHY usually performs alternating nadir and limb measurements. Nevertheless, the number of collocations (i.e. measurements at the same place on the same day) between GOME and SCIAMACHY is usually quite high (see Fig. 1).

Fig. 2 shows as an example a comparison of GOME and SCIAMACHY water vapour columns for all collocated data on 27 January 2003. For this comparison all data have been gridded to $0.5^\circ\times0.5^\circ$. From the scatter plot it can be seen that GOME and SCIAMACHY data agree quite well. The correlation between the two data sets is about 0.93, but SCIAMACHY columns seem to be slightly higher than the GOME columns.

This tendency is also visible in Fig. 3 where the (global) mean deviation between the GOME and SCIAMACHY water vapour results is plotted as a function of time for the whole year 2003. The black dots denote the mean deviation of all collocated data for one day, the blue vertical bars the corresponding standard deviation. The standard deviation is

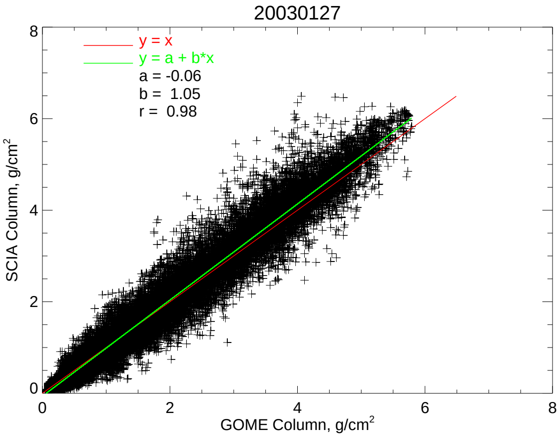

Figure 2. Comparison between GOME and SCIAMACHY AMC-DOAS water vapour columns (both gridded to 0.5°×0.5°) for 27 January 2003. r is the Pearson's linear correlation coefficient.

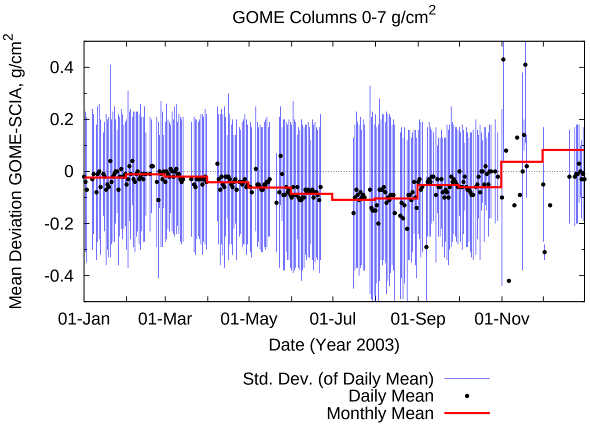

Figure 3. Mean deviation between GOME and SCIAMACHY water vapour columns (gridded to 0.5°×0.5°) for the year 2003. Note that GOME data since June 2003 provide no longer global coverage.

in the order of ±0.2 g/cm^2 which is – due to the similar instruments and orbits – smaller than the typical scatter of about 0.5 g/cm^2 when comparing to SSM/I or ECMWF data (see [5]). The red line denotes monthly mean deviations derived from the daily means. There seems to be a small seasonal trend in the data which is not visible when comparing SCIAMACHY columns with SSM/I or ECMWF data [5]. Therefore it is assumed that these seasonal variations are caused by the GOME data, probably by the varying coverage or by missing actual solar reference spectra. An intercomparison of 2002 data which is planned in the near future may help to solve this issue.

4. TREND ESTIMATES

The results from the intercomparison between GOME and SCIAMACHY water vapour data shows that a combination of the two data sets is possible. To further support this statement, a first application of a combined GOME/SCIAMACHY water vapour data set is described in this section.

For this purpose, monthly mean data have be determined from the gridded GOME and SCIAMACHY water vapour columns at a spatial resolution of 0.5°×0.5°. For this exercise we concentrate on the European region, defined by the longitudinal/latitudinal range 10°W to 20°E and 35°N to 60°N, respectively.

The water vapour time series to be analysed here is then combined from averages over this area, resulting in one water vapour column per month for the European region, using GOME data until December 2002, and SCIAMACHY data from January 2003 until February 2006[1].

We use a simple trend model consisting of a constant offset μ (equivalent to an average water vapour column over the time interval analysed), a linear trend ω and a seasonal component S:

$$Y(t) = \mu + \omega t + S(t) \tag{1}$$

where Y is the measured monthly mean water vapour as a function of the time t (given in fractions of a year, relative to 1 January 2000). $S(t)$ is a combination of several seasonal components described by:

$$S(t) = \sum_{j=1}^{4} \left[\beta_{1,j} \sin(2\pi jt) + \beta_{2,j} \cos(2\pi jt)\right] \tag{2}$$

This trend model is very similar to the one used by [13], except that noise on the data is not considered (yet) in our calculations.

Fig. 4 shows the variation of the water vapour columns over Europe as a function of time. Note that all available GOME (red squares) and SCIAMACHY (green crosses) data are plotted, although the trend model is only fitted to complete years, i.e. 1996 to 2005. The blue line shows the result of the fit including the seasonal component, i.e. $Y(t)$, whereas

[1]There is one exception: November 2003 data are taken from GOME measurements because there are currently no SCIAMACHY water vapour data available over Europe for this month. This problem will be solved by the next reprocessing.

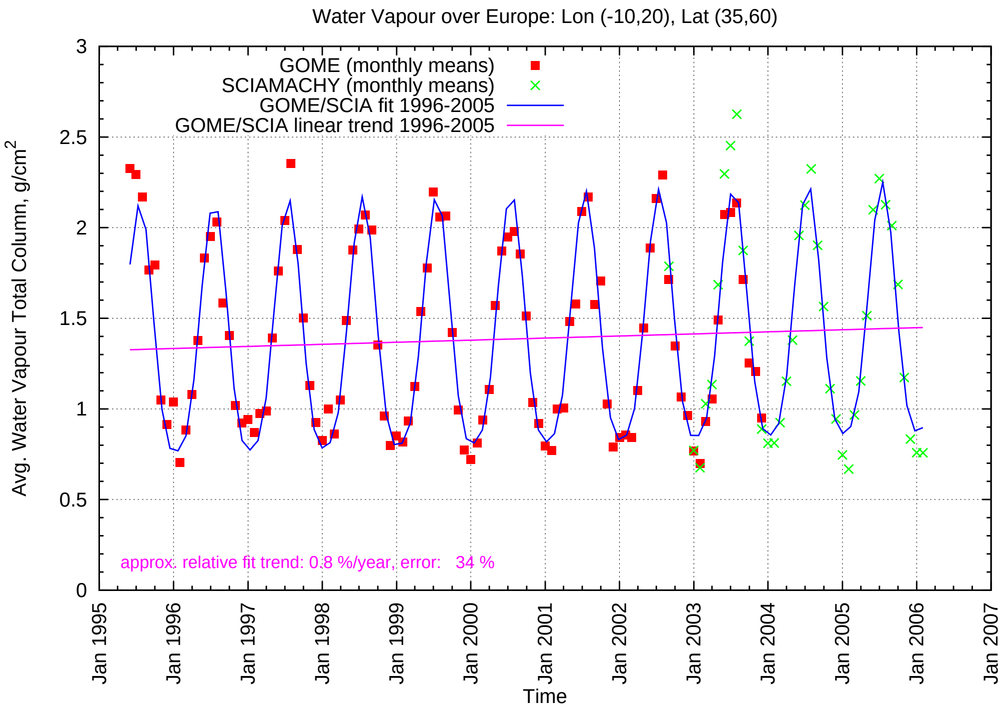

Figure 4. Preliminary water vapour trend over Europe derived from GOME and SCIAMACHY data.

the magenta line is only the linear trend part, i.e. $\mu + \omega t$. The resulting relative fit trend which we define as ω/μ is about 0.8% with an approximate error of 34%. This error results from the fit procedure and does not include any systematic effects. Therefore, and because of the preliminary nature of the SCIAMACHY data, the significance of the retrieved trend requires further investigation.

In a second step we compare the GOME/SCIAMACHY water vapour time series over Europe with surface temperature data (HADCRUT2V data set) obtained from the Climatic Research Unit (CRU), University of East Anglia, Norwich, UK (see e.g. [14]). This data set provides monthly temperature anomaly data on a $5^\circ \times 5^\circ$ spatial grid. For the comparison to these data the GOME and SCIAMACHY water vapour columns are gridded to the same resolution. Water vapour anomalies are then determined by subtracting for each grid point the average monthly water vapour from the 1996 to 2005 combined GOME/SCIAMACHY data set (i.e. one value per month). The resulting anomalies are then averaged over the European region.

As can be seen from Fig. 5, there is a clear correlation between the water vapour and the temperature anomalies. As expected, the water vapour contents increases with an increasing surface temperature. The resulting correlation for the complete GOME/SCIAMACHY data set (left plot of Fig. 5) is about 0.65, which is quite fair, but when looking only at the SCIAMACHY data (right plot) the correlation is much better (0.92), which is the same magnitude as e.g. the correlation between GOME and SCIAMACHY water vapour columns (see Fig. 2). However, it has to be admitted that this correlation is based on a much smaller data set which may not be too representative as it contains some very large values for the water vapour anomaly (from the hot summer in 2003) which correlate quite well with the temperature data. Also this subject needs further investigation.

5. CONCLUSIONS

A first intercomparison between GOME and SCIAMACHY water vapour total columns derived with the AMC-DOAS method revealed a good agreement between the two data sets, although SCIAMACHY data tend to be slightly higher than GOME data. A small seasonal trend in the deviation requires further investigation.

Nevertheless, the investigation showed that it is possible (and reasonable) to combine the GOME and SCIAMACHY data to achieve a completely new and independent global water vapour data base covering already now more than 10 years. This data base will be extended by further SCIAMACHY measurements and most likely also by data from the GOME-2 instruments on the forthcoming Metop series of meteorological satellites.

The usefulness of the combined GOME/SCIAMACHY water vapour data set for climatological studies has been shown by a first trend analysis of water vapour changes over the European area. The results of this trend study are very preliminary and their significance is currently unclear. Nevertheless, a slight positive water vapour trend over Europe could be derived

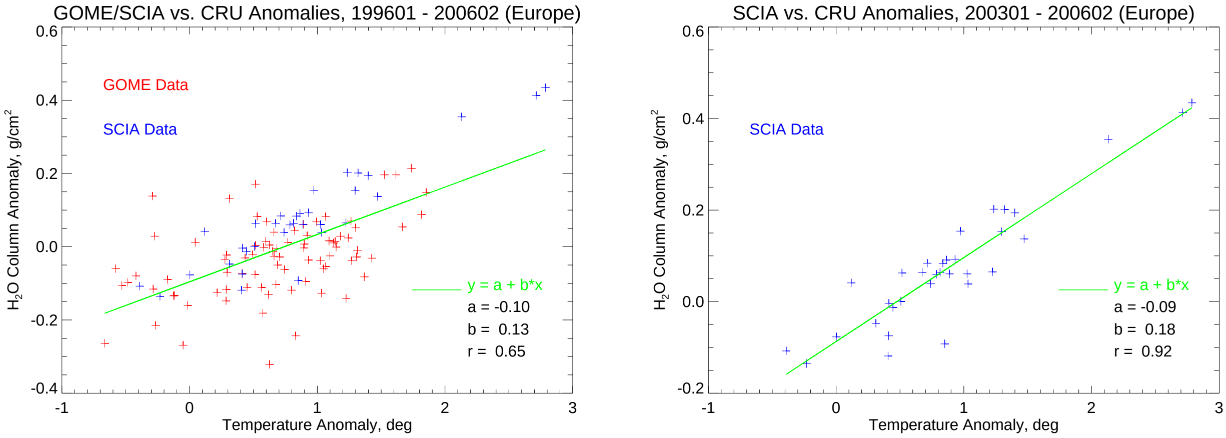

Figure 5. Comparison between the measured temperature anomaly over Europe (taken from CRU data) and corresponding GOME/SCIAMACHY water vapour anomalies. Left: Correlation for GOME (red crosses) and SCIAMACHY (blue crosses) data. Right: Correlation for SCIAMACHY data only.

from the data which correlates well with CRU surface temperature anomalies, especially for the SCIAMACHY part of the data.

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