VERIFICATION OF SCIAMACHY LEVEL 1 DATA BY AMC-DOAS WATER VAPOUR RETRIEVAL

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ABSTRACT

The Air Mass Corrected Differential Optical Absorption Spectroscopy (AMC-DOAS) approach [1] is an independent method to derive global total water vapour column amounts from nadir measurements in the spectral region around 700 nm. The AMC-DOAS method has been successfully applied to SCIAMACHY and GOME data; it is planned to implement the AMC-DOAS retrieval method into the SCIAMACHY operational processing chain.

Water vapour column retrievals based on the AMC-DOAS approach have been used to assess the quality of the SCIAMACHY v6.0 Level 1 data product. In this paper we report on the outcome of the following activities:

1. Verification of the SCIAMACHY operational Level 1 v6.0 master set with the corresponding v5.0 data set.
2. Comparison between retrievals using v6.0 validation master set data with different solar reference spectra (ASM diffuser vs. ESM diffuser).

Additionally, as a first application, preliminary results of combining GOME and SCIAMACHY water vapour columns for a global trend analysis are shown.

1. INTRODUCTION

Water vapour constitutes the most important greenhouse gas and is heavily involved in atmospheric chemistry. Moreover in the context of climate change it is desperately necessary to detect trends or changes in water vapour concentrations. Such climate change could dramatically alter the geographic distribution of major vegetation types–savannas, forests, and tundra [2].

The detection of trends in environmental data requires long time series of high quality to reduce undesirable factors such as noise. Long-term time series of water vapour on a global scale, but with moderate resolution, are derived from satellite measurements. Two spectrometers, GOME (Global Ozone Monitoring Experiment, see e.g. [3]) - flying since 1995 on ERS-2 - and SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY, see e.g. [4]) - since 2002 on ENVISAT - provide a combined time series of 10 years of global measurements which will be extended by GOME-2 on METOP (METeorological OPerational satellite).

The water vapour columns are derived from spectral data via the Air Mass Corrected Differential Optical Absorption Spectroscopy approach (AMC-DOAS) [1]. The basic principle of the method is to calculate the difference between the measured Earthshine radiance and the solar irradiance at wavelengths where water vapour absorbs radiation (here we use the wavelength band from 688 nm to 700 nm) and relate this absorption-depth to the water vapour column concentration.

For the above mentioned importance of high quality long-term data we are looking forward to processing the Level 1 v6.0 data which will hopefully improve the quality of the water vapour product, e.g. by filling gaps currently found in the v5.0 consolidated data.

As an outlook and a first application, we present an example of a combined GOME and SCIAMACHY time series.

2. VERIFICATION AND VALIDATION

The verification and validation activities of the SCIAMACHY operational Level-1 v6.0 master set product comprise the comparison of retrieved AMC-DOAS water vapour columns v6.0 with corresponding v5.0 validation master set products. Moreover a comparison between retrievals using v6.0 validation master set data with different solar reference spectra (ASM diffuser vs. ESM diffuser) to determine the most suitable choice for a later operational processing are performed.

In all cases the extraction of the master set data is done using scial1c_rev1.23. For the combination with calibrated ESM diffuser data ("D0" spectrum) the nadir radiances have been extracted using full calibration. For the combination with "uncalibrated" ASM diffuser data only cal-

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ibration flags 0,1,5 have been activated. Because no actual ASM diffuser data are available for 2002, the 2002 data were processed using the fixed ASM diffuser spectrum ("D9" for v5.0, "A1" for v6.0), later data use the actual ASM diffuser spectrum ("D6" for v5.0 and "A0" for v6.0).
For both v6.0 and v5.0 master set data we used the AMC-DOAS retrieval version 1.0.

2.1. Version 5 vs. Version 6

Figure 2 shows in the top left a scatter plot of SCIAMACHY water vapour columns derived with the AMC-DOAS method based on v5.0 master set data against the corresponding v6.0 data. Note that the v5.0 validation master set only contains data from 2002, therefore this comparison is also restricted to 2002 data. In the top right part of Fig. 2 the corresponding relative and absolute deviations are shown as a function of the derived (v6.0) water vapour column. The two lower sub-figures depict the relative and absolute deviations as function of orbit number, i.e. time.

The scatter plot shows an in general good agreement between v5.0 and v6.0 columns, notice the thin black line crossing the first quadrant with slope one. The relative differences between v5.0 and v6.0 are usually in the order of some percent, except for very low columns where it reaches 10%. The absolute differences show little dependence on the column. There is also not much variation over time as the differences are almost independent from the orbit number. However, for some individual measurements, e.g. around orbit 2500, there are larger discrepancies. As an example the data from orbit 2526 are depicted in Fig. 3 together with the geolocation of orbit 2526 plotted on the world map as red dots. As can be seen from this figure, the branch of higher absolute deviations seen in Fig. 2 can be mainly attributed to one individual state over South America. The reason for these larger deviations is currently unknown, but the statistical contribution to the overall results is very small.

This can be seen from Fig. 1, where a histogram of the relative water vapour column differences, i.e. $(\mathrm{v5.0} - \mathrm{v6.0})/\mathrm{v6.0}$ is shown, with the density distribution on the ordinate and the differences on the abscissa. Fitting a standard Gaussian normal distribution $N(\mu, \sigma)$ to the data results in a mean $\mu = -0.001$ and a standard deviation $\sigma = 0.01$. Figure 1 reveals, that the data can be well described by a normal distribution in the outer regions, but the density of the very small deviations is about 1.5 times the density of the Gaussian. An alternative characterisation is in terms of quantiles. For the relative differences the median, i.e. the 50% quantile, is -0.0008. The 2.5% and 97.5% quantiles are calculated to -0.02 and $+0.02$, respectively, which means that 95% of the data lie between these values. From these findings it is clear that the relative deviations reaching the 0.1 at small columns in Fig. 2 and also the branch of absolute differences in Figs. 2 and 3 crossing the 0.1 g/cm^2 are very rare events.

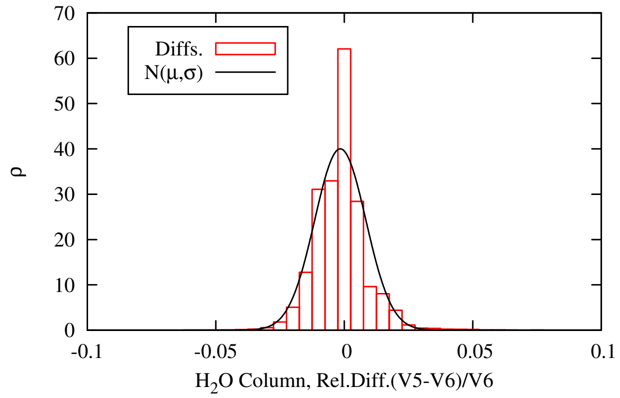

Figure 1. Density distribution of the relative water vapour column differences from Fig. 2 together with a fitted standard Gaussian $N(\mu, \sigma)$ with mean μ and standard deviation σ.

2.2. ASM vs. ESM diffuser (Version 6 data)

Figure 4 shows in a similar way to Fig. 2 the results of the comparison between retrievals using a solar spectrum based on either (uncalibrated) ASM diffuser data or calibrated ESM diffuser data. In this context the complete v6.0 L1b master set data (as far as available in September 2006) have been analysed, i.e. data covering 2002 to 2005. The scatter-plot (Fig. 4) v6.0 ESM vs. v6.0 ASM for the complete master set (2002-2005) shows good agreement between the derived water vapour columns.

The relative errors are mostly below 10% except for very small columns. Although the relative differences are up to 30% in this case the absolute differences are considerably small. The histogram of the relative water vapour column differences together with a fitted standard Gaussian are shown in Fig. 5. The relative differences are not normally distributed and a characterisation in terms of quantiles is quite suitable. Thus, 95% of the data lie between the 2.5% quantile at -0.004 and the 97.5% quantile at 0.063; the median is calculated to 0.019, which is a systematic offset. As the derived deviations are typically well below 10% , they lie within what is expected from the accuracy of the retrieval. There also seems to be no systematic dependence on time. The AMC-DOAS method produces very similar results by the use of both solar spectra. However, we prefer to use the ASM diffuser data, which exhibit the best fitting results, i.e. the smallest residuals, performed by the retrieval.

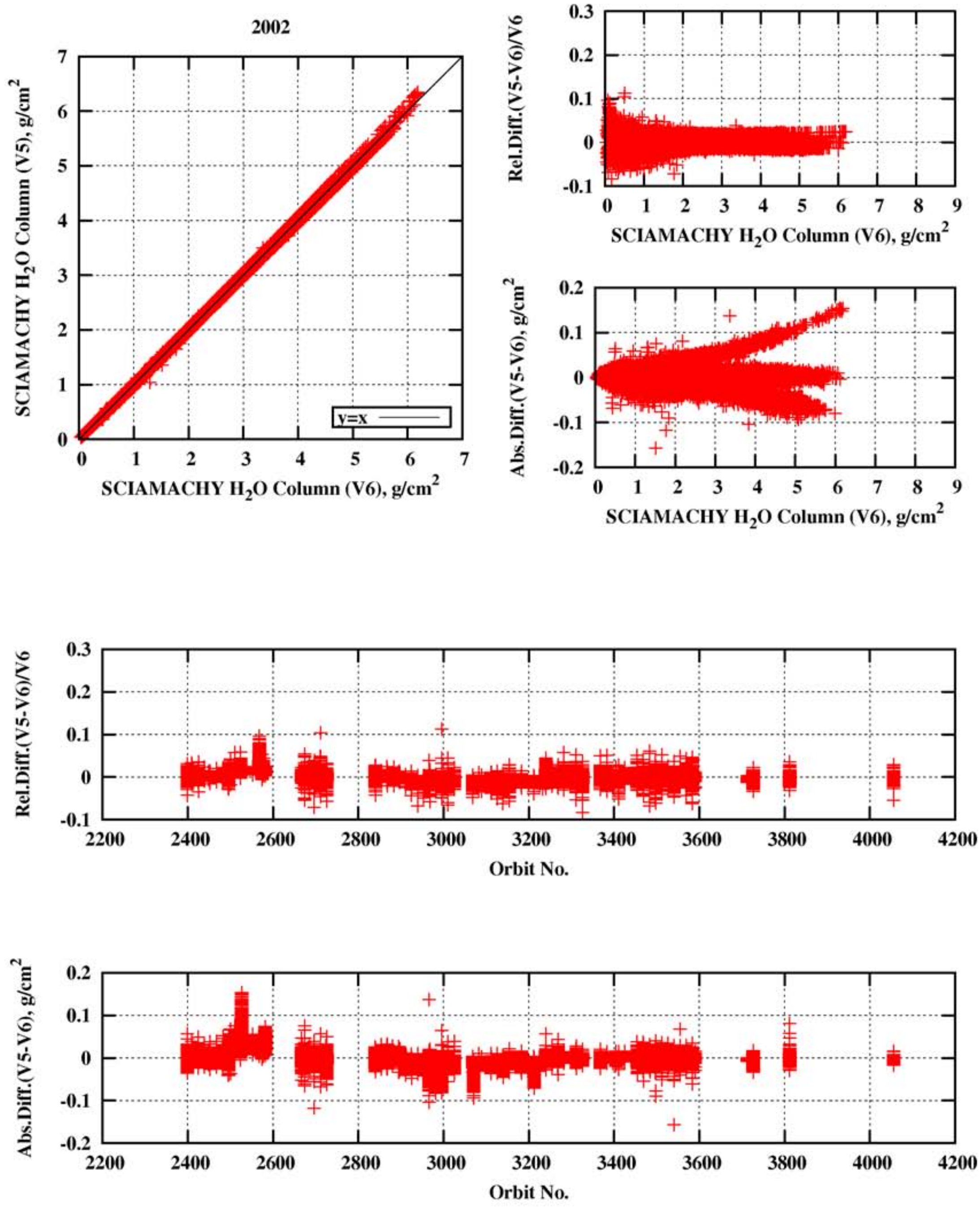

Figure 2. Top left: Scatter plot of SCIA v5.0 vs. v6.0 Top right: Relative and absolute differences of v5.0 and v6.0 against the v6.0 data. Bottom: Relative and absolute differences vs. orbit, i.e. time.

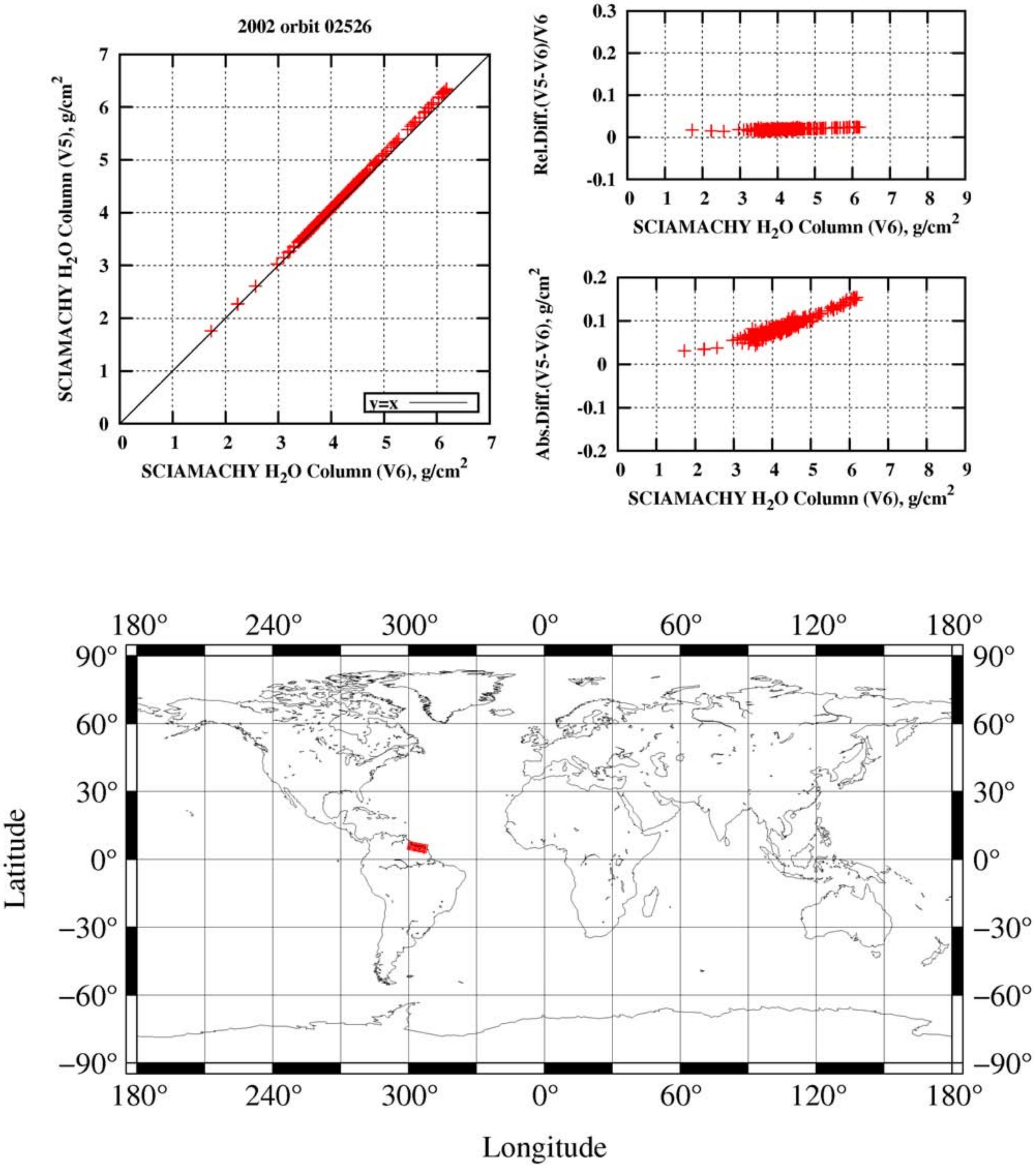

Figure 3. Top left: Scatter plot of SCIA v5.0 vs. v6.0 (orbit 2526). Top right: Relative and absolute differences of v5.0 and v6.0 against the v6.0 data (orbit 2526). Bottom: Geolocation of orbit 2526 (South America) indicated by red colour.

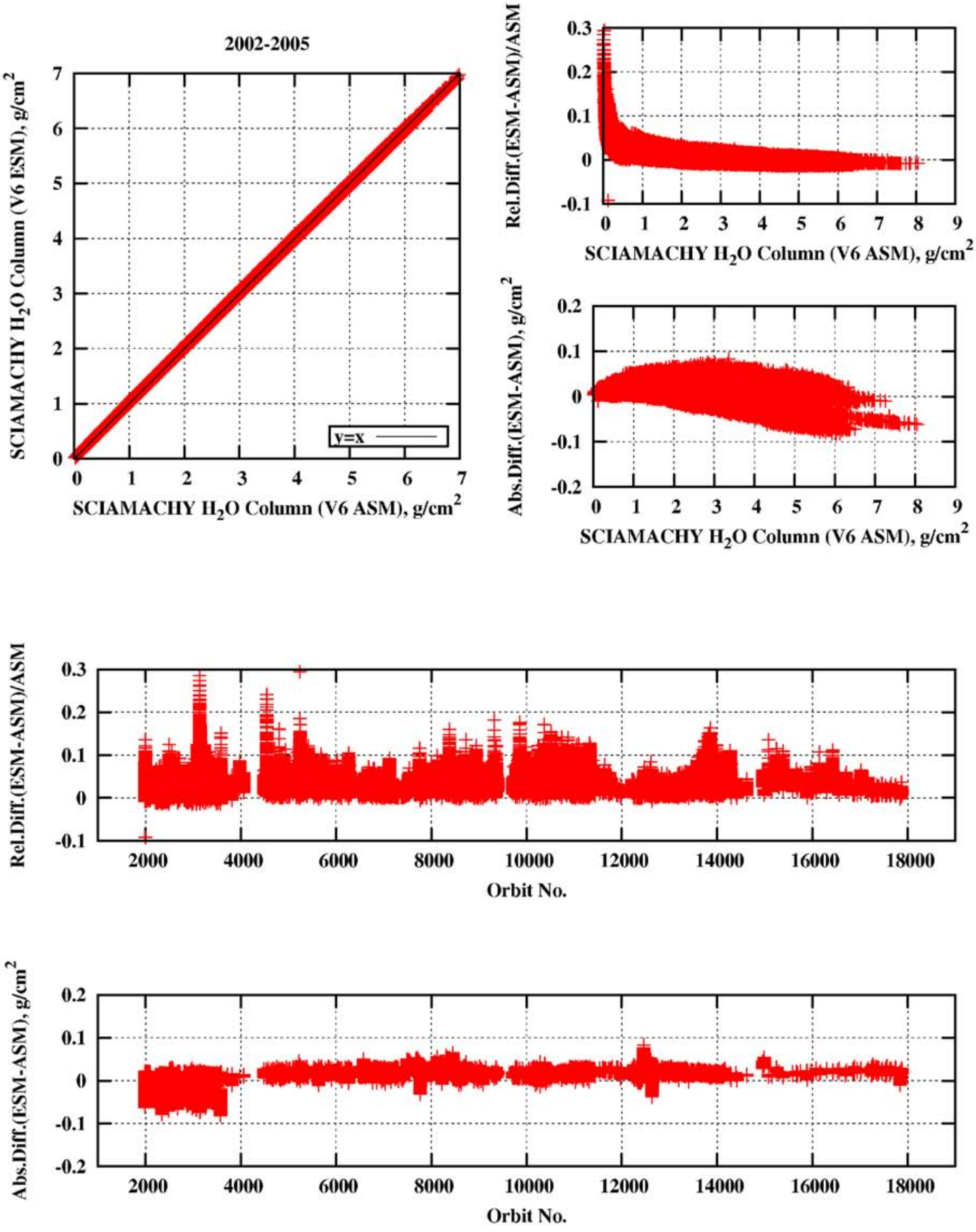

Figure 4. Top left: Scatter plot of SCIA v6.0 (ESM) vs. v6.0 (ASM). Top right: Relative and absolute differences of v6.0 (ESM) and v6.0 (ASM) against the v6.0 (ASM) data. Bottom: Relative and absolute differences vs. orbit, i.e. time.

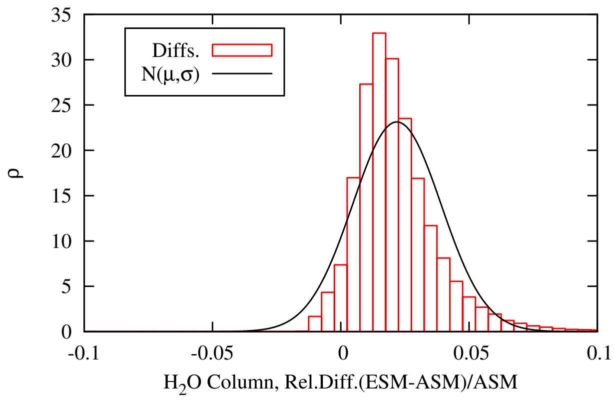

Figure 5. Density distribution of the relative water vapour differences from Fig. 4 together with a fitted standard Gaussian $N(\mu, \sigma)$ with mean μ and standard deviation σ.

3. COMBINATION OF GOME AND SCIAMACHY AND PRELIMINARY TREND ANALYSIS

To illustrate the usefulness of a long-term H_2O dataset we present preliminary results of a trend analysis of combined GOME and SCIAMACHY data, which cover a time span of 10 years (SCIAMACHY water vapour columns were derived from processing the consolidated v5.0 data). A linear trend model is fitted to the time series of $0.5° \times 0.5°$ globally gridded water vapour concentrations, whereupon two important aspects have to be considered by combining the time series:

- **Level shift between GOME and SCIAMACHY:** GOME on ERS-2 crosses the equator at 10:30 local time whereas SCIAMACHY onboard ENVISAT crosses the equator at 10:00 local time. That means SCIAMACHY and GOME measure at different times slightly different states of the atmospheric composition. Single time series of individual locations show offsets at the changeover from GOME to SCIAMACHY. To account for this, an additive term has to be implemented to the fitting routine.

- **Amplitude change:** The spatial resolution of the GOME data is typically $40\,\text{km} \times 320\,\text{km}$ whereas it is $30\,\text{km} \times 60\,\text{km}$ for SCIAMACHY data. Thus the SCIAMACHY instrument has a better resolution of peaks in the water vapour distribution which could be the cause for measuring larger amplitudes than GOME. By adding a multiplicative term to the fitting function the differences in the spectral resolutions are considered.

The time series is fitted using the following model according to [5]:

$$Y_t = \mu + S_t + \omega X_t + \eta U_t + N_t\,, \qquad t = 1,\ldots,T\,, \quad (1)$$

where Y_t are the observations, i.e. the H_2O columns, μ is a constant term ω is the magnitude of the trend, X_t is the time and N_t is the unexplained portion of the data, the noise. η depicts the magnitude of a mean level shift term at a specified time $t = T_0$ $(0 < T_0 < T)$; where

$$U_t = \begin{cases} 0, & t < T_0 \\ 1, & t \geq T_0 \end{cases}\,, \qquad (2)$$

and T_0 is the time of changeover from GOME to SCIAMACHY. The seasonal component is described by

$$S_t = \sum_{j=1}^{4} [(\beta_{1,j} + \gamma U_t)\ \sin(2\pi j t/12) + (\beta_{2,j} + \gamma U_t)\ \cos(2\pi j t/12)]\,. \qquad (3)$$

In contrast to [5] an additional term γU_t is used and works as an amplitude change at time $t = T_0$.

As an example for a successful application of this method a combined time series for a single grid point (Lat$(-6.25°)$, Lon$(41.25°)$, i.e. North-East border of Portugal) is shown in Fig. 6.

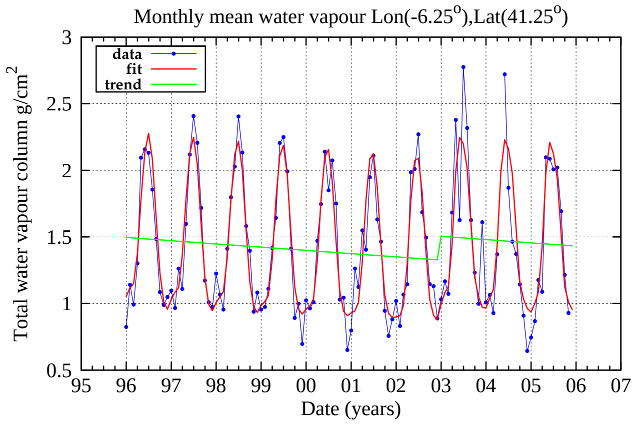

Figure 6. Example for a trend study based on the combination of GOME (January 1996 to December 2002) and SCIAMACHY (January 2003 to December 2005) monthly mean water vapour data.

The global analysis, significance estimation and interpretation of the trends is in preparation.

4. CONCLUSION

The performed validation/verification activities indicate that the operational v6.0 Level 1b data products are in good shape. All determined deviations of the derived water vapour columns for different Level 1b product versions and different solar reference spectra lie within the expected accuracy range of the AMC-DOAS water vapour product. However, it has to be noted here that the AMC-DOAS retrieval method is quite insensitive to calibration issues and the choice of the solar reference data. Insofar the quality of the derived water vapour columns is not much affected by the Level 1b product update. Nevertheless, we are looking forward to a v6.0 reprocessing as these data might for instance fill gaps currently present in v5.0 data, which will improve the long-term time series.

The AMC-DOAS method, which is also applied to the GOME data, is able to provide water vapour data from both instruments, GOME and SCIAMACHY and in the future additionally from GOME-2. As it is shown, the two datasets can be merged together and offsets at the changeover can be explained. The availability of the combined data set, derived by the AMC-DOAS retrieval, is an important step to the better understanding of changes in the global water vapour concentrations in respect to climate change.

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