

COMPARISON OF H₂O RETRIEVALS FROM GOME AND GOME-2

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Abstract

Climatologically relevant time series of total column water vapour may be derived from the family of GOME instruments. We compare the performance of two different algorithms for the retrieval of H₂O total columns from the GOME and GOME-2 instruments: the AMC-DOAS method from University of Bremen, and a classical DOAS method from University of Heidelberg / M.P.I. Mainz. The data from these two algorithms are compared to each other, to SSM/I data, and to data of the global radiosonde network.

We find a tight correlation between the retrieved columns from both algorithms. There is an offset difference of 0.2-0.3 g/cm² and a difference in slope of 7-9%, depending on selection criteria. In the comparison to external data, the algorithms show slightly different behaviour, but overall we judge their performance to be on a comparable level.

INTRODUCTION

Long time series of global satellite measurements of total column water vapour have traditionally been derived from microwave instruments. In particular, the series of SSM/I instruments and the microwave instruments on TOVS and ATOVS have been providing H₂O records since the late 1980s. The dependence of microwave retrievals on surface temperature limits reliable H₂O retrievals to ocean surfaces. In recent years, global H₂O satellite measurements over land have become available from near-infrared hyperspectral imagers such as MODIS on Aqua/Terra, MERIS on ENVISAT, VISSR on GOES and SEVIRI on MSG, but their accuracy has to be established. High-precision H₂O measurements over land are available from radio-sonde and GPS networks, but with restricted spatial coverage.

Several studies have shown the capability to retrieve total column H₂O from space-born spectrometers operating in the visible spectral region, in particular for the GOME family of instruments (see e.g. Noël et al. 1999, Maurellis et al. 2000, Casadio et al. 2000, Lang et al. 2003, Wagner et al. 2003). These instruments have the following properties:

- The Global Ozone Monitoring Experiment (launched 1995 on ERS-2, see e.g. Burrows et al. 1999) and its successor GOME-2 (launched 2006 on MetOp, first of 3 instruments) are nadir-looking UV-VIS grating spectrometers – they measure reflected Sunlight.
- Besides the ozone bands in instrument channels 1-3, they also cover several H₂O and O₂ bands in channel 4 (610-970 nm), with a resolution of around 0.5 nm.
- GOME flies a Sun-synchronous orbit near 10:30h local time, GOME-2 flies near 9:30h
- GOME reaches global coverage at the equator every 3 days, GOME-2 reaches almost daily global coverage. GOME lost complete global coverage in 2003, but in the same instrument family, SCIAMACHY (launched 2002 on ENVISAT, 10:00 local time) may be used to close the gap.
- The GOME/SCIAMACHY/GOME-2 series of instruments will cover a projected timespan of at least 20 years.

The climatologically relevant time span, and the ability to retrieve H₂O over sea and over land, makes the GOME family of sensors interesting for climatology studies (Wagner et al. 2006, Lang et al. 2007, Noël et al. 2008). Furthermore, the current GOME H₂O retrieval schemes do not rely on external data (in contrast, the microwave data are usually calibrated on the radiosonde data, see e.g. Wentz 1997, and GPS retrievals usually employ temperature input from Global Climate Models).

While this may not allow the highest absolute accuracy, it does make the GOME H₂O dataset a truly independent one. On the downside, GOME measurements are hampered by clouds (like the near-infrared imagers), which may be an issue because of poor spatial resolution (80x40 km minimum); the GOME H₂O climatology will therefore not be completely independent of cloud climatology.

In this paper, we compare the performance of two different algorithms for the retrieval of H₂O columns from GOME:

- The AMC-DOAS method from University of Bremen (Noël et al. 1999). The algorithm uses the H₂O bands around 695 nm, in combination with the O₂-B band.
- A classical DOAS method from MPI Mainz / University of Heidelberg (Wagner et al. 2006). The algorithm uses the H₂O bands around 650 nm, in combination with the O₂-C band.

Data from these two algorithms are compared to each other, to data of the SSM/I F15 instrument, and to data of the global radio-sonde network.

INTERCOMPARISON OF GOME RETRIEVALS

For a direct inter-comparison of both GOME retrieval algorithms, we used two datasets. For GOME/ERS-2 we used data for 2 days per month, between August 2002 and June 2003. For GOME-2 we used data for one day, 10 July 2007; note that GOME-2 has approximately 6 times more pixels per orbit as GOME/ERS-2.

Fig. 1 shows that there is a tight correlation between the retrieved columns from both algorithms. There is an offset difference of 0.2-0.3 g/cm² and a difference in slope of 7-9%. These figures are slightly dependent on selection criteria, as will be discussed below.

We investigated the dependency of the result on geophysical parameters, such as Solar Zenith Angle (SZA), line-of-sight angle (scan mirror angle), cloudiness, and surface type.

We find no significant dependence on SZA below SZA=70 degree. However, for increasing SZA we see increasing differences (Fig.1 lower panels). For SZA>80° the differences Mainz – Bremen are on average ~0.5 g/cm² larger than those given by the relation for SZA<70°.

For GOME/ERS-2 data, we find no significant dependence on scan angle. For GOME-2, there is a slight scan angle dependence. In Fig.2 (left panels) we compare “narrow swath” pixels having scan angles with line-of-sight |LOS|<30° (which corresponds to the GOME/ERS-2 scan range) to extreme East pixels with LOS < -40° and extreme West pixels with LOS > 40°. Extreme East pixels have differences Mainz – Bremen ~0.09 g/cm² smaller than narrow swath pixels. Extreme West pixels have differences Mainz – Bremen ~0.07 g/cm² smaller than narrow swath pixels. This may be one contribution to the width of the standard deviation of the relation Mainz – Bremen (for all pixels with SZA<70°), which is 0.12 g/cm². Selecting the narrow swath pixels only, the GOME-2 results are more in line with those of GOME/ERS-1.

We find a slight dependence on cloudiness. As cloud proxy we use the “airmass correction factor” (ACF) as calculated as part of the Bremen algorithm. The ACF accounts (amongst others) for the difference between the modeled and the measured O₂ absorption; ACFs smaller than 1.0 usually indicate interference from clouds. Fig.2 (right panels) show that “cloudy” points with ACF < 0.85 have differences Mainz – Bremen ~0.09 g/cm² larger than “cloud-free” points with ACF around 1.0.

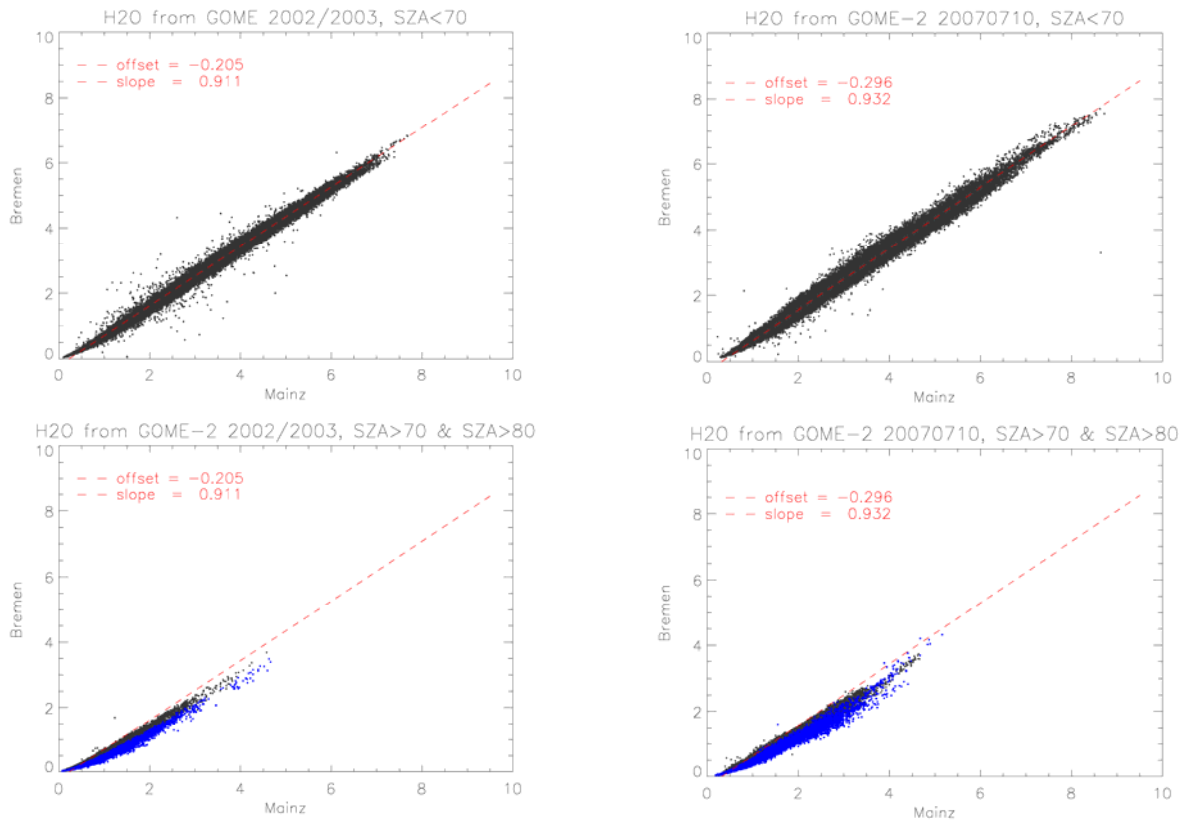


Figure 1: Inter-comparison of total H₂O [g/cm²] from the two GOME algorithms: Bremen versus Mainz. Left: data from GOME/ERS-2, Right: data from GOME-2/MetOp. Top panels are for data with solar zenith angle (SZ) below 70, bottom panels are for 70<SZ<80 (gray) and SZ>80 (blue, overplotted).

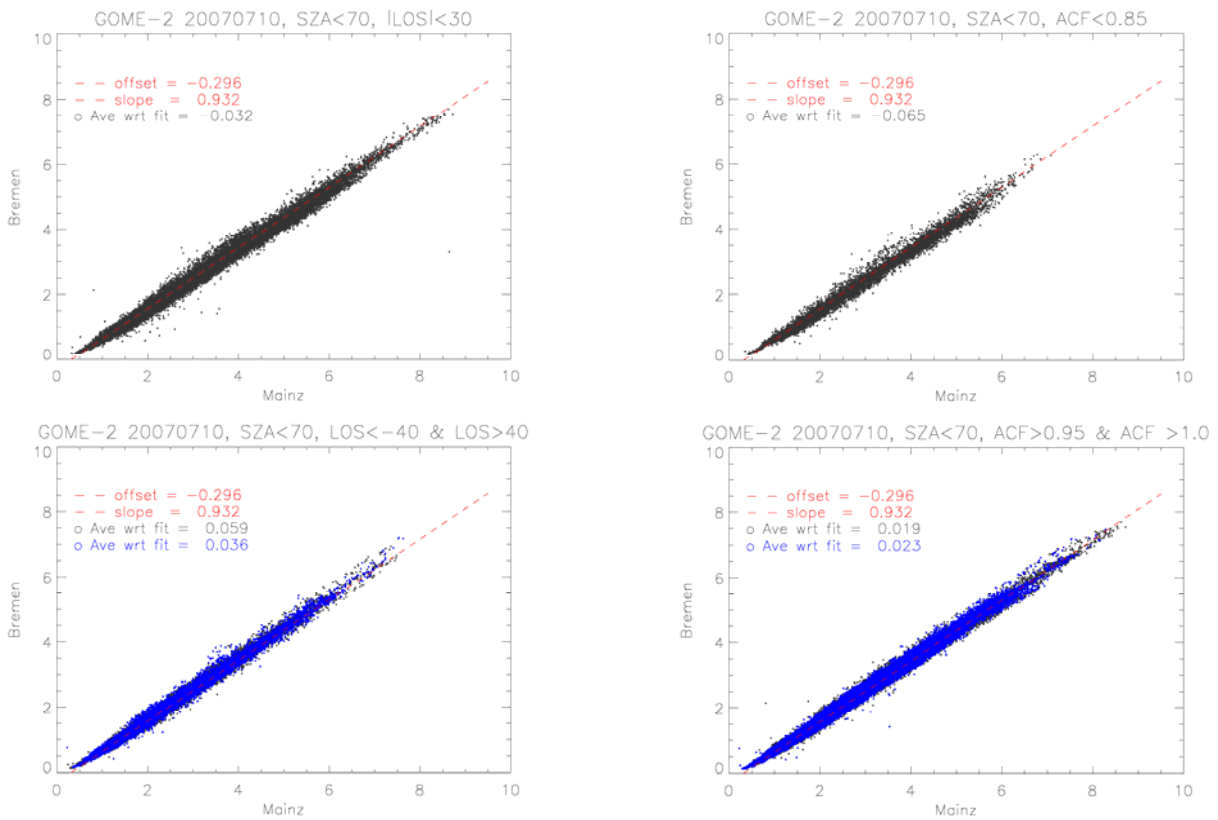


Figure 2: GOME-2 total H₂O [g/cm²] Bremen versus Mainz. Left panels: dependence on line-of-sight. Right panels: dependence on ACF (cloud proxy).

A possible dependence on surface type was checked by selecting points from two scenarios. The first scenario only regards pixels over the Sahara. Here we find an extremely tight correlation between Bremen and Mainz retrievals, with Bremen and Mainz slightly closer together as for the general case. However, since the number of pixels in this region is quite low, it is unclear if the correlation is statistically really so much tighter as for all pixels in the complete day of data. The second scenario only regards pixels over rainforest areas. We selected an area over the core of the Amazon rainforest, and, to increase statistics, also over the African rainforest. Here we observe a scatter similar to that of the observations of the complete day, possibly a bit larger, but without any clear systematic deviation from the daily averages. The number of pixels in the special scenarios was too small to obtain a conclusive result, but it seems that they do not differ significantly from the general picture.

COMPARISON TO SSM/I DATA

For this comparison we used global GOME/ERS-2 data for 2 days per month, from January 2003 to July 2003. We used SSM/I data calculated by DWD with the water vapour retrieval algorithm HOAPS (Schulz and Bakan 1998). Data were available for SSM/I F14 and F15, but since the latter provided much more collocations with GOME, we limited ourselves to the F15 data. Collocations were only used if the time difference between GOME and SSM/I measurements was less than 1 hour.

The SSM/I measurements which lie inside the GOME pixel (as projected on the ground) are averaged into a single value. A bias might occur here, since often the measurements are more weighted towards the west side of the GOME pixel. A collocation is rejected if less than 6 SSM/I measurements points lie inside the GOME pixel. The number of collocations is strongly weighted to points in the south Atlantic and south Pacific, just above Antarctica (see also Fig. 4) and this has to be taken into consideration when interpreting the results.

Figs. 3 presents the data in 2D histogram form: the H_2O values from SSM/I (x-axis) are binned into 2 kg/m^2 (0.2 g/cm^2) wide bins, and the differences in H_2O values $\text{GOME} - \text{SSM/I}$ (y-axis) are binned into 0.5 kg/m^2 (0.05 g/cm^2) wide bins; the number of points in each bin is colour-coded from grey-blue to red-brown.

Fig.3 shows that the Mainz data are systematically closer to SSM/I than Bremen data, but the Bremen data show somewhat lower scatter. The difference between Mainz and Bremen is within the standard deviation of $\text{GOME} - \text{SSM/I}$. Both GOME algorithms show a negative trend towards higher H_2O columns, probably due to cloud shielding.

Note that the clustering of points at low H_2O columns is caused by the collocation with SSM/I which selects on ocean data near the Antarctic continent, see also Fig. 4a.

A comparison of Fig.3b (for cloud-free pixels) to Fig.3a (all pixels) shows that cloud cover has little influence on the biases between GOME and SSM/I; only for Mainz there is some indication that in cloud-free conditions it overestimates slightly at H_2O columns above 25 kg/m^2 .

The 2D histogram of Fig.4a show that the spatial distribution of data points is weighted to southern mid- and sub-arctic latitudes. The difference $\text{GOME} - \text{SSM/I}$ becomes more negative towards the equator. This is probably caused by cloud shielding: here we have higher H_2O columns, and shielding a constant fraction of a higher column leads to larger absolute deviations.

Fig. 4b shows that both algorithms have a slight trend w.r.t. Solar Zenith Angle (SZA). Towards high SZA, Bremen shows a slight negative trend, whereas Mainz shows a slight positive trend. Note that the lowest H_2O columns occur almost exclusively at high SZA; it is therefore not possible to conclude if there are retrieval effects as function of H_2O column or as function of SZA.

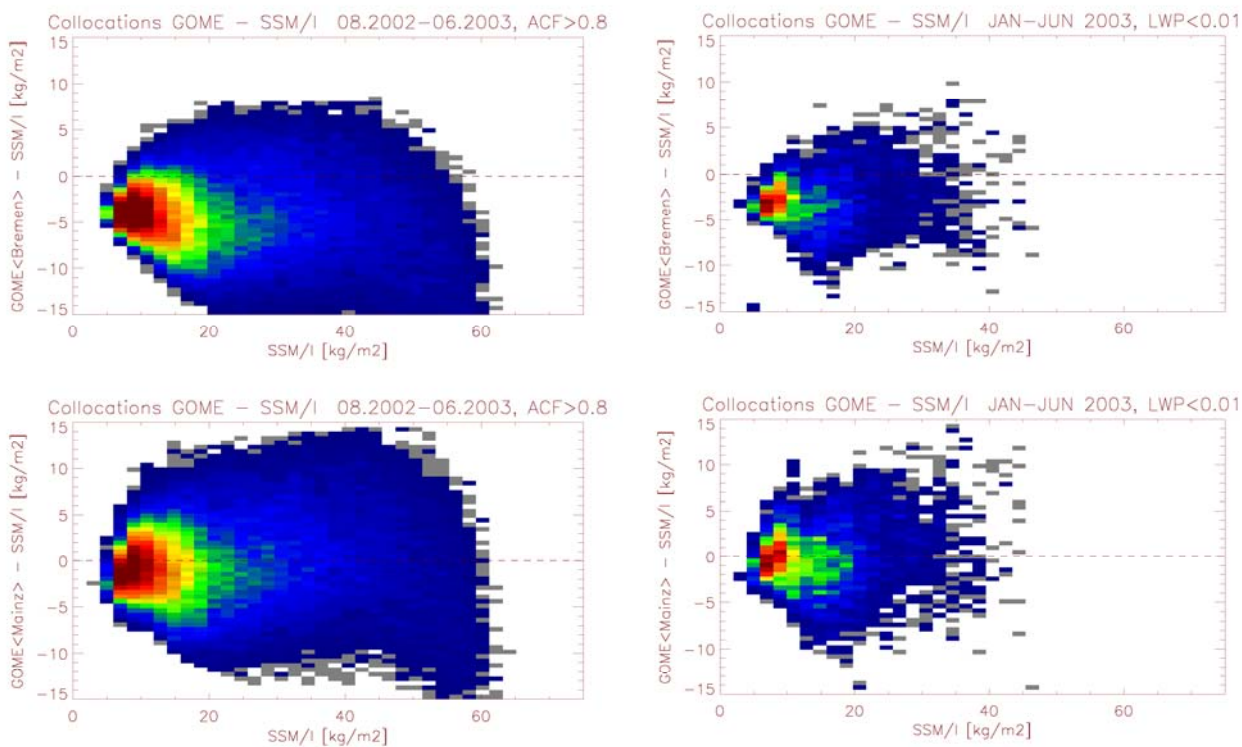


Figure 3: 2D histograms of difference (GOME – SSM/I) versus SSM/I [kg/m²], top: H₂O from Bremen, bottom: H₂O from Mainz. Left panels: all GOME data common to Bremen and Mainz (i.e. those with ACF from Bremen ≥ 0.8). Right panels: using only cloud-free SSM/I pixels. Colour scale is linear, from 5-10 collocations (gray) to >1200 collocations per bin (brown).

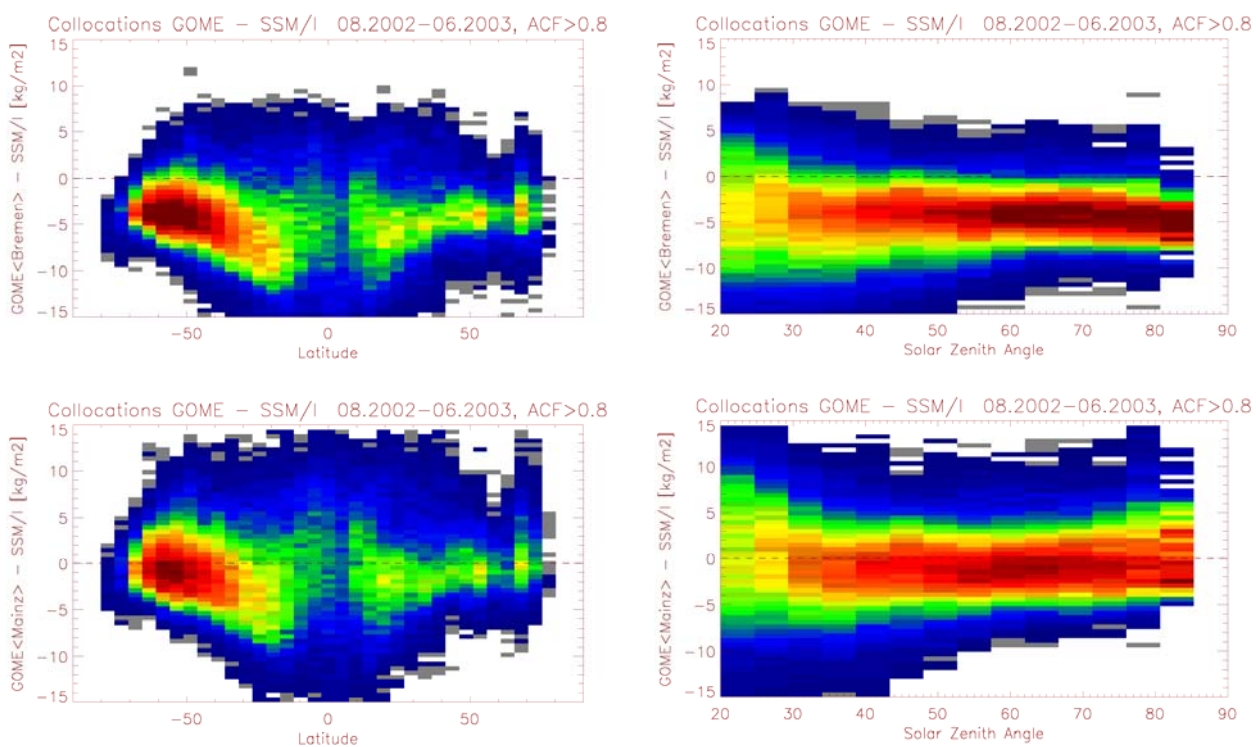


Figure 4: As Fig. 3a, but difference (GOME – SSM/I) [kg/m²] versus latitude (left panels), and versus Solar Zenith Angle (right panels)

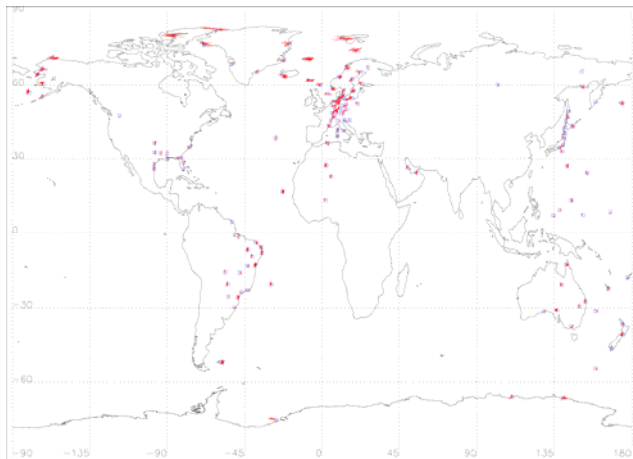


Figure 5: Distribution of ground stations for radiosonde data. The stations are indicated by blue squares; the red lines indicate for each collocation the distance to the centre of the GOME pixel.

COMPARISON TO RADIOSONDE DATA

Radiosonde data taken between August and October 2002 were compared to GOME/ERS-2 data. A total of ~1400 collocations have been used. The geographical distribution of the ground stations is shown in Fig. 5.

Fig. 6 shows the difference between the GOME measurements and the radiosonde measurements.

Bremen data lie systematically slightly below the sonde data; the difference increases for larger H₂O columns.

The distribution of Mainz values peaks at radiosonde values, but the distribution is wider than that of Bremen and asymmetrical. This results in an average value above that of the radiosondes. There is no apparent dependence on H₂O column.

In general, the scatter in the differences are somewhat larger for Mainz than for Bremen.

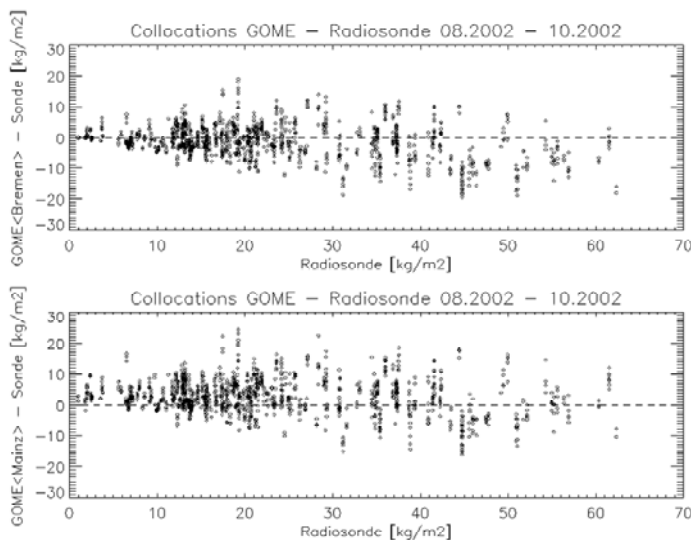


Figure 6 : Difference (GOME – Sonde) versus sonde. Top: H₂O from Bremen. Bottom: H₂O from Mainz

DISCUSSION

For each of the two GOME H₂O retrieval algorithms, a comparison to SSM/I data has been performed in the past (Noël 1999, Wagner 2006). In this study, we have for the first time made a direct comparison of the algorithms: against each other, and against exactly the same data from other instruments.

We find that both algorithms deliver very consistent results w.r.t. each other, although with a systematic bias. The correlation between the two GOME H₂O columns is much better than the correlation to external data. The latter is of course negatively influenced by natural variability, both in time and in space. In addition, both GOME algorithms are affected by clouds in a similar way.

In comparison to radiosonde data, Bremen delivers somewhat lower values and Mainz somewhat higher values, but the scatter is too large to make this significant.

Mainz data are on average somewhat closer to SSM/I F15 data than Bremen, but show somewhat larger scatter. Here we must remark that also the different SSM/I instruments show small differences amongst each other. Moreover, our collocations were strongly biased towards lower H₂O values in the southern Atlantic and southern Pacific, and are possibly not representative for the global average.

Deviations from the strong correlation between the two GOME algorithms occur at high solar zenith angles. Here we observe that Mainz shows a positive SZA trend w.r.t. SSM/I data, while Bremen shows a negative SZA trend.

On the whole, we find that the performance of the two algorithms, in comparison to external data, is balanced. On the basis of this, somewhat limited, dataset there is no strong argument to prefer one algorithm over the other.

One final remark is that both algorithms may be further developed, and that this study reflects the status at the beginning of 2009.

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