**Atmospheric
Chemistry
and Physics
Discussions**

Interactive comment on "Comparison of ground-based Brewer and FTIR total $O_3 monitoring techniques" by M. Schneider et al.$

M. Schneider et al.

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We appreciate all the comments made by the referees and other colleagues. All of them are very welcome and help to further improve the quality of our publication. Below we answer all of them in detail:

Comments of Anonymous Referee #2:

We agree with the Referee: the title will be changed to "Comparison of ground-based Brewer and FTIR total column O_3 monitoring techniques". However, we would like to point out that the FTIR technique produces also O_3 profiles.

(1) The Referee asks for the key component that improves the FTIR data quality: The recipe to reach the high quality is given in Sect. 4 of Schneider and Hase (2008). Naturally, the

measurements must be of certain quality. This includes that the observation geometry, instrumental functions, detector properties are well known and that intensity fluctuations during scanning are avoided or eliminated. At Izaña we perform regular cell measurements (and apply the results in the retrieval), use very linear detectors (photo-voltaic detectors), and perform an absolute calibration of our spectra (by means of internal black body measurements). Furthermore, at Izaña the intensity fluctuation during scanning are relatively small. For all these reasons the Izaña measurements are of high quality and are very well characterised. In this case a simultaneous temperature retrieval strongly improves the O_3 products and is essential to reach a precision of better than 0.5%.

However, if you deal with spectra of poor quality (e.g. measured by an instrument with poorly known instrumental function, insufficiently well known observation geometry, or if you did not correct possible non-linearities and intensity fluctuations), you should first improve the quality of your spectra. Otherwise, it will be difficult to reach a precision of better than 5%.

In case of observations at very low solar angles a very accurate solar tracker is the most important component.

(2) The mid-infrared FTIR measurement program covers the spectral region from 700-4200 cm-1, excluding the region between 1400-1700 cm-1, which is not useful for ground-based measurements due to strong water vapour absorptions. The spectral range is split up in 6 filter regions. For the longer wavelength region we use a filter from 700-1400 cm-1. From this broadband measurement we select the microwindows shown in Fig. 1 in Schneider and Hase (2008) (between 780 and 1015 cm-1).

(3) With spectral bins we refer to an independent measurement point. Spectral windows consist of many neighbouring spectral bins. The applied spectral windows contain several thousand spectral bins. They contain sufficient information to distinguish between the atmospheric absorptions and the extraterrestrial spectrum. The background continuum is calculated from the wings of the absorption lines. In addition we fit a linear straight line to the measured spectra which accounts for instrumental sensitivities and broadband signatures (e.g.

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caused by scattering).

(4) Both the BA02 and the SH07 method apply the same measurements. The only difference is the retrieval approach. The upper panels of Figure 6 depict the difference for all 312 measurements performed between January 2005 and February 2007. The lower panels depict only the measurements for slant column amounts smaller than 400 DU. This is only the case for 132 observations. We additionally plotted the differences for small slant columns since under such conditions wrong ILS assumptions are expected to produce slightly larger errors. Figure 7 shows how the difference between BA02 and SH07 depends on the slant column amounts. The upper panels show the dependence for the time span 4/2005-11/2005 (112 observations) and the lower panels for the time span 12/2005-1/2007 (200 observations). We observe that in 2005 the difference depends stronger on the slant column amounts than in 2006, which we attribute to an insufficient ILS characterisation in 2005.

(5) There is a confusion in the numbers cited by the Referee. If we limit to observations between 12/2005 and 2/2007 we get a correlation coefficient between Brewer and FTIR (BA02) of 0.984 and for Brewer and FTIR (SH07) of 0.996. The 1σ scatter between the measurements reduces from 1.0 % to 0.5 %. These values are already given in the text and document the very important qualitative improvement that is achieved by the SH07 approach.

We will introduce all technical corrections into the final manuscript version.

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Comments of Anonymous Referee #3:

At the end of the abstract we state that both the Brewer and the FTIR are able to continuously monitor total O_3 amounts with a precision of better than 0.4 %. In the Referee's opinion this concluding statement is maybe a bit too strong. Our response:

We agree with the Referee that the word 'continuously' leads to a too strong conclusion, since in 2005 the FTIR performs slightly poorer than expected (although the reasons for this poor performance are understood (see end of Sect. 5.1)). What we clearly demonstrated in our paper is that between 12/2005 and 2/2007 both experiments agree within 0.5 %. During this time span, i.e. when the FTIR instrument was well characterised, both experiments have a precision of better than 0.4 %. There remain two important questions: (A) Can this high precision be achieved everywhere and under different measurement conditions? (B) Can the high precision be maintained over many years (i.e. can experimental drifts be avoided)?

(A) Concerning the Brewer instruments double monochromator and regular calibration experiments are essential for a precision better than 1 %. High precision FTIR data need: the most advanced retrieval stratagies, a spectrometer of type Bruker IFS 120/5 HR (with sufficiently stable ILS), a precise solar tracker, linear detectors, and optionally a DC signal recording (in order to correct possible intensity fluctuation during scanning). All these requirements are listed in Schneider and Hase (2008). Furthermore, a precise characterisation of the instrument is very important. Our studies clearly recommend to perform regular cell measurements and to apply the results of this measurements in the retrieval. If the instrument is a Bruker IFS 120/5 HR and if it is installed on solid ground and under stable conditions it is sufficient to perform these measurements four times per year. We think that this should be practicable. Most of the NDACC FTIR measurements have the potential to measure with a similar precision as in the Izaña FTIR.

(B) In order to assure that the measurements are comparable over many years any degradation of the instrument (optical alignment, experimental elements like mirrors or detectors) has to be avoided or at least well documented. In this context regularly performed calibration

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measurements are essential (i.e. yearly calibration against world traveling and continuous internal standard lamp calibrations for the Brewer and regular cell calibration measurements for the FTIR). Additionally, 'super sites' like Izaña are very important when aiming on long term high precision measurements needed for trend studies. The possibility to compare the data of different experiments is very helpful to identify instrumental drifts: the combination of high quality Brewer and FTIR measurements at a single site makes both experiment much more valuable for trend studies as if they were performed individually at different sites.

We will change the last sentence of the abstract to: "Our study confirms that a combination of FTIR and Brewer measurements, has the potential to continuously monitor total O_3 amounts with a precision of 0.4 %."

Specific questions/comments:

(1) Ok, we will define ETC at its first occurrence.

(2) Ok, we will add a sentence which gives the limits of the applied microwindows.

(3) We agree. These assumptions cause both systematic and random errors.

(4) We think that the text in section 2.3 facilitates a thorough understanding of Table 1. We will try to eliminate redundant elements.

(5) We agree. We will skip the comment about TCCON here.

(6) Here we compare Brewer and FTIR if both measurements are taken within at least 30 minutes. However, in most cases measurements are made within a few minutes. But we agree, maybe it would have been more logical to apply a coincidence criterion based directly on the observed airmass. On the other hand, this would only slightly have changed the results of our comparison. This can be seen in Figs. 11 and 12. The observed airmasses are especially different at large slant column amounts, but the scatter between both experiments does not significantly depend on the slant column amount.

(7) Many thanks for this reference. It nicely confirms our results. We will cite it in the final

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version of our paper.

(8) The difference between the 2005 and 2006/07 data is due to an insufficient characterisation of the FTIR instrument in 2005. The reasons are given at the end of Sect. 5.1. A wrong ILS assumption causes especially large errors at low slant column amounts. This is nicely seen in Figs. 7 and 11. Concerning the Brewer, uncertainties in the ETC and slit function calibration or not ideal filters introduce systematic errors. An error due to incorrect ETC assumptions would also depend on the observed slant column amount. They are larger at low slant column amounts. In 2006/07 we observe a much reduced dependence of the difference Brewer-FTIR on the slant column than in 2005. Consequently the 2006/07 data is less affected by systematic errors of instrumental nature. However, we still observe some dependence and can not fully exclude that the systematic difference between Brewer and FTIR of 4.5 % is partly affected by instrumental errors. Furthermore, neglecting the error due to not ideal filter attenuations introduces an systematic error of around 0.5% (see response (3) to Volodya Savastiouk).

It is very unlikely that the remaining systematic errors due to ILS, ETC, attenuation filters, ... are larger than 1%. Consequently, we can make the following statement: "It is very likely that there is a systematic inconsistency between the infrared and UV spectroscopic coefficients of around 4 %." This is in good agreement to the mentioned laboratory study of Picquet-Varrault et al. (2005).

(9) The step in the time series of the difference between 2005 and 2006/2007 is caused by the FTIR data (see explication at the end of Sect. 5.1). We are quite convinced that this step would not have appeared if in 2005 the conditions had been as stable as in 2006/07 and if the experimental setup had been kept the same. Furthermore, the effects of unstable instrumental characteristics could have been widely reduced if we had performed more cell measurements during 2005. However, in 2005 unfortunately we performed only very few cell measurements. Consequently, the 2005 FTIR data are not representative for the FTIR potential.

(10) The Brewer instrument measures at elevation angles larger than $10°$.

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Comments of Klemens Hocke:

Precision/standard deviation: In our paper we talk about the precision of the Brewer and the FTIR that we deduce from the comparison of both techniques. It is an empirically deduced precision. It is the standard deviation of the difference (or the scatter) between both experiments divided by $\sqrt{2}$. Divided by $\sqrt{2}$ since we compare 2 independent experiments.

Accuracy/systematic difference/standard error of the mean: It is always very difficult if not impossible to empirically determine the accuracy of a measurement technique. One would need an absolute truth as reference. Instead the comparison of two different techniques allows an empirical estimation of the systematic difference between both techniques. This empirically deduced systematic difference is the mean of the difference between both experiments. Due to the scatter between both experiments this mean can only be determined at a certain confidence level and with a certain error. This error is called the standard error of the mean. In our paper we use the 95 % confidence level. The standard error of the mean taking 3 months ensembles is depicted as black area in the left panel of Figs. 3, 6, 9, and 10. This standard error would be smaller if we were using larger ensembles, e.g. an ensemble with all observations made between 12/2005 and 2/2007. In the plots that show the dependence on the slant column amounts we use ensembles covering a radius of 12.5 % of the corresponding slant column amounts (black area in the left panels of Figs. 4, 7, 11, and 12).

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Comments of Volodya Savastiouk:

Volodya Savastiouk suggests an improved analysis algorithm in his paper from 1998. An validation of this algorithm by comparison to other experiments (e.g. FTIR) would be interesting. However, this is beyond the scope of our paper. Our paper validates the standard Brewer algorithm. The validation is made with operational O_3 data. We demonstrate that for carefully calibrated double monochromator instruments the standard Brewer retrieval algorithm produces very precise O_3 data.

(1) The O_3 effective temperature at Izaña is 223K with a little seasonal fluctuation of 5K. The algorithm uses 228K. With the parametrisation of Van Roozendael et al. (1998) we get an uncertainty of 0.4%.

(2) The criterion for the Brewer-Brewer intercomparison is 3 minutes. The criterion for the Brewer-FTIR intercomparison is 30 minutes.

(3) There are five grey filters assuring that an adequate light intensity enters the photomultiplier. The filters are numbered from 1 to 5, whereby filter #1 is weakly attenuating and filter #5 is strongly attenuating. The Brewer #185 is more sensitive than the Brewer #157. Even at large solar elevation angles the filter #3 is sufficiently attenuating for the Brewer #157, whereby for the Brewer #185 occasionally filter #4 is needed. The reason for the noise in the Brewer #185 data is that Brewer #185 frequently switches between filter #3 and #4: the filters are not ideal grey filters, i.e. their attenuation depends weakly on wavelength. This not ideal attenuation is different for each filter and causes a filter dependent error in the retrieved O_3 amounts.

We are able to reduce the noise of Brewer #185 by correcting the error caused by the not ideal grey filters. This correction is not part of the the standard retrieval algorithm, and thus not applied for the data presented in our paper. The correction also reduces the systematic difference of (Brewer-FTIR)/FTIR by 0.5%.

References: Van Roozendael M., Peeters P., Roscoe H.K., De Backer H., Jones A.E., Bartlett

L., Vaughan G., Goutail F., Pommereau J.-P., Kyro E., Wahlstrom C., Braathen G., and Simon P.C.: Validation of Ground-Based Visible Measurements of Total Ozone by Comparison with Dobson and Brewer Spectrophotometers, Journal of Atmospheric Chemistry, 29, 55–83, 1998.

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