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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Technical Note: New trends in column-integrated atmospheric water vapor – Method to harmonize and match long-term records from the FTIR network to radiosonde characteristics" *by* R. Sussmann et al.

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We thank the editor and both referees for their comments which helped to prepare an improved revised manuscript. Our final point-to-point response is given thereafter.

1. Title

Title of the revised manuscript:

"Trends in column-integrated atmospheric water vapor from the FTIR network: Harmonized retrieval strategy and first results for Zugspitze and Jungfraujoch"

We prefer to keep "trend" in the title because

- the goal of our study is to obtain IWV trends; it is not to present an IWV retrieval from FTIR for its own purpose

- the outcome of our paper is the 2 first FTIR-based decadal IWV trends in the literature (for Zugspitze and Jungfraujoch)

- the trend results, i.e., significant differences in trends between Zugspitze and Jungfraujoch are geophysically interesting. The results confirm the relatively new finding that large differences in IWV trends do occur above land, more or less independent on surface temperature trends

- the geophysical discussion of the trend results will be widened in the revised manuscript because a number of reviewer comments focused on various aspects of the trend issue.

2. Abstract – the retrieved quantity is IWV not trend

Corrected.

3. Introduction - water vapor is key climate variable not IWV

Corrected.

4. How does radiosonde dry bias impact retrieved IWV?

Obviously reviewer #2 missed reading our page 13209, line 6: "...we quantified the known effect of the temperature-dependent dry bias (mainly at low temperatures) by applying the correction suggested by Leiterer et al. (2005); to visualize this see Fig. 1 (left center image) in Suortti et al. (2008). The effect of the correction on IWV is only of the order of 1 permille."

5. What does harmonization scientifically mean? Is it homogenization?

It is not "homogenization" in the sense of Ross and Elliott [2001] or Durre et al. [2009]

which is dealing with abrupt changes in the time series median (“change points”) as a result of changes in observing and reporting practices, instrumentation and processing algorithms at (radiosonde) stations. In the FTIR network there is much less need for this kind of “homogenization” because there are no abrupt changes in instrumentation and no drifts that would significantly impact IWV retrievals (see also point 6).The FTIR retrieval of the whole IWV time series is done with one batch run of one algorithm. However, scientists at different FTIR stations would most probably set their algorithms in a different manner leading to differing response characteristics of the IWV retrievals at different stations. This issue is addressed by “station-to-station harmonization” which we understand as a process of setting the algorithms for retrieving IWV from FTIR measurements at different stations in a way to operate consistently. After harmonization, the FTIR sounding systems of different stations (comprising the instruments and retrieval algorithms) should show the same response to true variations in IWV. We will add a short definition to the beginning of Section 2.6.

6. Are there any changes to instrument measuring at a particular station which can introduce change points in the time series?

No, see also response to point 5. The most critical thing to drift in a FTIR spectrometer is the instrumental line shape (ILS). However, any possible degradation in ILS impacts essentially profile retrievals but not the retrieved column integral, which is the target of this paper. Furthermore, the ILS is monitored regularly at all stations. Another possible drift could be in zero level of the spectra due to detector non-linearity in combination with degrading optical components. However, this would impact retrieved columns by typically < 1 %, i.e., 0.02-0.03 mm for mean IWV levels. This is negligible compared to the IWV variations we are talking about in this paper (e.g., 0.8 mm/decade). We will add information on these points to the revised manuscript (Section 2.6).

7. What does it mean "complementing radiosonde data"? It is very well known that radiosondes have different kinds of biases and spurious changes over time, thus they are not reliable for climate trend analysis.

Exactly this problem in radiosonde (and early satellite) records has been the motivation for our FTIR-network-based effort which should be less impacted from such issues (see points 5 and 6). In that sense “complementing radiosonde data” may be a vague formulation. However, we prefer to keep it and thereby acknowledge the achievements from the existing IWV trend studies based on radiosonde (and early satellite) data (and we will add reference to the recent radiosonde-based trend study by Durre et al. [2009]).

8. The argument for no trend at Jungfraujoch is not consistent with previous results. There are studies showing specific humidity increase even in the upper troposphere (e.g., Soden et al., 2005) so one should expect the same for 3.5 km. Is it possible to check how surface temperature is changing for this station and how IWV is co-varying with it?

We thank for this input and agree that our first possible explanation for the differing trends between Zugspitze and Jungfraujoch (altitude dependency, see Sect. 3.3) might be less striking. The more probable explanation would be our second one, namely that significant trend differences may arise above land in spite of similar surface temperature trends due to differing regional impacts. We will consider the following points in extension of Sect 3.3 of our revised manuscript:

a) Soden et al. [2005] presented trend results for global-mean time series. This cannot be compared with our FTIR measurements which are representative on local to regional scales in case of IWV.

b) The surface temperature trends for the time period 1996-2008 are in fact significantly positive and show practically the same magnitude for Zugspitze and Jungfraujoch (0.5 K/decade). However, a co-varying of IWV and surface temperature is not expected above land, see point d).

c) Above the oceans water-vapor column trends are thermodynamically linked (strongly correlated) with SST trends (Bates et al. [2001], Vonder Haar et al. [2005], Wagner et

al. [2006], Mieruch et al. [2008]). This is because of the quasi-infinite ocean reservoir. The column trends are consistent with the assumption of a constant relative humidity. This holds true for both free troposphere and total columns.

d) Above land significant differences and even changes in sign in water vapor trends do occur on relatively small regional scales - in spite of similar surface temperature trends. This holds true for both free troposphere and total column trends (Bates et al. [2001], Vonder Haar et al. [2005], Wagner et al. [2006], Mieruch et al. [2008]).

All in all, our differing Zugspitze and Jungfraujoch trend results represent a confirmation of the relatively new but more and more established finding that, above land, significant differences in water vapor trends do occur on regional scales, in spite of the relatively homogenous surface temperature trends.

9. Does increased density in temporal sampling in the time series impact the trend analysis?

Sampling issues may impact slightly the absolute magnitude of the trend, but sampling issues do not impact the principal decision on the existence of a significant trend (this is the only result exploited in our geophysical interpretation). This may be understood reading the literature on bootstrap resampling (e.g., Gardiner et al. [2008], and references therein). Briefly, the pdf of the magnitude of all water vapor columns comprising the time series of a station is typically right skewed (non-Gaussian) with occasionally very high spikes, especially in summer. In years with less dense measurement sampling, such high values could be missed and this could impact the linear trend result. However, a possible decision on significant trend existence is not impacted. This is because the bootstrap technique resamples the residuals (differences between inter-annual-plus-linear trend model and individual measurement points), i.e., exchanges dates and times of measurements within the series; this is repeated several thousand times and each time a new linear trend is derived. Thereby a pdf of linear trend values is constructed that is consistent with all residuals of the whole time series,

not dependent when in the time series they arose. Therefore, from this pdf a 95 % confidence interval for the trend can be read out to make the decision on significant trend existence (yes/no, depending on whether or not this interval contains zero). The confidence interval tends to become narrower in case of a denser and more uniform sampling. Therefore, the finding of the existence of a significant trend (yes) would not be reversed (no trend) on more uniform sampling. We will add a related explanation to the revised manuscript (Sect. 3.3).

10. Wouldn't it be better to remove seasonal cycle before doing the trend analysis?

There seems to be a misunderstanding: in fact this was done in our study, see also point 9. We will double check and make sure that this is made clear in the revised manuscript.

11. Page 4, 2.1 retrieval strategy: The authors mention that the approach suggested can be included in SFIT2. So far the chapter gives the impression that SFIT2 performs a least square fitting of the total column only. SFIT2 performs also a profile retrieval, based on optimal estimation. It has been shown that the optimal estimation method and the Phillips Tikhonov approach are very similar. This need to be discussed.

We will add an appropriate note to the revised manuscript.

12. The ideal slope retrieved is not very important, the correlation among several datasets is the most important quantity.

There seems to be some misunderstanding (see also point 13): Our strategy is to achieve the same slope for every station in order to guarantee a best-possible correlation among several data sets. We just tune towards the ideal slope because there is no reason for tuning all stations to a non-ideal slope.

13. Harmonisation for stations with different altitudes and latitudes?

We have presented a general concept for harmonization of all NDACC FTIR stations, see page 13212, line 10:

“In order to find a harmonized optimum alpha value for each station, clearly, the best approach would be to use a set of coincident radiosondes and follow the approach described for the Zugspitze in Sect. 2.3 for the other stations. However, if this kind of data is not available for some stations or if the stations have similar geophysical characteristics (IWV levels, station altitude), a simplified approach would be to just use the same value of alpha_opt = 183 as found for the Zugspitze.”

We demonstrated this concept for two stations with similar altitude and latitude (Zugspitze and Garmisch). Demonstration of the harmonization for the full NDACC FTIR network with 20 or so stations is beyond the target of this paper and will be presented in an upcoming publication together with a network-wide trend analysis.

14. The authors might consider to discuss the tropospheric H2O profile retrieval, with its uncertainties, and deviations compared to the sondes, as done here for the total columns.

We understand this would be interesting. However, FTIR retrievals optimized for profile-shape information are different from the one presented in this paper targeting at an optimized and harmonized retrieval of the column integral. By this reason we prefer to keep the focus of this paper on columns.

15. The discussion of the two time series is too short, and does not give any interesting results. The trends at both stations are different, which is not discussed. Since the discussion of a total water column is questionable I suggest to show just one time series

We respectfully disagree:

- Section 3.3 is already two pages long and it will be widened according to points 8 and 9.

- We are quite confident that our time series analysis yielded an interesting result due to positive response on various international workshops and conferences: the differing

Zugspitze and Jungfraujoch trend results represent an important confirmation of the relatively new but more and more established finding (Bates et al. [2001], Vonder Haar et al. [2005], Wagner et al. [2006], Mieruch et al. [2008])that significant differences in water vapor trends do occur on regional scales above land in spite of the relatively homogenous surface temperature trends.

- We discussed possible reasons for the differing trends in Sect. 3.3 which will be widened.

- If the discussion of total water columns would be questionable then a dozen or so frequently cited per reviewed papers on that subject (including the IPCC report) would be questionable as well (see our literature list).

- We do not see the scientific benefit of showing only one time series instead of two.

End of response.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 13199, 2009.