

Interactive comment on “A multi-instrument comparison of integrated water vapour measurements at a high latitude site” by S. A. Buehler et al.

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We thank the reviewer for the constructive comments. Below, reviewer comments are in italics and marked by ‘**R:**’, our response is in normal font and marked by ‘**A:**’.

***R:** This paper is well written and carefully assesses the capability of different techniques to determine the column amount of water vapour (IWV) at a high latitude site. While several papers have been published so far about inter-comparisons of IWV, this paper addresses material that to my knowledge has not been covered in detail and that is of relevance and definitely merits publication: the assessment of a representative-*

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ness error in data sets obtained by instruments at different locations, the correction of altitude from where instruments are operated relative to a reference and finally how the measurements obtained at Kiruna fit in the overall picture.

As the paper is clearly and carefully written and as the figures are well presented and of relevant information content I recommend to accept the paper with some minor corrections.

A: Thanks!

***R:** p. 21016, l 17: and the the repr...*

A: Fixed.

***R:** p. 21017, l 5: Table 6 gives a summary. . . actually it is Table 2*

A: Fixed.

***R:** p. 21019: paragraph starting at l 10 gives the wrong impression that radiosondes measure water vapour up to 20-40km. I suggest that it is stated that conventional sondes measure water vapour reliably up to approx. 8km. But as almost all H₂O is below 5km . . .*

A: Yes, this was poorly formulated. In the revised draft, the passage now reads: “Conventional radiosondes do not reliably measure water vapour at high altitudes (close to or above the tropopause), due to the low temperatures and low humidity concentrations there. However, the total column water vapour value is strongly dominated by the high water vapour concentrations near the surface. We therefore here assume that the radiosonde IWV values are accurate.”

***R:** p. 21020: paragraph about microwave data: This paragraph explains that IWV has been retrieved from measured spectra of ozone as a byproduct of the tropospheric*

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correction. This in principle is possible with limitations as the authors are explaining. The "normal" way to retrieve IWV, and indeed also the column amount of liquid water, is by using a so called dual channel radiometer with frequencies around 20 and 30 GHz. There exist several of these instruments and they are not susceptible to the cloud problem. In order to prevent that the wrong impression is drawn from this paper that microwave radiometers in general suffer from the cloud problem please add two or three sentences and make reference to the dual channel approach. Make clear that the cloud problem arises in your configuration.

A: That was indeed misleading. We made changes in several places to make the difference to dedicated microwave humidity radiometers clear. In the instrument sections, we added: "The instrument used in this study should not be confused with conventional microwave radiometers dedicated to measurements of tropospheric temperature and humidity, which operate at much lower frequency. In their simplest configuration, already described by Westwater [1978], they have two channels, one close to the 22.235 GHz water vapour line, and one at higher frequency, typically around 30 GHz. As explained for example in Rose [2005], the two channels of such instruments can be used to independently measure IWV and the liquid water path (LWP). This is not possible for our instrument, which leads to problems in the presence of clouds, as discussed in Section XXX."

The last paragraph of the microwave results section now reads: "We conclude that the KIMRA microwave data would be useful for IWV studies, but only if a cloud-flag would be added to it, or would be available from some other source. (Estimating cloudiness from the microwave spectra themselves is not possible for this instrument.) It should be kept in mind here that KIMRA is a stratospheric ozone radiometer, not a dedicated tropospheric water vapour and cloud liquid radiometer, as discussed in Section XXX."

To the caption of Table 5 we added: "Note that, with the exception of the Palm et al. study, MW for the other studies typically implies a dual channel microwave radiometer designed for IWV and LWP measurements, not an ozone radiometer as in our study."

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Finally, in the conclusions section, we added a paragraph: "In the case of the KIMRA groundbased microwave data there is the caveat that cloudy data have to be discarded, because KIMRA cannot distinguish the signal of water vapour from cloud liquid. This caveat should not apply to more conventional tropospheric water vapour radiometers."

R: The reference to Raffalski et al., 2002 is to conference proceedings that probably are not easy to obtain. Please give another reference to a paper or give a link to where this Proc. can be downloaded from.

A: There is no better reference, unfortunately. However, the proceedings have been published as a regular book. We have added the ISBN number (92-894-5484-9) to the reference. The book can be purchased for example from the EU bookshop (<http://bookshop.europa.eu/>). We have also added a download link for the article itself (http://www-imk.fzk.de/asf/mira/Publicat/Dokus/Gotebg02_KirunaIRF.pdf).

R: It is difficult to assess how IWV is retrieved in detail as the reference to Palm et al. does not really help as only an empirical equation is given there. I guess that the opacity is determined and that an effective temperature of the troposphere has to be used. This effective temperature can be quite variable, particularly at high latitudes. If this is not taken into consideration in detail this might affect the retrieval of IWV in addition to the cloud effect. May be the authors would like to investigate this effect in the future.

A: There are two separate issues here, (1) the retrieval algorithm description for IWV and (2) the possible contribution of temperature errors to the observed variability. On issue (1) we added a paragraph to the microwave instrument description, that reads: "The actual IWV retrieval procedure is as follows: In order to retrieve ozone profiles the measured spectrum has to be corrected for the varying concentration of tropospheric water vapour, which results in an offset and a scaling of the ozone line. The first step of this correction is a radiative transfer calculation for a standard water vapour profile

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with the actual temperature and pressure profiles (from the ECMWF analysis). In a second step the water vapour profile is scaled, in order to match the offset shown in the measurement. For the ozone retrieval this offset is subtracted while the stratospheric part of the spectrum is scaled by the tropospheric transmission. IWV is calculated by integrating over the scaled water vapour profile.”

On issue (2), we added the following paragraph in the results section: “Our experiment is not strict proof that it is only the clouds that affect the KIMRA measurements. Temperature uncertainties may also play a role. The KIMRA data analysis uses analysis data from ECMWF to estimate the tropospheric temperature profile, and the error implied by that may be correlated with cloudiness, since cloud free conditions are likely to be also meteorologically more stable. We have made no efforts to disentangle these different effects, but suspect that the direct cloud radiative effect is the dominant cause of error.”

R: p. 21030, l 24: Please state what NICAM stands for.

A: Fixed (nonhydrostatic icosahedral atmospheric model).

R: p. 21034, l 12: Please indicate what spectral information is used, HITRAN?

A: HITRAN 2008. We added this information, but with the FTIR instrument description in Section 2.3, where we think it fits better than in the results section.

R: p. 21034 just a suggestion: I could imagine that if you further restrict the selection of microwave data by not using data obtained in case of strong temperature inversions, the comparison would be improved.

A: Yes, maybe. Note that we already have added a more general paragraph on temperature errors here, in response to the reviewer comment on the microwave IWV retrieval method above. The speculation about temperature inversions affecting the microwave

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retrieval is quite plausible. But nevertheless we decided to not add it in the text, since we cannot verify it, because we do not have local temperature profile measurements coincident with the microwave data.

R: p. 21035. I suggest to move para 4.5 after para 4.1 as it refers to Figure 6 top right. Otherwise the para about ERA comes after the reader has gone through Figures 6-8.

A: Done.

R: p. 21049, Table 2 I suggest to add an additional column with information about "bias" or "restrictions" such as GPS – > snow cover of radome FTIR – > clear sky microwaves – > no clouds AMSU – > IWV < 8mm.

A: Done. We did not add the snow cover for the GPS, though, since the snow cover is not a restriction in the sense that we can filter out affected data. Rather, it is one of the possible sources of error in the measurement. The main reason to mention it specifically in the text is to make the point that the snow is supposed to be regularly removed by Esrange staff.

R: p. 21059, Figure 5 The equation stands there without being an equation. Say that it is $\sigma^2 = 0.0131|d| + 0.79$

A: Fixed. (We made it a proper equation, and also moved it from the figure itself to the caption, a more appropriate place for it.)