Diurnal variations in middle atmospheric water vapor by ground-based microwave radiometry

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Response to the comments from Referee #2 on the manuscript acpd-13-3859-2013:

We thank Referee #2 for his comments on our manuscript. In the following, we answer these comments point-by-point. The Referee's comments are given in *green and italic* font, our answer in black.

Specific comments:

- *Page 3860, line 21: "The highest diurnal variations are found in the mesopause. . ." Is this relevant here? The instrument sounds only up to 75 km. At least it should be clarified that this is derived from WACCM simulations only.*

  In the revised manuscript, we clarified that this derived from the WACCM data.

- *Page 3862, lines 7-9: The long term water vapour analysis of Hartogh et al., J. Geophys. Res., 115, D00I17, doi:10.1029/2009JD012364, 2010 and the first paper on stratospheric warmings seen in water vapour at 22 GHz of Seele & Hartogh Geophys. Res. Lett., 27(20), 3309–3312, 2000 should be mentioned here, too.*

  We included these two references.

- *Page 3864, line 21: "For every retrieval, the measured spectra are integrated until they reach a noise level of 0.01." From my understanding you also calibrated the spectra before you integrated them in order to reach the required noise level. So please add this (". . . the measured and calibrated. . .", or just ..."the calibrated. . .)*

  This is true, every individual spectrum is calibrated before we integrate them. So we state now „... the measured and calibrated ...".

- *Line 5: Information about the spectral resolution is missing here. Please add what spectral resolution is baseline here.*

  We added information about the spectal resolution of the two instruments (61 kHz for MIAWARA and 30.5 kHz for MIAWARA-C).

- *Line 8: ". . .can introduce a baseline on. . .." The correct term here would be "baseline ripple", since there is always a baseline, even without ripple.*

  You are correct. We change the term to „baseline ripple".

- *Lines 10-11: ". . . a polynomial fit of order 3 and a sine-fot with 6 periods . . .". What are the periods? How did you determine them? You should mention here that you fitted phases and amplitudes (I guess you did). How did you make sure that the line shape information was not modified incorrectly? Taking into account 9 fit parameters just for the baseline ripple: did you fit with fixed amplitudes and phases over the whole data set? If not, how can you assure that the diurnal variation you see is not an artifact of the baseline ripple fit (since the baseline ripple is depending on the tropospheric opacity as you mention above). Which baseline ripple fitting algorithm did you use and why? Please describe what you did in more detail, addressing these questions.*

  The periods were determined by doing a first retrieval *without* a sinefit and then applying a sinefit with 6 terms to the residuals between the measurements and the forward model from the first

retrieval. The determined dominant periods of these residuals were then used as periods for a second retrieval *with* a sinusoidal fit. Since the baseline fitting is part of the Optimal Estimation, the baseline fit does not modify the line shape information, but we lose information at the lower measurement limit. The amplitudes, periods and phases were fitted individually for each retrieval. Since the baseline ripple only affects the retrieval on the lower altitudes (i.e. below approximately 1 hPa), we do not expect to see an artificial diurnal cycle in water vapor above 1 hPa due to the baseline fit. This is mentioned in the discussion section of the manuscript. In the revised version of the manuscript, the part on the baseline fitting procedure is now described in more detail addressing these questions.

- *Page 3865, lines 8-10: for readers not familiar with WACCM: why was this configuration used? What does "free-running" mean? Does it mean that no nudging/data assimilation was used? Please clarify.*

  „Free-running“ means that there is no nudging to actual atmospheric data. This implies that the „free-running“ model run differs from the actual state of the atmosphere for any particular day. However, since we are interested in diurnal deviations from the mean state, we take the average diurnal cycle in water vapor from this model run as representative for the middle atmosphere. We tried to clarify the section on the model description in the revised version of the manuscript.

- *Lines 24-25: moving average: better use the term "running mean", or even better say that you applied a 1 day low pass filter, i.e. you convolved the data set with a 24 h time window.*

  We now use the term „running mean“ instead instead of „moving average“.

- *Page 3866, lines 22-24: “The remaining terms on the right hand side are the. . .” Better: “. . .on the right hand side determine how the temporal changes are modulated due to zonal, meridional. . ..”*

  Done.

- *Page 3867, line 9: replace “month” by “months”.*

  Done.

- *Line 21: “. . .cycle remains constant in each data set.” Perhaps better “. . . cycle persists in each data set”.*

  We did not change this. „Remains constant“ refers to the constant phase of the diurnal cycle throughout the mesosphere. „Persists“ would be the wrong word to describe this.

- *Page 3868, line 25: I miss an interpretation here. Any idea why the amplitudes may be much larger?*

  An interpretation follows in the discussion section of the manuscript.

- *Page 3869, lines 2-3: “Going down. . . in the morning”. The significance seems not to be very high taking into account the small amplitudes of the diurnal variation. Not convincing at all. Please discuss the significance.*

  We rewrote that sentence such that we state first that the amplitudes of the diurnal variations decrease strongly with decreasing pressure, but that one still sees the phase shift in the diurnal cycle. Since model data are not noisy, even small amplitudes are „significant“, especially in this case here where *all* averaged data points in the morning are below the daily average and *all* averaged data points in the afternoon/evening are higher than the daily average.

- *Lines 8-10: “Similar to . . . in Fig 4.” It is very difficult to distinguish between the different WACCM months data. A slight expansion of the plots and/or use of colors for the individual months rather than symbols may increase to ability to evaluate the WACCM variations.*

  We tried to increase the visibility of the curves for the different months of the WACCM data. But using different colors actually decreases the visibility of the individual curves and expanding the

plots does not help either because the variations in WACCM are very small. We therefore did not change the figure. Instead of looking at a print-out of the manuscript, zooming into the PDF on the computer screen helps to distinguish the different curves.

- *Lines 13-14: It seems not to be very obvious that the diurnal WACCM amplitude increases after convolution with the microwave radiometer averaging kernels. If this is not a mistake, please explain the effect behind this behavior.*

  The convolved WACCM data on 0.05 hPa has a larger diurnal amplitude than the original curve because there is a strong influence from the layers above and below 0.05 hPa due to the convolution. At this particular pressure level, the diurnal variation in water vapor increases strongly with altitude, which is why the convolved data has a stronger diurnal variation than the original curve.

- *Lines 20-22: How were the amplitudes determined (pp or rms)? Is it really WACCM or WACCM convolved?*

  The amplitudes were determined by fitting a sine wave with a period of 24h to the data. It is a sinusoidal amplitude, not a peak-to-peak amplitude. Yes, in the figure which we refer to in the text that you comment on, we show the original WACCM data, not the convolved data.

- *Page 3870, lines 1-2: How? Does it mean that water richer air replaces the photochemically destroyed water? Where does the information come from that the vertical advection damps the chemical induced amplitude? Is this information derived from the plot?*

  You are correct. It is water vapor rich air from lower altitudes that replaces the photo-chemically destroyed water during daytime. The diurnal cycle in vertical advection in the mesopause region is such that there is upwelling during the day and downwelling during the night. This information is derived from the phase (not shown in the plot) of the fitted diurnal sine wave.

- *Lines 11-12: Here a short discussion would be helpful. Obviously there is a strong annual variation of water vapour in the upper mesosphere. The strongest relative diurnal variation due to chemistry appears certainly above the mesopause. This is not reflected in the absolute variation plots. For clarification it would be helpful to add a figure about the relative variation. i.e. the absolute variation/vmr or at least a discussion including numbers.*

  We include numbers of the relative diurnal variations into the discussion section.

- *Page 3872, lines 25-27: An interpretation of these results would be nice (vertical and horizontal water vapour gradients, chemistry, etc.).*

  We rewrote this last section of the conclusions including the discussion about vertical and meridional water vapor gradient. The change in these gradients is the main reason for the change of the dominant process for the diurnal variations in water vapor.

- *Fig. 2 caption: please mention here and in Fig. 4 that the black WACCM curve represents the 5-months average (e.g. WACCM average, same with the convolved data).*

  Done.

- *Fig. 4: How is it possible that the convolved WACCM curve at 0.05 hPa shows a larger amplitude than the original curve (see also comments above)?*

  See answer above.