The quasi 16-day wave in mesospheric water vapor during boreal winter 2011/2012

D. Scheiben, B. Tschanz, K. Hocke, N. Kämpfer, S. Ka and J. J. Oh

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Response on the comments from Referee #2:

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.

General comment:

- *This is a generally clearly written paper which does a nice analysis of variations in mesospheric water vapor on ~16-day scales. My primary concern is with the presentation of the Seoul data, where the 20-day wave which is ~180 degrees out-of-phase compared to the MLS measurements is referred to as "insignificant", despite the fact that it has only a slightly smaller amplitude than the 16-day wave from this Seoul. There is also an apparently inconsistency in the manuscript between sensitivity claims made in Section 2 and variations of H_2O with pressure mentioned in Section 4. Below are detailed comments.*

Specific comments:

- *By implication it seems that there were no gaps in the Seoul data over the 4-month period shown. Is this true?*

  This is true, there were no data gaps in the Seoul data. However, the retrieval for the Seoul radiometer SWARA uses a fixed-noise-level integration of the measured spectra (i.e., the measured spectra are integrated until a certain noise level is reached). Therefore, the temporal resolution is varying. For the data period of this study, the longest integration time required to reach the given noise level was 2 days, hence much less than the period of the 16-day wave.

- *In Section 2 it is stated that "Data used for the analyses performed in this study are only considered if the measurement contribution to the retrievals is higher than 0.8 …". This statement that >80% of the contribution comes from the measurements is inconsistent with the authors statement in 4.1 that "the increase in the relative wave amplitude cannot be observed in our data due to the decrease of measurement sensitivity above 0.02 hPa".*

  The increase in the relative wave amplitude with altitude only starts just at the upper measurement limit of our radiometers, i.e., above 0.02 hPa. This is the reason why the increase in relative wave amplitude cannot be observed with our radiometers, since we simply do not have measurement sensitivity above 0.02 hPa. We have rewritten this section in the revised manuscript to clarify why we do not observe the increase in relative wave amplitude above 0.02 hPa.

- *"Since the data from Aura MLS on 0.05 hPa has a vertical resolution comparable to the one from the ground-based microwave radiometers" – what is the vertical resolution of Aura MLS at 0.05 hPa?*

  The vertical resolution of the water vapour retrieval of Aura MLS at 0.05 hPa is approximately 8 km (according to the data quality document for the Aura MLS v3.3 retrievals). The vertical resolution of our ground-based radiometers at the same pressure level is approximately 14 km. As both satellite and ground-based instruments have a relatively low vertical resolution, it can be regarded as comparable.

- *In Figure 5 the phase of the wave at Seoul appears to be almost exactly 180 degrees out of phase with respect to the MLS wave at that point. The authors claim that "The phase difference in Seoul can be explained by the fact that the 20 day wave above Seoul is practically inexistent and therefore the phase difference is insignificant.", but the amplitude of the 20 day wave shown on Figure 5 (~2%) is only slightly smaller than that of the 16-day wave at Seoul shown on Figure 6 (which is 2-3%). Given this discrepancy, it is not obvious to that the Seoul measurements contain any useful information on these waves. The authors need to either: 1) state clearly that the amplitude of the 20-day wave in the Seoul data is comparable to that of the 16-day wave and which has a phase nearly 180 degrees out of phase with MLS data. 2) show somehow, by comparison with MLS, that there is useful information about these waves in the Seoul data. 3) drop the Seoul data.*
  The problem here is that it is very difficult to adequately determine the phase of a weak wave that is superposed by measurement noise, such as the 20-day and the 16-day wave at Seoul. The quasi 16-day wave is very weak at Seoul, which is shown by the ground-based *and* the satellite data. This is why we think that there *is* useful information in our ground-based Seoul data, although there is the discrepancy in the phase of the observed 20-day wave at Seoul. In the revised manuscript, we therefore clearly state that the amplitudes of the 20-day wave at Seoul observed by ground-based and satellite data are comparable and that the amplitude is very weak and that we therefore have the problem of adequately determine the phase of the weak 20-day wave. In the revised manuscript, we reworded the corresponding sentences according to the explanation given here.

- *Are the MLS measurement longitudes shown in Figure 5 the longitudes of the actual measurements, or have they been put on a standard grid? Are the MLS measurements at different times of day combined? Is there a diurnal difference in the MLS measurements at 0.05 hPa at the ~2% level of the smallest observed waves?*
  Both day and night measurements of the Aura MLS data have been averaged into bins of 20 degrees longitude and 2 degrees latitude with the central latitude being the latitudes of the measurement locations of the ground-based radiometers. This information is now contained in the revised manuscript. Diurnal differences in water vapour at 0.05 hPa are not expected to exceed 1% in a statistical average. Even if there was a diurnal cycle with an amplitude of more than 1%, there would be no aliasing effect on the investigation of the quasi 16-day wave, since the period of the diurnal variation (1 day) is much less than 16 days.

- *The authors point out that no water vapor variations will be seen unless there are vertical and/or horizontal gradients. Can they distinguish between these? Given the observed vertical/horizontal gradients, what are the changes in pressure/latitude required to produce the observed variations?*
  We cannot distinguish between vertical and horizontal gradients that lead to the quasi 16-day waves observed. However, we can estimate the vertical and/or meridional movement of air required to match the observed changes in water vapour.
  Assuming solely vertical movement of air and a vertical gradient of 0.25 ppm_v H_2O per km at 0.05 hPa during typical mid-latitudinal winter conditions, a *vertical amplitude of 1.6 km* is required to generate a wave in water vapour at 0.05 hPa as observed with an amplitude of 0.4 ppm_v. For a wave with a period of 16 days, this relates to a vertical motion of up to 7 mm/s. Assuming solely meridional movement of air and a meridional gradient of 0.05 ppm_v H_2O per degree at 0.05 hPa during typical mid-latitudinal winter conditions, a *meridional amplitude of 8 degrees* latitude is required to generate a wave in water vapour at 0.05 hPa as observed with an amplitude of 0.4 ppm_v.
  Both the amplitudes of vertical and meriodional movements of air (1.6 km and 8 degrees, respectively) seem realistic for the generation of the observed quasi 16-day wave. In reality, it is most probably a combination of vertical and meriodional advection that leads to the observed quasi 16-day wave.