Comments on the ACPD manuscript entitled “Variability of water vapour in the Arctic stratosphere” by Laura Thölix, Leif Backman, Rigel Kivi and Alexey Karpechko.

The present paper discusses the variability of water vapour in the Arctic stratosphere. For that mainly simulations from FinROSE and ECMWF are used. In addition also observations from Aura/MLS, frost point hygrometers and CALIPSO are considered. The manuscript is quite comprehensive in the meaning that it touches upon a wide range topics that concern Arctic water vapour. This comprises water vapour variability in general, but focuses also on the winter season and polar stratospheric clouds. Particular in that sense it is an interesting manuscript. My main criticism is that it just touches upon all these interesting topics, scratching at the surface, many details and discussions are missing. There is much potential and I can easily see the manuscript being split in two, as there is so much interesting stuff. For time being I go along with major revisions. Please find my detailed comments below:

Comments:

- Abstract in general: There are a few abbreviations here, but none of them is defined. As this is typically the first encounter I prefer to have them here already. Later in the manuscript there some abbreviations that remain undefined. This should be not the case.

- page 1, line 5 to 7: I presume you are referring here to the top panel of Fig. 4. That is the only time observations are involved at where the timing matches. This should be made clear.

- page 1, line 9 to 12: There are two sentences in a row that convey almost the same information. In the first sentence the message comes across more uncertain or speculative though.

- page 2, lines 35 and 36: Somehow the sentence concerning NAT clouds does not fit the natural flow here.

- page 2, line 41 to 44: You could add a reference to the model evaluation study by Gettleman et al. (2009) that shows the simulated change of the tropical tropopause. Also increasing methane could be added.

- page 2, line 51: “… is therefore controlled by …” - Somehow I would squeeze in here “largely” or “to a first order” as there are other processes that can contribute on different scales.

- page 3, line 61 to 63: Satellite measurement across the tropopause are challenging, not only for water vapour. But this is not the reason for why there are no long-term observations.

- page 3, line 69: "… continuous …" - This is really a question how do you define that. If you use the daily coverage of Aura/MLS as reference, then UARS/MLS was not as continuous. Typically there was coverage between 34° on one hemisphere and 80° on the other hemisphere, switching roughly every five weeks by a 180° yaw manoeuvre of the spacecraft. Hence in the tropics and subtropics there was "continuous" (daily) coverage while at mid- and high latitudes this was not the case. The balloon measurements at Boulder are typically performed only once a month, just to give another example.

- page 3, lines 69 and 70: "… since 2004 …" - This only applies for Aura/MLS but not for UARS/MLS.

- page 3, line 70 to 72: In the list also POAM III (1998 - 2005), SAGE III (2001 - 2005) and SOFIE (since 2007) are missing. POAM and SOFIE focused actually only on the polar regions. MIPAS and SMR (at least in boreal winter) had/have coverage all the way to the poles, while MLS only goes to 82° latitude.

- page 3, line 87 to 89: There is more to these negative trends as they are related to the sudden water vapour in 2000 (e.g. Hegglin et al., 2014). After a few years with very low water vapour mixing ratios a recovery started in 2005. In 2011 again a substantial drop was observed, but this one was more short-lived (Urban et al., 2014).

- page 3, line 89 to 91: The study by Hegglin et al. (2014) should me mentioned here. Even though there is no focus on polar latitudes, they show at least water vapour trends up to 80° latitude for the time period between the late 1980s and 2010. The reported trends in the lower stratosphere are actually negative. On the other hand one should acknowledge that the coverage before 1998 using HALOE and SAGE II was far from optimal and that some caution is warranted.

- page 4, line 108: "ctm" - Does this refer to CTM = Chemistry Transport Model?

- page 4, line 117: For me prescription of the number density profile for the individual PSC types seems like a profound restriction. Has that been quantified?

- page 4, line 123 to 125: Where is the boundary for the prescribed tropospheric water vapour? If it is too close to the tropopause, in particular in the tropics, you may get a dry bias due to the cold bias of ECMWF there. A more general question at this point regards

the complexity of the methane oxidation scheme? Depending on that you may get different trend estimate, in particular in the upper part of the stratosphere were methane oxidation is more effective. Does FinROSE include water vapour production from the molecular hydrogen reservoir (Wrotny et al., 2010)?

- page 5, line 138 to 140: This sentence seems to imply that satellite measurements are not accurate, which I would definitely argue against. Please rephrase.

- page 5, line 143 to 159: This whole part needs a better structure. There is some jumping between campaigns and instruments; back and forth. Maybe a summary table with the two campaigns and the relevant instruments could be helpful. CFH observations are mentioned for both campaigns but then only used for the second campaign. Why? In the paragraph following these lines Aura/MLS and CALIPSO are described, but they only contribute to the second campaign. That should be made clear.

- page 6, line 176 to 178: Given this statement here, the section description in the final part of the introduction and earlier experiences of mine with ECMWF water vapour I wondered a couple of times along the manuscript why ECMWF water vapour is shown at all. I have to admit that compared to earlier incarnations of this data product the current water vapour data set looks relatively fair but you should have in mind that is based on a simple methane oxidation parametrisation and relaxes to 6 ppmv at the stratopause. Overall, for this analysis here, I do not see the value and would focus more on the observations.

- page 7, line 205 to 207: I guess the standard deviation is simply derived from all the profiles that fitted your coincidence criteria. Maybe the approach could be made clearer. The standard deviation can be quite tricky to interpret. For the observations measurement and retrieval characteristics contribute to the standard deviation (it is not all natural variability); for the simulations the model setup plays a role. That should be kept in mind!

- page 8, lines 252 and 253: Why does the time axis in Fig. 4 starts first in 1994?

- page 8, line 257 to 260: This discrepancy between the simulations and observations certainly warrants more attention. Effects of the coarser altitude resolution of Aura/MLS compared to the simulations certainly, I think, can be neglected here. The only exception in general would be if there are dehydration features or if you would look closer to the hygropause. But 56 hPa seems fine given a typical MLS altitude resolution of about 3 km for water vapour in this altitude range. Also in the figure it looks like as there may be a time delay between the simulations and the observations that may hint on different transport time scales.

- page 8 and 9, line 270 to 288: I definitely think there should be more analysis and discussion of the variability here. After all it is the main key topic of the manuscript. The analysis may involve a thorough regression analysis. In terms of discussion there is more than these linear short-term changes (the term trend feels somewhat exaggerated), like those drops in water vapour (e.g. Randel et al., 2006; Urban et al., 2014), influence of sudden stratospheric warmings (e.g. Straub et al., 2012; Tschanz and Kämpfer, 2015) or the QBO that shows up quite prominently. Also considering more the Aura/MLS measurements would be great.

- page 9, lines 277 and 278: After the drop in 2000/2001 there was a recovery afterwards.

- page 9, line 278 to 280: "As for …" - Somehow this does not sound the right way. The implication by Hegglin et al. (2014) that observations at Boulder should not be generalised in to describe the global stratosphere has in my opinion two sides. There could be local effects that would make this location different from the global behaviour. However, for the time being, it seems that there is more a discrepancy between two sets of data, i.e. the data from the frost point hygrometers and the satellite data merged using a nudged model. The last word has certainly not been spoken regarding this inconsistency.

- page 9, line 283 and 288: The QBO signal is more general due to its influence on the Brewer-Dobson circulation. That affects the tropical tropopause temperatures but also along the way there are variations of the transport. Mixing is certainly less important, except when the polar vortex breaks up.

- page 10, line 328 to 339: I seek more discussion on Fig 6. I am definitely not a PSC expert. Hence my first order expectation would be a linear relationship between the cold area and the PSC area. Hence the large cold areas with small PSC areas stick out for me. Why is that? I do not think that water vapour is the decisive factor here and there are reddish, greenish and orange colours visible there. The relationship between large cold areas and PSC areas accompanied by high water vapour seems more clear. A large cold area means you have a stable vortex where moist air from the stratopause is brought down to the lower stratosphere. This has been recently addressed by Khosrawi et al. (2015). In that regard it makes sense to me to look at the vortex average water vapour volume mixing ratio. Beyond that I really wondered why this was used given the more localised dehydration layers in connection with PSC. What temperatures do you use to get the area for $T < 190$ K for CALIPSO? At least I am not aware that CALIPSO provides temperatures.

- page 11, line 346: "… the vortex moved to the south …" - Really to the south? At least my simple expectation would be different. Or was this something filament-like?

- page 11, lines 346 and 347: "… mixing with moister mid-latitude air …" - Under typical conditions, leaving dehydration aside, the water vapour mixing ratios in the lower stratosphere are lower outside the polar vortex than inside (e.g. Nassar et al., 2005; Lossow et al., 2009). If there is dehydration than things may be the opposite, but it is unclear if there was still dehydration by 11 February 2011.

- page 12, line 390 to 394: I find that that the changes in water vapour are very difficult to see. Frost point temperatures are certainly not optimal here.

- figure 2: Could you use the x-axis range more efficient? Also a legend would be very helpful!

- figure 4: I wondered if it is an idea to split Fig. 4 into two figures, one showing the absolute volume mixing ratios at Sodankylä (top panel) and the other showing the residuals for 70°N - 90°N. This change in latitude, data sets shown and lacking legends made it difficult to digest. I do not know how often I read the caption. Having Aura/MLS data in the residual plots would be great too.

- figure 7: The colour bars have no annotation of what is shown. Also there is some overlap of the x-axis labels, which does not look particular nice.

Technical corrections:

- page 4, line 94: replace "… polar regions and the mesosphere …" by "polar regions, the mesosphere …".

- page 4, lines 127 and 128: "Carbon dioxide CO_2 …" should likely be "Carbon dioxide (CO_2) …".

- page 5, line 143: Something seems to be missing here at the beginning of the sentence.

- page 9, line 205: "… ration …" should read "… ratio … " or "… ratios …".

- page 10, line 336: "… allways …" should read "… always …".

- page 11, line 367: "… at level 56 hPa …" should read "… at the level of 56 hPa …".

- page 11, line 368: "… timeperiod …" should read "… time period …".

- page 13, line 435: "… AURA …" should read "… Aura …".

- page 25, line 435: "All the maps are from 56 hPa altitude" could read "All maps consider the 56 hPa pressure level.".

References:

- Gettelman, A., et al., "The tropical tropopause layer 1960 – 2100", *Atmospheric Chemistry & Physics*, 9, 1621 – 1637, 2009.

- Hegglin, M. I., et al., "Vertical structure of stratospheric water vapour trends derived from merged satellite data", *Nature Geoscience*, 7, 768 – 776, doi:10.1038/ngeo2236, 2014.

- Khosrawi, F., et al., "Sensitivity of polar stratospheric cloud formation to changes in water vapour and temperature", *Atmospheric Chemistry & Physics Discussions*, 15, 17,743 – 17,796, doi:10.5194/acpd-15-17743-2015, 2015.

- Lossow, S., et al., "Middle atmospheric water vapour and dynamics in the vicinity of the polar vortex during the Hygrosonde-2 campaign", *Atmospheric Chemistry & Physics*, 9, 4407 – 4417, doi:10.5194/acp-9-4407-2009, 2009.

- Nassar, R., et al., "ACE-FTS measurements across the edge of the winter 2004 Arctic vortex", *Geophysical Research Letters*, 32, L15S04, doi: 10.1029/2005GL022671, 2005.

- Randel, W. J., et al., "Decreases in stratospheric water vapor after 2001: Links to changes in the tropical tropopause and the Brewer-Dobson circulation", *Journal of Geophysical Research*, 111(D10), D12,312, doi: 10.1029/2005JD006744, 2006.

- Straub, C., et al., "Transport of mesospheric H_2O during and after the stratospheric sudden warming of January 2010: observation and simulation", *Atmospheric Chemistry & Physics*, 12, 5413 – 5427, doi:10.5194/acp- 12-5413-2012, 2012.

- Tschanz, B., and N. Kämpfer, "Signatures of the 2-day wave and sudden stratospheric warmings in Arctic water vapour observed by ground-based microwave radiometry", *Atmospheric Chemistry & Physics*, 15, 5099 – 5108, doi:10.5194/acp-15-5099-2015, 2015.

- Urban, J., et al., "Another drop in water vapor", *EOS Transactions*, 95, 245 – 246, doi: 10.1002/2014EO270001, 2014.

- Wrotny, J. E., et al., “Total hydrogen budget of the equatorial upper stratosphere”, *Journal of Geophysical Research*, 115(D14), D04,302, doi:10.1029/2009JD012135, 2010.