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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Sensitivities of modelled water vapour in the lower stratosphere: temperature uncertainty, effects of horizontal transport and small-scale mixing" *by* Liubov Poshyvailo et al.

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General Comments

This discussion paper addresses the impact of two important yet poorly understood processes controlling water vapor in the UTLS: horizontal transport and small-scale mixing. The CLaMS model is well suited to study this problem. The results help to constrain parameterizations of these processes in climate models, and thus the scientific merit of this paper is significant. My main criticism concerns the somewhat confus-

ing interpretation of the transport barrier simulation results in relation to other metrics such as age of air. The paper would greatly benefit from clearer descriptions and interpretations of the results, aided by improved visualization of some of the figures. I also strongly suggest that the paper focus on the impacts of horizontal transport and small-scale mixing only, which are the novel aspects of this study. The fact that different reanalysis datasets with different tropical tropopause temperatures yield different water vapor results is well known and not particularly interesting. In my opinion, this paper is suitable for publication in Atmospheric Chemistry and Physics after consideration of the specific comments and suggestions provided in detail below.

Major Specific Comments

1. This study describes the effects of three processes - dehydration controlled by tropical tropopause temperature, horizontal transport, and small-scale mixing - on stratospheric H2O. While the results of the latter two processes are novel and interesting, the impact of tropical tropopause temperatures is well known and distracts from the overall significance of this study. Therefore, I strongly suggest that the study focus on the impacts of horizontal transport and small-scale mixing only. There have been many studies that have carefully examined this topic: trajectory modeling sensitivity to temperatures (e.g., Wang et al., 2015), comparison between reanalysis and observed (aircraft, radiosonde) temperatures in the TTL and effect on TTL H2O (e.g., Ueyama et al., 2014, 2015), impact of waves on temperature and dehydration in the TTL (e.g., Jensen and Pfister, 2004; Kim and Alexander, 2015). At least some of these literatures should be referenced to more accurately reflect our current understanding of this issue: while H2O simulations are highly sensitive to tropical tropopause temperatures that still come with some uncertainty, we have a better handle on the accuracy of these temperatures than this paper implies. You may also want to check S-RIP activities and reports (https://s-rip.ees.hokudai.ac.jp/index.html) that discuss the temperature differences between the reanalysis products.

2. The discussion of the effects of the transport barriers (p12-14) could be improved. a.

Specifically, please explain how you are able to discern the direction of transport from these experiments. I understand that the PDFs (Fig. 6) provide a clue, but it is difficult to interpret the relative importance of the two-way transports from these graphs. For example, the barrier at 15N/S makes the tropics drier, which is interpreted as the the lack of equatorward transport of moist air from the subtropics. However, the PDFs in Fig. 6b indicate that there are also more low H2O mixing ratios in the tropics in the BAR-15 experiment (not just a decrease in high H2O mixing ratios). Therefore, this suggests that the drier tropics in BAR-15 simulation is also due to the dry air not being transported out of the tropics towards the higher latitudes. Please clarify these points. b. Also, the relationship to the AoA results seems inconsistent at times. The barrier at 35N makes NH extratropics slightly wetter (Fig. 6c), which is explained as a result of the lack of poleward transport of high H2O mixing ratios from the subtropics. The tropical mean H2O is unaffected. On the other hand, the barrier at 35N decreases the AoA globally (Fig. 7b), which suggests the importance of the recirculation of aged air from the extratropics into the tropics. Perhaps I'm confusing recirculation with transport, and thus a brief explanation of these terminology in the context of Fig. 11 would be beneficial. c. Please also clarify what you mean on p14, L1-2: "The fact that his drying occurs only with . . .." d. The second paragraph of p14 states that horizontal transport exports dry (moist) air out of the tropics in the winter (summer). This is followed by a statement that "the entire annual cycle of LS H2O in the NH extratropics is related to horizontal transport out of the subtropics". There is some disconnect between these two statements that need to be clarified.

3. Please reconcile the seemingly contradicting results between Fig. 6c vs. Figs. 8acd and Figs. 9acd. Fig. 6c suggests that the lower stratosphere in the NH extratropics is wetter with BAR-15 than with BAR-35, but the opposite seems to be true in Figs. 8 and 9.

4. p18, L3 - p19, L8: The descriptions and explanations provided in this section are confusing. For example, although it states (on p18, L3-4) that a clear response to

mixing is found in the lower stratosphere below 430K (i.e., moistening with increased small-scale mixing), I see significant drying in the UTLS $\sim$350K with the addition of weak small-scale mixing in Figs. 12b and f. Also, on p18, L15, it states that an analogous (drying) signal is found in methane (Fig. 13b), but the figure shows moistening?

5. In the description about small-scale mixing in the CLaMS model, the authors cite the Riese et al. (2012) study. Please include a more detailed explanation of how realistic this mixing parameterization might be, and how it relates to observations. I am assuming that the small-scale mixing refers to both horizontal and vertical diffusion. A recent study by Podglajen et al. (2017) quantified the magnitude of vertical diffusion in the TTL using aircraft observations and found the average diffusivity to be about 0.1 m2s-1 with a strong vertical gradient. Ueyama et al. (2015) found that the "an increase in vertical diffusivity coefficient by 2 orders of magnitude (from 0.001 to 0.1 m2s-1) moistens near the cold point tropopause by approximately 0.5 ppmv". How do your results based on your small-scale mixing parameterization compare to these results? Also, on p6 L15, why are there two numbers for the Lyapunov coefficients that lead to good agreement between observations and simulations?

6. Some of the terminology needs to be better described. For example, please define what you mean by stratospheric H2O (e.g., p14, L1: "global stratosphere becomes substantially drier (up to about 1 ppmv)". Is this a vertically integrated quantity averaged from 90S to 90N? Also, the term "subtropics" is used rather liberally. Sometimes it refers to barriers at 15N/S and other times it refers to the barriers at 35N/S, which can be very confusing. Please clarify your definition and be consistent throughout the text. Along the same line, the barrier is sometimes defined at a specific latitude (e.g., "at 15S/S", p14 L2) and other times within a range of latitudes (e.g., "between 10 and 30 S/N", p13 L23)

7. The Introduction lacks a discussion on the role of convection in lower stratospheric (or TTL) H2O. It is briefly mentioned in the Discussion Section as a possible explanation for the biases in JRA-55 simulations, but convection is an important feature that

needs to be discussed early on. The role of convectively-injected ice is discussed in the Introduction, but its relative importance on stratospheric humidity is still a topic of debate.

8. Figures 6 and 10: The vertical lines are very difficult to see because of the size of the plots and the overlapping lines (e.g., black solid line in panel c?). Vertically stacked panels like Fig. 17 are much easier to see.

Minor Specific Comments

1. It would be helpful to provide the approximate magnitudes (∼x ppmv) of the effects of horizontal mixing and small-scale mixing on stratospheric H2O in the Abstract and Conclusions (e.g., in the sentence at the top of p22, "Furthermore, our results suggest that the NH subtropics are a critical source region of moisture for the global stratosphere, . . ."). It is worth pointing out that the impacts of these processes are of same order of magnitude as the impact of temperature difference of ∼2K.

2. Dessler et al. (2013) paper may not be the most appropriate reference for the first sentence of the Introduction, unless you're specifically emphasizing the feedback effects of stratospheric water vapor. In addition to the papers by Forster and Shine, I would consider the Shindell (2001) paper instead.

3. p 2, L13-14: In your discussion of the rapid transport from the tropics to mid latitudes above the subtropical jets, are you distinguishing between transports in the "tropically controlled transition region" vs. the shallow branch of the Brewer-Dobson circulation, as in Rosenlof et al. (1997)?

4. p2, L15-19: You may want to clarify that the dehydration occurs due to the nucleation and sedimentation of ice crystals, which in essence is a microphysical process controlled by TTL temperatures. Hardiman et al. (2015), which is a study based on global climate models that have difficulty simulating cloud microphysical processes, is not the most appropriate reference here. I would consider citing Jensen et al. (2004,

2005, 2012) studies on the modeling of detailed cloud microphysical processes. Several papers have examined the effect of cloud microphysical processes on humidity of the TTL and stratosphere using cloud models of varying complexity (e.g., Schoeberl et al., 2014; Ueyama et al., 2015).

5. p3, L3-6: I see now that the discussion of temperature and freeze-drying process appears here. I would move this ("The tropical stratospheric entry H2O mixing ratios . . . temperature and vertical velocity fields.") after the paragraph on TTL transport processes in the previous page.

6. p3, L8-10: What exactly are you referring to with respect to the relationship between summer max tropical H2O and the monsoons? Mixing processes? Deep convection in the monsoon regions? Relatively high tropopause heights?

7. p 3, L18-24: The discussion of TWV here seems a bit out of place. Could you better tie this to the overall discussion about processes that affect lower stratospheric H2O?

8. p5, L20: In the sentence, "Thus, we use the fifth year. . .for our further analysis", make it clear that you are referring to the analysis of the sensitivity simulations.

9. Table 2: What is "PR"? Would a graph be better for illustrating your point?

10. p7, L1: Is "10-15%" an annual mean value?

11. Figure 2: What is the reason for showing the annual cycle at 400K? What about the 380K level (Figs. 5 and 16 are based on this level)? A brief statement of the sensitivity of your results to the different potential temperatures in the lower stratosphere may be useful. Also, is the MLS averaging kernel applied to the model data for a more accurate comparison to MLS data?

12. p8, L9-10: "The impact of horizontal transport. . ..mixing strength covered." Effects look very similar to me. I would suggest removing this statement to avoid confusion.

13. Figure 5: There are four temperature contours in panels a and b, but only three

contour levels are mentioned in the caption. Devise a better way to label these temperature contours?

14. p11, L7: Please be more specific about what you mean by “agree slightly better” (quantify).

15. p11, L14: I think you mean to say “. . . show that the interhemispheric transport is rather unimportant. . .”

16. p13, L11: Where is the “double peak structure”?

17. Figures 12 and 13: Why are these two figures separated? It makes more sense to combine the two and make a 4 x 4 panel figure: TWV, H2O, 2CH4, AoA. Does the sum of Fig. 12a and Fig. 13b equal Fig. 12e?

18. Figure 15: The lines in these figures are very difficult to see.

19. p20, top: It appears that during boreal summer, weak mixing moistens the Asian monsoon region while very strong mixing moistens the N American monsoon region. Do you have an explanation for this interesting result?

20. p20, L30-: Where do you get “380K”? The explanation you provide is certainly plausible, but do these biases occur in mid and high latitudes where the H2O biases are observed?

21. Figure 17: It would be helpful to add MLS data to these plots.

Technical Corrections

1. p6, L15: “. . ..our study, . . .”

2. p8, L7: “. . . tropical (10S-10N) entry of H2O . . .”

3. p8, L14: Rewrite this sentence “. . . reaches the values of $\sim$0.8 ppmv” as “. . . drying of $\sim$0.8 ppmv in (month)”.

4. p10, L17: “. . . LS H2O between MLS and ClaMS simulations . . .”

5. p11, L13; p12, L1: I’m slightly confused by the use of the term “vanishing difference”. Are the differences decreasing over time?

6. p 12, L3: “. . . barrier at 15 N/S changes the PDF . . .”

7. p12, L5: “. . . (blue line in Fig 6b), . . .”

8. p12, L7: Rearrange the sentence: “equatorial transport barrier has no effect and cross-equatorial transport is unimportant”

9. p14, L9: Replace with “. . .very weak drying effect on. . .”

10. p16, L5: I’m not sure what you mean by “Therefore”

11. p16, L12: “ H2O (a-d) and total water (e-h)”

12. p20, L18: “On the contrary, . . .” is a very long sentence.

References

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Schoeberl, M. R., et al. (2014): Cloud formation, convection, and stratospheric dehydration.

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