Author Comment to Referee #1

ACP Discussions doi: 10.5194/acp-2016-463
(Editor - Peter Haynes)
'Long-range transport pathways of tropospheric source gases originating in Asia into the northern lower stratosphere during the Asian monsoon season 2012'

We thank Referee #1 for further guidance on how to to revise our paper. Following the reviewers advice we have elaborated some minor points, which strengthen our findings. Our reply to the reviewer comments is listed in detail below. Questions and comments of the referee are shown in italics.

This paper presents an analysis of the evolution and transport of air with emission sources in the Asian monsoon region to the northern hemisphere extratropical lower stratosphere using primarily output from the Chemical Lagrangian Model of the Stratosphere (CLaMS) driven with winds from the ERA-Interim reanalysis. Aircraft observations are used to establish confidence in the model simulations and demonstrate linkages between transport signatures and air masses observed in the extratopical lower stratosphere downstream. The main conclusions of the study are that the air lofted into the Asian monsoon anticyclone is confined to the tropical upper troposphere during the monsoon season, but is transported poleward into the extratropical lower stratosphere during the breakup of the Asian monsoon anticyclone in early fall via mostly Rossby wave breaking events over the Pacific and Atlantic ocean basins. The paper is well-detailed, well-structured, and well-reasoned. I do not find any fundamental errors in the analysis or questionable claims in the attendant discussion, but I believe the paper will benefit from a bit more cohesion of arguments throughout and a bit more analysis of the seasonality of transport. I recommend that the paper be considered for publication after mostly minor revisions. My general and specific comments to help guide the revisions are provided below.

General Comments

1. The linkages between transport of the monsoon upper troposphere air to the extratropical lower stratosphere and poleward Rossby wave breaking downstream of the anticyclone are clearly established in the manuscript. However, I feel the authors miss an opportunity to strengthen these points as their analysis expands in the latter part of the paper. Namely, the recent climatological studies of Rossby wave breaking cited in the paper provide support for the observed seasonality and timing of "flooding" of moist monsoon air into the extratropical lower stratosphere and for the dominant locations of poleward wave breaking events pointed out in Figure 16. Such additional detail on these linkages will provide better continuity in the Results section and strengthen the presentation and discussion of the conceptual model given in Figure 16.

Many thanks for this suggestion. We agree that such details would strengthen our results and added therefore the following paragraph to the introduction:

"Exchange of air masses from the troposphere to the stratosphere occurs preferably in poleward flow structures such as tropospheric intrusions (e. g. Sprenger et al., 2007; Pan et al., 2009; Vogel et al., 2011). These intrusions develop into elongated potential vorticity (PV) streamers and are manifestation of Rossby wave breaking. Rossby wave breaking is identified as an important mechanism for exchange of air masses between the tropical upper troposphere and the extratropical lower stratosphere with a pronounced peak during summer in each hemisphere controlled by the presence of monsoon anticyclones, in particular of the Asian monsoon (e. g. Homeyer and Bowman, 2013; Kunz et al., 2015). High frequency of PV streamers are found over the eastern North Pacific and over the Atlantic in summer demonstrated in a recently published climatology of PV streamers (Kunz et al., 2015)."

2. While the authors do a good job of including observational support for the model results with analysis of a few flights during the TACTS/ESMVal campaign, a more thorough test of the CLaMS model (particularly related to the influence of Asian monsoon air on extratropical lower stratosphere water vapor – i.e., Figure 15) using the same chemical dataset that was used for initialization – Aura MLS – is requested. Is the enhancement in extratropical lower stratosphere water vapor at 380 K following breakup of the Asian monsoon anticyclone an observed characteristic? I expect this is a

straight-forward test of the model and would go a long way in strengthening the perceived impact of this paper. If not an observed characteristic, this is a questionable result.

We followed the reviewers advice and performed a comparison between CLaMS and MLS water vapor in the extra-tropical northern lower stratosphere. Overall, MLS water vapor measurements confirm our model results. Both MLS and CLaMS water vapor clearly show an increase of water vapor during summer and autumn 2012 in the northern extra-tropical lower stratosphere. However some differences between CLaMS and MLS remains. This differences are discusses within the revised version of our paper as follows.

"Because water vapor is an important greenhouse gas and even small perturbations of water vapor mixing ratios in the ExUTLS have a significant impact on surface climate, we are interested to estimate the impact of the Asian monsoon on moistening the lower stratosphere. From our simulations, we roughly estimate the fraction of H_2O originating in India/China, Southeast Asia, and tropical Pacific Ocean contributing to the water budget in the lower northern hemisphere stratosphere. Fig. 1 shows the mean water vapor content in the northern lower stratosphere for PV values larger than 7.2 PVU (10 PVU) and northward of 30° N at 380 K (400 K) calculated with CLaMS (black line). In CLaMS at this altitude, contributions of cirrus clouds to the total water content are of minor importance. An increase of H_2O in the northern lower stratosphere is found in our simulation during summer and autumn as reported in previous studies (e.g. Ploeger et al., 2013; Zahn et al., 2014; Müller et al., 2015). The fraction of H_2O from different boundary tracers is indicated by different colors. End of October 2012, a contribution of approximately 1.5 ppmv (1.0 ppmv) H_2O originates from source regions in Asia and the tropical Pacific compared to a mean water vapor content of $\approx$ 5 ppm (4.5 ppm) at 380 K (400 K). Total H_2O without contributions of all boundary tracers i. e. the contribution of aged air (see Fig. 1, green line) shows a decrease during summer and autumn. Mean H_2O from AURA-MLS (version 3.3 and version 4) in the northern stratosphere calculated similar as mean CLaMS H_2O values for PV values larger than 7.2 PVU (10 PVU) and northward of 30° N at 380 K (400 K) also show an increase of water vapor within the lower northern stratosphere during summer and autumn 2012 (see Fig. 1, gray and purple line) and therefore support our findings from CLaMS simulations. Differences between CLaMS and MLS mean values in

the lower northern stratosphere in particular at 380 K could by explained by sampling issues (different spacial resolution of MLS and CLaMS), vertical resolution of MLS limiting measurements of steep tracer gradient around the tropopause and the initialization of CLaMS H_2O at 1 May 2012 (above 400 K: AURA-MLS; below 350 K: CLaMS multi-annual simulation based on ERA-Interim water vapor with a linear transition between 350 K and 400 K, more details see (Vogel et al., 2015)). Previous comparisons between CLaMS and MLS (v3.3) water vapor demonstrate that differences in H_2O found in the lower stratosphere at high latitudes are likely an artifact of the MLS averaging kernels (Ploeger et al., 2013). Further, a comparison of water vapor climatologies from international limb sounder by Hegglin et al. (2013) demonstrate that Aura-MLS (v3.3) H_2O measurements tend to be low at high latitudes in the lowermost stratosphere. Because of the good agreement between CLaMS H_2O and in situ water vapor measurements by the FISH instrument during TACTS/ESMVal in the lower northern stratosphere (see Figs. 9-11) we are confident that CLaMS water vapor simulations within the extra-tropical lower stratosphere are reliable."

3. The naming convention for emission sources outside of the Asian monsoon region is inconsistent in the text and Figures of the manuscript. While the use of "residual" is common and seems to be the primary intention of the authors, "residue" appears in other places (e.g., Figures 5, 6, 14, and 15; Table 2; and Page 12, line 23; Page 12, line 29). Please update the text and figures to refer to this as "residual" throughout.

We agree that within the paper the naming convention should be consistent and would like to thank the reviewer for carefully reading the manuscript. We changed "residue" to "residual" overall in the revised version of the paper (both within text and figures).

4. While the figures are (for the most part) visually appealing, an effort should be made to have the spacing, scaling, and text sizes consistent throughout. For example, the color bar labels run into the latitude axes in Figures 3 and 4, the cross-sections are misaligned in Figures 5 and 6, text sizes of the two panels in Figure 7 are different, the bottom panel is unnecessarily displaced from the top three in Figure 12, and the text sizes in Figures 14 and 15 are not legible at normal zoom.

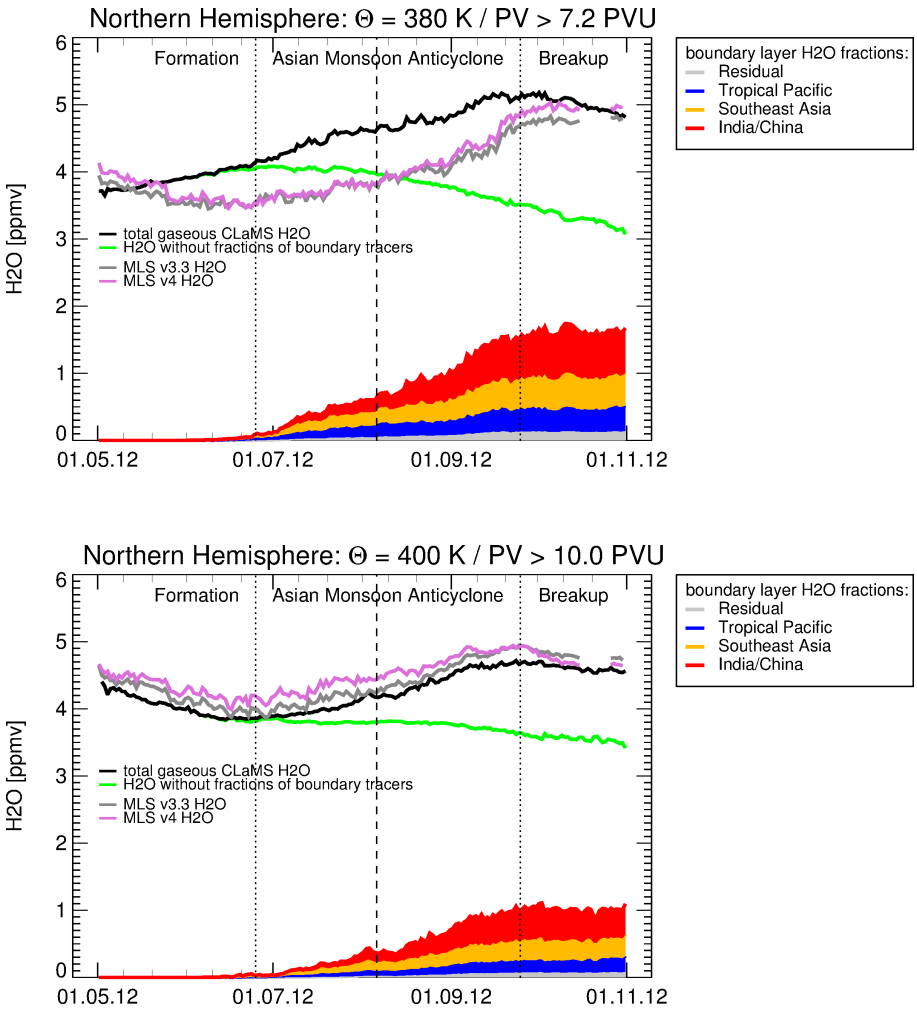

Figure 1: **(see Fig. 15 in ACPD paper)** The increase of H_2O mixing ratios in the lower northern hemisphere stratosphere at 380 K (top) and at 400 K (bottom) during summer 2012 is shown (black line). The green line indicated H_2O mixing ratios without fractions from the Earth's boundary layer. Mean H_2O mixing ratios derived from MLS version v3.3 (gray) and version v4 (purple) in the northern extra-tropical lower stratosphere show also an increase in water vapor during summer and autumn. A rough estimation of the fraction of H_2O mixing ratios originating in India/China (red), Southeast Asia (yellow) and the tropical Pacific Ocean (blue) in the northern lower stratosphere is also given.

We revised the figures according the reviewers advice.

Specific Comments

1. *Page 1, line 7: "...jet such as the..." should be "jet such that the"*
   done

2. *Page 1, lines 16-17: This statement is confusing here. This should be clarified to say that sources from Asia and the tropical Pacific account for ∼1.5 ppmv of the ∼5 ppmv mean in the extratropical lower stratosphere.*

   We revised the sentence as follows: "End of October 2012, approximately 1.5 ppmv H_2O is found in the lower northern hemisphere stratosphere (at 380 K) from source regions both in Asia and in the tropical Pacific compared to a mean water vapor content of ≈ 5 ppmv."

3. *Page 2, line 3: "...is acting..." should be "...acts..."*
   done

4. *Page 3, lines 16-23: This discussion is limited to large-scale transport processes, correct? For example, we know that moist convection (apart from a large organized system like a typhoon) is capable of transporting air across the tropopause but such small-scale processes (though possibly represented to an extent) are not resolved in these models. A bit more detail and context should be given to clarify these points here, which you do reflect on near the end of the paper.*

   The following sentence is added: "In addition to this large-scale transport process of water vapor by air mass exchange between the tropics and the extratropics, convection induced injections of water vapor in mid-latitudes can also occur in large storm systems such as tropical cyclones and by deep continental convection (e. g. Anderson et al., 2012; Homeyer et al., 2014; Vogel et al., 2014)."

5. *Page 3, line 27: "...are used..." should be "...is used..."*
   done

6. *Page 4, line 14: "Measurements of..." should be "Measurements from..."*
   done

7. *Page 6, line 30: "...occurs like for all..." should be "...occurs in an equivalent fashion to all..."*

   on page 5, line 30: "...occurs in an equivalent way to all chemical species" is added

8. *Page 7, line 20: "...as for..." should be "...to..."*
   done

9. *Page 8, line 12: "...into stratosphere." should be "...into the stratosphere."*
   done

10. *Page 8, lines 15-18: The Homeyer et al 2011 paper you cite can be referenced here as well.*
    done

11. *Page 10, lines 11-12: What do you mean by this statement? It takes 5 weeks for the parcels to be transported from their surface emission locations to the lower stratosphere over Europe? This statement needs to be clarified a bit.*

    The following sentence is added: "These air masses uplifted by typhoon Bolaven are transported from the Earth's surface over the West Pacific within 5 weeks to the lower stratosphere over Europe [Vogel et al. 2014]."

12. *Page 10, lines 19-21: Based on the time series, No. 3 is an aircraft-only signature (i.e., no apparent plume in the CLaMS simulation – at least not to me!).*

    That is correct, therefore we revise the text as follows: "During the second part of the flight on 26 September 2012 (see Fig. 9, top), further signatures of tropospheric air are measured during the flight (No. 3-6). Also here, enhanced percentages of the emission tracers for India/China and Southeast Asia / tropical Pacific Ocean up to 18 % are simulated, except for region No. 3."

13. *Page 10, lines 26-18: But is this really dynamics of the AMA or of a downstream RWB event? You have already demonstrated that the latter is the reason this particular air mass crossed the tropopause, correct?*

    We revise the sentence (page 10, line 26-28) as follows: "Our simulations in agreement with measurements show that the amount of water vapor and pollution in the lower stratosphere is enhanced in the Northern Hemisphere in September 2012 associated with both the dynamic of the Asian monsoon anticyclone and the transport of air masses from both Asia and the tropical Pacific along the subtropical jet."

14. *Page 10, line 35: "Northern Hemisphere" should be "stratosphere"*
    revised to "... into the northern extratropical lower stratosphere..."

15. *Page 11, line 22: Remove "these"*
    done

16. *Page 12, line 25: "...masses on the..." should be "...masses to the...", and "End October..." should be "End of October..."*
    done

17. *Page 12, line 27: "Here, highest contributions are from tropical..." should be "Here, the highest contributions are from the tropical..."*
    done

18. *Page 12, line 31: "This is in particular..." should be "This is particularly..."*
    done

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