Author Comment to Referee #1

ACP Discussions: acpd-15-9941-2015
(Editor - Federico Fierli)
'Impact of different Asian source regions on the composition of the Asian monsoon anticyclone and on the extratropical lowermost stratosphere'

We thank Referee #1 for further guidance on how to to revise our paper. Following the reviewers advice we added further statistical analysis in the revised version of our paper. Our reply to the reviewer comments is listed in detail below. Questions and comments of the referee are shown in italics.

General comments

This study concerns an important physical process and contains interesting hypotheses that could illuminate the role of the Asian summer monsoon anticlone for the transport of boundary layer into the stratosphere. However, the analysis is incomplete and the manuscript is not suitable for publication in its present form. For the most part, the analysis is restricted to instantaneous 'snapshots' of constituent (tracer) concentrations and dynamical quantities, detailed descriptions of those snapshots, and speculation about the underlying dynamics. However, there is very little analysis performed that proves - or even demonstrates - that the speculation is meaningful. What the authors have are interesting hypotheses that can form the basis for analysis, but not much more. The Asian anticyclone is an extensively studied phenomenon that warrants careful analysis. Furthermore, the diagnostic tools necessary for such an analysis are readily available and long familiar to this field; there is no justification for settling for speculation and anecdotal evidence for such a mature subject. To provide further guidance, the Specific Comments that follow discuss the analysis that could support individual statements in the Abstract.

We agree that we show as example individual days ('snapshots') of the Asian summer monsoon period 2012 to illustrate some basic characteristics of the anticyclone. We think that is very helpful because in the literature often only mean values of the Asian monsoon anticyclone for July/August are shown, which hides the strong day-to-day variability of the Asian monsoon anticyclone. Further, we want to emphasise that as an addition animations showing the temporal evolution (on a daily basis) of the contribution of emission tracers for India/China and PV at 380 K potential temperature on the Northern Hemisphere during the Asian monsoon season 2012 (1 May 2012 - late October 2012) are available as a Supplement of this paper showing the intraseasonal variability of the Asian monsoon anticyclone. Most importantly, the main result of the paper is the intraseasonal variation of the contribution of different boundary source regions to the composition of the Asian monsoon anticyclone (Fig. 8, ACPD vers. + rev. vers.), which is performed over the whole period and not only for single days. Finally, in response to the reviewers comments, we have added two new figures to the paper (Fig. 4+5, rev. vers.) in which CLaMS results are compared with observations and PV from ERA-Interim over the entire monsoon period using pattern correlations.

Specific comments

1) Abstract, lines 5-9: Regarding the statement: 'Our simulations show that the Asian monsoon anticyclone is highly variable in location and shape and oscillates between 2 states: first a symmetric anticyclone and second, an asymmetric anticyclone either elongated or split in two smaller anticyclones.' To demonstrate this behavior, the authors show 4 snapshots of tracer concentrations and potential vorticity with the claim that these snapshots are typical. I do not question the author's contention that they observe these patterns often in the data. However, the human eye is often too adept at finding patterns. If the anticyclone is truly dominated by two patterns, those patterns will emerge from an EOF (or similar) analysis as the two leading modes.

First, we want again to point out that in the electronic supplement of the paper, animations are available that illustrate the oscillation between a symmetric anticyclone and an asymmetric anticyclone. However, we agree that a statistical analysis by Empirical Orthogonal Functions (EOF) could help to investigate the variability the spatio-temporal distribution of the emission tracer for India/China during the monsoon season in a more quantitative way. Indeed, we did first tests of an analysis with EOFs addressing this issue. However, adding an EOF analysis to our paper would extend the paper considerably and therefore would go beyond the scope of this paper. However, as also recommended by Reviewer #3, we plan to write a separate paper with additional statistical analysis to show our results regarding the oscillation (2 modes) of the anticyclone in 2012. Therefore, we removed the following part of the abstract and all other paragraphs within the paper related to this point.

$\surd$ The following paragraph in the abstract is removed in the revised version of the paper:

'The Asian monsoon anticyclone ... oscillates between 2 states: first a symmetric anticyclone and second, an asymmetric anticyclone either elongated or split in two smaller anticyclones. A maximum in the distribution of air originating from Indian/Chinese boundary layer sources is usually found in the core of the symmetric anticyclone, in contrast the asymmetric state is characterised by a double peak structure in the horizontal distribution of air originating from India and China.'

2) Abstract, lines 9-14: Regarding the statement: 'A maximum in the distribution of air originating from Indian/Chinese boundary layer sources is usually found in the core of the symmetric anticyclone, in contrast the asymmetric state is characterised by a double peak structure in the horizontal distribution of air originating from India and China.' An EOF analysis would work here as well. Also, if the two modes are separated via an EOF analysis of PV, then the structures of tracers that accompany those PV patterns will be revealed by projecting tracer variations onto the principal components of each PV EOF.

As mentioned before, we agree that a statistical analysis by Empirical Orthogonal Functions (EOF) will help to investigate the variability the spatio-temporal distribution of the emission tracer for India/China during the monsoon season, however to add an EOF analysis to our paper would extend the paper to much. However, we did address this point raised by the reviewer, albeit on a somewhat different way: we calculated the correlation between the horizontal distribution of PV to the spatial distribution of the emission tracer for India/China, Southeast Asia and CLaMS CO at 380 K (here Fig.1

= Fig. 5, rev. vers.)

√ We added the following text and Figure 1 to Section 3.:

'To link the temporal variation of the spatial distribution of the emission tracers also to areas of low PV during the entire Asian monsoon period 2012, pattern correlation between PV and the emission tracer for Indian/China (red), the emission tracer Southeast Asia (grey) and CLaMS CO (blue) are calculated as shown in Fig. 1. The correlation coefficients are calculated in a region between 15 and 50 N and 0 and 140 E (shown as black box in Fig. 2; ACPD paper) at 380 K similar as for the MLS/CLaMS correlations described above (above in the revised version of the paper, here see next point 3.). CLaMS results and PV are interpolated on 1×1 latitude longitude grid at 380 K and thereafter normalised to one.

Fig. 1 shows that the spatial distribution of PV and CLaMS CO is very well correlated during the formation (-0.89 to -0.95) and the existence (-0.74 to -0.93) of the Asian monsoon anticyclone. After the breakup the correlation gets worse. During the Asian monsoon season, a good correlation between the spatial distribution of low PV and and high percentages of the emission tracer for India/China of -0.71 − -0.87 is calculated. During the formation of the anticyclone the correlation coefficients increases because the emission tracer has to be transported up to the UTLS. The decrease of the correlation coefficients after the breakup is caused by the missing convection in Asia occurring during the monsoon season (see comparison between MLS and CLaMS in Sect. 3.1.1). In contrast, the correlation coefficient between the spatial distribution of PV and the emission tracer for Southeast Asia shows a completely different behaviour. During the formation of the Asian monsoon the contributions of the emission tracer for Southeast Asia increase similarly as for the emission tracer for India/China. During the existence of the anticyclone a high correlation coefficient up to -0.90 is calculated at the early- and late-phase of the anticyclone, however in early August (mid-phase) no correlation between the spatial distribution of PV and the emission tracer for Southeast Asia is found (indicated by the grey dotted line in Fig. 1). This shows that in the mid-phase the spatial distribution of air masses originating in Southeast Asia is not connected to region of the Asian monsoon anticyclone indicating that air masses from Southeast Asia experienced upward transport outside of the Asian monsoon anticyclone (see Sect. 3.2).

The good correlation found between the emission tracer for India/China and MLS measurements as well as PV confirms that the spatial distribution of the emission tracer for India/China is a very good proxy for the location and shape of Asian monsoon anticyclone from end-June to end-September.'

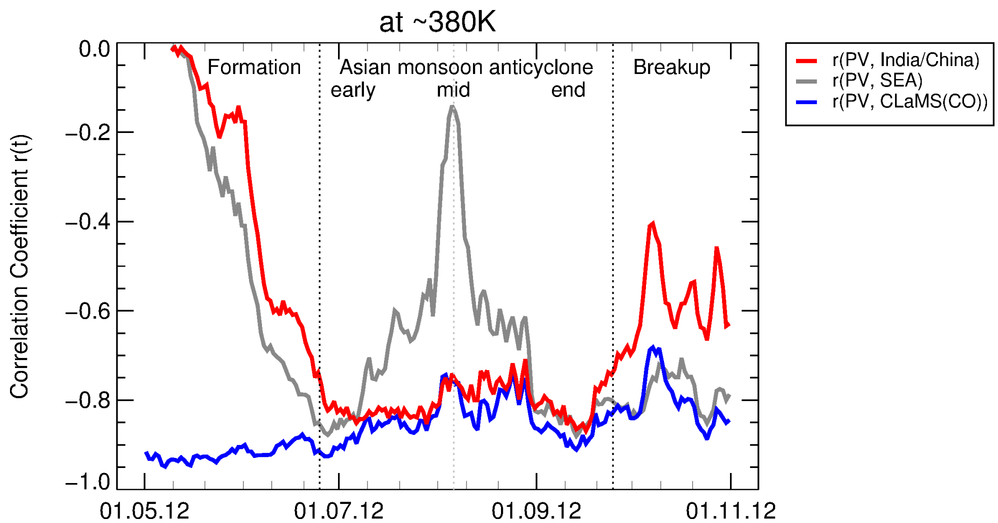

Figure 1: Time dependent correlation coefficients for the spatial distribution between PV and the emission tracer for India/China (red), the emission tracer for Southeast Asia (grey), and CLaMS CO (blue) at 380 K potential temperature. (added to the revised version of the paper as new Fig. 5)

3) Abstract, lines 14-17: Regarding the statement: 'The simulated horizontal distribution of artificial emission tracers for India/China is in agreement with patterns found in satellite measurements of O3 and CO by the Aura Microwave Limb Sounder (MLS).' The pattern agreements can be easily verified via pattern correlations - which should be performed for the entire season, not just 4 days.

√ Following the reviewers advice, we performed pattern correlation between MLS and CLaMS for the entire monsoon season 2012.

We revised Section 3.1.1 as follows:

Comparison to MLS measurements

‘To compare our simulation with MLS O_3 and CO measurements (Version 3.3) (Livesey et al., 2008), pattern correlation between MLS measurements and CLaMS results, namely MLS(CO)/CLaMS(CO), MLS(O_3)/CLaMS(O_3) and MLS(CO)/CLaMS(India/China), were calculated (see Fig. 2). It is expected from satellite measurements that CO mixing ratios are stronger within the Asian monsoon anticyclone than outside and vice versa for O_3 indicating that air masses inside the anticyclone have a higher tropospheric characteristic than air masses in the UTLS outside of the anticyclone. At all days between 1 May 2012 and 31 October 2012, MLS measurements of O_3 and CO in a region between 15 and 50 N and 0 and 140 E (shown as black box in Fig. 2) at 380 ± 20 K potential temperature are correlated to CLaMS results as described in the following. At each day, CLaMS results are interpolated on locations of the MLS measurements transformed to synoptic 12:00 UTC positions. For each day, both MLS measurements and CLaMS results are normalised so that the maximum value of each trace gas is equal one. Afterwards the linear Pearson correlation coefficient r(t) between MLS measurement and CLaMS results is calculated for each day. This procedure allows to be compared the spatial distribution of trace gases neglecting possible differences in the absolute mixing ratios between model and measurement and to compare the spatial distribution of different quantities such as measured CO and simulated emission tracers (here India/China).
Correlation coefficients r(t) ranging between 0.72-0.86 were calculated for MLS(O_3)/CLaMS(O_3) during the monsoon season 2012 between end of June and end of September. Before the monsoon season in early May an even higher correlation coefficient up to 0.95 was found. Correlation coefficients of 0.57-0.81 were calculated between both MLS(CO)/CLaMS(CO) and MLS(CO)/ CLaMS(India/China) between end of June and end of September. These high correlation coefficients confirm that CLaMS has the capability of simulating the spatial distribution of tropospheric trace gases such as CO and stratospheric trace gases like O_3 measured by MLS. To illustrate this, the same horizontal cross-sections as in Figs. 2 and 3 at 380 K potential temperature for MLS CO and O_3 as well as for CLaMS CO and O_3 are shown in the Supplement of this paper.

Thus, high contributions of the emission tracers for India/China are simulated in regions where high values of CO are measured indicating that the emission tracer for India/China is a good proxy for the spatial distribution of tropospheric trace gases measured in the region of the Asian monsoon anticyclone. The correlation coefficient of MLS(CO)/CLaMS(India/China) increases from 0. to ≈ 0.8 during the formation of the Asian monsoon anticyclone, as expected because in the model the tracer has first to be transported from the ground to the UTLS. After the breakup of the monsoon anticyclone the correlation coefficient of MLS(CO)/CLaMS(India/China) decreases because further upward transport of the tracer for India/China does not occur due the the missing convection in this region and therefore the spatial CO distribution in the UTLS is dominated by other processes. In the region of the Asian monsoon anticyclone, the correlation coefficients of MLS(O3)/CLaMS(O3) are somewhat higher than those of MLS(CO)/CLaMS(CO). Reasons for that could be deficiencies in MLS CO data (v3) in the lower stratosphere as suggested by Hegglin and Tegtmeier (2015). '

Figures 4 and 5 in the ACPD paper were moved to the Supplement of the paper and were replaced by the following Figure 2:

4) Regarding the CLaMS simulations; Sec. 3.1.3 - 3.2.2: First, the analysis of transport paths is both anecdotal and speculative. The authors have a transport model; they should use it to perform focused analysis with model experiments designed to enlighten. Second, it seems clear from the upward trends of tracer concentrations in Fig. 8 that the CLaMS simulations have not spun up - that is, tracer concentrations in Fig. 8 are not true representations of actual concentrations. For example, there are potentially more tracers in the anticyclone in August than in June simply because those in August have had more time to get into the anticyclone - regardless of any physical transport process. In this context, it is still interesting that the SE Asia tracers dominate in June. Presumably this is because transport for those tracers is faster than for other regions. Nevertheless, that spin up is occurring during the analysis period makes that figure, and all CLaMS results very difficult to interpret.

First, CLaMS is a Lagrangian chemistry transport model and is very well suited to describe transport and mixing processes in the UTLS as shown in many previous studies (e. g. Pan et al., 2006; Konopka et al., 2010; Vogel et al., 2011; Konopka and Pan, 2012; Ploeger et al., 2013). Second, chemical trace gases in the model are initialised by satellite measurement and

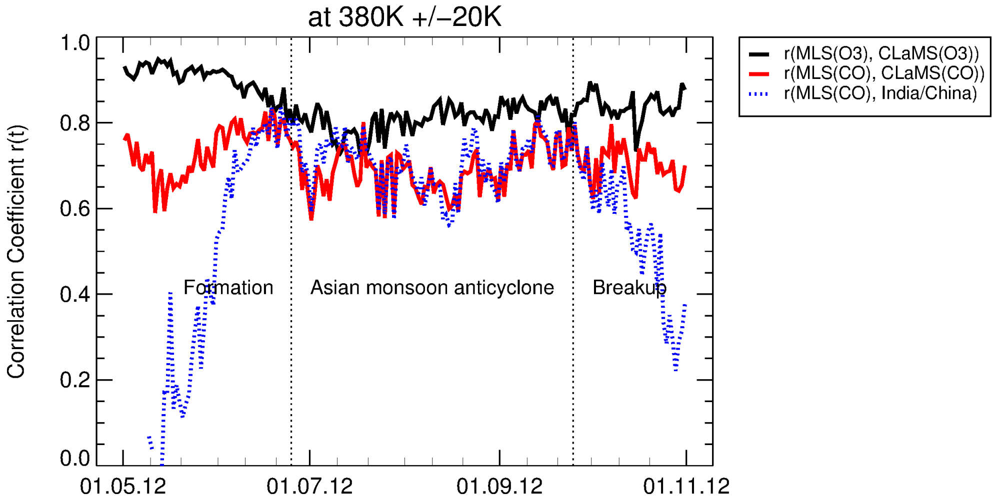

Figure 2: Correlation coefficients depending on time for tracer correlations patterns between MLS O_3 and CLaMS O_3 (black), between MLS CO and CLaMS CO (red), and between MLS CO and the CLaMS emission tracer for India/China (blue) for levels of potential temperature between 360 and 380 K (more details see text).

by results of a multi-annual CLaMS simulation started on 1 October 2001 as described in Sect. 2.1. This procedure ensures that the concentrations of chemical trace gases such as CO or O_3 used as initialisation for the 1 May 2012 do not need a spin up. Therefore, CO and O_3 mixing ratios simulated with CLaMS correspond to actual measured concentrations. CLaMS simulated CO and O_3 values are now used more extensively in the revised version (see here Fig. 2)

In contrast to these chemical tracers, the artificial emission tracers in CLaMS are designed to identify possible boundary source regions in Asia that could contribute to the composition of the Asian monsoon anticyclone in a particular monsoon season. Thus, we argue that both in the model and in the real world it takes time for boundary tracers to reach the anticyclone in the early stages of the monsoon season. In response, to the review comment and to explain this in more detail we added the following paragraph in the revised version of the paper:

in Sect. 2.1.1 Model Description / Emission tracers:

'The artificial emission tracers in CLaMS are designed to identify possible boundary source regions in Asia that could contribute to the composition of the Asian monsoon anticyclone in a particular monsoon season, here as a case study for the year 2012. At each time step of the model (every 24 hours) air masses in the model boundary layer are marked by the different emission tracers, i. .e. the emission tracer for North India (NIN) of an air parcel in the boundary layer over Northern India is set equal to one (NIN = 1). If an air parcel has left the model boundary layer over North India, the value of the emission tracer for NIN (=1) is transported to other regions of the free troposphere or stratosphere. Successive mixing processes between air masses from North India with air masses originating in other regions of the atmosphere (here NIN= 0) during the course of the simulation yield values of NIN differing from the initial distribution (NIN = 1 or NIN = 0). Therefore, the value of the individual emission tracer count the percentage of an air masses that originated in the specific boundary layer region since 1 May 2012 considering advection and mixing processes.'

in Sect. 3.2.1 Temporal evolution of different emission tracer:

'The artificial emission tracers in CLaMS are designed to identify possible boundary source regions in Asia that could contribute to the composition of the Asian monsoon anticyclone during the monsoon season 2012 (as defined in Sect. 2.1) considering advection and mixing processes. E. g. the fact that the contribution of the emission tracer for Southeast Asia dominates in June demonstrates that in June upward transport or convection in the region of Southeast Asia is stronger than in other regions over Asia causing higher contributions of the emission tracer of Southeast Asia within the Asian monsoon anticyclone compared to other emission tracers in June. By this technique contributions of the boundary layer with a transport time from the boundary to the UTLS longer than one monsoon period (contributions from the boundary layer that are released before 1 May 2012) are not covered by the artificial tracers used here. Therefore, the composition of different emission tracers within the Asian monsoon anticyclone is a fingerprint of the regional and temporal variations of convective processes causing strong upward transport within the Asian monsoon anticyclone in summer 2012.

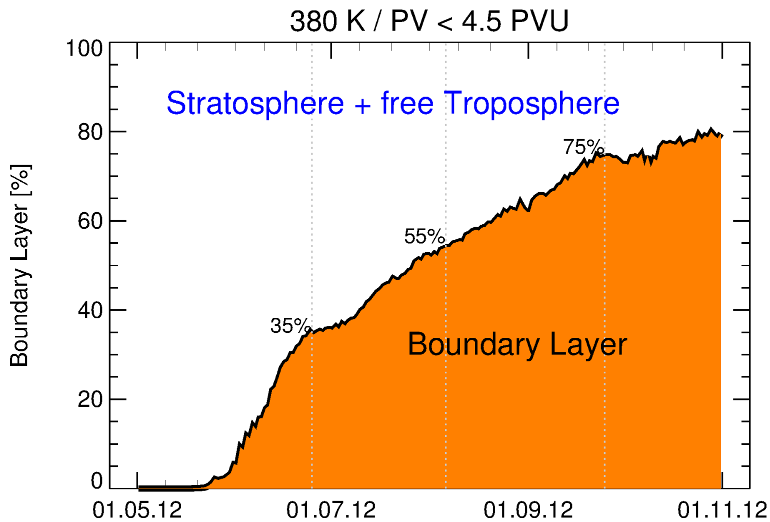

Figure 3: Temporal evolution of contributions of air masses from the boundary layer to the composition of the Asian monsoon anticyclone. The shown percentages are mean values calculated for air masses in Asia in the region between 15 and 50 N and 0 and 140 E at 380 ± 0.5 K (see black box in Fig. 1 in the paper) with PV values lower than 4.5 PVU that marks the edge of the anticyclone.

The sum of all emission tracers shown in Fig. 8 (ACPD vers.) is less than 100 % because air masses originating in the free troposphere or stratosphere also contribute to the composition of Asian monsoon anticyclone. End of June, a contribution of 35 % of the model boundary layer to the composition of the Asian monsoon anticyclone is calculated (see here Fig. 3). The remaining 65 % of the composition of the anticyclone is from the free troposphere and the stratosphere. The contribution of the model boundary layer rises to 55 % in early August and to 75 % at the end of the monsoon season in late September. '

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