Deep convective influence on the UTLS composition in the Asian Monsoon Anticyclone region: 2017 StratoClim campaign results

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Answer to reviewer 1

We want to thank the reviewer for the precious comments. We will answer point to point to them in the following:

In this manuscript, the convective source is identified when the trajectory is found with a pressure higher than the high cloud top pressure, and the highest and opaque cloud classes are representative of the deep convective events. The features of cloud top height will determine how the convective contribution changes with height, as discussed in the later part of this manuscript. So whether the cloud top heights of these highest and opaque cloud classes can represent the deep convective main outflow levels is a critical issue. I'm wondering the uncertainty in this issue. The manuscript should have some detailed description about the uncertainty

The work done in preparation of this paper included an extensive sensitivity study on the cloud top retrieval, as well as the choices of the Cloud Type classes as identified by the SAF algorithm. We decided not to report this whole part to avoid loading the paper too much. We agree nevertheless that this should be mentioned in the manuscript, as also the second reviewer pointed out. We report here for representativeness an example of this sensitivity study. The SAFNWC cloud top is an operational EUMETSAT product which has been extensively validated (see for example Sèze et al. 2015). One common aspect that is often raised is the negative bias, of around 1 km, of the cloud top from geostationary with respect to LiDAR measurements (see for example Sherwood et al 2004, Haman et al 2014). We therefore repeated the analysis adding a shift of 1 km to the cloud top from the CTTH product.
We show here the result of the analysis for the same flight shown in the main text (flight 6):

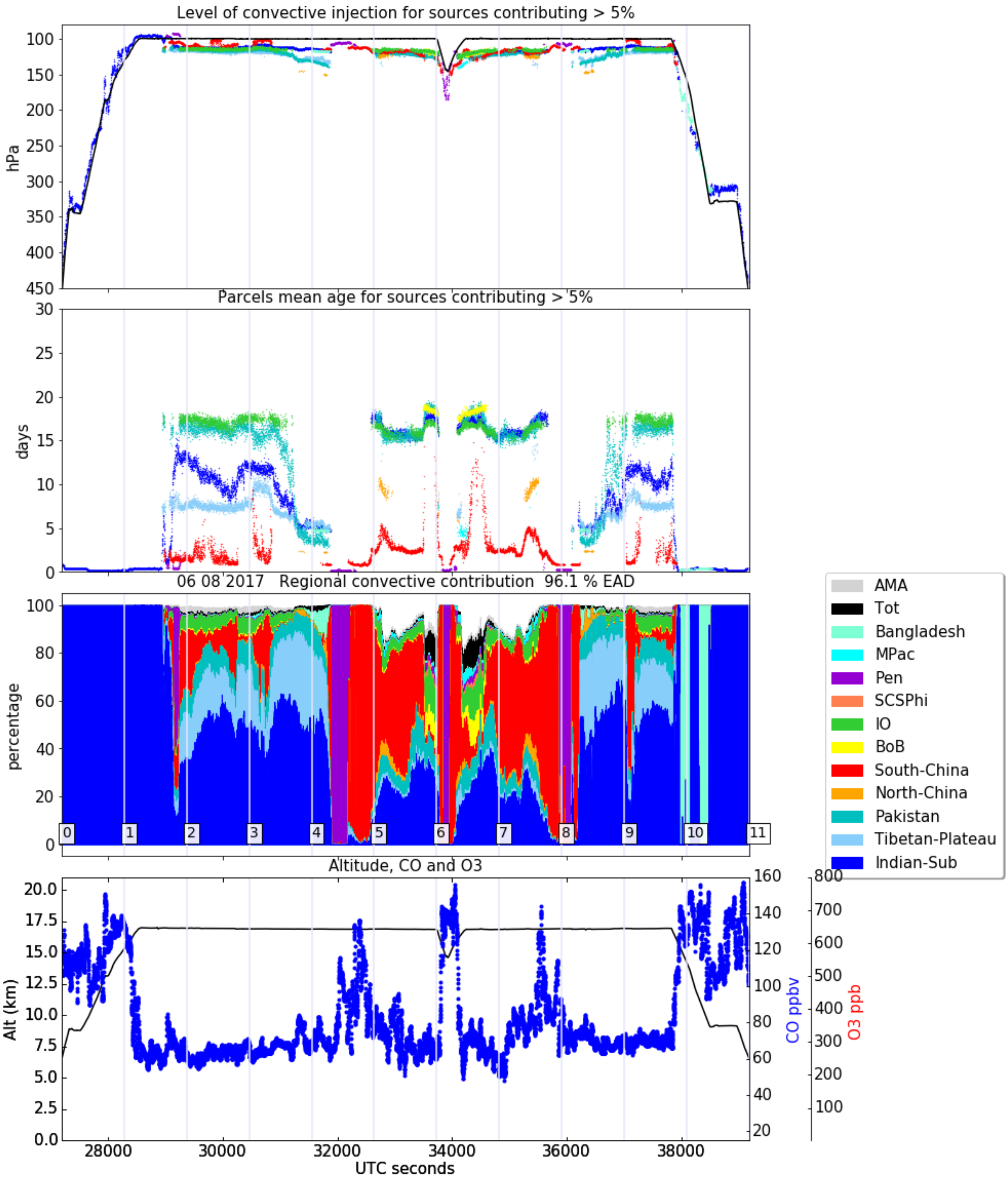

Figure 1A: as in figure 7c but with a +1km correction to the CTTH from the SAF product

Comparing with figure 7c, it is possible to notice that the analysis shows a higher presence of convective influence, younger age and higher level of convective injection (this last comes by construction). The enhancement of CO are now associated to higher amounts of convective air from Pen (for the points close to segments 4 and 8) and from South-China (for the enhancement close to segment 5 and slightly before 8). Looking more in details into the source distribution (Figure2A) it appears that, in the +1Km corrected cloud top algorithm, the convective source regions (like Myanmar or South China) are associated to a larger amount of encountered trajectories, as expected. If we now give a look to the reconstructed CO concentration (figure 3A), we see how the increase in the altitude of the clouds leads to the loss of the capture of the pollution injections (right after seconds 32000 and before 36000) that are instead seen in the non-corrected version. The trajectories are indeed "captured" as in a convective source too early in their travel back in time, marking as convective source a region that is instead not carrying the CO enriched air. The correction would give therefore more weight to clouds that are not actually influencing the observed contribution. We repeated the same study on all the fights and, while in some cases there are no remarkable changes in the results (it happens especially when there is no intense convective influence captured by the flight), when those changes are visible they appears as a degradation in the consistence of the results, as in the shown case.

A good estimation of the cloud top height is necessary for the correct reproduction of the transport in the UTLS. Using the measurements from the StratoClim campaign, we found out that the method is giving the best results when using the cloud top altitudes from the SAF without any adjustments. Physically speaking, this is also not surprising, since in this analysis we are looking for the altitude where the detrainment from the convective cloud is large enough to generate a dominating influence in the environment, that does not corresponds to the highest point of the cloud top, as it may be detected from a LiDAR profile. A more accurate specification of this notion would certainly be useful but is beyond the scope of this study.

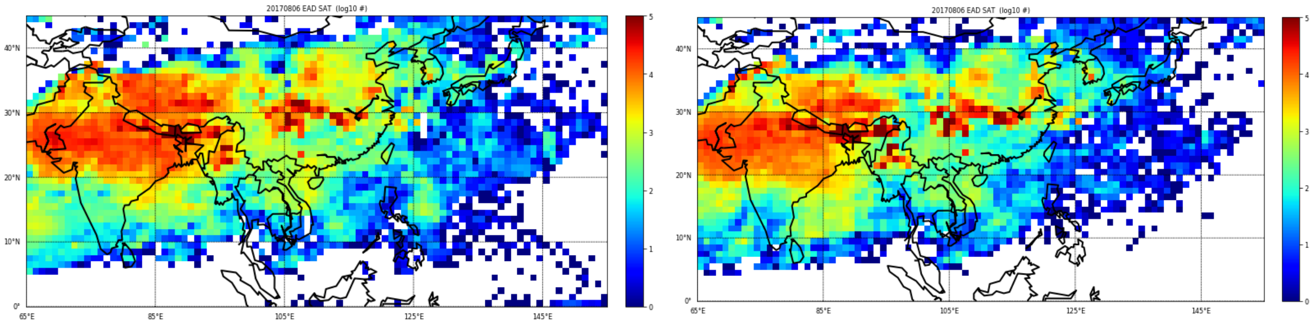

Figure 2A: Figure 7b (left) compared to the convective source distribution for flight 6 (as in figure 7b) but with the +1km correction to the cloud top height.

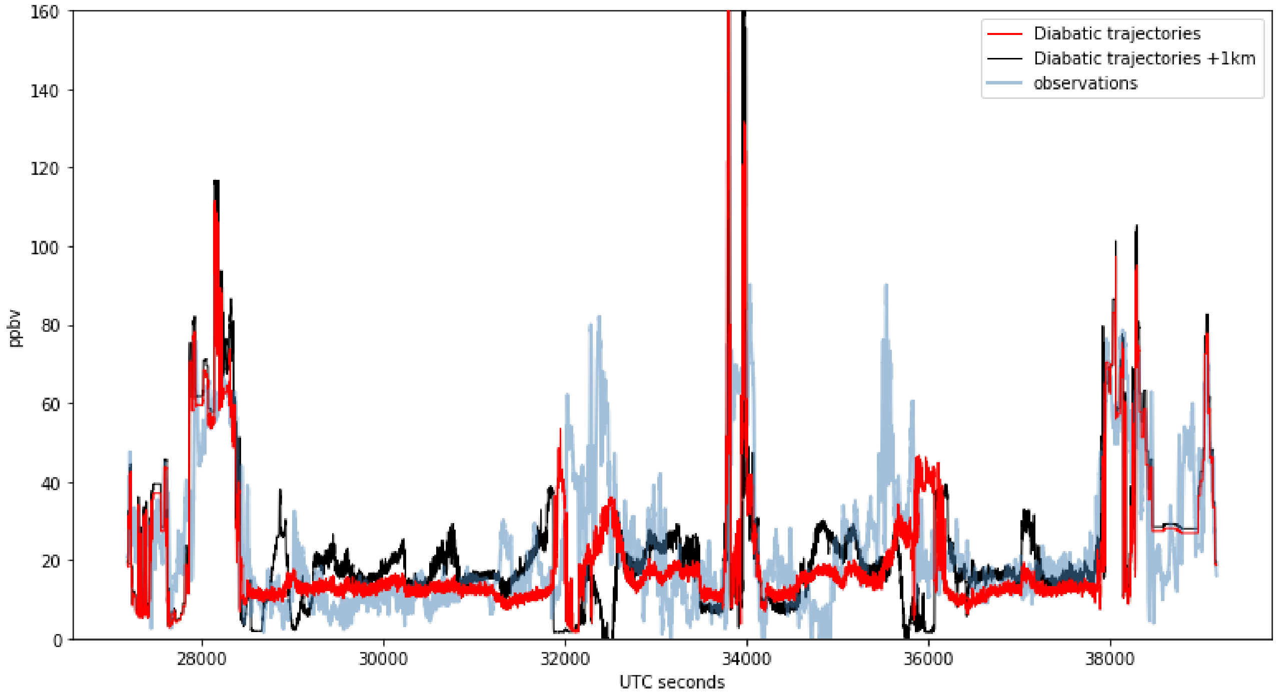

Figure 3A: as in figure 5e (but diabatic only) with (black) and without (red) a +1km correction to the cloud top height. The grey line represents the observations from COLD2

We therefore added the following discussion to the manuscript:

“In this study we exploited the availability of the in-situ measurements of trace gases to tune for the best use of the geostationary-retrieved cloud top. While some studies indicate generally a negative bias for the geostationary-retrieved cloud top with respect to the LiDAR-retrieved one (Hamann et al. 2014), no correction to the CTTH altitude from the SAF product appears needed for the presented analysis. A sensitivity study has been performed adding different positive biases to the cloud top altitudes from the CTTH (not shown), indicating that a correction would lead to a misplacement in the identification the convective sources. A consistent interpretation of the observed tracer enhancements is instead obtained when keeping the cloud top altitudes from the SAF without any shift. The altitude on which we are interested in this study is that at which the detrainment of convective cloud is large enough to dominate the environment and the cloud top from the geostationaries may indeed be more representative of this level rather than the optical top of the cloud as it could be seen from a LiDAR profile. The selection of the cloud types to be included in the study has also been based on the same measurements-based comparison.”

The convective sources diagnosed in this manuscript are based on the StratoClim flight tracks, which only cover a small part of the Asian monsoon anticyclone, and to the south of the anticyclone center. Whether the convective sources diagnosed here are different from other regions and can represent the whole anticyclone is a critical issue, which should be considered with caution. The manuscript should discuss this issue

The reviewer rises an important point, related to the representativeness of the convective influence captured during the campaign. The source regions that are participating the most to the composition of the air masses observed during the campaign may indeed not be the most influencing when looking to the whole AMA composition. In fact, it is instead true that the convective events captured during the flights were strongly related to the position of the flights (mostly toward the south-center of the anticyclonic circulation) as well as to the period in which the campaign took place (including a break phase of the monsoon). While it's not the scope of the paper to give an assessment of the sources of convective activity in the whole AMA, this work provides an assessment on the quality of the approach that will be indeed exploited for a more extended analysis on the deep convective impact in the Asian Monsoon region. The question of the whole AMA source has been addressed in a companion paper (Legras and Bucci, ACPD, 2019). We therefore added the following modifications in the "discussion and conclusion" section:

"It is important to point out that the convective sources influences observed during the campaign are strongly related to the position and time period of the campaign itself. The region spanned by the aircraft is limited to the central-southern part of the anticyclone and the sources observed are therefore mainly the ones that are found upwind of the anticyclonic circulation with respect to the aircraft position. Similarly, a sampling region located more South would have likely captured more maritime convection (that is expected to be dominant with respect to the continental contribution for extension and frequency) and an additional prolongation of the campaign period after the break phase would have probably allowed to sample more intense convective events. This analysis nevertheless provided an in-situ measurement assessment of the combined satellite-modelling approach to represent the convective transport in the region, providing a tool for a reliable analysis on a longer period and a wider region. On the other hand, the analysis of the StratoClim flights provided evidence on how the convective events over these regions, even if very short-lasting and localized, may be intense enough to allow a fast and direct injection of highly polluted air at the UTLS level, spanning a large domain, that can then keep rising to enter the stratospheric circulation. As the campaign was conducted in a phase of weak convective activity and having spanned only a limited region of the AMA, it is reasonable to expect the occurrence of more intense and frequent events of fresh and eventually polluted air into the UTLS along the whole season. Those events may in principle strongly impact the chemical composition of the stratosphere. Some of these intense convective injections, while bringing polluted air at very high levels (peaks detected at 17.7 \unit{km} up to 50 \unit{ppbv} over the background) play also a role in the hydration-dehydration of the stratosphere. The discussion of the hydration effects, based on the analysis of the more resolved visible images, and the analysis on the frequency and seasonal relative impact of deep convection on wider time/space scales, are matter of ongoing investigation."

Page 2 Line 7: This statement is valid in the upper troposphere and lower stratosphere.

We added this information in the sentence.

Page 2-3: These papers (Chen et al., 2012; Bergman et al., 2013; Vogel et al., 2015) have different targeted parcels (within the AMA or not) and therefore different sources, which should be noted.

That is correct, we now mention it in the text.

Page 3 Line 8: In situ balloon soundings over the Tibet Plateau by Bian et al. (GRL, 2012) could be mentioned here.

Reference added.

Page 6 Lines 19-30: The comparison among EAD, EAZ, EID and EIZ is also done by Li et al. (ACPD, 2019), which could be cited here

Reference added

Page 7 Line 5-6: The plume is located at #6 at 34000s UTC?

No, we refer here to the two enhancements right after seconds 32000 and before 36000s. We specified this in the text.

Page 9 Line 5: F6 therefore sampled the inner part of the AMA. Whether the parcels sampled during F6 are called "inner part" depend how the inner part of the AMA is defined. The 100 hPa circulation is centered around 33N, while the flight track position is 20-26 N, where is 7-13 degrees from the center. China sources make a critical contribution to the south part of AMA, which has also been shown by Yan & Bian (AAS, 2015)

Inner side here is used not with the meaning of "centre" but rather to indicate that, with respect to the geopotential contours, we are not on the outer side of the anticyclonic circulation, whatever metric is used. Indeed, in the case of flight 6 (figure S7 panel f) the circulation of the AMA was such that the Chinese sources were not just on the south part of the AMA (which fluctuates a lot) but are ventilated by the streamlines close to the centre of the circulation.

Page 9 Line 6: The cold point pressure is derived from ERA5?

Yes, we added the indication in the text.

Page 9 Line 7-8: flight. The mean winds around the flight position were purely Easterlies, transporting air from the center of South China along the anticyclonic circulation, which is also the main reason why South China contributes a lot in the convective sources as discussed in Page 7. This issue should be mentioned there.

We agree on the importance to mention that the relative importance of the sources is dependent on the position of the flight. We therefore added the discussion of this aspect in the "conclusion and discussion" section.

Page 9 Line 11-12: I'm curious if there were no aircraft dive here, would the CO peak be observed?

The dependence of the CO concentration on the altitude has been taken in account subtracting the average CO profile. The variations in CO concentration shown in figure 5 are therefore not consequence of the variation of the flight level but to the presence of the convective plume. The dive may have had nevertheless a role in the sense that it may have increased the possibility of encounter of convective air by sampling a lower altitude where the chance of convective presence is larger. We added this discussion in the text.

Reference:

Hamann, U., Walther, A., Baum, B., Bennartz, R., Bugliaro, L., Derrien, M., Francis, P. N., Heidinger, A., Joro, S., Kniffka, A., Le Gléau, H., Lockhoff, M., Lutz, H.-J., Meirink, J. F., Minnis, P., Palikonda, R., Roebeling, R., Thoss, A., Platnick, S., Watts, P., and Wind, G.: Remote sensing of cloud top pressure/height from SEVIRI: analysis of ten current retrieval algorithms, Atmos. Meas. Tech., 7, 2839–2867, https://doi.org/10.5194/amt-7-2839-2014, 2014

Sèze, G., Pelon, J., Derrien, M., Le Gléau, H. and Six, B. (2015), Evaluation against CALIPSO lidar observations of the multi-geostationary cloud cover and type dataset assembled in the framework of the Megha-Tropiques mission. Q.J.R. Meteorol. Soc., 141: 774-797. doi:10.1002/qj.2392

Sherwood, S. C., Minnis, P., and McGill, M. (2004), Deep convective cloud-top heights and their thermodynamic control during CRYSTAL-FACE, J. Geophys. Res., 109, D20119, doi:10.1029/2004JD004811