M. Fromm

We would like to thank Michael Fromm for the detailed questions and comments made. As a general remark: we do not contradict other possible transport mechanisms of various fire plumes into the tropics, but rather analyze this specific case of a far northern fire and the fast transport pathway within the jet to the Asian monsoon region and into the tropics. We will emphasize this issue better to avoid misunderstandings.

1) Abstract. In the first sentence (": : :reached the tropics, and subsequently the tropical stratosphere: : :") Kloss et al. seem to suggest that the Canadian smoke plume, upon entry into the area of the AMA, had a discernible tropospheric component. Only subsequently was it lofted into the stratosphere by the BDC according to this claim. This is a fairly provocative claim. However I could not find any evidence given or figures showing upper tropospheric smoke adjacent to and wrapping around the AMA. They attribute all the aerosols displayed below the tropopause to the ATAL. The evidence in Figure 1 and Khaykin et al. (2018) shows that by late August the smoke near the AMA was already at stratospheric heights and potential temperatures. If my understanding of the claim set forth in the abstract is correct, to defend it would require two things. 1. an unambiguous discernment of upper tropospheric smoke upstream of the tropical observations, and 2. evidence ruling out quasi-isentropic transport of the observed stratospheric smoke to the tropics. If on the contrary it is acknowledged that the smoke moving into Asia in late August was already spanning the lower stratosphere (as Khaykin et al. (2018) show) then it is hard to defend the abstract's claim convincingly.
We agree that this sentence is misleading. We really only analyze the fire plume signature that already reached the Asian monsoon area within the stratosphere. We emphasize the 'tropical stratosphere' because there it has the potential to be uplifted within the BDC and reach the 'global' stratosphere. We do not want to indicate here that we analyze any tropopause crossing into the stratosphere.
The respective sentence in the abstract was chaned to: "We show that a fire plume injected into the lower stratosphere at high northern latitudes during the Canadian wildfire event in August 2017 reached the tropics, and was subsequently further lifted in the tropical stratosphere within the ascending branch of the Brewer-Dobson Circulation (BDC). "

2) On a technical but important note, the Abstract mentions "July" as part of the Canadian smoke event. There is no evidence here or in other papers that July was in play. This wording should be removed.
Ok, the corresponding sentence was changed (see answer to comment 1).
3) Introduction, L2-3. The manuscript stipulates that pyroCb activity is the source pathway for this plume. Hence it is critical to accurately establish the pyroconvective source. That is best done by citing Peterson et al. (2018) in this sentence. Peterson et al. give detailed and accurate constraints on both the pyroCb injection in the Pacific Northwest and the 3D footprint of the pyroCb plume on 14 August. Khaykin et al. (2018) points the reader to fires that did not exhibit pyroCb activity. (Sergey and I have had a personal communication on that matter.) Hence that paper is not fitting as a citation here.

Thank you! We changed the citation to Peterson et al.

4) On that topic, the choice of initializing CLaMS over three days centered on a box that is neither focused on the Pacific Northwest pyroCbs nor the pyroCb plume on a subsequent day seems destined to introduce many spurious or useless trajectories. The growing realization that there was significant diabatic lofting of the smoke further diminishes the applicability of the CLaMS construct and setup. Consequently little confidence can be gained from a set of these trajectories at a single potential temperature surface (especially since the plume was lower than 380 K in the first days (See Fig. 4 of Khaykin et al. (2018)).

The CLaMS simulation is initialized at the time and altitude level of observed enhanced CO values (IASI measurements) due to the fire (see caption of Fig. 3). From the CLaMS simulation we do not derive any quantitative results of 'how', 'when' and 'how much', but rather use it as a qualitative (2D) visualization of the estimated transport pathway. We agree with M. Fromm that our initialization could also tag some air masses outside the IASI CO plume, although the box was chosen around the observed plume. To address the robustness of the deduced transport pathway we also initialized air masses (inside the same horizontal box) on each single day between 12th and 14th August, and on the different potential temperature levels between 345 and 465K.The transport pathway via the Asian monsoon circulation into the tropics emerged very robustly from all these sensitivity experiments. Therefore, for the paper we decided to show the transport of the total mass tracer tagging all air masses in the Canadian box for 12.-14. August and the entire layer 345-465K.

For clarification, the respective paragraph has been modified:

"To investigate the dynamics of the fire plume transport to the AMA region, an air mass origin tracer has been initialized between August 12th and 14th 2017 in the box over western Canada (green box in Fig. 3), using the CLaMS model.The point in time and space of the initialization box was chosen according to the position and time of high observed IASI CO vaues due to the fire. The simulation with box initialization as presented here, is a good indicator for possible large-scale transport pathways, but however should not be taken for quantitative estimations as some air masses within the box could not belong to the fire plume. The model fire tracer was injected in the respective box throughout the layer 345-465K, as observed by IASI . This approach was found to be very robust, by initializing air masses on different potential temperature levels (345-465K) and on each day between August 12th and 14th. Therefore, uncertainties arising from the observed time and injection altitude do not interfer with our line of arguments. After initialization, the tracer has been advected passively during the following weeks. This approach is similar to the one presented in (Vogel et al. 2015): the plume is first transported eastwards, at latitudes >40_N and passes over Europe in early/mid-August (Fig. 3A). After reaching the Asian monsoon area at the end of August, a fraction of the fire tracer is partly transported along the eastern flank of the AMA circulation from the extratropics into the tropics (Fig. 3B). In the simulations, part of the plume even reaches the southern hemisphere (Fig. 3C). It is shown that the plume reaches the tropics (<10_N) first through the AMA circulation (Fig. 3C). This is consistent with the SAGE III observations shown before. With the slow breakdown of the AMA, plume air masses mix into the area that has before been confined by the AMA transport barrier from the northern side (Fig. 3D). By mid-September most of the NH is

filled with the artificial fire tracer at 380 K potential temperature (Fig. 3D). This pathway of the fire plume transport to the tropics within the eastern flank of the AMA circulation is further confirmed by OMPS aerosol extinction observations (see Figure S2 of the supporting material)."

5) Introduction, L29. Of the 3 papers cited on this line, only one postulates the Nabro troposphere-ASM -convection pathway: Bourassa et al. (2012). Fairlie et al. Dispute that claim. Sellito et al. seem to be noncommittal on the pathway. Considering that Kloss et al. are apparently attempting to draw parallels with the Nabro publications and the 2017 AMA/smoke interaction (P2, L30), it is important to accurately portray the literature on the Nabro event.

The respective sentence was changed to: "For the Nabro volcano eruption, for example, the emitted aerosol and precursors have been partly injected directly into the lower stratosphere (Vernier et al. 2013, Fromm et al., 2013) at altitudes of about 15-18 km (Clarisse et al., 2014, Fromm et al., 2014). It has been suggested that a fraction might have been transported into the stratosphere via the upwelling in the Asian monsoon (Bourassa et al., 2012, 2013). Satellite observations of volcanic effluents as SO2 (Clarisse et al., 2014) and sulphate aerosols (Sellitto et al., 2014) have shown the interaction of the plume horizontal dispersion and the AMA dynamics."

6) P3, L22. Why was it decided to use "cloud unfiltered" SAGE 3 data? Thomason and Vernier (ACP, 2013) were compelled to go to great lengths to adopt a rigorous cloud clearing in SAGE II data for the study of tropospheric aerosols (indeed the ATAL). For inadequately constrained data sets such as SAGE and OMPS it is essential to either attempt aerosol-cloud discrimination or acknowledge that the tropospheric information content is uncertain. This is especially true for a regime like the particularly cloudy ASM.

We have originally done both (filtered and unfiltered) and actively decided among the coauthors to use the unfiltered version. We have decided for the unfiltered version, because we focus on the fire plume signature near the tropopause and the conclusions drawn were the same (+ the filtering process by Vernier and Thomason did not remove all cloud-like features in the new data product of SAGEIII). Note that newly cloud-filtered SAGEIII data are currently developped (Jean-Paul Vernier, personnal communication). The OMPS data are 'cloud-filtered' (only data above the 'top of cloud'-altitude are taken).

7) P6, L17. Like one of the reviewers, I do not see evidence of descent. In fact it can be argued from this figure that aerosol is ascending. Indeed Khaykin et al. (2018) show that the extratropical smoke plume height increased dramatically, presumably due to diabatic forcing. What is the indicator of descent?

"To exclude most cloud features and also background aerosol, we focus on the aerosol extinction region from ~0.6-0.9 km-1 for our analysis. A strongly enhanced aerosol extinction signature appears in the SAGE III data set, in the whole NH >40_N mid to end of August (Fig. 1B), after the beginning of the major fire event in Canada, confirming the results of multiple previous studies (Khaykin et al., 2018; Ansmann et al., 2018; Haarig et al., 2018). Between November 2017 and ~March 2018, the aerosol signature descends with 0.64 mm in altitude per second based on aerosol extinction values > 0.8 km-1 (5 km in three month, October to Janurary). This is in the order of the rate expected for the downwelling of the BDC (see Abalos et al.,2015). The effect of sedimentation is expected to play an important role. However, the contribution of

sedimentation as well as dilution/mixing is not quantified here, microphysical and dynamical sensitivity studies would be necessary. The troposphere and lower stratosphere are filled with enhanced aerosols until mid-April 2018."
We have added a line to guide the eye in Fig 1B and D, as also suggested by one of the reviewers.

8) P6, L20. I don't see any difference in the extinction pattern after mid-April as compared to just prior to mid April. In fact tropospheric extinction appears to be saturated red throughout the timeline. I refer back to my comment above regarding cloud contamination and suggest that it is not possible to argue that the preponderance of the unfiltered tropospheric extinction signal on display is from aerosol.
We agree that this paragraph as written is not clear. We have added a sentence in the beginning (see answer to comment 7) to clarify what aerosol extinction range we focus at.

9) P6, discussion of Fig. 1C. The value and information content of this figure panel is not obvious. As the authors state, detailed interpretation of smoke layers is hindered by the lack of filtering. In addition, half of the period rendered is the winter season, when there is no anticyclone and confinement. Presumably smoke aerosols would be in evidence in any other longitudinal sector in the winter. Hence some additional explanation of the meaning of Figure 1C is called for meaning of Figure 1C is called for.
We believe this plot is very important and have added another statement about the arrival of the plume already in the lower stratosphere.
"Fig. 1C shows the SAGE III aerosol extinction values in the inner AMA region (black box in Fig. 1A). The unfiltered cloud structures in the SAGE III data set masks the first appearance of the plume in the back box in Fig. 1C. However, the first SAGE III profile that we can track back to the fire plume signature originating from the Canadian wildfire appears on August 30th 2017 at 17 km altitude. The relatively high altitudes of this signature (17-20 km) indicate that the fire plume arrived in the TTL region in the Asian monsoon area, where the upward motion inside the AMA might have forced the fire plume to rise, as it was the case for the Sarychev aerosol plume in 2009 (Vernier &,Thomason 2011). A clear signal is still apparent in April 2018, 8 months after its first appearance and long after the break down of the AMA confinement. However, it has to be noted that there are no previous years of SAGE III measurements available so that no comparison with background conditions in April can be made."

10) P6, L29. Like the discussion of descent earlier, it is not evident what feature suggests ascent in Figure 1D. Moreover, there are additional plausible explanations for a sloping aerosol feature in a time series set in a localized domain. For instance, wind shear upwind of the domain box can generate a sloping aerosol feature within the time series; an apparent descending slope for aerosols below the jet max, apparent ascent for above the jet max. Khaykin et al. (2018) actually allude to this as a factor in the transport of the 2017 smoke plume. Considering that the smoke plume was transported from afar to the Asian sector, the role of wind shear in the transport and deformation should be acknowledged and investigated.

The respective paragraph in the manuscript has been modified: “To see whether the fire plume has entered the AMA circulation and has been transported to the tropics (as it has been shown for the Sarychev eruption by Wu et al. (2017)), another box south of the core Asian monsoon box has been chosen (Fig. 1A, magenta box). We attribute the ascending signal starting at around 16km in mid September and reaching altitudes of around 21 km about 6 months later to the Canadian wildfire, as its origin coincides in time and altitude with the fire signal in the AMA region (black box, Fig. 1C). In the tropics, the fire plume signature rises about 0.2-0.3 mm per second (about 5 km from September to April) in the magenta box according to aerosol extinction values of around 0.6 km-1. This tropical upwelling velocity estimate is in good agreement with the tropical upwelling velocity in current reanalyses (e.g., Abalos et al., 2015, Fig. 6). Similar ascending features are visible around the globe 0-25C. ~~It reaches approximatively the same altitude as the one above the black box in January 2018 (Fig. 1D).~~ The reversed vertical transport of the aerosol particles in Fig. 1B compared to 1D (i.e. the observed descent in the northern latitudes and ascend in the tropics) reflects the contribution of the ascending and descending branch of the BDC. The average signal for the magenta box remains also until April 2018 at ~19 km altitude. The AMA generates a strong connection between the mid-latitudes and the tropics during the summer season.”

11) As a general matter, it has been shown in published results, of this case and other pyroCb stratospheric smoke plumes, that large meridional excursions of the plume from extratropics to subtropics and tropics is routine and not beholden to the AMA. Khaykin et al. (2018) show that for the 2017 event; their Figure 3 shows Canadian smoke south of 30N over the western Atlantic Ocean. Jost et al. (GRL, 2004) showed Canadian stratospheric smoke at subtropical latitudes. (In a paper under review, Fromm et al. extend the Jost et al. case study and findings to latitudes as low as 14N.) Fromm et al. (JGR, 2008) showed stratospheric pyroCb smoke at a tropical location (Hawaii). The path there did not involve nor require the AMA circulation. Pumphrey et al. (ACP, 2011) showed Australian stratospheric pyroCb CO in the tropical southern hemisphere. Siddaway and Petelina (JGR, 2011) showed the tropical aerosol aspect of the CO plume that Pumphrey et al. presented. Hence the challenge for the present work is to convincingly show that the AMA was of consequence to the exclusion of (or together with) other demonstrable tropical plume excursions (E.g. Khaykin et al.’s Atlantic smoke).

Those papers are relevant to our work and will be mentioned.

We do not contradict other possible transport mechanisms into the tropics.We want to emphasize that we do not exclude the possibility that fire plume aerosols can also occur in the tropical stratosphere without any Asian monsoon anticyclone circulation interaction. Of course, the location of the occurring fire event is highly sensitive to the following transport mechanisms and also the time scale. In this case study we focus on the fire plume that was transported within the jet, reaching the Asian monsoon region and then transported around the anticyclone. We do, however, show for the first time that a fire plume originating from northern latitudes is transported within the circulation of the AMA (while not interacting with the isolated center of the AMA). Figure 3 by Khaykin et al. (2018) is limited to August 2017 and ~30°N while our Figure 1 and 3 (and discussions) focus also on September and the following months. From this point of *view, the Khaykin study does not contradict our work, but is rather taken as an input location from where part of the plume is transported around the anticyclone (e.g. see Figure B2 of the supplements).*

12) Kloss et al. claim that there is no profile showing fire plume presence inside the AMA black box (Conclusions, P12, L14) but also infer (P6) that there is a SAGE smoke profile on 30 August inside that box. Their claim is at odds with Khaykin et al. (2018) who show (their Figure 3) CALIPSO plume detections well inside the black AMA box on two dates in late August. Back trajectories that I calculated show that these plume segments connect with the synoptic-scale plume from a few days earlier over Europe, as shown in this paper (Figure 4) and Khaykin et al. (2018). This is seemingly at odds with the contention that the smoke plume bypassed the AMA center. Moreover, it is consistent with the general antecedent conditions of a large and expanding smoke plume advected from Canada to Europe to east Asia, including the region of the black box. Hence the big picture, as shown in this paper and Khaykin et al. (2018), is more in line with advective transport equally under the influence of all the flow regimes present throughout the northern hemisphere at that time.

The sentence says 'inside the AMA' and not 'inside the AMA black box'.

Our sentence (P12 L14) "There is no profile showing that the fire plume passes the barrier, mixing with the air masses inside the AMA." is true and important (one of the main messages of the paper). It is neither at odds with Khaykin 2018, nor with the plume being above Europe a few days before. There are several profiles inside the transport barrier of the AMA with no fire signature (e.g. see Figure B3 of the supplements, with the ATAL signal).

The black box from Figure 1 is chosen for a statistical approach, showing that this is an area of mostly being inside the AMA. The SAGEIII profile of the 30th of August is analyzed in detail and it is shown that this profile (on that particular day and on that particular altitude level) is within the flow of the anticyclone and not within the transport barrier.