

## **Author Responses to Reviewer Comments**

**<https://doi.org/10.5194/egusphere-2025-5587>, 'Modelling the deep convective transport of trace gases (CO, NH<sub>3</sub> and SO<sub>2</sub>) from the planetary boundary layer to the Asian summer monsoon anticyclone' by J. Ma et al.**

The authors would like thank Dr. Rolf Müller for handling this manuscript and the two anonymous reviewers for their useful and constructive comments. Below are author replies to reviewer comments in detail.

## Reply to Referee #1 Report on “Modelling the deep convective transport of trace gases (CO, NH<sub>3</sub> and SO<sub>2</sub>) from the planetary boundary layer to the Asian summer monsoon anticyclone” by Ma et al. (egusphere-2025-5587)

*The referee comments are written in this font style and color.*

Our answers are written in this font style and color, with the page and line numbers referring to the track-changes version of the revised manuscript.

Changes in the revised version of the manuscript are written in red.

**Summary:** *This study investigates the model representation of convective transport from the Asian boundary layer into the Asian summer monsoon anticyclone (ASMA) over the period 2010-2020. Three trace gases are considered in the analysis. The examined simulation indicates that convective transport tendency is strongest over the Tibetan Plateau for CO and NH<sub>3</sub>, and over India and China for SO<sub>2</sub>.*

We thank the anonymous referee for reading our manuscript carefully and providing constructive comments. Below are our point-by-point responses to referee’s comments in detail.

**Overall Thoughts:** *Overall this is a well-written study that makes an important contribution, and I believe that it should eventually be published. The authors include and discuss a large amount of relevant literature, which is a nice feature of the work. My primary concern is that I do not believe that the lone simulation presented can be trusted as representative of the real ASMA without some comparison to available observations. As the authors point out in the introduction, there have been a number of satellite, ground-based, and airborne measurements in the ASMA region, and I believe leveraging these for evaluation prior to detailed analysis of the model results is an important but currently missing feature.*

The EMAC model had been evaluated in previous work by airborne measurements in the ASMA region, which is described and referred to the literature in Sect. 2 ‘Model description and setup’ of the manuscript. For the completeness of this work, we have added comparisons with satellite observations of deep convection frequency (diagnosed using the convective cloud top heights from DaYu-GCP), CO (from MLS), NH<sub>3</sub> and SO<sub>2</sub> (from MIPAS) in the ASMA regions, as suggested by the referee. Thanks to the referee, we believe these comparisons would bring an improvement of our manuscript.

**Recommendation:** *Major revision*

**General Remarks:**

- *As mentioned above, the comprehensive literature review in this study is quite nice. One aspect*

*that appears missing is the recent discovery of the importance of East Asian emissions for the composition of the ASMA (see for example Smith et al., 2025 already cited and Pan et al., 2024, <https://doi.org/10.1073/pnas.2318716121>). This seems point seems to be missing in the first Introduction paragraph.*

We have added this information (Smith et al., 2025 and Pan et al., 2024) to the first Introduction paragraph of the revised manuscript.

Page 2, Line 1-3:

Deep convection plays an important role in the vertical redistribution of trace gases and the pollution transport from the planetary boundary layer (PBL) to the upper troposphere and lower stratosphere (UTLS) (Chatfield and Crutzen, 1984; Dickerson et al., 1987; Lelieveld and Crutzen, 1994; **Pan et al., 2024**).

Page 2, Line 8-12:

Deep convection can transport Asian pollutants, especially those from South Asia **and East Asia**, to the Asian summer monsoon anticyclone (ASMA) (Hoskins and Rodwell, 1995), where they are confined by the ASMA flow, forming a distinct chemical regime in the UTLS of the Northern Hemisphere during summertime (Randel and Park, 2006; Park et al., 2007; Park et al., 2008; Randel et al., 2010; **Smith et al., 2025**).

- *On page 3 the authors imply that the DC3 campaign has fully characterized and quantified deep convective transport, which I don't think any airborne campaign could truly do. I suggest instead that this remark be reframed that airborne measurements alone, however valuable, are not sufficient to fully characterize and quantify deep convective transport due especially to limited sampling in space and time, thus necessitating the use of numerical modeling to provide such estimates. This can serve to nicely motivate the present study as well.*

We have rewritten the sentence in the revised manuscript (Page 3, Line 18-23).

The chemical composition of the convective inflow and outflow was measured during the Deep Convective Clouds and Chemistry (DC3) field experiment taking place in North America (Barth et al., 2015); these airborne measurements alone, while valuable, are not sufficiently to fully characterize and quantify deep convective transport due especially to limited sampling in space and time, and numerical modeling considering detailed chemical, physical and dynamical processes are still needed to provide such estimates (Barth et al., 2007; Barth et al., 2012; Barth et al., 2026).

- *The model representation of convective transport is integral to this study, but I don't see any mention or reference to how the CVTRANS submodel actually works. Moreover the cited Tost et al. (2006b) study does not seem to explicitly mention either the CONVECT or CVTRANS submodels. It would be helpful for the authors to provide some more information or documentation here for reader interest.*

It is true that either the CONVECT or CVTRANS was mentioned in Tost et al. (2006b) although the two submodels were developed based on the work of Tost et al. (2006b). We

are sorry for leaving out a literature, Tost et al. (2010) (which provides the names CONVECT and CVTRANS for the two respective submodels), in the original version of the manuscript. We have added this citation and provided a brief description of CVTRANS in the revised manuscript. More detailed information on CVTRANS can be found in Tost et al. (2010) and Jeske and Tost (2025).

Page 5, Line 3-4:

Convective cloud processes and convective tracer transport are calculated using the CONVECT and CVTRANS submodels (Tost et al., 2006b; **Tost et al., 2010**),

Page 5, Line 10-13:

CVTRANS calculates the tracer transport following the bulk approach (“leaky pipe”) based on Lawrence and Rasch (2005). It is implemented with an interface to collect the required updraft and downdraft air mass fluxes and the respective entrainment and detrainment rates from CONVECT for a selected convection scheme (e.g. the Tiedtke-Nordeng scheme in this study) (Tost et al., 2010; Jeske and Tost, 2025).

- *Related to the above comment, it would be good if the authors could clarify whether convective transport tendency and convective transport efficiency calculations are performed within the model physics code immediately prior to and following convective transport. If not, I would expect that other processes would need to be considered too, such as horizontal transport from surrounding regions and chemical losses.*

Yes, the convective transport tendency calculations are performed within the model physics code immediately prior to and following CVTRANS. This information is provided in the first paragraph of Sect. 3.4 of the revised manuscript (Page 10, Line 2-7).

The tendency of a tracer due to convective transport alone can be obtained by extracting a corresponding variable (named ‘x<sub>tte\_cvtrans</sub>’), which is the difference in the tracer’s mixing ratio before and after the implementation of CVTRANS. Simulated results for x<sub>tte\_cvtrans</sub> are saved at 5-hr intervals as done for other variables, and these instantaneous values of x<sub>tte\_cvtrans</sub> can be considered as averages over each time interval, with its unit changed from mol mol<sup>-1</sup> s<sup>-1</sup> to nmol mol<sup>-1</sup> hr<sup>-1</sup> (ppbv hr<sup>-1</sup>) or pmol mol<sup>-1</sup> hr<sup>-1</sup> (pptv hr<sup>-1</sup>). For the cases without convection, the tendency is set as zero and is accounted for when doing seasonal and climatic averaging.

For the original manuscript, the seasonally mean convective transport efficiency was calculated by using the seasonally averaged updraft mass fluxes over all the convective period. For the revised manuscript, we have changed the statistic method by calculating the individual convective transport efficiency from the instantaneous updraft mass fluxes in each convection column first, and then calculating the seasonally mean convective transport efficiency using its individual values for each convection case. This information is provided in the caption of Figure 6 of the revised manuscript. It appears that this change of the calculation method does not affect the results and conclusions described in the manuscript text.

**Figure 6.** EMAC simulated averages of deep convective transport efficiency (CVE), i.e., the ratio of the updraft mass flux (UMF) at 10 km height above sea level to its maximum in each convection column (expressed in percent), for CO (a), NH<sub>3</sub> (b) and SO<sub>2</sub> (c), in JJA during the years 2010-2020.

- *The first three sentences in Section 3 seem unnecessary to me, as the information should have already been made clear in Sections 1 and 2. The middle sentence in particular doesn't make sense to me, as there doesn't appear to be any "observed" convection involved in this study, only simulated convection.*

We have deleted these sentences in the revised manuscript

- *It's worth noting that CAMS emissions of SO<sub>2</sub> over China likely underestimate recent reductions due to environmental policies over 2010-2020, as described by an upcoming publication (<https://doi.org/10.22541/essoar.175682819.92297398/v1>). This might be the reason why SO<sub>2</sub> convective transport is highest over China in the simulation presented herein. This could be mentioned as Figure 1c is described, as these model PBL values are mostly controlled by the emissions used as input.*

We have added the following sentences in the revised manuscript (Page 6, Line 31 – Page 7, Line 2).

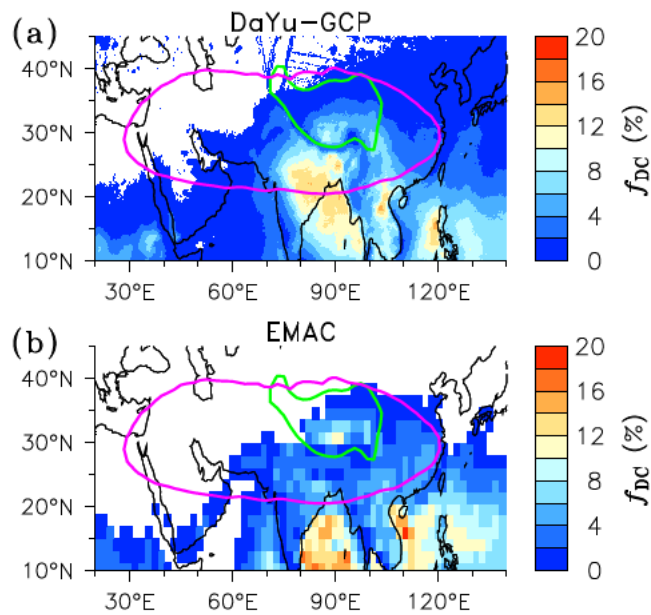
It should be noted that CAMS emissions of SO<sub>2</sub> over China might underestimate recent reductions due to environmental policies over 2010-2020, which can result in an overestimation of its PBL abundance and convective transport to the upper troposphere over eastern China (Smith et al., 2025b).

- *Are the results in Figure 2 supported by observations? It seems that convection is mostly concentrated over high terrain and it's important to verify that with observations if we want to believe the subsequent model results of convective transport tendency. Figure 1 of Smith et al (2025, already cited) does not show this same signal in satellite observations over the Tibetan Plateau, albeit for a single and different year.*

As suggested, we have added comparisons of our model results with satellite observations. Please see revised Figure 2 and added discussion in Sect. 3.2 of the revised manuscript (Page 7, Line 14 – Page 8, Line 3).

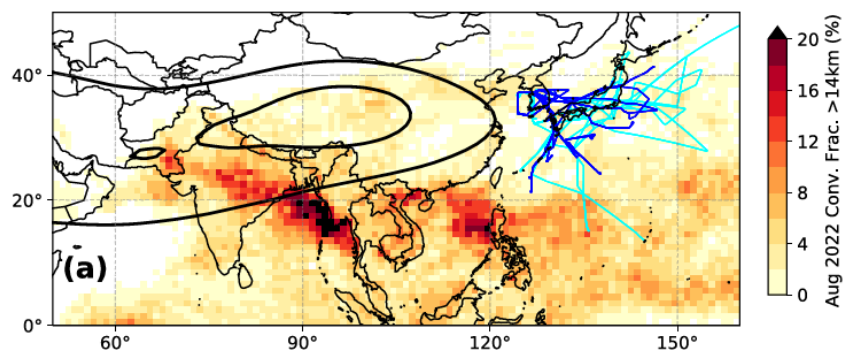
In this study, we employed the all-day Global Cloud Product derived from a single-layer cloud retrieval model within the DaYu cloud analysis system (DaYu-GCP), based on the merged thermal infrared brightness temperature of the global geostationary satellite from the Gridded Satellite project (Knapp et al., 2011), to evaluate the EMAC model.....

.....Our model results of enhanced deep convection frequency over the Tibetan Plateau are also supported by satellite observations presented in previous work (see Figure 2 of Fu et al. (2006), which has shown that number counts of convective clouds over the Tibetan are larger than those over the Tibetan southern slope at an altitude range of 11-16 km and those over the Indian monsoon region throughout all the altitude range.



**Figure 2.** Comparison of EMAC simulated relative deep convection frequency ( $f_{dc}$  in percent) for convective cloud top heights reaching above 14 km above sea level with DaYu-GPC satellite data (a) in JJA during the years 2010-2020. Purple lines are the 16.64 km geopotential height contour at 100 hPa, highlighting the main ASMA area (see Figure S1). Green lines represent the 3 km terrain height contour, highlighting the Tibetan Plateau.

In addition to Fu et al. (2006) cited in the revised manuscript, recent analysis of FY-4B geostationary satellite data by Zhao et al. (2025) also shows that there are enhanced deep convection system number counts over the central (66611) and southern (67477) Tibetan Plateau during the summer period.



**Smith et al., 2025** (<https://doi.org/10.1029/2024JD042732>), Figure 1: flight tracks overlain on a distribution of deep convective occurrence fraction, calculated as the fraction of August 2022 where a given location featured a convective cloud top altitude of at least 14 km. Convective cloud top altitudes are derived from CloudSat/CALIOP satellite observations using the method described by Pfister et al. (2022).

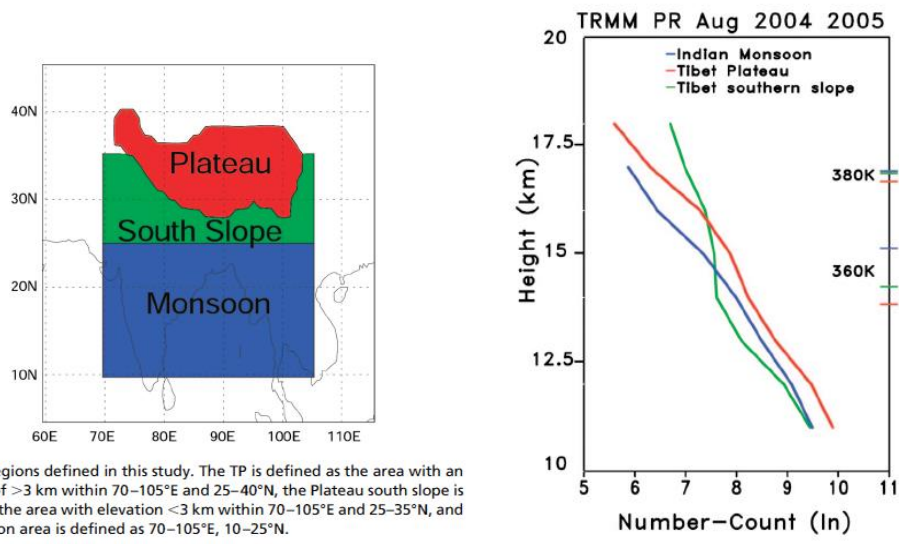
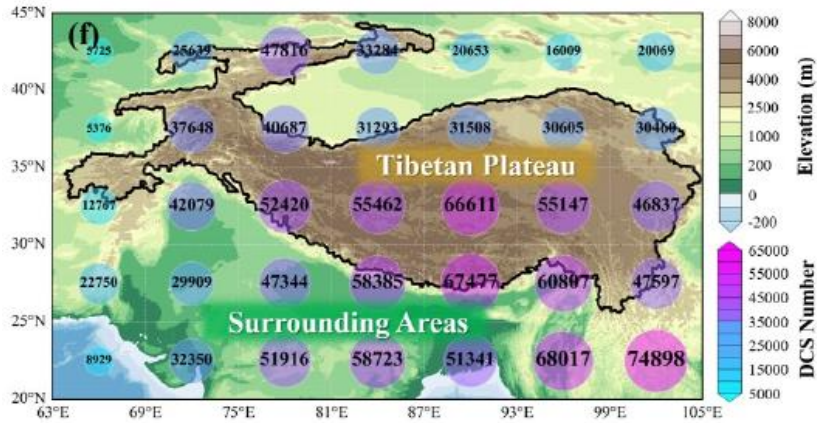


Fig. 1. Regions defined in this study. The TP is defined as the area with an elevation of  $>3$  km within  $70\text{--}105^\circ\text{E}$  and  $25\text{--}40^\circ\text{N}$ , the Plateau south slope is defined as the area with elevation  $<3$  km within  $70\text{--}105^\circ\text{E}$  and  $25\text{--}35^\circ\text{N}$ , and the monsoon area is defined as  $70\text{--}105^\circ\text{E}$ ,  $10\text{--}25^\circ\text{N}$ .

Fu et al., 2006 (<http://www.pnas.org/content/103/15/5664.abstract>), Figure 2: Number counts of convective tops  $> 10$  km as a function of altitude over the TP (red), Plateau south slope (green), and monsoon region (blue) during the period of August 2004 and 2005 derived from TRMM PR rain rate (product2A25). The tropopause (380 K) and 360 K in these three regions are indicated on the right axis with the same color as defined for the profiles.



Zhao et al., 2025 (<https://doi.org/10.1029/2025GL118433>), Figure 1: The spatial distribution of the deep convection system number and elevation across the study area during the summer of 2022-2024 from the Fengyun-4B satellite observations.

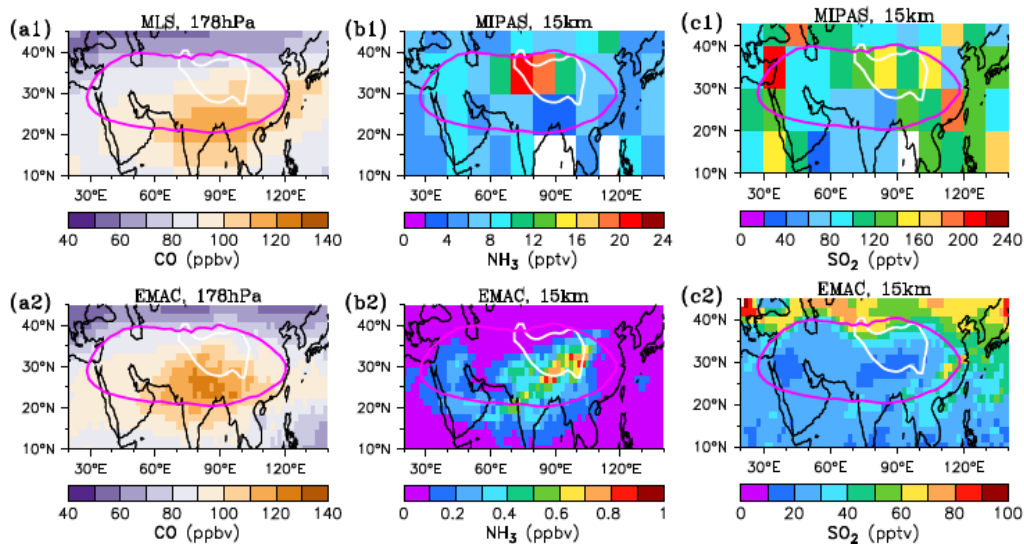
It appears that there are some disagreements in the distribution of deep convective occurrence over the Tibetan Plateau and surroundings between different satellite observations, perhaps due to the differences in sensor's sensitivity, overpass time, cloud filtering, and statistic method.

- As suggested above, I think it is also important to compare the results presented in Figure 3 (volume mixing ratios) with available observations to demonstrate the simulation's realism. Otherwise it is hard to know whether the subsequent model results are likely to be representative of the real ASMA environment.

We have added comparisons of our model results with MLS CO and MIPAS NH<sub>3</sub> and MIPAS SO<sub>2</sub>. The comparison results indicate that EMAC can well simulate deep convective transport of typical pollutants like CO from the PBL to the ASMA. Please see added Figure 3 and detailed description of comparisons in first three paragraphs of Sect. 3.3 of the revised manuscript (Page 8, Line 9 - Page 9, Line13).

We evaluate the model's performance in simulating CO, NH<sub>3</sub> and SO<sub>2</sub> within the ASMA, using satellite measurements of CO from the Aura Microwave Limb Sounder (MLS) (Livesey et al., 2018; Yan et al., 2019 and reference therein), NH<sub>3</sub> and SO<sub>2</sub> from the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) (Höpfner et al., 2015b; Höpfner et al., 2016).....

.....The comparisons presented here have provided the regional distribution characteristics of trace gases in the ASMA and its surroundings under cloud-free conditions. Since convective transport is generally associated with cloud processes, below we analyse the model results using the data for both the clear-sky and cloudy conditions.

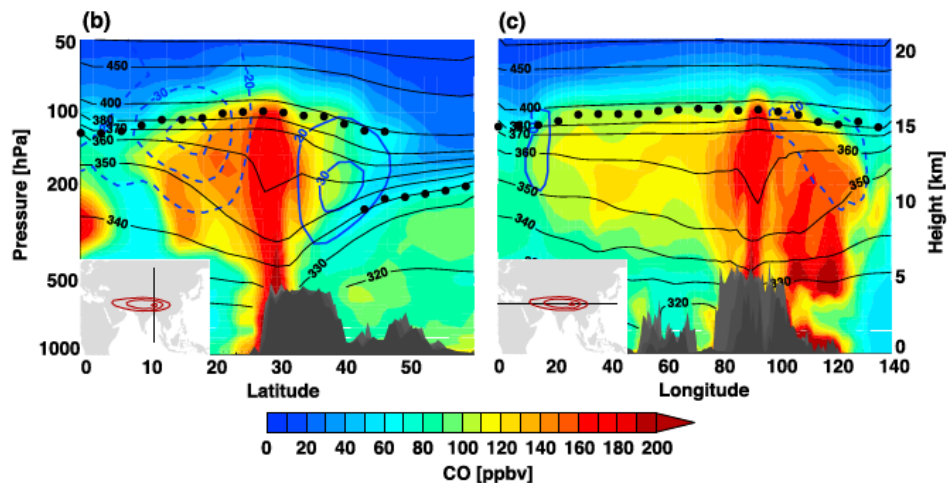


**Figure 3.** Comparisons of EMAC simulated cloud-free CO (a2) with MLS observed CO (a1) at 178 hPa for JJA over the years 2010-2020 and EMAC simulated cloud-free NH<sub>3</sub> (b2) and SO<sub>2</sub> (c2) with MIPAS observed NH<sub>3</sub> (b1) and SO<sub>2</sub> (c1) at 15 km above sea level for JJA 2010-2011. Purple lines show the 16.64 km geopotential height contour at 100 hPa, highlighting the main ASMA area. White lines represent the 3 km terrain height contour, highlighting the Tibetan Plateau. White grid cells in (b1) and (c1) indicate the default values in MIPAS dataset.

- I question how useful the convective transport efficiency calculation presented in Figure 5 is, as it seems to just highlight the same region where most of the model convection is (the Tibetan

Plateau, Figure 2). Perhaps transport efficiency is high there because of the enhanced convection, but the Plateau is a region where emissions are comparatively low (Figure 1) so this efficient transport still shouldn't impact ASMA composition all that much.

It is true that emissions are very low in the Tibetan Plateau, but pollutants from the surroundings (e.g., South Asia) can be transported to the lower troposphere over the Tibetan Plateau (at least over its southern edge by convergence flow as shown in Fig. 1 of this study) and further transported to the ASMA by enhanced convection there. Although the amounts of pollutants transported to the Tibetan Plateau are very small compared to their emission source regions, they can impact ASMA composition due to efficient convective transport there (e.g., for CO). These have been shown in previous studies, e.g., Fu et al., 2006 (<http://www.pnas.org/content/103/15/5664.abstract>) and Pan et al., 2016 (<http://dx.doi.org/10.1002/2016JD025616>) (see a copy of figure below). On the other hand, we showed that if the amounts of pollutants transported to the Tibetan Plateau are extremely small, due to efficient wet scavenging while being transported, they would not impact ASMA composition above the region, despite the enhanced convection there (e.g., for SO<sub>2</sub>). Here we would like to highlight high convective transport efficiency of the pollutants over the Tibetan Plateau.



**Pan et al., 2016** (<http://dx.doi.org/10.1002/2016JD025616>), Figure 2: (b) Latitude-pressure/altitude cross section of CO (ppbv) along 90 E (as shown on the locator map at the lower corner). (c) Same as Figure 2b but for longitude-pressure/altitude cross section.

- I don't believe that the title of "Discussion" for Section 4 is appropriate, I would suggest something related to model scavenging processes instead. It seems to me that this section is meant to provide additional analysis to give context to what was presented in Section 3. In my view a discussion is a reflection of past analysis rather than a presentation of new analysis.

As suggested, we have removed this title and merged Sect. 4 in to Sect. 3 using a new section title name of ‘Results and discussion’.

- I believe that the conclusions section is missing some big-picture link(s) back to ASMA research as a whole. The early literature review is nice, and I think it would help to discuss how previous studies can be put into context by these targeted model results, or specifically how future research in this field should be guided. Compatibility of the simulation with observations will add critical confidence that the real ASMA behaves in a similar way to support such claims.

We have added the following sentences to the last paragraph of the revised manuscript (Page 14, Line 15-22).

The ASMA has unique physical-chemical features, influenced by deep convective transport of pollutants from the Asian PBL, with the Tibetan Plateau acting as a well-defined conduit. In this study, our model simulations, together with satellite-based observational data analysis, further demonstrate the role of deep convection over the Tibetan Plateau in effectively transporting CO, an insoluble reactive gas, from the Southern Asian PBL to the ASMA. Our model simulations show that deep convective transport to the ASMA over the Tibetan Plateau is also effective for NH<sub>3</sub>, but ineffective for SO<sub>2</sub>. However, these model results for NH<sub>3</sub> and SO<sub>2</sub>, the two soluble reactive gases, are not entirely supported by the satellite observations. The causes of the discrepancy between model simulations and satellite observations of NH<sub>3</sub> and SO<sub>2</sub> in the ASMA cannot be determined in this study, posing a challenge for modeling and remote sensing of these two gases in future research.

**Technical Remarks and Typos:**

- Page 1 Line 24: typo, remove “is”.

Done.

- Page 2 Line 7: I recommend removing “a convective manifestation”.

Done.

- Page 2 Line 15: consider replacing “outside it” with “its surroundings”.

Done.

- Page 2 Line 18: I see that the term “smokestack” appears once in the Yu et al. (2017) study, but I think the “vertical conduit” terminology from Bergman et al. (2013) is much more widely accepted. I believe it should be used throughout this paragraph.

We have changed “an efficient smokestack” to “a vertical conduit” in the revised manuscript (Page 2, Line 18).

- Page 3 Line 4: I suggest removing “dynamic”.

Done.

- *Page 3 Line 16: The appropriate citation for the ACCLIP campaign is the recently published overview paper (Pan et al., 2025, <https://doi.org/10.1029/2025JD044417>).*  
Added.
- *Page 6 Line 30: “mPa” should be “hPa”.*  
Corrected.
- *Page 7 Line 7: whether a 10% frequency is “high” is subjective. I would rephrase to just say that the frequency reaches 10%. The same thing occurs on Page 8 Line 23.*  
Rephrased.
- *Page 7 Line 16: I don’t think that “respectively” is required in this case.*  
Deleted.
- *Page 7 Line 21: I suggest replacing “model study before” with “past model studies”.*  
Done.
- *Page 8 Line 30: missing period.*  
Added.
- *Page 12 line 6: missing period.*  
Added.
- *Figure 7 caption: I suggest changing both instances of “in the rains” to “in precipitating downdrafts”.*  
Done.
- *Figure S1 caption: typo, “hPa”.*  
Corrected.

**Many thanks!**

## Reply to Referee #2 Report on “Modelling the deep convective transport of trace gases (CO, NH<sub>3</sub> and SO<sub>2</sub>) from the planetary boundary layer to the Asian summer monsoon anticyclone” by Ma et al. (egusphere-2025-5587)

*The referee comments are written in this font style and color.*

Our answers are written in this font style and color, with the page and line numbers referring to the author’s tracked-changes version of the revised manuscript.

Changes in the revised version of the manuscript are written in red.

**Summary:** *This study uses the EMAC chemistry–climate model to diagnose deep-convective transport of CO, NH<sub>3</sub>, and SO<sub>2</sub> from the planetary boundary layer (PBL) into the Asian summer monsoon anticyclone (ASMA) during JJA for 2010–2020, and interprets inter-species differences using convective cloud partitioning and wet deposition diagnostics.*

*The topic is relevant and potentially informative. However, key conclusions are not sufficiently supported because (i) the diagnostics are interpreted beyond what they can uniquely demonstrate, and (ii) the manuscript lacks an observational evaluation of the modelled convection and UTLS tracer distributions that underpin the results.*

We thank the anonymous referee for reading our manuscript carefully and providing constructive comments. As mentioned in the manuscript, the model results in the ASMA area have been previously largely evaluated with in situ and remote sensed observations (e.g. Gottschaldt et al., 2017; Lelieveld et al., 2018; Tomsche et al., 2019; Johansson et al., 2020; Ma et al., 2019; Rosanka et al., 2021; Xenofontos et al., 2024; Becker et al., 2025). Nevertheless, we have added comparisons with satellite observations of deep convection frequency (diagnosed using the convective cloud top heights from DaYu-GCP), CO (from MLS), NH<sub>3</sub> and SO<sub>2</sub> (from MIPAS) in the ASMA regions, as suggested by the referee. The comparison results show that EMAC can simulate the general features of deep convection and associated transport to the ASMA. These have been added to the revised manuscript.

### **Overall assessment / recommendation**

**Major revision.** *The current evidence is not yet sufficient to substantiate the stronger claims about the “dominant role” of deep convection and tracer-specific pathways into the ASMA, especially given the reliance on seasonal averages, the lack of explicit budget attribution (e.g.,*

*horizontal advection vs convective injection), and the potential influence of non-PBL SO<sub>2</sub> sources.*

In this study we focus on the role of deep convection on the enhancements of selected tracers within the ASMA from a climatology point of view. Therefore, we calculated the seasonal averages of the convective transport tendencies (CVTs) of CO, NH<sub>3</sub> and SO<sub>2</sub> (Fig. 4 and old-Fig. 3) and compared them with the seasonal averages of the mixing ratios of CO, NH<sub>3</sub> and SO<sub>2</sub> (Fig. 5 and old-Fig. 4). Comparison results clearly show the consistence in the location between the CVT maximums and the mixing ratio maximums for all the selected tracers, indicating a role of deep convection in the enhancements of these tracers within the ASMA. Even so, we agree with the referee that it would be better to use ‘**a role of deep convection**’ than ‘a dominant role of deep convection’ in the revised manuscript (Page 10, Line 14).

We had also used the seasonally-averaged mass fluxes to calculate the mean deep convective transport efficiency (CVEs) of CO, NH<sub>3</sub> and SO<sub>2</sub> (Fig. 6 and old-Fig. 5). As suggested, we have used instantaneous mass fluxes to calculate CVEs for each convection case first, and then averaged them to get the seasonal mean values of CVEs. No matter which methods used, the CVEs are found to be higher over the Tibetan Plateau than its surrounding areas. It should be noted that the amounts of a tracer transported to the upper troposphere via the Tibetan Plateau are determined not only by tracer’s CVEs, but also by tracer’s amounts available in the PBL and lower troposphere in the area. To make this point more clearly, we have changed the phrase ‘is an effective pathway’ to ‘**can be a potentially effective pathway**’ in the revised manuscript (Page 10, Line 28).

An explicit budget analysis might show the potential influence of various processes (e.g., horizontal advection vs convective injection) on the loadings of tracers in a relatively large area, e.g., the ASMA. But the horizontal advection tendency of a tracer in a model grid cell is determined by both the winds (speed and direction) and the tracer mixing ratios in this and surrounding cells. It may not be suitable for investigating the sources of a tracer in a relatively small area, e.g., one or several model grid cells, due to high variability of wind fields. Especially, the tracer mixing ratios used to calculate the horizontal advection fluxes are influenced by the convection injection, making the separation between the two processes difficult for a relatively small area, e.g., over southern Tibetan Plateau. Our model simulations have shown that SO<sub>2</sub> levels are generally lower inside the ASMA than its surroundings due to limited convective transport from the PBL. The non-PBL SO<sub>2</sub> sources, e.g., volcanic erupted SO<sub>2</sub> plumes, can influence SO<sub>2</sub> levels within the ASMA to some extent, as shown in added figures (Fig.3a and Figs. S4 of revised manuscript). Since such kind of non-PBL sources are from the outside of the Asian summer regions, their impacts should be smaller inside the ASMA than its outside due to a dilution effect during transport.

## **Major comments**

1. *The manuscript makes a broad novelty statement (“for the first time... quantify the deep convective transport efficiency...”). As written, this is too broad, as convective “efficiency” metrics and convective injection diagnostics are used in the broader convection–chemistry literature. The paper does not clearly delineate what is new (e.g., the specific CVTRANS/UMF framework applied to a multi-year ASMA climatology for these tracers), versus an application of existing diagnostics.*

We have deleted the phrase ‘for the first time’ in the revised manuscript (Page 13, Line 26).

2. *The convective transport tendency (CVT) is defined as the difference in mixing ratio before and after the CVTRANS step, isolating the convective effect. However, the manuscript states that the mean CVT is calculated by averaging across all time intervals, not only deep convection events. But a time-mean over all intervals blends convective and non-convective periods and is not equivalent to a convective-conditional tendency. Yet the Results/Discussion uses correspondence between CVT and seasonal-mean mixing ratios to argue a “dominant role” of deep convection. This inference is not robust without explicitly demonstrating the relative roles of other processes that shape ASMA composition (horizontal advection/recirculation in the anticyclone, large-scale ascent, mixing, chemical loss, wet scavenging). This is particularly important for CO, which is long-lived and readily redistributed horizontally after injection.*

We did calculate the CVTs for each deep convection event individually, and then average the CVTs across all time intervals, including no deep convection cases (i.e., CVT = 0). In this way, the individual CVTs are weighted by number counts of deep convection, and derived seasonally mean CVTs can be compared to the seasonally mean mixing ratios reasonably.

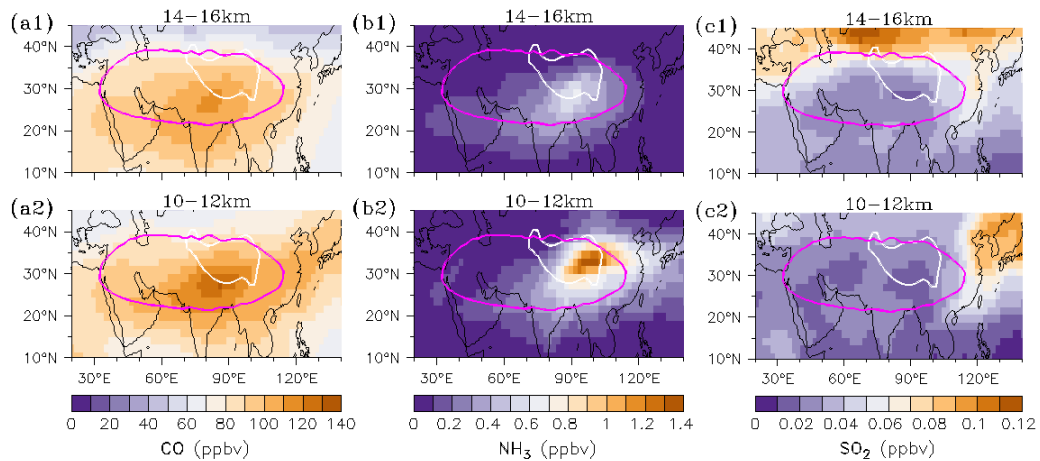
Here we may take two different areas (A and B) to illustrate the rationality of our calculation method. For instance, over a period with 100 of time intervals, there are 50 deep convection events over Area-A and 1 deep convection event over Area-B, with a CVT value of 10 pptv/hr for each event. We get a period-mean CVT of 5 pptv/hr for Area-A (by  $10 \times 50 / 100$ ), and a period-mean CVT of 0.1 pptv/hr for Area-B (by  $10 \times 1 / 100$ ). If we had calculated an average only for the deep convection events (i.e., neglecting the number counts of deep convection), we could get a mean CVT of 10 pptv/hr for both Area-A and Area-B, which would not match to the changes in mixing ratios due to deep convection over the two areas during the entire period. Note that we do not focus on one or several deep convection events in this study.

Tracers tend to undergo dilution process during horizontal transport. We cannot assume any strong emission sources of CO, NH<sub>3</sub> and SO<sub>2</sub> existing in the UTLS to explain their

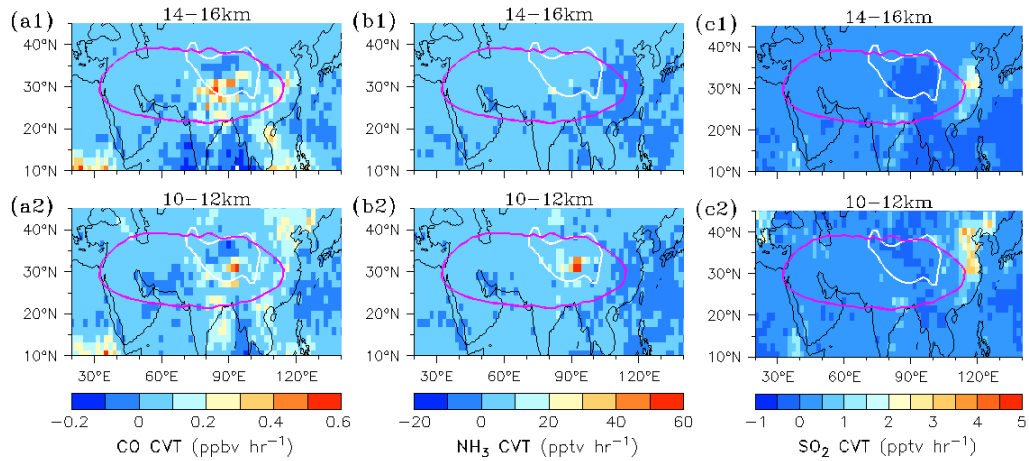
enhancements within the ASMA. The chemical loss and wet scavenging would reduce the tracer mixing ratios. Large-scale ascent, mixing and redistribution horizontally of tracers (e.g., CO, as pointed by the referee) can occur in the ASMA. But these transport processes might increase the tracer mixing ratios of transport-targeted areas only after injection of higher levels of tracers by deep convection to transport-sourced areas in the ASMA. While the latter (deep convection effect) is demonstrated by our analysis of CVT, the former (follow-up effect after injection) is not the focus of this study.

3. *The model configuration includes explosive volcanic SO<sub>2</sub> plumes during 2010–2020, added to the UTLS background SO<sub>2</sub>. Because the central goal is PBL to ASMA convective transport, this introduces a significant attribution ambiguity on the UTLS/ASMA SO<sub>2</sub> burden. The diagnostics (including CVE/CVT interpretations) presented here may not reflect boundary-layer Asian emissions alone. The manuscript notes this issue only briefly, but it directly affects the interpretability of SO<sub>2</sub> spatial patterns and transport conclusions.*

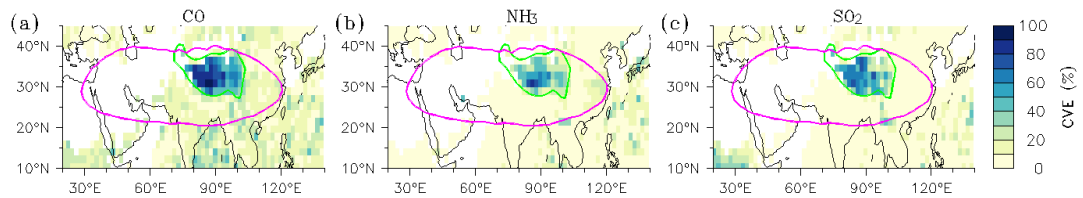
The Nabro volcano erupted on 12–13 June 2011 is a typical case that impacted SO<sub>2</sub> in the UTLS over the Asian summer monsoon region. We examined the case of the year 2011 (see Figs. A1-A3 below) in comparisons with the climatically averages of 2010-2020 (Figs. 4-6 of revised manuscript). It appears that the impacts of explosive volcanic SO<sub>2</sub> plumes on the calculated CVE/CVT within the ASMA are limited, although the increases in the SO<sub>2</sub> mixing ratio outside the ASMA are significant. This can be explained by the facts that the ASMA is a transport barrier separating trace gases between inside and outside and that the exchanges can take place to some extents along the edge of it.



**Fig. A1** Same as Fig. 4 (old-Fig. 3), except for 2011



**Fig. A2** Same as Fig. 5 (old-Fig. 4), except for 2011



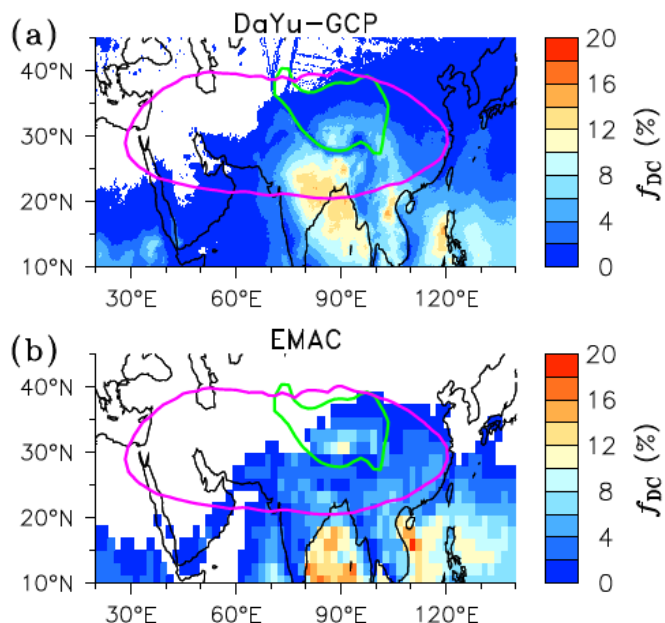
**Fig. A3** Same as Fig. 6 (old Fig. 5), except for 2011

4. *The manuscript references prior evaluations of EMAC but does not provide a focused evaluation of the modelled deep convection frequency and vertical reach in JJA over the ASMA region, and UTLS distributions of CO, NH<sub>3</sub>, and SO<sub>2</sub> during the study period with observations. Given that the paper’s conclusions hinge on convection and scavenging processes, this absence weakens confidence in the interpretation.*

We have added comparisons of model results with satellite observations in the revised manuscript. Please see revised Figure 2 and added discussion in Sect. 3.2 of the revised manuscript (Page 7, Line 14 - Page 8, Line 3).

In this study, we employed the all-day Global Cloud Product derived from a single-layer cloud retrieval model within the DaYu cloud analysis system (DaYu-GCP), based on the merged thermal infrared brightness temperature of the global geostationary satellite from the Gridded Satellite project (Knapp et al., 2011), to evaluate the EMAC model.....

.....Our model results of enhanced deep convection frequency over the Tibetan Plateau are also supported by satellite observations presented in previous work (see Figure 2 of Fu et al. (2006), which has shown that number counts of convective clouds over the Tibetan are larger than those over the Tibetan southern slope at an altitude range of 11-16 km and those over the Indian monsoon region throughout all the altitude range.

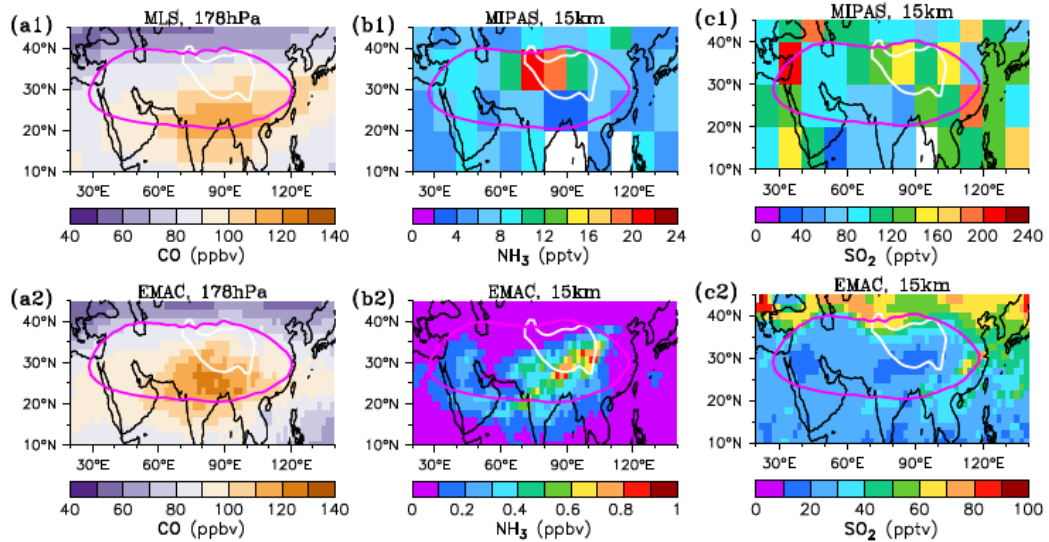


**Figure 2.** Comparison of EMAC simulated relative deep convection frequency ( $f_{DC}$  in percent) for convective cloud top heights reaching above 14 km above sea level with DaYu-GPC satellite data (a) in JJA during the years 2010-2020. Purple lines are the 16.64 km geopotential height contour at 100 hPa, highlighting the main ASMA area (see Figure S1). Green lines represent the 3 km terrain height contour, highlighting the Tibetan Plateau.

Also please see added Figure 3 and detailed description of comparisons in first three paragraphs of Sect. 3.3 of the revised manuscript (Page 8, Line 9 - Page 9, Line13).

We evaluate the model's performance in simulating CO, NH<sub>3</sub> and SO<sub>2</sub> within the ASMA, using satellite measurements of CO from the Aura Microwave Limb Sounder (MLS) (Livesey et al., 2018; Yan et al., 2019 and reference therein), NH<sub>3</sub> and SO<sub>2</sub> from the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) (Höpfner et al., 2015b; Höpfner et al., 2016).....

.....The comparisons presented here have provided the regional distribution characteristics of trace gases in the ASMA and its surroundings under cloud-free conditions. Since convective transport is generally associated with cloud processes, below we analyse the model results using the data for both the clear-sky and cloudy conditions.



**Figure 3.** Comparisons of EMAC simulated cloud-free CO (a2) with MLS observed CO (a1) at 178 hPa for JJA over the years 2010-2020 and EMAC simulated cloud-free NH<sub>3</sub> (b2) and SO<sub>2</sub> (c2) with MIPAS observed NH<sub>3</sub> (b1) and SO<sub>2</sub> (c1) at 15 km above sea level for JJA 2010-2011. Purple lines show the 16.64 km geopotential height contour at 100 hPa, highlighting the main ASMA area. White lines represent the 3 km terrain height contour, highlighting the Tibetan Plateau. White grid cells in (b1) and (c1) indicate the default values in MIPAS dataset.

### Minor/technical comments

1. In the abstract, “there is can even be a decrease...” needs correction  
Done (see Page 1, Line 26).
2. There appears to be a latitude typo (20–40 N) and a pressure-unit typo (100 hPa) in lines 6-7.  
Corrected (see Page 7, Line 9-10).
3. CVT is defined as a before/after CVTRANS mixing ratio difference, but the reported tendency units ( $\text{ppbv hr}^{-1}$ ) require explicit time normalization; this step is not clearly stated in the methodology description.

We have added following description in the revised manuscript (Page 10, Line 2-7).

The tendency of a tracer due to convective transport alone can be obtained by extracting a corresponding variable (named ‘x<sub>tte\_cvtrans</sub>’), which is the difference in the tracer's mixing ratio before and after the implementation of CVTRANS. Simulated results for x<sub>tte\_cvtrans</sub> are saved at 5-hr intervals as done for other variables, and these instantaneous values of x<sub>tte\_cvtrans</sub> can be considered as averages over each time interval, with its unit changed from  $\text{mol mol}^{-1} \text{s}^{-1}$  to  $\text{nmol mol}^{-1} \text{hr}^{-1}$  ( $\text{ppbv hr}^{-1}$ ) or  $\text{pmol mol}^{-1} \text{hr}^{-1}$  ( $\text{pptv hr}^{-1}$ ). For the cases without convection, the tendency is set to be zero and is accounted for when doing seasonal and climatic averaging.

4. *In the introduction, “a convective manifestation observed...” is a vague term; it should be revised.*

The phrase ‘a convective manifestation’ has been removed in the revised manuscript (Page 2, Line7).

5. *Figure 1 caption; correct “overlayed” to “overlaid.*  
Done.

6. *In section 3.2, correct the unit “pptbv”*  
Done.

7. *What do you mean by “in the rains” in figure 7 caption?*

It has been changed to ‘in the precipitating downdrafts’ in the revised manuscript.

**Many thanks!**