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Sydney NSW, 2052
AUSTRALIA

Weather and Climate Dynamics Editor
Dear Dr Roberto Rondanelli,

Re: Manuscript egusphere-2025-5743. *Stratosphere-Troposphere Exchange and Surface Ozone Pollution over Tropical Regions: A Case Study of Rossby Wave Breaking and Tropopause Folding*

We thank you and the reviewer for the review and constructive comments and helpful recommendations. We have carefully revised the manuscript and addressed each comment. The major changes are summarised below:

- We clarified the scientific framing of the study, including the distinction between tropopause folding, stratosphere-troposphere exchange, and the transport of stratospheric ozone into the troposphere.
- We expanded the Discussion to emphasise the potential role of the STE event in increasing regional background ozone and the risk of surface ozone exceedances over Mexico City. We also acknowledge the challenge of separating the stratospheric contribution from local emissions, and photochemical production.
- We added a discussion of uncertainty and predictability. The revised manuscript explains that large-scale precursors may indicate elevated ozone risk, but the timing and magnitude of the surface response remain uncertain due to local meteorology, boundary-layer evolution, emissions, and chemistry.
- We incorporated comparisons with previous subtropical studies, particularly Rondanelli et al. (2002) and Seguel et al. (2018). We also revised the trajectory analysis and Figure 7 caption to identify where parcels crossed the dynamical tropopause.

We believe these revisions improve the clarity, scientific context, and societal relevance of the manuscript, while maintaining a cautious interpretation of the STE contribution to surface ozone pollution.

Sincerely,
Dr. Clemente Lopez-Bravo

Reviewer #1

Authors response:

We sincerely thank the reviewer for their comprehensive review and valuable feedback. We have carefully considered all suggestions and addressed each point in the revised manuscript. Our detailed responses are provided below. All lines refer to the track-changes version of the manuscript.

Review for

Stratosphere–Troposphere Exchange and Surface Ozone Pollution over Tropical Regions: A Case Study of Rossby Wave Breaking and Tropopause

Folding by

Clemente Lopez-Bravo et al.

Summary: In their study, Lopez-Bravo et al. consider a stratosphere-troposphere exchange (STE) event over Mexico that is triggered by Rossby-Wave Breaking (RWB), tropopause folding and quasi-isentropic downward ozone transport. This STE event contributes to the background ozone concentrations in Mexico city, and the surrounding region, and contributes to the exceedance of ozone concentrations above regional air-quality thresholds.

The study does present the meteorological conditions leading to the STE event, making use of trajectory analysis, Eulerian diagnostics of tropopause folding and RWB and isentropic transport. The basic ingredients leading to the events are not novel, hence the study does **not** substantially contribute to our process understanding of STE events. Still, I think there are also several good reasons why the study is of interest to the STE community:

1. *The study clearly describes the temporal evolution leading to the downward and southward ozone transport, where it reaches tropical regions far south and thus leads to enhanced ozone concentrations in Mexico city. It is an untypical example of STE reaching the tropical region and thus is a good example of extratropical-tropical interaction. There are also some aspects untypical in this event, e.g., the persistence of the folding event. In summary, the STE evolution might not particularly novel in the processes/weather systems involved, but it clearly illustrates how they can influence tropical regions.*
2. *To me, the main conclusions and novel insights of the study are, therefore, not in the physical understanding of the processes leading to STE, but more on the societal relevance of events like the one discussed. This is nicely highlighted in the discussion and conclusion sections of the paper, where it is discussed how STE can contribute to enhanced background ozone*

concentrations in a city like Mexico city, thereby – in addition to other (industrial, combustion,...) sources of ozone – leading to concentrations above air-pollution thresholds. I am not sure whether the ‘community’ is already fully aware of this impact of large-scale-induced STE on local ozone concentrations and exceedances. In short, I enjoyed the discussion where exactly these aspects are addressed.

3. *Elaborating on 2), the study also makes clear that this kind of large-scale STE events can contribute to ozone (air pollution) exceedances that are not only localized, but cover a larger region. I think it is important to make the community (metropolitan administrations) aware of the fact that not all ozone enhancing processes can be controlled on a local scale, but that there are larger-scale drivers that can substantially contribute to it and this on a regional scale. In this sense, the study is important that it exactly addresses this aspect.*

4. *In the discussion and conclusion, the authors also address the predictability aspect of ozone exceedances. The synoptic-scale weather systems involved (RWB, tropopause folds,...) can be predicted with some lead time, and thus they might contribute to warning times. In essence, if the synoptic situations favors substantial STE, the local communal administration might be warned about a higher risk that air-pollution threshold might be surpassed. It is a weakness of the study that this aspect is mentioned in the discussion/conclusion, but not further elaborated. I would have appreciated if some more concrete discussion on this predictability aspects would have been addressed. So, maybe the authors could be somewhat more explicit in their discussion on how predictable the driving weather systems are, and how this might transfer to the predictability (and warning times) of ozone exceedances.*

Authors response:

We appreciate the reviewer's constructive assessment. We agree that the main contribution of this study is not the identification of a new physical mechanism of STE. We have revised the manuscript to clarify that its primary contribution is documenting an unusually persistent extratropical STE event reaching tropical central Mexico, characterising its Lagrangian and isentropic transport pathways, and examining its potential relevance to background ozone and regional air-quality exceedances.

We have strengthened the discussion of regional implications by distinguishing the large-scale stratospheric contribution from local anthropogenic emissions and photochemical ozone production. The revised text now describes STE as a dynamical preconditioning mechanism that elevated regional background ozone and may have increased the likelihood of exceedance, rather than as the sole or directly quantified cause of the observed surface episode. We also emphasise that the ozone enhancement extended beyond Mexico City to several urban regions, highlighting the relevance of these events to regional air-quality management.

In response to the reviewer's comment on predictability, we have expanded the forecasting discussion. We now distinguish between the predictability of synoptic-scale STE precursors and that of the resulting surface ozone concentrations. Large-scale features such as Rossby wave amplification, cutoff-low development, tropopause depression, and high-PV intrusions can be identified in numerical weather prediction several days in advance. We propose a staged approach: an initial regional-risk outlook based on these dynamical precursors is refined within 24 to 48 hours using predicted intrusion depth, trajectories, boundary-layer evolution, and chemical-transport forecasts.

For the March 2016 event, the diagnosed arrival of ozone-rich air in the lower troposphere about one day before the environmental contingency demonstrates the potential for short-term warning. However, we now explicitly acknowledge that the exact magnitude and timing of surface exceedances are less predictable because they depend on terrain and flow interactions, boundary-layer dynamics, local emissions, and photochemical production. We also clarify that the proposed lead times are indicative, as this study uses reanalysis and does not assess operational hindcast skill. Dedicated forecast experiments are an important direction for future work.

The revised discussion is provided *in Lines 510–540*

In summary, I think the study is interesting, however possibly somewhat less because of detailed process discussions but because of the impact of STE events on regional ozone exceedances and their predictability.

I think the presentation of the processes involved is clear and their temporal evolution is well described, but at several places the discussion could be improved, sometimes also become more concise. This aspects will be discussed in greater detail in my major concerns listed below. Whereas I see a few weaknesses in the process discussion, I really enjoyed the discussion and conclusion sections, which go beyond the physical processes and address the societal relevance of such STE events.

Given the aspect mentioned before, I can recommend the publication of the study if the following (major and some minor) concerns are addressed. I also see that the authors have already revised an initial version of their manuscript, and it seems to me that they have already improved this initial submission substantially.

Major concerns:

The introduction (section 1) already includes everything that is needed for the paper, but while reading I sometimes missed a clear storyline. Hence, the structure of the introduction could be improved. A few specific points:

- *Is L40-43 really needed in introduction? Possibly remove. But, instead what is written in L63-68 would more nicely fit into the text here than at its current later place in the text?*

- *Is the anticipation of the results needed in L78-81? I would remove them, as it somewhat disturbs the reading flow.*
- *The topic 'STE reaching a subtropical city' could be highlighted somewhat earlier in the introduction,*
- *Sometimes, some keywords are misleading (at least to me): Why 'However' in L23; why 'Although' in L56? These are minor points, but sometimes wrongly set key words can distract the reader. If a sentence starts with 'However', as a reader I am looking for the contrasting aspect, and in L23, for example, it is not immediately clear to me what the contrasting aspect is.*

In brief, the authors could 'streamline' the introduction somewhat.

Authors response:

We agree that the original Introduction contained the necessary background but that its organisation did not communicate the storyline as clearly as intended. We have reorganised and streamlined the Introduction and believe that these revisions provide a more coherent storyline and more clearly establish the central motivation of the study. The revised Introduction shows in Lines 18-125.

The revised Introduction now follows a clearer progression from the general mechanisms of stratosphere–troposphere exchange (STE), Rossby wave breaking, and tropopause folding to their potential effects on lower-tropospheric and surface ozone. It then introduces the challenge of identifying stratospheric influences in polluted tropical and subtropical cities before focusing specifically on Mexico City, the existing knowledge gap, and the objectives of this study.

In response to the reviewer's specific suggestions, we made the following changes:

1. We removed or condensed the material identified in former Lines 40-43 (Lines 39-47) and incorporated the relevant discussion from former Lines 63-68 (Lines 44-65) earlier in the Introduction. This material is now used to explain why diagnosing the surface influence of STE is particularly challenging in tropical and subtropical cities, where stratospheric transport interacts with local emissions, photochemistry, boundary-layer processes, and regional transport.
2. We removed the anticipation of the results in former Lines 78-81 (Lines 94-110). We deleted the statements that the STE event produced measurable surface-ozone impacts and acted as a dynamical precursor to the pollution episode. The revised Introduction now presents the study through four research questions without stating the conclusions in advance.
3. We introduced the relevance of STE to subtropical and tropical regions earlier in the section. We also now identify Mexico City explicitly as a tropical megacity in which the potential descent of stratospheric air into the lower troposphere and its relationship with surface ozone can be investigated.
4. We improved the transitional language throughout the Introduction.

5. We clarified the scientific distinction between the occurrence of Rossby wave breaking or tropopause folding and the diagnosis of STE. The revised text now states that these dynamical features alone do not necessarily demonstrate STE, and that additional evidence of cross-tropopause transport and sustained descent is required.
6. We condensed repeated material concerning the Mexico City knowledge gap and clarified how the combination of Lagrangian trajectories, isentropic diagnostics, reanalysis, satellite products, and surface observations addresses that gap.

Section 2) [Data and Methods] is 'jumpy', i.e., I would reorganize it to enhance the reading flow. Some aspects are also unclear and ask for further details. Some concrete suggestions:

- *In section 2.2, the tropopause is defined; section 2.7 also deals with tropopause definition.*
- *Would it make sense to combine 2.2 and 2.3, and thus to have all observations in one section? Possibly, 2.1 (ERA5) and the tropopause definition could be handled in one section?*
- *Transport modelling now comes in 2.4 (trajectories) and in 2.6 (isentropic analysis of tropopause fold transport); how about combining all transport aspects in one section?*
- *There is some repetition in 2.5, 2.6 and 2.7., for example, in discussion the 2-PVU contour and the identification of PV streamers (as proxy for RWB).*

Authors response:

We thank the reviewer for these helpful suggestions. We agree that the previous organisation separated closely related methods, resulting in some repetition. We have therefore substantially reorganised Section 2 to improve its coherence and readability. The revised Methods section now comprises three main subsections. The revised Methods section is presented in Lines 130-225.

1. Data sources and event selection: This subsection integrates ERA5 reanalysis, surface ozone observations, satellite ozone products, and event-selection criteria.
2. Dynamical tropopause, tropopause folds, and RWB diagnosis: This subsection consolidates definitions and diagnostic criteria for the dynamical tropopause, tropopause folds, the 2-PVU contour, PV streamers, PV overturning, and PV cutoffs.
3. Transport diagnostics: This subsection brings together the LAGRANTO trajectory analysis and isentropic transport analysis.

We have also removed repeated explanations of the 2-PVU dynamical tropopause and PV-streamer identification. These concepts are now defined once in the dynamical-diagnostics subsection and are referenced subsequently where required. In addition, the revised text more clearly distinguishes between PV streamers, overturning structures, and cutoffs and provides the operational definition of RWB-event intensity.

L110-111: Here, it is described how tropopause folds are identified by low PV (<1 PVU) and 'enhanced O3 mixing rates'. How much enhanced? A concrete threshold is missing.

Authors response:

The threshold ($\text{O}_3 > 2 \times 10^{-7} \text{ kg kg}^{-1}$) has been added in Lines 190-194.

- L117-119: I couldn't follow how the 'tropospheric ozone columns are calculated'. More details are needed

Authors response:

We have added further information to address the reviewer's comment. The revised explanation appears in Lines 153-163. The new section reads as follows:

"Tropospheric column ozone was obtained from the DSCOVR EPIC Level-4 tropospheric ozone product using a residual-based approach, in which the MERRA-2 stratospheric ozone column was subtracted from the EPIC total ozone column. The MERRA-2 stratospheric ozone column was calculated by integrating three-hourly ozone profiles from the top of the atmosphere to the tropopause, defined using the combined 2.5-PVU and 380-K criteria. The MERRA-2 fields were spatially and temporally collocated with the EPIC observations, and the resulting tropospheric ozone columns were provided on a $1^\circ \times 1^\circ$ grid in Dobson Units."

*- L142: How is the *intensity* of a RWB event defined?*

Authors response:

Thank you for pointing this out. We have included new information to explain the calculation of the RWB intensity for this event. The RWB intensity definition has been added in Lines 195-207.

- L142: 'identifying streamers' – really streamers or cutoffs? I would also always refer to it as a PV streamer or a PV cutoff, as streamer/cutoff might be not completely clear.

Authors response:

WaveBreaking provides two different indices for PV streamers and PV cut-off. We have clarified this in the manuscript. The response is supported by Lines 195-203. The new section reads as follows:

“The Streamer and Cut-off Indices were then applied to identify connected filamentary features and separated closed features of the 2-PVU contour, respectively. As a result, the March 2016 feature was classified as transitioning from a PV streamer to a PV cutoff.”

- L166-167: *“Tropopause folds occur ... cross tropopause exchange”. Is this statement from literature (which reference?)*

Authors response:

We have added the references to support this statement. The supporting references were added in Lines 184-188.

Spreitzer, E., Attinger, R., Boettcher, M., Forbes, R., Wernli, H., and Joos, H.: Modification of Potential Vorticity near the Tropopause by Nonconservative Processes in the ECMWF Model, *Journal of the Atmospheric Sciences*, 76, 1709 – 1726, <https://doi.org/10.1175/JAS-635> D-18-0295.1, 2019.

Sprenger, M., Croci Maspoli, M., and Wernli, H.: Tropopause Folds and Cross-tropopause Exchange: A Global Investigation Based upon ECMWF Analyses for the Time Period March 2000 to February 2001, *Journal of Geophysical Research: Atmospheres*, 108, 6402, <https://doi.org/10.1029/2002JD002587>, 2003.

-L154-156: *Incomplete sentence.*

Authors response:

We thank the reviewer for pointing this out. We have rephrased the sentence. The sentence was revised in Lines 168-176:

“Rossby waves originate from the latitudinal variation of the Coriolis parameter. In a stratified atmosphere, their dynamics are described using Ertel PV, which is materially conserved under adiabatic and frictionless conditions (Hoskins 1985). RWB occurs when a baroclinic Rossby wave amplifies sufficiently for PV contours on isentropic surfaces to experience meridional overturning and irreversible deformation. Consequently, RWB was identified based on these changes in PV-contour geometry.”

Section 3.1) [Results] starts with a case overview, then makes a link to ozone observations and tropopause folding in section 3.1.1, and continues in section 3.1.2

(very short section!) with a diagnostic perspective on the intrusion. The next section 3.2 then starts again with a synoptic-scale evolution... Here, I think there is a lot of repetition, and these first two parts of section 3 could become much more concise. As concrete suggestions:

- *I am not sure whether Figure 1 (relative vorticity) is actually needed because later the PV charts (at several time instances) are shown to discuss the evolution of the RWB event.*

Authors response:

We thank the reviewer for this suggestion. We agree that the purpose of Fig. 1 was not sufficiently distinguished from that of the subsequent PV figures. Nevertheless, we have retained Fig. 1 because it provides the pressure-level synoptic context needed to identify the upper-tropospheric trough associated with the event. In particular, the relative-vorticity field at 300 hPa shows the location, orientation, and intensity of the trough before the more specialised isentropic diagnostics are introduced. Lines 235-250.

Figures 4 and 5 serve a different purpose: they use potential vorticity on isentropic surfaces to diagnose the deformation of the dynamical tropopause and the evolution of the RWB structure from overturning and streamer formation to cutoff development. Thus, Figure 1 establishes the upper-level synoptic circulation, whereas the later PV figures provide the dynamical-tropopause and RWB diagnostics.

To make this distinction clearer and address the reviewer's concern about repetition, we have shortened the discussion accompanying Fig. 1 and removed material that duplicated the subsequent PV analysis. We have also revised the text and caption to state explicitly that Fig. 1 provides the pressure-level synoptic context rather than an additional diagnosis of the RWB evolution.

- *Possibly, the whole discussion in L177-190 could, concisely, be combined with section 3.2. to present the synoptic-scale evolution of the RWB event? For me, it would even work starting with the observations (section 3.1.1 and Figure 2), before then proceeding to the detailed discussion of the RWB event (now section 3.2 and Figure 3-5).*

Authors response:

Thank you for your constructive suggestion. We agree that the previous organisation led to repetition, as the synoptic evolution, tropopause disturbance, and RWB event were described separately in the case overview and in Sections 3.1.2 and 3.2. We have now substantially reorganised and condensed the opening of Section 3. The opening Results sections were reorganized in Lines 235-280.

Section 3.1 now begins with surface ozone observations and Fig. 2, establishing the timing, magnitude, duration, and regional extent of the ozone episode before addressing its possible relationship with the preceding tropopause disturbance. We state our interpretation cautiously, as temporal correspondence alone does not confirm a stratospheric origin for the observed surface ozone.

We have consolidated the former case overview, diagnostic subsection, and synoptic-scale discussion into Section 3.2, now titled “Synoptic evolution, Rossby wave breaking, and tropopause folding.” This section follows a single diagnostic sequence: the pressure-level structure of the baroclinic cyclone and upper-tropospheric trough (Fig. 1), vertical deformation of the dynamical tropopause (Fig. 3), morphology and evolution of the RWB event on the 330 K surface (Fig. 4), and the lower-isentropic and mid-tropospheric expression of the resulting cutoff (Fig. 5).

- *Figure 3: In the figure caption, the left panel refers to the mean over *North America*, the right one to the mean *over Mexico*. I assume that in both panels it is the same, but once as a monthly mean and once as a specific time instance. This is misleading for the reader.*

Authors response:

We have revised the Fig. 3 caption to clarify that both panels use the same spatial averaging domain, while representing the March monthly mean and the event-specific time, respectively. The edited text in Fig. 3 caption read as follows (Lines 266-270.):

“(a) March 2016 monthly mean over Mexico.”

- *It is also not completely clear what can be learned from Figure 5 compared to Figure 4. Both figures show PV at isentropic surfaces (330 and 320 K).*

Authors response:

We thank the reviewer for pointing out that the different purposes of Figs. 4 and 5 were not clear in the original manuscript. While both figures show PV on isentropic surfaces, each highlights a different aspect of the event. This distinction is explained in Lines 260-280 and in the revised captions.

Figure 4 presents PV on the 330 K surface to analyse the horizontal evolution and morphology of the Rossby wave-breaking event. At this level, changes in the dynamical-tropopause PV contour illustrate the transition from overturning and filament formation to a narrow PV streamer and, eventually, a detached PV cutoff. Figure 4 establishes the occurrence, classification, and temporal evolution of the RWB event.

Figure 5 examines PV on the lower 320 K isentropic surface together with the 500 hPa circulation. Its purpose is to determine whether the PV disturbance at 330 K was limited to the upper-level tropopause or part of a deeper, vertically coherent circulation. The PV anomaly on 320 K, aligned with the closed mid-tropospheric cyclonic circulation, shows that the cutoff extended vertically and was dynamically linked to the 500 hPa circulation. This lower-level structure is important for understanding the formation of the deep tropopause disturbance and the subsequent transport analysis.

We have revised the text and figure captions to make this distinction explicit. Figure 4 is now discussed exclusively as the diagnosis of RWB morphology and evolution, whereas Fig. 5 is presented as evidence of the vertical structure and mid-tropospheric dynamical characteristics of the cutoff.

The points listed above point also to some repetitive parts. In summary,, I think that the manuscript would benefit if such repetitive parts are removed. Particularly, in L305-327 the text could become much more concise, removing repetitions.

Authors response:

We thank the reviewer for this comment. As mentioned in our previous response, we have reorganised the opening Results sections to remove repeated descriptions of the synoptic evolution, Rossby wave breaking, tropopause folding, and cutoff development. We have also condensed the content previously found in Lines 305 to 327. The edited section reads as follows:

“The corresponding vertical evolution of PV and ozone is shown in Fig.~\ref{fig:x 8}. Between 10 and 13 March, before the environmental contingency in Mexico City, the downward displacement of isentropes within the tropopause fold and associated subsidence facilitated the transport of ozone-rich air from the lowermost stratosphere into the troposphere over central Mexico. ERA5 O₃ mixing ratios reached approximately $8 \times 10^{-7} \text{ kg kg}^{-1}$ between 150 and 400 hPa, spatially coinciding with elevated PV. The subsequent downward movement of ozone and PV anomalies provides consistent dynamical and ozone concentration evidence for the descent of stratospheric air into the middle and lower troposphere. Figure S4 also demonstrates that the regional ozone enhancement extended across densely populated and industrialized areas of central Mexico. This sequence of events establishes a plausible pathway through which STE could have contributed to the regional ozone enhancement. However, the magnitude of its contribution to observed surface exceedances cannot be determined from these diagnostics alone”

At several place, the arguments are not completely clear to me or remain somewhat vaguely supported by the analysis. For instance,

- In L L61-262 it is stated that the combined use of PV, N₂, ozone and humidity diagnostics establishes a comprehensive framework for identifying STE. Why is it completely clear that this is STE? In L274-275 it is further stated that the amplification of the 1-PVU contour reflects STE. I assume that this is indeed the case, however, the authors should also be careful in directly linking tropopause 'distortion' to STE. STE means that air parcels actually cross the tropopause, but if the tropopause becomes distorted, it does not necessarily mean that the air parcels cross the tropopause. They might remain stratospheric, and later – when the tropopause 'relaxes' to an undistorted state – just move with the 'tropopause' while always staying in the stratosphere. In brief, some careful discussion (a few sentences) would be appropriate to clearly distinguish between STE and tropopause distortions/intrusions.

Authors response:

We thank the reviewer for identifying the need to distinguish more carefully between tropopause deformation, a stratospheric intrusion, and parcel-scale STE. We agree that the downward displacement or amplification of a PV contour does not, by itself, demonstrate that air parcels crossed the tropopause, because parcels may remain on the stratospheric side of a temporarily deformed tropopause and subsequently move with the tropopause as it relaxes.

We have revised the section Tropopause fold depth and structure. The following summarises these changes (285–315):

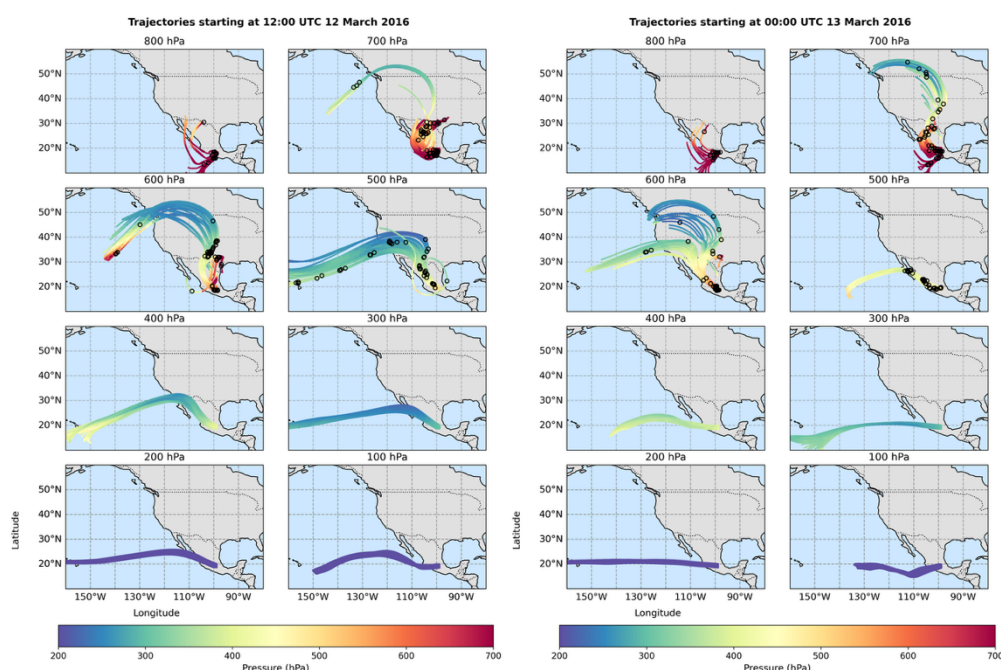
We clarified that the PV, N₂, humidity, and ozone fields provide Eulerian evidence of tropopause deformation and descending stratospheric air, but do not confirm parcel-scale STE. We removed the direct link between displacement of the 1 PVU contour and STE and now use trajectory analysis to assess tropopause crossing. We also describe cutoff-low development, noting it creates conditions favourable for tropopause deformation and potential stratospheric intrusion.

- *Where do the back trajectories shown in Figure 7 cross the tropopause? It would be interesting to see these locations marked in a map, thereby highlighting whether the tropopause crossing happens locally over Mexico City or further upstream.*

Authors response:

We thank the reviewer for this suggestion. We agree that the original trajectory analysis demonstrated stratospheric origin and subsequent descent. The geographical locations for these trajectories are shown in Fig. S3. We have therefore diagnosed the first sustained stratosphere-to-troposphere transition

along each trajectory. The resulting crossing locations are shown in Fig. S3. Our analysis indicates that the crossings occurred primarily over central Mexico, demonstrating that the parcels crossed the tropopause upstream and local over central Mexico. Figure S3 is displayed below.



- *To me, Figure 9 and its discussion in L346-354 is difficult to understand. Either rephrase in clearer way, or consider removing Figure 9. Is it really need to make the key points of the manuscript? If not, I would remove it.*

Authors response:

We thank the reviewer for this comment. We agree that the previous description of Fig. 9 was difficult to follow and did not clearly explain the figure's distinct contribution. We have therefore rewritten the corresponding text and revised the figure description. The revised explanation appears in Lines 405-430 and the revised Fig. 9 caption.

We have retained Fig. 9 because it provides a time-isentropic-level summary of the intrusion, complementing the spatial cross-sections and backward trajectories in previous figures. It shows that the ozone-rich, high-PV signature was initially concentrated at approximately 340-360 K, then extended to lower isentropic levels after 10 March, and was detected on the tropospheric side of the dynamical tropopause at approximately 310-320 K during 10-13 March. This figure clarifies the timing and isentropic depth of the intrusion over Mexico City and its Metropolitan Area, which is less apparent in the individual cross-sections or trajectory maps.

To improve clarity, the revised text now explicitly explains the marker shapes and colours and presents the figure as complementary evidence of the progressive downward extension of air with stratospheric characteristics. We have removed the stronger claims that Fig. 9 independently demonstrates irreversible cross-tropopause mixing or directly quantifies the contribution of stratospheric ozone to surface exceedances. With these revisions, we believe Fig. 9 provides a useful and distinct summary of the temporal evolution and vertical extent of the diagnosed intrusion.

Editor comments:

We thank the Associate Editor for this positive assessment and for recommending the studies by Rondanelli et al. (2002) and Seguel et al. (2018). We have incorporated these studies into the Discussion as subtropical Southern Hemisphere comparisons.

We have revised the manuscript to emphasise that the March 2016 STE event likely increased regional background ozone, raising the risk of surface exceedances over central Mexico. However, we now clarify that the available analyses cannot quantitatively distinguish stratospheric ozone from local production. This uncertainty is especially relevant for Mexico City due to its complex terrain, high elevation, strong precursor emissions, and active photochemistry, and it extends beyond our expertise.

We have expanded the discussion of predictability. The revised manuscript explains how large-scale proxies such as Rossby wave breaking, cutoff-low development, high-PV intrusions, and tropopause depression could serve as probabilistic indicators of elevated background ozone risk. However, the magnitude and timing of surface exceedances remain less predictable, and the proposed warning times are only indicative.

The new section reads as follows:

“Comparable stratospheric intrusions over complex terrain in subtropical South America have been shown to increase both surface and tropospheric-column ozone concentrations (Rondanelli et al., 2002; Seguel et al., 2018). The March 2016 event demonstrates that STE contributed to elevated regional ozone background and increased the probability of exceedances in Mexico City. However, the influence of local emissions complicates exclusive attribution to STE, and further research is necessary to distinguish between stratospheric and local sources.”