Dear Reviewer

First, we would like to thank you and the reviewers for your effort and the time spent to evaluate the manuscript entitled "**Ozone Downward Flux Revealed by High-Resolution Differential Absorption Lidar over Tibet during Stratosphere-Troposphere Exchange" (egusphere-2026-3261)**" We are sure that their valuable comments will improve the quality of our research work. We also would like to thank the editorial board for his guidance to proceed further. Following the reviewers' suggestions, we have revised this manuscript and highlighted the modifications in the revision. The point to point response to the comments are given below.

Response to Reviewer :

We would like to thank the reviewer for the efforts and time and appreciate the encouraging review. Thank you for pointing out our mistakes. We really believe that your feedback has helped us to improve the presentation of our manuscript and the quality of our paper.

General Remarks

The topic of this manuscript is both necessary and scientifically meaningful for research on stratosphere-troposphere exchange over the Tibetan Plateau. The observational dataset used in this study is relatively rare. In particular, the lidar system employs four differential absorption wavelengths together with two nitrogen Raman channels, allowing simultaneous measurements of tropospheric and stratospheric ozone profiles as well as temperature profiles over the Tibetan Plateau. This dataset therefore has considerable scientific value. The short-duration and rapid ozone downward-transport event presented in the manuscript is also worthy of attention.

The overall research framework is reasonably complete. I am particularly interested in the relationship established in this study between lidar-observed ozone downward transport and variations in the temperature profile. The main conclusions of the current manuscript are generally reasonable. Nevertheless, the descriptions of several methods and the associated uncertainty analysis require further improvement. I recommend that the authors address the following comments in the revised manuscript.

Our Response:

We sincerely thank the reviewer for the positive assessment of the scientific significance of this study and the value of the simultaneous ozone and temperature lidar observations over the Tibetan Plateau.

Following the reviewer's suggestions, we have carefully revised the manuscript to improve the clarity and rigor of the analysis. In particular, we clarified the identification of the T0-T6 features and strengthened their event-by-event comparison with temperature variations. We also distinguished the direct lidar observations from their dynamical interpretation, clarified the respective roles of ERA5 and the lidar data, improved the discussion of tropopause folding and wave-related oscillations, and refined the cross-tropopause flux diagnosis. In addition, the descriptions of the lidar system, retrieval methodology, validation, and uncertainties have been expanded, and the identified errors have been corrected.

We believe that these revisions have substantially improved the manuscript. Detailed responses to the individual comments are provided below.

Comments and Suggestions #1

P. 4, Lines 95-99

The manuscript states that the raw backscatter signals were stored at 1 min intervals, while the stratospheric signals were accumulated over 30 min and processed using a moving window to obtain continuous profiles. Under this processing scheme, retrievals at adjacent output times may share a large proportion of the same raw signals. The authors should therefore distinguish between the effective integration time and the independent temporal resolution.

For example, the expression "1 min temporal resolution" could be revised to "a 1 min output interval with a 30 min effective integration time." These two concepts should not be treated as equivalent.

Our Response:

Thank you for the careful evaluation of our work and for your valuable suggestion. We have revised the corresponding description to clarify the temporal output interval and the presentation of the wavelength-dependent photon-count profiles and signal-to-noise ratios. We appreciate this comment, which has helped improve the clarity and methodological rigor of the manuscript.

Changes in the manuscript:

The corresponding description in Lines 144-148 of the revised manuscript has been revised as follows: "In routine operation, the system records raw signal files at a 1-min output interval … the resulting wavelength-dependent photon-count profiles and signal-to-noise ratios are shown in Fig. 2(a-d)."The corresponding revisions are highlighted in green in the revised manuscript.

Comments and Suggestions #2

P. 6, Lines 111-116

This section presents the merged ozone number-density profiles obtained from the lidar measurements, but no uncertainty range is provided. Considering that the ozone flux calculated later in the manuscript depends simultaneously on ozone concentration, mass flux, and the diagnosed tropopause position, the authors should provide a reasonable estimate of the uncertainty in the retrieved ozone profiles.

Our Response:

We thank you for the careful evaluation of our work and for the valuable suggestions.

The ozone lidar system employs six return wavelengths and ten signal channels, together with a range-dependent retrieval strategy using separate low and high-altitude channels, to ensure an adequate signal-to-noise ratio (SNR) over each altitude range. In the ozone retrieval, the altitude-dependent variation of the molecular absorption cross-sections associated with changes in atmospheric temperature is also taken into account. To construct a continuous ozone profile, the five retrieved profile segments are merged using three-bin overlap regions at the boundaries between adjacent segments. This multi-channel and range-dependent retrieval strategy helps reduce the retrieval uncertainty and ensures continuity between the different altitude ranges.

The detailed retrieval procedure, error analysis, and performance evaluation of the USTC Ozone Lidar have been reported in Fang et al. (2019), particularly in Figs. 7 and 8. In the revised manuscript, we have also expanded the relevant parts of Section 2 to provide a more accurate and rigorous description of the lidar configuration, retrieval procedure, profile merging, interference terms, validation, and principal sources of uncertainty.

Changes in the manuscript:

The descriptions of the lidar configuration, measurement channels, and data-acquisition strategy have been expanded in Lines 116-148. The retrieval procedure, profile merging, interference terms, validation, and principal sources of uncertainty are further clarified in Lines 153-165 of the revised manuscript.

Comments and Suggestions #3

P. 10, Lines 219-229

The authors select 3 PVU as the dynamical tropopause for this event based on changes in the calculated mass flux under different potential-vorticity thresholds and on the spatial continuity of the corresponding PV surfaces. This choice is generally understandable, but the current selection criteria remain somewhat qualitative.

I suggest that the authors provide a comparison of the main results obtained using, for example, the 2, 3, and 4 PVU surfaces. If the principal conclusions remain consistent under these different thresholds, such a comparison would provide stronger evidence for the robustness of the results. Alternatively, the statement that "3 PVU is the most appropriate threshold" could be moderated. A more precise formulation would be that "3 PVU is adopted in this study as a representative threshold for this event."

Our Response:

Thank you for this helpful suggestion. The rationale for selecting 3 PVU as the dynamical-tropopause threshold is described in Lines 298-319 and illustrated in Figs. 6 and 7.

The sensitivity analysis in Fig. 6 shows that thresholds below 3 PVU produce relatively large upward and downward transport with stronger tropospheric characteristics, whereas thresholds above 3 PVU yield markedly smaller transport with stronger stratospheric characteristics. The zonal and meridional PV cross-sections in Fig. 7(a-b) further show that lower-PVU surfaces become discontinuous in some regions, while their continuity and stability improve for thresholds of 2 PVU and above. Based on both the flux sensitivity and the spatial structure of the PV surfaces, we adopt 3 PVU as a reasonable and representative dynamical-tropopause threshold for this event. The corresponding surface is indicated by the orange lines in Fig. 7(a-b).

Following the reviewer's suggestion, we have also replaced statements describing 3 PVU as "the most appropriate threshold" with the more precise wording "a representative dynamical-tropopause threshold for this event," including the corresponding statement in the Abstract (Lines 15-16).

Changes in the manuscript:

The rationale for selecting the 3-PVU dynamical tropopause has been clarified in Lines 298-319 of the revised manuscript. The revised text now describes both the sensitivity of the diagnosed upward and downward mass fluxes to different PV thresholds, as shown in Fig. 6, and the spatial continuity and stability of the corresponding PV surfaces, as shown in Fig. 7(a-b). The orange lines in Fig. 7(a-b) indicate the adopted 3-PVU dynamical tropopause.

In addition, statements describing 3 PVU as "the most appropriate threshold" have been moderated throughout the manuscript. They now state that "3 PVU is adopted as a reasonable and representative dynamical-tropopause threshold for this event." The corresponding wording in the Abstract has also been revised in Lines 15-16.

Comments and Suggestions #4

Pp. 8-13, Figs. 4 and 8 and the related discussion

The most distinctive aspect of this study is the simultaneous observation of high-resolution ozone and temperature profiles by the lidar system. I recommend that the authors further strengthen this part of the manuscript.

In particular, the identification criteria for the T0-T6 stages should be described more clearly. The manuscript should also explain more explicitly how the observed temperature gradients correspond to the ozone anomalies. A quantitative or event-by-event comparison would be especially useful. Further development of this analysis would make the observational contribution of the study more prominent. It would also reduce the extent to which the main conclusions depend on a single flux-diagnostic method.

Our Response:

We thank you for the careful evaluation of our work and for the valuable suggestions.

We agree that the co-located and co-temporal observations of ozone and temperature profiles constitute one of the most distinctive observational contributions of this study. Following the reviewer's recommendation, we have substantially expanded the discussion associated with Figs. 4 and 8 and have revised Sections 3.1 and 3.2 to make the identification and interpretation of the T0-T6 episodes more explicit.

First, we have clarified the observational criteria used to identify T0-T6. These labels denote coherent, short-lived episodes in which an ozone-enhanced structure near the tropopause can be tracked over adjacent moving-window retrievals and exhibits a discernible downward displacement relative to the surrounding observations. Only episodes for which co-temporal 387-nm Raman temperature profiles with an adequate signal-to-noise ratio were available over the corresponding altitude range were included in the comparison. We also clarify that T0-T6 are observational event labels used for comparative analysis and are not, by themselves, interpreted as direct proof of irreversible cross-tropopause transport.

Second, we have strengthened the event-by-event comparison between the ozone and temperature observations. For each episode, the temperature gradient is now evaluated over the same observation window and the corresponding altitude interval of the ozone-enhanced structure. The revised manuscript explicitly shows that six of the seven episodes (T0, T1, and T3-T6) are associated with temperature gradients exceeding 8 K km^{-1}, whereas T2 exhibits a weaker but still distinct gradient of 4.2 K km^{-1}.

We have also revised the discussion to distinguish more clearly between observational correspondence and dynamical interpretation. The co-temporal and co-altitudinal correspondence between the ozone displacements and temperature variations is presented as a direct lidar-based observational result, while the ERA5-derived PV fields and the Wei flux diagnostic are used subsequently to place these local observations within the regional dynamical context of the overall STE event. We no longer use the flux diagnostic as the sole basis for interpreting each individual T0-T6 feature.

These revisions strengthen the independent observational evidence provided by the simultaneous ozone and Raman-temperature measurements and reduce the extent to which the main interpretation depends on a single cross-tropopause flux-diagnostic framework. We thank the reviewer for this suggestion, which has helped us better highlight the principal observational contribution of the study.

Changes in the manuscript:

Sections 3.1 and 3.2 and the discussions associated with Figs. 4 and 8 have been revised. An event-by-event comparison of the ozone and temperature observations has also been added. The revised manuscript further distinguishes the direct observational correspondence between ozone and temperature variability from the subsequent dynamical interpretation. T0-T6 are now treated as observational event labels rather than direct evidence of irreversible cross-tropopause transport, while the ERA5-derived PV fields and Wei flux diagnostic are used to place these local observations within the regional dynamical context of the overall STE event.

Comments and Suggestions #5

P. 17, Lines 280-285

The description in this section is somewhat confusing. The authors are advised to carefully check the relevant text and clarify the intended meaning.

Our Response:

Thank you for pointing this out. We agree that the original description was confusing because it discussed the spatial pattern, domain-mean temporal evolution, and local contributions of the different mass-flux components within the same paragraph without clearly distinguishing among them.

We have carefully revised this section. In particular, we now clarify that the close similarity between the horizontal-advection term and the total flux in Fig. 9 refers primarily to the spatial distribution of the 6-h mean flux field. It does not imply that horizontal advection alone controls the net downward mass transport. In contrast, the domain-mean time series in Fig. 7(c-d) show that the horizontal- and vertical-motion contributions are largely compensating, such that variations in the tropopause-motion term exert an important influence on the temporal evolution of the net flux. At the Yangbajing lidar site, the vertical-motion term also contributes locally to the diagnosed downward flux.

We have therefore revised the paragraph to distinguish clearly between (1) the component controlling the regional spatial heterogeneity of the flux, (2) the component influencing the domain-mean temporal evolution, and (3) the local contribution at the lidar site.

Changes in the manuscript:

The corresponding revisions can be found in Lines 378-385 of the revised manuscript.

Comments and Suggestions #6

P. 17, around Line 343

The reference “shown in Fig. 10” appears to refer to Fig. 11. Please check and correct the figure citation.

Our Response and changes in the manuscript:

Thank you for your careful review and for raising this point. We have revised the manuscript accordingly; please see Lines 454-455 of the revised manuscript.

After the modification, we found the reviewer’s comments are quite helpful. Once again, we appreciate for your warm work earnestly, and hope that the correction will meet your standards.

Best Regards.

Yours Sincerely,

All authors