Dear Editors and Reviewers,

Thank you very much for your careful review on our manuscript egusphere-2024-268. We appreciate very much your encouraging comments and constructive suggestions on improving our manuscript. We have accordingly made the careful and substantial revisions. The revised portions are marked up in the revised manuscript. Please find our point to point responses to the reviewers' comments as follows:

Responses to the reviewer #1

[My main concern is that surface observations (Figure 5) seem not to strongly support the claim that this SI reached the surface. The diurnal cycles of ozone and temperature seem not to be disturbed by the SI event, but the ones of carbon monoxide and humidity seem indicative. This can be due to that the average over NCP was considered. The authors are encouraged to examine the observations at individual sites for stronger indications of the SI to the surface.]

Response : Thanks to the reviewers for the valuable suggestion on our manuscript. Following the reviewers' suggestion, the changes in observed meteorological and environmental elements from the representative sites SJZ and JN (The red dots in Fig. S3) were examined in Fig. S6 with the following discussions:

The changes in observed meteorological and environmental elements from the representative sites SJZ and JN in the NCP (The red dots in Fig. S3) were examined in Fig. S6. The results showed the distinct characteristics compared with the regional averages that the diurnal cycles of O_3 concentrations were disturbed with the O_3 peaks by the SI event . The SJZ in the northwest NCP received stratospheric O_3 earlier and reached the spike at 10:00 LST on May 19. Then the O_3 concentrations gradually decreased under the influence of strong winds but still maintained a high level in the early morning of May 20. The JN in the southeast NCP was affected by the stratospheric intrusion later. While under meteorological conditions conducive to the dissipation of pollutants (wind speed up to 8 $m \cdot s^{-1}$), higher O_3 concentrations than the previous day were still observed, reflecting the additional contribution of stratosphere intrusion to near-surface O_3.

We have added the above discussion to lines 256-263 in Section 3.2 and Fig. S6 was added in the supplement.

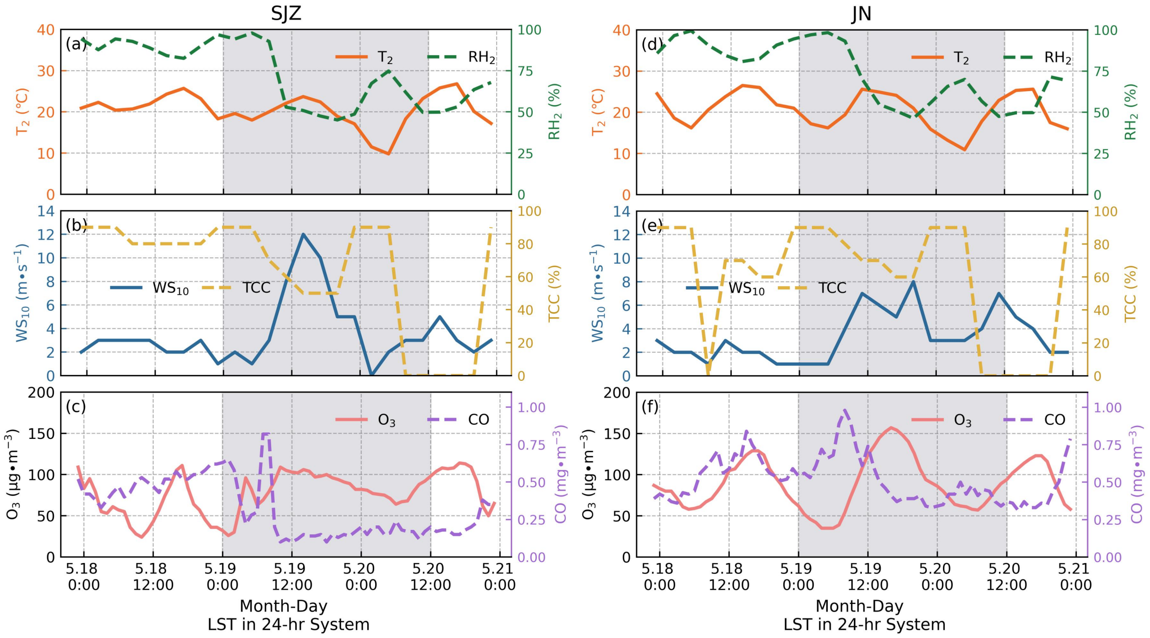

Figure S6: Hourly variations of (a, d) T_2, RH_2, (b, e) WS_{10}, and total cloud cover (TCC), (c, f) near-surface O_3 and CO concentrations in representative cities SJZ and JN from the observations in the NCP region. The shaded areas mark the periods of the SI to the near-surface layer.

Additionally, We understand the reviewer's concern on Fig.5 that the surface observations seem not to strongly support the claim that this SI reached the surface. We explain the Fig. 5 as follows:

Once stratospheric O_3 transports down to the troposphere, it will undergo the identical physical and chemical processes as tropospheric O_3, and the conventional surface observations cannot distinguish whether O_3 comes from the stratosphere or is generated in the troposphere. In our proposed mechanism of "upper westerly tough-middle the Northeast Cold Vortex-lower extratropical cyclone", the vertical configuration of the entire system generated strong northwest horizontal winds (Figs. 2a-c and 4). The regional average wind speed at 10m exceeded 7 $m \cdot s^{-1}$ and reached a maximum of 20 $m \cdot s^{-1}$ at a single site. Although the stratospheric O_3 contributed 26.77 % of surface O_3 to the entire NCP, the fierce northwest wind quickly diffused O_3 (including O_3 originating from the stratosphere and troposphere) to downstream areas. For the near-surface O_3, the positive contribution of vertical stratospheric intrusion and the negative contribution of horizontal winds occurred almost simultaneously (Fig. 6), so it was difficult to observe a remarkable increment in surface O_3 than usual. However, under such favorable diffusion conditions, the observed near-surface O_3 on May 19 was slightly higher than the previous day (Fig. 5c), which hinted at the additional contribution of stratospheric O_3.

Minor comments

[1. L22, please provide the information on latitudes, longitudes of the North China Plain, and the time the SI event occurred.

Response : Many thanks for the careful comments and helpful suggestions on our manuscript. Following the reviewer's suggestion, we have added these information to lines 22 in the revised manuscript as follow:

In this study, a SI event over the North China Plain (NCP, 33–40°N, 114–121°E) during May 19–20, 2019 was taken to investigate the mechanism of the cross-layer transport of stratospheric O_3 with the impact on the near-surface O_3 based on the multi-source reanalysis, observation data and air quality modeling.

[2. L23, remove "and" .]

Response : It has been corrected.

[3. L45, remove "the" before "stratospheric O3"]

Response : The word "the" before "stratospheric O_3" in line 48 of the revised manuscript was removed.

[4. L60-61, "In the mid-latitudes of the northern hemisphere, approximately 20 – 30% of the O3 reserve in the troposphere is sourced from the stratosphere" ? The number looks high.]

Response : Indeed, the principal source of surface O_3 is the photochemical reaction, and less stratospheric O_3 could reach the near-surface. While in the middle and upper troposphere, the stratosphere contributes a large amount of O_3, thereby increasing the stratosphere's contribution to tropospheric O_3 reserves.

Many previous studies have evaluated the contribution of stratospheric O_3 to the troposphere and obtained widely varying results. Roelofs and Lelieveld (1997) estimated that O_3 originating from the stratosphere contributed about 40% on average to O_3 in the troposphere and between 10% (in summer and at the equator) and 60% (in winter) at the surface. These values are higher than those previously published by Austin (1991) and Follows (1992), who estimated that stratospheric O_3 contributed 25% at 300 hPa and less than 5% at the surface. It follows that the stratospheric contribution to tropospheric O_3 reserves of 20-30% is a reasonable range.

References

Austin, J. F., and Follows, M. J.: The ozone record at Payerne: An assessment of the cross-tropopause flux. Atmospheric Environment. Part A. General Topics, 25(9), 1873-1880, https://doi.org/10.1016/0960-1686(91)90270-H, 1991.

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Roelofs, G. J., and Lelieveld, J. O. S.: Model study of the influence of cross-tropopause O_3 transports on tropospheric O_3 levels. Tellus B: Chemical and Physical Meteorology, 49(1), 38-55, https://doi.org/10.3402/tellusb.v49i1.15949, 1997.

[5. L115, the supplement should be cited, instead of the references.

Response : We keep the the references because the purpose of citing the literature here is to illustrate that the WRF-Chem model used in previous studies could reproduce the SI process well, rather than to evaluate the WRF-Chem simulation results in our study.

[6. L117, leave a space between a number and its unit.]

Response :we have added spaces between the numbers and units to lines 125-126 of the revised manuscript.

[7. L190, at "the" before "western plateau". It is better to make the sentence clearer: western of what?]

Response : Thanks to the reviewer for pointing out our oversight. We have modified the sentence as follow (lines 205-207 in the revised manuscript):

The mountain airflow on the lee slopes of the plateau and mountains in western NCP could also contribute to strengthening the subsidence motion in the lower troposphere (Ning et al., 2018).

[8. L214, "Wang, H. et al. 2020" are not found in References.]

Response : "Wang, H. et al. 2020" which we cited in line 314 of the original manuscript was listed on lines 509-510 of the original manuscript (lines 554-555 of the revised manuscript).

[9. L226-227, No much change in temperature is observed in Figure 5a. Temperature seems to follow a normal diurnal cycle.

Response : Yes, we agree with the reviewer's comment that no much change in temperature is observed in Figure 5a. Therefore, we proposed that "the rising air temperature required for the stronger photochemical reaction was not observed on May 19, 2019" (lines 242-243 in the original manuscript) to illustrate that the photochemical reaction might not generate more surface O_3 compared with the previous day.

[10. L227, change to "Precipitation" .]

Response: We have corrected "the precipitation" to "Precipitation" to line 243 in the revised manuscript.

[11. L138-139, "Therefore, our simulation results are available and convincing." ?]

Response : Thanks to the reviewer for pointing out our inappropriate expression. We have corrected this sentence in lines 154-155 as follows:

All these evaluations indicate that our simulations performed well in reproducing the variations of O_3 and meteorological parameters during the SI process.

[12. L241 and L242, what kind of disturbance? Where did the disturbance come from?]

Response : This kind of westerly jet disturbance originates from the changes in the north-south differential in solar radiation. When air temperature difference between the north and the south gradually increases, the atmospheric baroclinicity strengthens, causing the westerly jet to shift from the zonal to the meridional circulation patterns, resulting in larger north-south airflow, eventually leading to the formation of cut-off low-pressure or blocking high-pressure systems.

[13. L339, "significant" is used a few times in the text, also in the title and abstract. I suggest removing the word throughout. Otherwise, the authors may explain "significant" in what sense? How does this proposed mechanism compare with others? Is this a dominant or not dominant mechanism?]

[14. L339, replace "atmospheric environment" with "tropospheric".]

Response : Thanks for the reviewer's suggestions on our manuscript. Follow the reviewer's comment, we have removed the word "significant" and replaced "atmospheric environment" with "tropospheric" in the revised manuscript.

[15. L355, 9.61 ppbv? on average over the NCP? How large is the affected area?]

Response : Yes, the amount of 9.61 ppbv is the average value for the entire NCP region during the SI process, covering from 33–40°N and 114–121°E.

[16. Figure 4, the quality is poor, too small, not supporting the points in the text.

Response : Thanks for the helpful suggestions on our manuscript. Since the selected O_3 concentration scale range in Figure 4 is large, the O_3 concentration change characteristics are not clear enough, so we narrowed the concentration scale range and redrawn Figure 4 with the better figure quality.

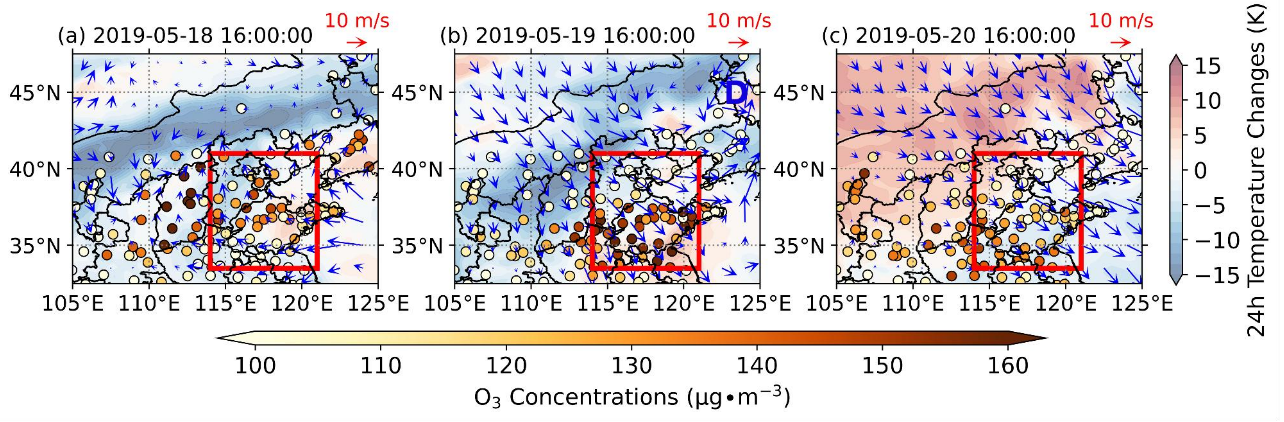

Figure 4: Horizontal wind vectors and 24-hour changes of air temperature (shaded colors) at 950 hPa from the ERA5 data and the observed near-surface O_3 concentrations (color dots) at 16:00 LST on May (a) 18, (b) 19, and (c) 20, 2019. The red rectangles cover roughly the NCP region.

[17. Figure S4, the blue lines are difficult to see.]

Response: Following the reviewer’s comment, we have redrawn Figure S4 to make it more readable.

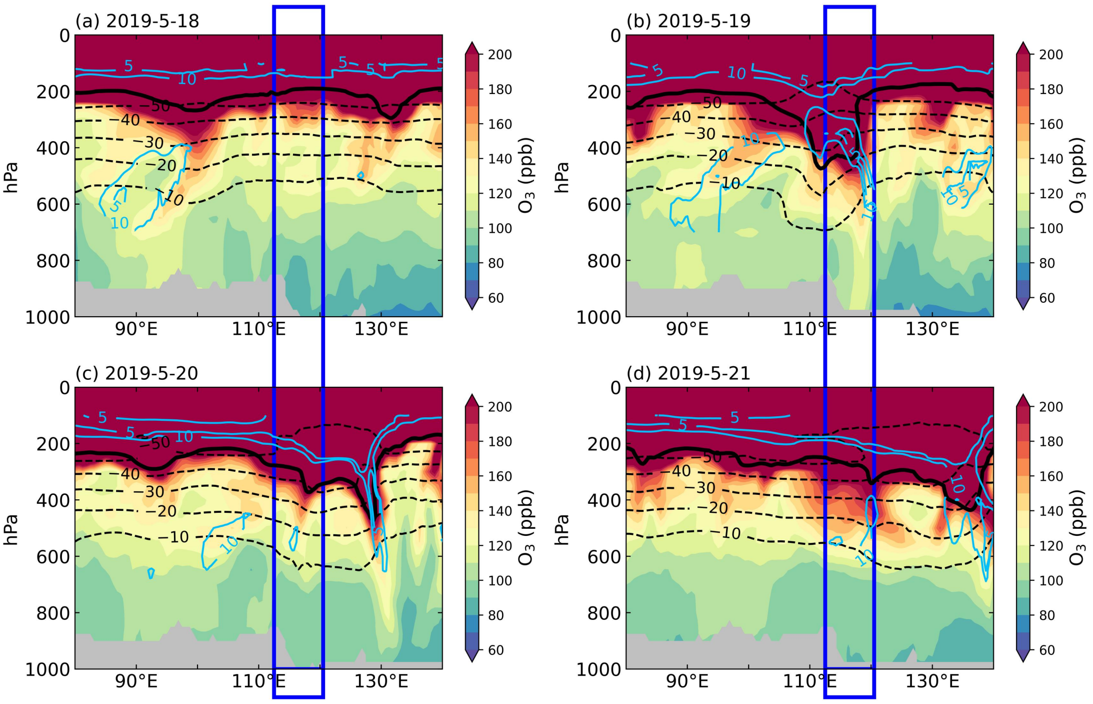

Figure S4: Latitudinal vertical sections of O_3 concentrations (color contours) averaged over 32 °N–40 °N from the MERRA2 data during May 18–21, 2019. Black solid lines indicate the dynamical tropopause labeled by PV=2. The dashed black lines represent air temperature (°C), the solid blue lines represent relative humidity (%), and the blue rectangles mark the NCP region.

[18. References are not fully listed alphabetically.

It is better to indicate data sources for each figure.

Please pay attention to recent literature on the topic.

MERRA2 O3 data were used substantially. However, a discussion on the data performance, especially for variable O3S, is lacking.]

Response： Thanks to the reviewers for pointing out our shortcomings. We have carefully checked and rearranged all cited references to ensure that they are in alphabetical order.

And we stated the data sources used in each figure and added some recent references on the topic.

Finally, we survey the works of literature and illustrate the availability of MERRA2 O_3 data. However, since O_3S is a model diagnostic variable and there are no corresponding observations, we cannot evaluate the accuracy of the O_3S data from EAC4. Follow the reviewer's comment, we added the following descriptions to lines 105-109 of the revised manuscript:

The MERRA-2 data set assimilates TCO satellite retrievals from ozone monitoring instruments and stratospheric O_3 vertical profiles from microwave limb sounders after 2004 (Gelaro et al., 2017; Levelt et al., 2006; Waters et al., 2006). The MERRA2 O_3 enables the study of SI events because it is consistent well with ozonesondes and could realistically represent the temporal and spatial variations of O_3, especially in the lower stratosphere and near the tropopause (Wargan et al., 2015; Wargan et al., 2017).

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