Response to Referee Comment 1 by Anonymous Referee #1

Itahashi et al. (2019) investigated the impacts of stratospheric intrusion on tropospheric ozone based on the relationship between potential vorticity and relative humidity. They found high surface O3 are often associated with emissions whereas stratospheric intrusion contribute to O3 at elevated sites. The manuscript is in general well written. Below are a few comments need to be addressed.

Reply:

We thank the reviewer for providing helpful and constructive comments. We have revised our manuscript according to the reviewer's comments and suggestions. We believe that these revisions address all points raised by the reviewer. Our point-by-point responses are provided below, and revisions are indicated in blue in the revised manuscript.

General comments:

Tropopause height

In this work, tropopause is determined at 2.0 PVU. How is the model performance in simulating PV? How different the tropopause height calculated in this work from the traditional approach (e.g., WMO 1992).

Reply:

It will be difficult to evaluate the simulated PV on upper layer using direct observations. Since the WRF simulations involve data assimilation of meteorological reanalysis fields (including upper level winds), via the nudging technique, we believe that our model-based PV should generally represent that estimated from observational data. The following figure shows the estimated tropopause altitude by PV (dynamic tropopause) and the traditional approach of WMO using the lapse rate (thermal tropopause). Both indicate a similar tropopause altitude, though some differences can be found noted in the lower latitude regions (higher altitude by PV and lower altitude by the traditional approach). To address the reviewer's question and further elaborate on the issue for other interested readers, we have included this figure in the supplemental information of the revised manuscript, and also included an additional reference to the work of Hoering et al., 1991 which investigated the tropopause altitude using two approaches. The discussion in in Section 2.1 was modified as follows in the revised manuscript:

"The calculation of the tropopause altitudes using PV (dynamical tropopause) and the traditional approach based on the lapse rate (thermal tropopause) defined by World Meteorological Organization (WMO) (WMO, 1992) have been reported (Hoering et al., 1991)." As shown in Figure S4, estimated tropopause altitudes averaged over April 2010 using PV in this work and the traditional approach of WMO are overall similar with below 10 km over high-latitude region and above 16 km over low-latitude region."

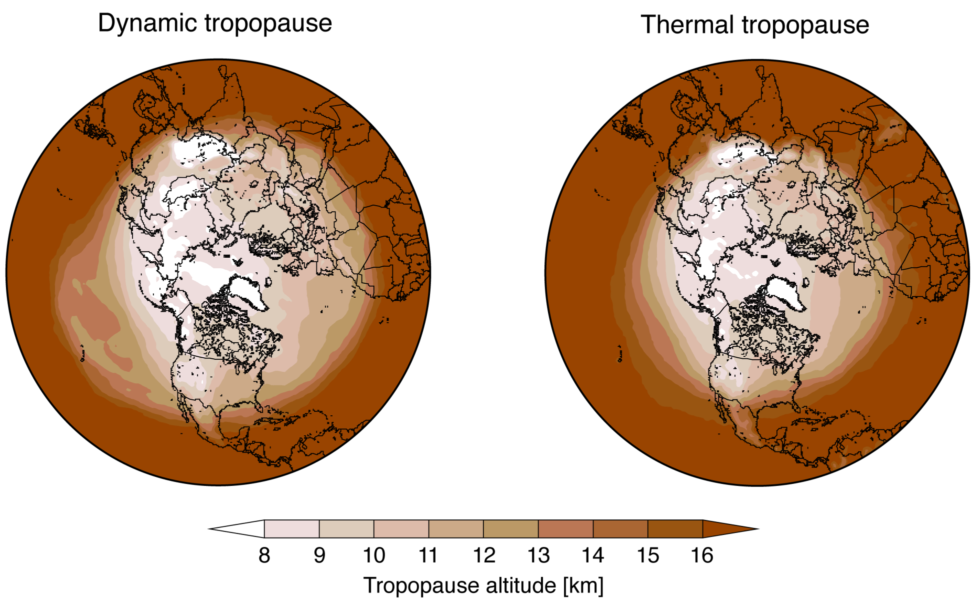

Figure S4: Estimated tropopause altitude averaged over April 2010 by (left) the dynamic approach using PV in this work and (right) the thermal approach using the lapse rate.

Tropospheric O3

O3 is underestimated in the free troposphere in the model. Does the model include lightning NOx emissions? If so, are they prescribed or on-line calculated? Underestimations in lightning NOx emissions could lead to the underestimations in O3.

Reply:

The reviewer raises an interesting point on the possible role of lightning NOx on the model free-troposphere O3 underestimation. In the simulations reported in this work, lightning emissions are prescribed using climatological averages as estimated by Price et al. (1997) in the GEIA database. To address the reviewer's question, we add the following clarification in Section 2.1 of the revised manuscript:

"The lightning emissions are prescribed using climatological averages as estimated in the Global Emission Inventory Activity (GEIA) as dataset (Price et al., 1997)."

As the possible reason of model underestimation for O_3, we have added the following statement in Section 3.1;
"In addition, the uncertainty of the lightning emissions prescribed as climatological averages in the current simulations may also contribute to the underestimation of O_3 in the free troposphere."

Trans-pacific transport
Trans-pacific transport is not really discussed in this paper although it is shown in the title. When O3PV/O3 is used to characterize air masses, how do you distinguish air masses from trans-pacific transport?

Reply:

Our sequential two papers are dedicated to the analysis of trans-Pacific transport, and we first focused on the stratospheric intrusion in this part 1 paper as high surface O_3 mixing ratio may be associated with stratospheric intrusion, in addition to trans-Pacific transport. As we have concluded in this part 1 paper, high O_3 mixing ratio is primarily related to emissions, indicating that trans-Pacific transport plays a dominant role in observed high O_3 episodes in the U.S.A. In part 2 paper, we then used sensitivity analysis technique to further perturb the emissions of O_3 precursors from East Asia and the U.S. to study the importance of trans-Pacific transport during high O_3 episodes. The two papers thus provide a comprehensive examination of the processes underlying the observed high O_3 episodes in the U.S.
To address the reviewer's comment, we have revised the title and the text to clarify the foci of the two parts papers as well as their relevance to "trans-pacific transport".

Specific comments:
Figure 5, this is very complicated figure and includes a lot of information. Is there any way to evaluate PV? Regarding O3PV and O3, should they be overlapping in stratosphere that you defined based on 2PVU? Note there are some differences between these two (e.g., at Huntsville site). Any explanations on that? For observed RH profiles, in most cases, there is a steep decrease in RH from tropopause to upper layers. But at Wallops Island site, there is no such large decrease in RH, especially in early to middle April while the model shows a decreasing trend. Any explanations?

Reply:

As mentioned above, simulated PV could not be evaluated because of lack of direct measurement data.

As indicated in our response to comments by Reviewer #2, the O_3 tracer (O3PV) is used to track O_3 specified above 110 hPa using the O3-PV correlation and undergoes transport, scavenging, and deposition processes similar to O_3, but no chemical loss. This O_3 tracer is also initialized by the prior simulation by Hogrefe et al. (2018). Therefore, the mismatch between O3PV and O_3 at some sites (e.g., at Huntsville site) is related to the chemical process, higher concentration of O_3 rather than O3PV found near tropopause (altitude of 2 PVU) and this suggests photochemical production of O_3.

The steep decrease of RH is an expected general characteristic of dry stratospheric air. While this feature is apparent both in the observed and modeled RH vertical profiles at many locations, it is not clear why it is missing in the early April profiles at Wallops.

To increase the readability of this figure, we have provided more detailed discussions to help the readers to better understand the information shown in this figure.

Figure 6, the profiles (row 5) are too small. On page 11, line 5, "flight #6 might be a case of STT because observed RH is less than 10% and observed O3 mixing ratios exceed 75 ppb", where is the tropopause for this case, below or above 6km?

Reply:

The row 5 of Figure 6 has been expanded in the revised paper. We have analyzed the PV at this aircraft site, and the value of 2 PVU was found near 10 km. We have added the following sentences in Section 3.1.

"the tropopause as diagnosed by the PV = 2.0 PVU locates near 10 km"

Figure 9, how do you distinguish the impacts of horizontal transport and stratospheric intrusion?

Reply:

We have revised the air mass characterization technique. The estimation of stratospheric intrusion is based on the decision on sequential intrusion (Fig. 8). In this manner, STT caused by the horizontal transport can be considered.

Other comments

There are a few places with grammar errors.

Reply:

We appreciate your careful checking. We have corrected all of them.

Page 3, line 13-16, “On one hand…, on the other hand… .”, split into two sentences.

Reply:

We have split the sentence in two as suggested by the reviewer.

Page 10, line 26, “over 500 ppbv at around 8 km The profiles…” these are two sentences.

Reply:

Thank you for catching the typo. We have added a period to separate two sentences.

Page 11, line 16, “Europe, the, model…” need correct

Reply:

We have revised this point as follows; “Europe, the model…”

Page 12, line 1, “lower RH…at lower latitudes (<40N) higher RH at higher latitude…” need correct grammar error

We have revised this sentence as follows;

Reply:

The relation between modeled PV and both modeled and observed RH shows a slight dependence on latitude with higher RH at higher latitudes (> 60°N).

Page 12, line 30-31, “…listed in Table 5 are based.”, based on what? Incomplete

Reply:

We have revised to remove Table 5, and this sentence was also removed.