We are very grateful to the two reviewers for the constructive comments on our manuscript, which greatly helped us to improve the quality of this manuscript. We have now revised the manuscript following your comments and suggestions. Our responses to your comments are listed below in red.

Reviewer #1

1. In the response letter, the authors provided a link to the prescribed emission data files (https://svnccsminputdata.cgd.ucar.edu/trunk/inputdata/atm/cam/chem/emis/CMIP6_emissions_1750_2015_2deg). However, the link is not accessible.

Response: We apologize for the confusion. The correct link is https://svn-ccsm-inputdata.cgd.ucar.edu/trunk/inputdata/atm/cam/chem/emis/CMIP6_emissions_1750_2015_2deg. Please note that the hyphen in "svn-ccsm-inputdata" is part of the official URL and not a typographical error.

We are very grateful to the two reviewers for the constructive comments on our manuscript, which greatly helped us to improve the quality of this manuscript. We have now revised the manuscript following your comments and suggestions. Our responses to your comments are listed below in red.

Reviewer #2

The authors have sufficiently addressed my questions. Here are some minor comments to improve the paper:

1. It would be good to provide the definition of elevated stratospause event due to the major sudden stratospheric warming. Please note that the ES event does not always happen after SSW. I would be even better to add some mechanism about ES occurrences after SSW (in the introduction section after Lines 84-86) based on previous studies. For example: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JD016840#

Response: We thank the reviewer for this helpful suggestion. The new text "Elevated stratopause (ES) events refer to episodes during which the winter polar stratopause initially descends, subsequently becomes indistinct, and eventually reforms at a significantly higher altitude (Manney et al., 2008). Such events arise from strong forcing of the zonal wind and meridional circulation by planetary waves (Torre et al., 2012). In certain cases, ES events occur in connection with SSW events. According to Chandran et al. (2013), ES-SSW events are distinguished by a prolonged reversal of the stratospheric jet, enhanced gravity wave forcing, and intensified mean meridional circulation, relative to winters when SSWs occur without an accompanying ES. Compared with typical SSWs, ES-SSW events are particularly noteworthy because their enhanced downward transport significantly modifies the concentration of minor species in the MLT region (Chandran et al. 2013), such as OH. Given these persistent anomalies, focusing on ES-SSW events provides a physically meaningful basis for composite analysis." has been inserted in the introduction (see lines 84–97).

2. In the line 152, it would be better to add "mesosphere" before OH. In factor, other altitude range for example in the lower stratosphere/troposphere OH will change if the emissions during 2015-2023 are set to zero below 15 km.

Response: We thank the reviewer for this helpful suggestion. We have revised the text to specify 'mesospheric OH' in the revised manuscript (see line 158).

3. Line 197-198: I am so surprised that it uses 20-100 km range for the stratosphere though we know what the temperature structure looks like. This must be narrowed down quite lot. The averaged stratospause altitutde is around 50-60 km and the elevated ES altitude is around 80 km. Not sure if any of stratopause altitude is below 45 km or above 90 km...

Response: We appreciate the reviewer's comment. This height range (20–100 km) is intentionally retained in the analysis because it effectively avoids potential truncation of the temperature maximum during ES-SSW events and ensures full coverage of both the descending and re-forming stratopause. For instance, during the 2009 SSW, the stratopause altitude descended to as low as ~37 km in the stratospheric warming phase, which justifies the need for an extended vertical range to accurately capture the complete evolution of the stratopause height. Similar vertical domains have also been adopted in previous studies (e.g., Chandran et al., 2013; Torre et al., 2012).

Reference:

Chandran, A., Collins, R. L., Garcia, R. R., Marsh, D. R., Harvey, V. L., Yue, J., and de la Torre, L.: A climatology of elevated stratopause events in the whole atmosphere community climate model, Journal of Geophysical Research-Atmospheres, 118, 1234–1246, https://doi.org/10.1002/jgrd.50123, 2013.

de la Torre, L., Garcia, R., Barriopedro, D., and Chandran, A.: Climatology and characteristics of stratospheric sudden warmings in the Whole Atmosphere Community Climate Model, JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 117, https://doi.org/10.1029/2011JD016840, 2012.

4. Unit: Sometimes the current version uses "in the unit of 10^-9" for OH concentration. It would be better to use a proper unit for example: volume mixing ratio (vmr). I thought the SABER OH emission unit is probably wrong (Fig1d), which should be ergs/cm3/sec, please double check it.

Response: We thank the reviewer for pointing this out. The OH concentration has been uniformly expressed in units of parts per billion by volume (ppbv) throughout the revised manuscript. In addition, the unit of the SABER OH emission shown in Figure 1d has been corrected in the revision.

5. I am not convinced by the explanation in Lines 265-271 becuase you are comparing two different things (one is the distribution of OH gas, the other is airglow emissions which is determined by the H+O3 reaction and can be largely affected by mesosphere dynamics (e.g., Plane et al., 2015, DOI: 10.1021/cr500501m), some of them have also discussed in the Section 4.1

Response: We thank the reviewer for this insightful comment. According to Damiani et al., (2010), OH in the mesopause region is primarily produced through the reaction between ozone and atomic hydrogen, forming excited OH* near 87 km, which constitutes the well-known mesospheric nightglow layer. This excited state is deactivated either via photon emission in the Meinel bands (observed as nightglow) or by collisional quenching. The latter process prevails at lower altitudes, where higher atmospheric density facilitates the formation of a ground-state OH layer near 82 km. Although the SABER OH emission and SD-WACCM-X OH concentration represent physically distinct quantities, both are governed by closely coupled mesospheric dynamical and chemical processes. For example, Gao et al., (2011) and Winick et al., (2009) demonstrated that variation in OH emission during the 2009 SSW were modulated by changes in atomic oxygen and mesospheric temperature, and Damiani et al., (2010) shown that the displacement of OH layer is coupled to variations in oddoxygen (Ox) and mesospheric temperature. These findings indicate that the variations of OH emission and ground-state OH concentration are dynamically linked.

In this study, we focus only on comparing the temporal evolution of OH during SSW events, rather than performing a quantitative comparison of their absolute magnitudes. Accordingly, a qualitative comparison between the two is physically meaningful. This clarification has been incorporated into the revised manuscript (see lines 284-297).

Reference:

Damiani, A., Storini, M., Santee, M. L., and Wang, S.: Variability of the nighttime OH layer and mesospheric ozone at high latitudes during northern winter: influence of meteorology, Atmospheric Chemistry and Physics, 10, 10291–10303, https://doi.org/10.5194/acp-10-10291-2010, 2010.

Gao, H., Xu, J. Y., Ward, W., and Smith, A. K.: Temporal evolution of nightglow emission responses to SSW events observed by TIMED/SABER, Journal of Geophysical Research-Atmospheres, 116, https://doi.org/10.1029/2011jd015936, 2011.

Winick, J., Wintersteiner, P., Picard, R., Esplin, D., Mlynczak, M., Russell, J., and Gordley, L.: OH layer characteristics during unusual boreal winters of 2004 and 2006, JOURNAL OF GEOPHYSICAL RESEARCH-SPACE PHYSICS, 114, https://doi.org/10.1029/2008JA013688, 2009.

6. The other very technique question about the Y-axis in all the figures regarding to "Altitude (km)". Have you interpolated the modelled goepotential heigt to fixed altitude, or you use some approximate relationship between pressure and height, or use the some equation to calculate the altitude. This is also important since the layer will move a little bit up and down depending on your method.

Response: We thank the reviewer for this technical question. In this study, the model pressure levels are converted to approximate geometric altitude using the standard hydrostatic relationship ($Z = -H \times \ln(P / P_s)$) (Andrews et al., 1987).

We compared the OH distributions derived from (a) log-pressure–based altitude and (b) model geopotential height interpolated onto fixed geometric altitude levels (see Figure R1). The two methods exhibit noticeable differences in the peak altitude of the OH layer. For example, after January 26, 2009, the OH layer peak in log-pressure height (Figure R1a) descends to ~78 km, whereas in geometric coordinates the descent is even larger (Figure R1b), reaching ~74 km. These phenomena are consistent with OH emission shown in Grygalashvyly et al. (2014), who showed that geometric altitudes are affected by shrinking of middle atmosphere (SMA), while pressure coordinates remain largely free of this effect. As a result, the OH peak expressed in log-pressure height tends to appear somewhat higher than when expressed in geometric height.

Previous studies (e.g., Pickett et al., 2006) demonstrated that the OH layer is markedly more stable in pressure coordinates than in geometric altitude. Meanwhile, as noted by Grygalashvyly et al. (2014), pressure coordinates are more natural for discussing chemical, physical, and radiative processes, as these processes are largely free of the SMA effects on pressure isosurfaces. Guided by these findings, we use log-pressure height ($Z = -H \times \ln(P / P_s)$) as the vertical coordinate for diagnosing the OH responses in SD-WACCM-X, while also providing an approximate geometric-height scale for reference. This clarification has been incorporated into the revised manuscript (see lines 221-229).

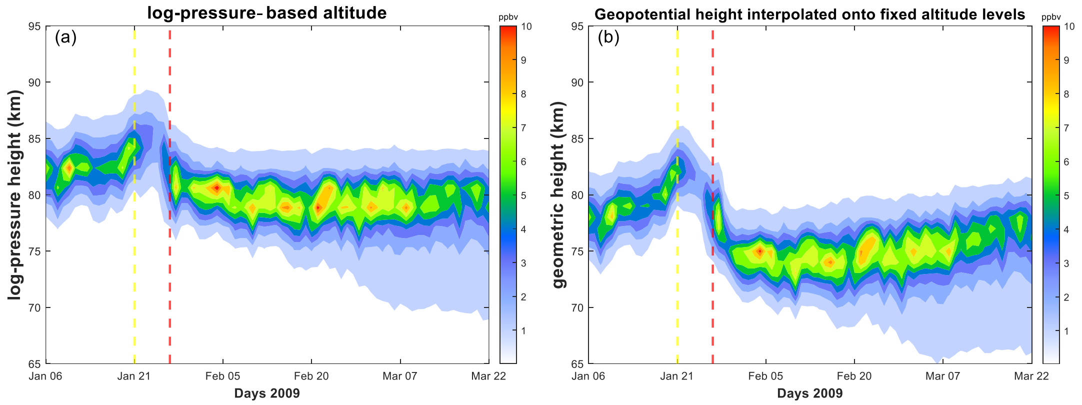

Figure R1. Comparison of the OH variations during the 2009 SSW event derived from (a) log-pressure–based altitude and (b) model geopotential height interpolated onto fixed altitude levels.

Reference:

Andrews, D. G., Leovy, C. B., and Holton, J. R.: Middle atmosphere dynamics, Academic press1987.

Grygalashvyly, M., Sonnemann, G., Lübken, F. J., Hartogh, P., and Berger, U.: Hydroxyl layer: Mean state and trends at midlatitudes, Journal of Geophysical Research: Atmospheres, 119, 12,391–312,419, https://doi.org/10.1002/2014JD022094, 2014.

Pickett, H., Read, W., Lee, K., and Yung, Y.: Observation of night OH in the mesosphere, Geophysical Research Letters, 33, https://doi.org/10.1029/2006GL026910, 2006.