REPLY TO REVIEWERS

Dear editor and reviewers:

Thanks for your time and comments for our manuscript entitled "**Contributions of lightning to long-term trends and inter-annual variability in global atmospheric chemistry constrained by Schumann Resonance observations**" (Manuscript Number: EGUSPHERE-2025-370). The manuscript has certainly benefited from these insightful revision suggestions. Below we provide point-wise response to reviewers′ comments. In the manuscript, revised or newly added sentences are highlighted in yellow color which relates to the reviewers′ comments.

[General comment]

This is an excellent paper scientifically and is also very well written. The authors use observations of the Schumann Resonance to modify the existing lightning parameterization in the GEOS-Chem model. The existing Price and Rind cloud-top height prediction scheme for flash rate, as modified by Murray et al. based on satellite lightning observations, produced an increase in flash rates over the 2013 to 2021 period. Correcting the parameterization using the Schumann Resonance yielded no significant trend, which is in line with observations. The authors used the revised scheme in GEOS-Chem simulations for the period, examining the effects of the change in lightning scheme on NO_x, O_3, and OH. The updated scheme does better at producing interannual variability in these species. The authors also examine the effects of a 10% decrease in lightning in 2020 on methane growth as a result of the decreased OH. I have some suggestions for minor changes. Once they are attended to, the paper should be ready for acceptance.

Reply:

We thank the reviewer for constructive suggestions!

[Main comment 1]

Lines 121-125: It would be worth noting that also the results of Allen et al. (2019,

JGR) and Bucsela et al. (2019, JGR) from use of OMI NO_2, also found little difference in LNO_x production per flash between midlatitudes and tropics.

Reply:

Thank you for the suggestion. We have cited these two studies to support our approach in Lines 129–130, 362–365 and 383–385, as follows:

Lines 129–130 (our setting of the P_{NO} value):

In addition, we also update the value of P_{NO} to be 330 moles NO per flash all over the world (Luhar et al., 2021), consistent with the global average derived from satellite NO_2 observations (Miyazaki et al., 2014; Marais et al., 2018). By comparison, the default P_{NO} value in GEOS-Chem is 500 moles NO per flash north of 35° N and 260 for the rest of the world (Murray et al., 2012). Such a large enhancement of P_{NO} in northern midlatitudes relative to the rest of the world is not supported by a recent analysis of observed NO_2 vertical profiles (Horner et al., 2024). NO_2 satellite observations also indicate little difference in P_{NO} between midlatitudes and tropics (Allen et al., 2019; Bucsela et al., 2019).

Lines 362–365 and 383–385 (adding new references):

Allen, D. J., K. E. Pickering, E. Bucsela, N. Krotkov, and R. Holzworth (2019). Lightning NO_x Production in the Tropics as Determined Using OMI NO_2 Retrievals and WWLLN Stroke Data, *Journal of Geophysical Research: Atmospheres*, *124*(23), 13498-13518, doi:10.1029/2018jd029824.

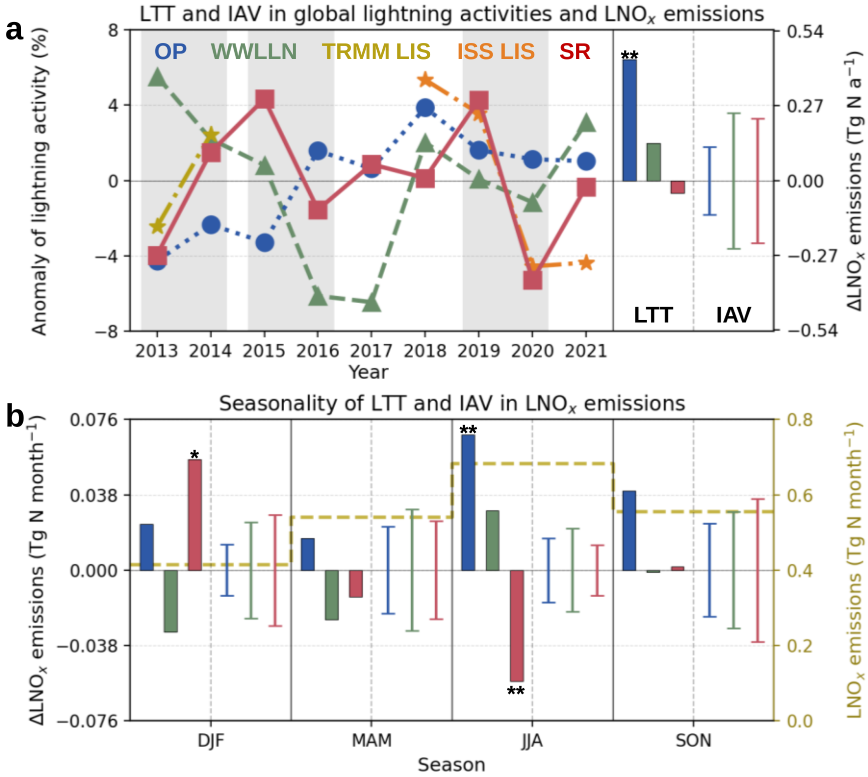
Bucsela, E. J., K. E. Pickering, D. J. Allen, R. H. Holzworth, and N. A. Krotkov (2019). Midlatitude Lightning NO_x Production Efficiency Inferred From OMI and WWLLN Data, *Journal of Geophysical Research: Atmospheres*, *124*(23), 13475-13497, doi:10.1029/2019jd030561.

[Main comment 2]

Figures 2, 4, 5, 6, and 7: It is difficult to tell the gray and blue bars and lines apart. A different color is needed for one of them.

Reply:

Thanks for your suggestion. We have modified these figures following your recommendation. Below shows an example of updated Fig. 2.



Updated Figure 2

[Main comment 3]

Figure 6: This figure needs better explanation. From this figure I don't see how the non-lightning contribution is a difference between the observation and the model lightning contribution. For 2020, how do these bars imply a 54% contribution of lightning to the methane growth? Why is there a methane growth rate bar for 2021, but not the lighting and non-lightning bars?

Reply:

Thanks for your suggestion and sorry for this confusion. We now clarify in the caption. Briefly, blue bars in Fig. 6 present annual atmospheric methane growth rates. The difference in annual growth rates between adjacent years are attributed to year-to-year changes in lightning (red) and non-lightning factors (green). For the 2019-to-2020 case, the global atmospheric methane growth rate base on observations increased by ~5.5 ppb a^{-1} (from 9.7 ppb a^{-1} to 15.2 ppb a^{-1}). Our analysis suggests that 3.0 ppb a^{-1} can be attributed to changes in global lightning activity, and thus explains 54% of the 2019-to-2020 methane surge.

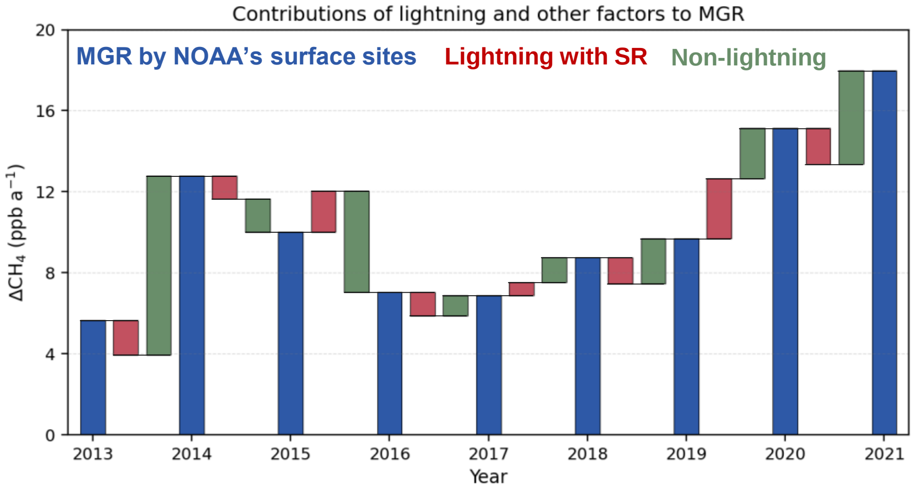


Figure 6: Contributions of lightning-driven variations in the methane sink by OH oxidation to annual atmospheric methane growth rate (MGR) from 2013 to 2021 based on SR observations. The differences in MGR between adjacent years are attributed to year-to-year changes in either lightning or non-lightning factors.

[Main comment 4]

Lines 271-273: There is a significant amount of fire in South America during September to November. I think you should choose a different set of months (maybe December to February).

Reply:

Thanks for the suggestion. Our choice was based on the relative importance of fire and lighting in these months. Although fire influence is non-negligible in September to November, the changes in lightning activity and LNO_x emissions between 2019 and 2020 are most significant in these months (Figure S3a). Our simulation indicates that the effects of fire emissions on the anomaly of NO_2 concentrations in the upper troposphere (300–100 hPa) of Northern South America are smaller (4.5±0.1 ppt) than the effects of lightning based on SR observations (-20.1±0.5 ppt). In contrast, changes in lightning are small during December to February (Figure S3a), making it difficult for evaluating the OP and SR methods. We now add more clarification in Text S1 to explain the selection of September–November.

[Main comment 5]

Figure 7 - cation: "green" should be "gray".

Reply:

Thanks for your valuable suggestion. The gray color in Fig. 7 has been revised to green, as shown below.

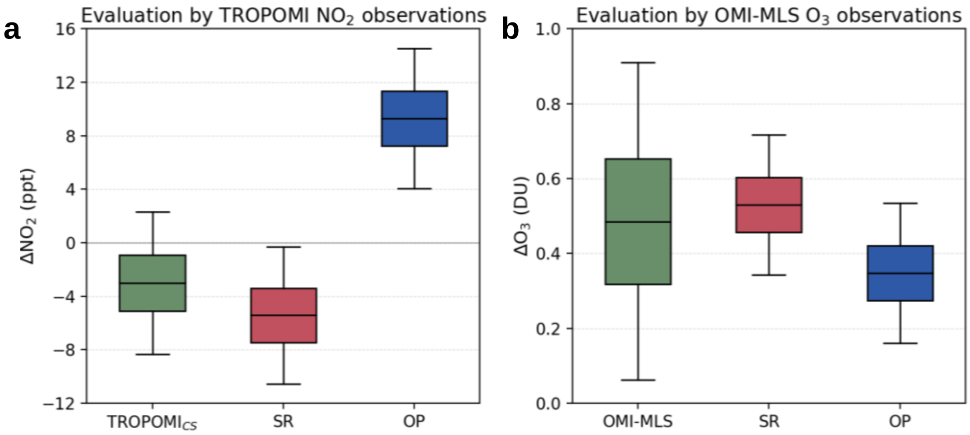


Figure 7: (a) Anomalies of NO_2 concentrations in the upper troposphere (300–100 hPa) of Northern South America (20° S–10° N and 80° W–40° W) in September-November 2020 relative to 2019 from the TROPOMI NO_2 observations by cloud-slicing technique (green), GEOS-Chem simulation with SR method (red), and GEOS-Chem simulation with OP method (blue). (b) Anomalies of tropospheric O_3 in the North Atlantic (0–60° N and 100° W–30° E) in 2015 relative to 2014 from the OMI-MLS O_3 observations (green), GEOS-Chem simulation with SR method (red), and GEOS-Chem simulation with OP method (blue). Uncertainties are calculated by 1,000,000 Monte Carlo simulations.