Dear referee, we sincerely appreciate your efforts to review our manuscript and give constructive comments related to it. We have carefully revised our manuscript based on your comments. Hereinafter, I shall respond to your comments point-by-point and explicitly point out changes with line numbers in the revised manuscript. The line number (or Section or Figure number, etc.) in orange is the line number (or Section or Figure number, etc.) in our revised manuscript. Additionally, we use LFR as an abbreviation of the "lightning flash rate".

Referee #3 comment:

This paper studies aerosol radiative impact and global warming impacts on lightning within a model. It looks at the multi-decadal trends, the effect of Pinatubo volcano in following years, impacts of lightning NO_x on methane lifetime, and compares to CMIP6 simulations of lightning. The paper concludes that Pinatubo reduced lightning, and that aerosol radiative effect and global warming roughly cancelled out the effect of each other on lightning over the study time period. As such there was little global trend in lightning.

Author comment: Many thanks for your dedicated time to review our manuscript.

Referee #3 comment:

The paper tries to cover a lot. Due to the spread in analysis directions, the detail is fairly light but generally still to a worthwhile level. The use of both the common cloud top height scheme and an ice-based scheme is commendable, as parametrisation uncertainty is large. My main issue with the paper is the mechanistic explanation of the aerosol impact of lightning trend. I feel the paper plots are more distracting than elucidating. I comment below on how I think that section should be refocused. I don't consider the paper ready to publish until that section is clearer - at the moment the paper would be better without the mechanistic explanation entirely, but some is required.

Author comment: We appreciate your affirmation of our manuscript. We also thank you for pointing out its shortcomings. We acknowledge that we can more clearly elucidate the mechanistic explanation of the aerosol impact of lightning trends. We have adopted your suggestions to clarify this issue (please see our comments below).

Referee #3 comment:

The Pinatubo result is interesting. It warrants much more focus, but in my mind it is not essential to take it further here for the paper to be publishable. I hope the authors will consider future work modelling both radiative and microphysical impacts of the volcano. There is also then scope for comparing model CAPE and Q to sonde and reanalysis data from the time period to provide observationally robust conclusions.

Author comment: Thank you very much for your good suggestions. We also hope to investigate this topic further by considering entire aerosol processes after the volcanic eruption. We agree with you that if we would like to take this topic further, comparing model CAPE and Q_{Ra} with observation-based data is necessary for providing robust conclusions.

Referee #3 comment:

Looking at the previous discussion for this paper, other reviewers have been concerned that the study only focuses on aerosol radiative effects, opposed to microphysical effects. This is certainly a limitation of the study, but the authors have now sufficiently acknowledged this, in my opinion. I also consider it useful to have the results published on this topic even with that caveat. Nevertheless, effects on lightning trends are likely to be very different if microphysics is considered and it should be a priority for anyone wanting to take this work further to include that within their scope.

Author comment: We appreciate your understanding that our manuscript has not considered the aerosol microphysical effects. As you mentioned, we agree that it is essential to consider aerosol microphysical effects if anyone wants to take this work further.

Referee #3 comment:

______Major comments_____

Sec3.2 - The biggest affect on lightning trends is fixing aerosol not climate (fig5). Yet figures have not been presented which show what model factor causes the larger trend in fixed aerosol experiments. Fig4 and fig6 both show larger deviations from the std expt in the fixed climate experiments, and relatively small changes in aero experiments. The figure that should be the basis of understanding this is fig S5 (also S4). This shows that lightning generally increases over tropical land and the warm pool in response to climate trends. It shows that lightning over tropical land generally decreases in response to aerosol radiative trends. We need to have composite changes in CAPE etc from these regions to know why they have the trends they do, and therefore how they affect the global mean response. The existing map plots focus on % changes instead of this absolute change. And as such, are a distraction from the responses that are driving the trends. I note that in fig12 you show absolute changes to describe Pinatubo effects – this is a better approach than in the preceding section. I think it's essential you rethink the narrative of Sec3.2 (most of the analysis is there, except for a few composites maybe).

Author comment: We agree with your comments, and we have revised Figs. 6c–6d to show absolute trends of CAPE and Q_{Ra}. As also demonstrated in our study (see Fig. 1), most lightning flashes occur over tropical and subtropical land regions. It is displayed in Figs. 6c–6d that the past increases in AeroPEs mostly suppress the CAPE and Q_{Ra} absolute trends within regions with high lightning densities (tropical and subtropical land regions). We further investigated the trends of ±35° latitude land region mean CAPE and Q_{Ra} anomalies, and the results are portrayed in Figs. 6e–6f. Figs. 6e–6f show that past increases in AeroPEs significantly suppress the Q_{Ra} trend (-0.08 % yr^{-1}) and slightly suppress the CAPE trend (-0.03 % yr^{-1}) within ±35° latitude land regions. Weaker convection activities (smaller CAPE) and fewer hydrometeors (cloud ice, graupel, snow) in the charge separation regions (0°C – -25°C isotherm) engender less lightning. In the case of the ECMWF-McCAUL scheme, CAPE and Q_{Ra} trends were suppressed within ±35° latitude terrestrial regions. This constitutes the main reason for the suppression of the historical global lightning trends induced by increases in AeroPEs through aerosol radiative effects.

We have added the above discussion to our revised manuscript (L433-L441).

Referee #3 comment:

Fig2 – what's the confidence interval on the trend estimates? I think these are essential to understand the results. The comment applies throughout the paper to trend estimates.

Author comment: Thank you very much for your good suggestion. We have estimated the confidence interval of all trends in our manuscript utilizing Sen's slope estimator (T. et al., 2002; Hussain and Mahmud, 2019). The results are shown in Table 2, Table 3, Table 4, and Table 6.

Referee #3 comment:

______Minor comments_____

L157 – This is an unusual implementation of price and rind. Please explain how adj_factor is calculated, and reference any evaluations of this implementation. What are the values of adj_factor used?

Author comment:

We used a simplified version of equations (Eq. (1) and Eq. (2)) to show the idea that each model layer's cumulus cloud fractions (Cu_CF_i) are used to weight the calculated lightning densities from that layer in the CTH scheme.

$$F_l = \sum_{i=1}^{n=36} adj\_factor \times Cu\_CF_i \times (H_i - H_{surface})^{4.9} \qquad (1)$$

$$F_o = \sum_{i=1}^{n=36} adj\_factor \times Cu\_CF_i \times (H_i - H_{surface})^{1.73} \quad (2)$$

The complete equation used in CHASER (MIROC) to implement the CTH scheme is shown below.

$$FLSHK(IJ) = \sum_{KT=1}^{n=Nlayer} FL0 \times HTOP(IJ,KT)^{FL1} \times \frac{HAREA(IJ) \times LNFRC(IJ,KT) \times CAFCT}{(\frac{CAMAX \times HTOP(IJ,KT)}{CHMAX})^2} \quad (3)$$

$FLSHK$: the total lightning flash rate from ground to top level at grid IJ.

IJ: grid index KT: vertical layer index $Nlayer$: the number of total vertical layer (here $Nlayer$=36)

$FL0, FL1$: coefficients ($FL0$=3.44×10^{-5} and $FL1$=4.9 for land; $FL0$=6.2×10^{-4} and $FL1$=1.73 for ocean)

$HTOP$: cloud top height $HAREA$: grid horizontal area $LNFRC$: cumulus cloud fraction $CAFCT$: constant factor (0.43)

$CAMAX$: maximum area of each cumulus (2.2×10^4) $CHMAX$: maximum height of cumulus cloud (12 km)

$HAREA(IJ) \times LNFRC(IJ,KT)$: actual cumulus area at each vertical layer

$(\frac{CAMAX * HTOP(IJ,KT)}{CHMAX})^2$: maximum possible cumulus area at each vertical layer

Terms except $LNFRC(IJ,KT)$ in $\frac{HAREA(IJ) \times LNFRC(IJ,KT) \times CAFCT}{(\frac{CAMAX \times HTOP(IJ,KT)}{CHMAX})^2}$ constitute adj_factor in Eq. (1) and Eq. (2).

Equation (3) aims to faithfully reflect the contribution of LFR from cumulus with different heights. This form of implementation (Eq. 3) originated from CHASER (Sudo et al., 2002). We have added a citation to our revised manuscript (L154).

Referee #3 comment:

Sec3.1 - Both models are poor over the ocean (for different reasons). This should be acknowledged.

Author comment: We have acknowledged this point in our revised manuscript (L292-L293).

Referee #3 comment:

Fig2 – As far as I can tell, there's no nudging? In which case it would be helpful to note for fig2 that we would not necessarily expect year-to-year variability to be captured, since the only control in the model is SSTs? If there is nudging, this needs to be described.

Author comment: Yes, the meteorological nudging was not applied to our simulations. We have noted this point in our revised manuscript (L319-L321).

Referee #3 comment:

L344 – Something like the PDO could also be a factor over that length of time.

Author comment: Thank you very much for your informative comment. Indeed, there is evidence showing that PDO can also affect lightning activities (Macias Fauria and Johnson, 2006; Mallick et al., 2022). We have added relevant discussion to our revised manuscript (L357-L358).

Referee #3 comment:

Fig11 – this would benefit from overplotting the pdf of a year of months following Pinatubo. The distribution could then be tested to show it is different from the climatology.

Author comment:

Thanks very much for your good suggestion. We have plotted the PDF of a year of months following Pinatubo in Fig. 11. We have added the relevant discussion to our revised manuscript (L551-L552).

Reference:

Hussain, Md. and Mahmud, I.: pyMannKendall: a python package for non parametric Mann Kendall family of trend tests., J. Open Source Softw., 4, 1556, https://doi.org/10.21105/joss.01556, 2019.

Macias Fauria, M. and Johnson, E. A.: Large-scale climatic patterns control large lightning fire occurrence in Canada and Alaska forest regions, J. Geophys. Res. Biogeosciences, 111, https://doi.org/10.1029/2006JG000181, 2006.

Mallick, C., Hazra, A., Saha, S. K., Chaudhari, H. S., Pokhrel, S., Konwar, M., Dutta, U., Mohan, G. M., and Vani, K. G.: Seasonal Predictability of Lightning Over the Global Hotspot Regions, Geophys. Res. Lett., 49, e2021GL096489, https://doi.org/10.1029/2021GL096489, 2022.

Sudo, K., Takahashi, M., Kurokawa, J. I., and Akimoto, H.: CHASER: A global chemical model of the troposphere 1. Model description, J. Geophys. Res. Atmospheres, 107, ACH 7-1-ACH 7-20, https://doi.org/10.1029/2001JD001113, 2002.

T., S., A., M., Anttila, P., Ruoho-Airola, T., and T, A.: Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen’s Slope Estimates the Excel Template Application MAKESENS, Publ. Air Qual., 31, 2002.