

Atmos. Chem. Phys. Discuss., referee comment RC3
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Comment on acp-2022-295

Anonymous Referee #3

Referee comment on "Robust evidence for reversal of the trend in aerosol effective climate forcing" by Johannes Quaas et al., Atmos. Chem. Phys. Discuss.,
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This manuscript reports the trends of aerosol optical depth, cloud properties, and top-of-atmosphere radiative fluxes in last two decades (2000-2019), mostly from satellite retrievals, to assess the anthropogenic aerosol radiative forcing trends. It also examines the consistency of the trends among AOD, clouds, and radiation. The paper concludes that the anthropogenic aerosol radiative forcing has become globally less negative in this 20-year period, which is consistent with the declining trends of anthropogenic aerosol and precursor emission, aerosol burden, fine-mode aerosols, cloud droplet number concentrations, and TOA fluxes. Based on the findings, it is concluded that the reduction of anthropogenic aerosol leads to an acceleration of the forcing of climate change through both aerosol-radiation and aerosol-cloud interactions.

I find that the manuscript provides an extensive measurement-based information to assess the aerosol radiative forcing on climate, but there are several major issues in synthesize the information to draw the conclusions. Several major issues and specific comments are listed below, and they should be addressed and clarified before the manuscript can be accepted for publication.

Major Issues:

- **Definition of ERF:** It is not clear what the definition of aerosol ERF is – is it (a) aerosol radiative effects from anthropogenically emitted aerosols and their precursors? Or (b) the ERF from present-day aerosols minus preindustrial aerosols (e.g. 1750)? Or (c) just the radiative effects of total aerosol? Using modern satellite data implies (c), which is

present-day total aerosol effects, but in the paper, it is often casually refer that as aerosol climate forcing or anthropogenic aerosol forcing. Clarification is needed.

- **Causality:** Even if the trends among aerosol, clouds, and radiative fluxes are “consistent” from satellite observations, it does not mean that the trends can be explained by the reduction of anthropogenic aerosols. There is no effort shown in the paper to separate causality with association. By showing the similarities among the variables is not enough to attribute the trends to the cause. CMIP6 or RFMIP models should be able to provide some insights.
- **“Consistency” between trends in Fig. 1-4:** Global map of trends shown in Figures 1-4 are informative, but more in-depth analysis is needed to not only better convey the consistency (or inconsistency) among the trends of AOD, clouds, and radiative fluxes but also different trends of those quantities in various regions. I would suggest show the 2000-2019 time series of each quantity averaged over selected regions (e.g., major pollution source regions, continental outflow regions, and remote regions) to reveal how linear the trends are and if they are indeed consistent with the change of anthropogenic emissions.
- **Significance of the trends:** Areas with “substantial” positive and negative trends are defined as those where the clear sky ERF trends are larger than 0.05 W/m²/year from RFMIP multi-model ensemble mean. According to the caption of Table 1, regions with negative trends cover just 7.3% of the Earth’s surface and that with positive trends covers 1.1%. That implies no trends or weak trends over 91.6% of the Earth’s surface area. How do you explain the significance of global changes of these quantities if the substantial trends are only confined in ~8% of the area?

Specific comments:

Line 8: “consistent” with what? With anthropogenic aerosol trend?

Line 16: “ERFari occurs through the scattering and absorption of sunlight by aerosols”: This is the aerosol radiation interaction, which referred to as “RFari” according to IPCC AR5. The ERFari includes additional “semi-direct effects”. Please use the terminology more carefully.

Line 22-25: If +1.01C temperature change is due to CO₂ and -0.51C due to aerosol, should the net temperature increase be $1.01 - 0.51 = +0.5C$? Or, in other words, it would have reached +1.01C temperature increase without aerosol cooling.

Line 38: Do you see a turning point from the 20-year data record when aerosol forcing became substantially less negative? That is why plotting time series is very helpful, as I mentioned in “Major issues” #3, to see if the trends are linear or showing a turning point.

Line 58-59: “anthropogenic aerosol emissions over China have been increasing until ~2010 and decreasing thereafter”: That means the emission trend is not only non-linear but also has shifted directions during the past two decades. It will be interesting to see if

AOD, clouds, and radiative flux shows similar or different decadal variations.

Line 68-69: CMIP6 used the CEDS_v2017 described in Hoesly et al. 2018, not the newest CEDS version (2021 version).

Line 74-75: Not very clear what you mean "mirror" here, which usually means opposite direction. Do you mean that OC and BC emissions have an increasing (decreasing) trend that mirrors the decreasing (increasing) trend of sulfur emission in the same region? In Figure 1, the regional trends of SO₂, OC, and BC are similar in the same directions, though.

Line 107-108: Over most oceanic area, MODIS and MISR have opposite AOD trends, especially the fine- mode AOD. What is the implication for global aerosol forcing since ocean covers 70% of the surface area?

Line 111 and 112: Is it Metop-A or Metop-B you are using?

Line 114-115: GOME-2 shows different trends over most land regions. Can you be more specific about what the "expected behavior" is? How can the opposite trends in some regions be described as "consistent"?

Line 115, "These trends are largely consistent with those from AERONET data": You have not shown any AERONET data here.

Line 131-133: Is CDNC less variable than cloudiness and cloud radiative properties? How large should the variability be to prohibit the detection of trend? Again, time series plots may better convey the story.

Line 147-151: There are clearly several regions that the directions or magnitudes of changes between aerosols and cloud properties are not in sync. Can you make more quantitative analysis of different regions, e.g., major pollution regions, immediate downwind regions, and more remote regions, and explain, to the degree you are able, the reason for the consistency or inconsistency between the changes of aerosols and clouds?

Figure 4: The terms in Figure 4 are confusing. For example, the caption of Fig 4a says "net broadband solar flux for clear-sky", but the figure title indicates it is "rsutcs", which is defined as "radiation shortwave upward TOA clear sky", not "net". Also it seems the quantities from RFMIP in Fig. 4d-f do not corresponding to the quantities from CERES in

Fig. 4a-c: CERES data are the radiative fluxes whereas the RFMIP the effective radiative forcing (meaning either PD – PI, or anthropogenic aerosol only). Lastly, $r_{\text{out}} + r_{\text{in}}$ is total (shortwave + longwave), not net. Please get the terms straight and clarify if you are compare the same or different quantities between CERES and RFMIP.

Figure 4 caption, third line from the bottom, the sentence started with "For the emissions...". What is the context of emission here? Besides, there is no grey shading anywhere in all panels.

Line 172: Delete "year" in "year 0.32 W m^{-2} ".

Overall, this section is confusing. As I mentioned in "Major Issues" #1, it is not clear whether the discussion is about TOA upward flux, or net flux, or shortwave + longwave flux, or surface downward flux, or if preindustrial condition is considered in the model, or how the RF is defined - is it PD - PI? or is it by anthropogenic aerosol?

Line 239: delete "but also".

Table 1 caption, 2nd line: Is CMIP6 or RFMIP models used in Fig. 4? Are they the same suite of models? Please be consistent.

Line 257-258: CEDS emission was not consider any aerosol satellite retrievals.

Line 269: Remove "aerosol" in "all three aerosol species". SO₂ is not aerosol, but an aerosol precursor gas.

Line 269-270: it is self-repeating that MODIS and MISR AOD increase or decrease at regions aerosols increase or decrease. AOD is a measure of aerosol. Maybe you mean at regions aerosol and precursor emission increase or decrease?

Line 272: What are the expectations? Are the expectations consistent with the aerosol trends or not and why?

Line 282-286: Again, it seems the terms you compare between CERES and CMIP6 (or RFMIP?) are not the same terms.

Figures 1-4: Since the color scales are not linear, it is hard to tell the data range covered by the color bars. Please add numbers for each color interval to help quantify the range.