Interpreting Differences in Radiative Feedbacks from Aerosols Versus Greenhouse Gases

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1. Abstract

Aerosols and greenhouse gases (GHGs) exhibit different forcing patterns, with GHGs causing more uniform forcing that only drops off gently from the tropics whilst aerosol forcing is focused in the northern hemisphere (NH) extra-tropics.

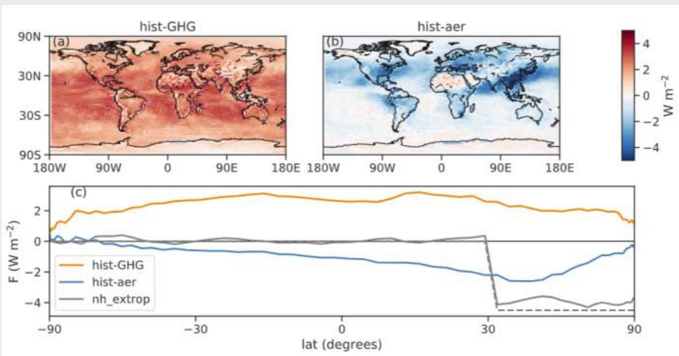

Figure 1. Top-of-atmosphere radiative forcing patterns over years 1995--2014 for hist-GHG (a) and hist-aer (b). (c) zonal-mean profiles. Grey lines in (c) show prescribed (*dashed*) and effective (*solid*) forcing for an extra HadAM3 simulation.

Past works are in disagreement, however, on whether this results in differences in warming/cooling efficacy (e.g. radiative feedbacks) of these forcing agents[1-5].

With the motivation that aerosols and GHGs are the two dominant drivers of historical climate change[6], we use CMIP6 historical experiments involving these forcing agents, in addition to single-model prescribed forcing pattern experiments, to answer the following questions:

- *Do feedbacks depend on forcing agent?*
- *What mechanism explains different feedbacks?*
- *What drivers explain differences in mechanism?*

2. Data

- CMIP6 data from ESGF
- AGCM experiments: piClim-[histaer,histghg,histall]
- AOGCM experiments: hist-aer, hist-GHG, historical
- 7 models: CanESM5, CNRM-CM6-1, GISS-E2-1-G, HadGEM3-GC31-LL, IPSL-CM6A-LR, MIROC6, NorESM2-LM
- Monthly data over years 1850-2014
- Extra: HadAM3 (and HadSM3) simulations of tropical and hemispheric extra-tropical forcing

3. Differences in feedbacks

- Response calculated as difference of AOGCM vs AGCM output, to remove adjustments from results
- Convention: less +ve feedback parameter α means more amplified temperature change
- Stability, measured as estimated inversion strength over 50S-50N oceans, used as measure
- Model-by-model variation in agent-dependent feedbacks
- More consistent picture in stability: aerosol causes less positive stability change per unit surface warming
- MMM shows more amplifying feedbacks for aerosol than GHG, consistent with dS/dT (greater dS/dT encourages formation of low clouds and increased lapse rate)

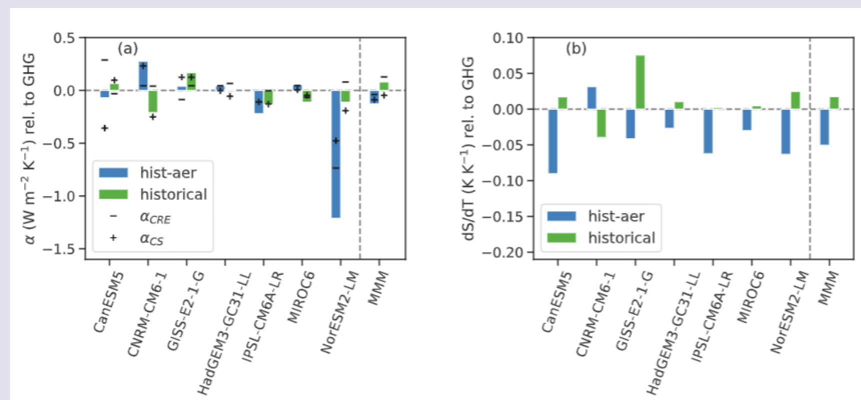

Figure 2. (a) Allsky radiative feedback parameter (α) alongside CRE (α_{CRE}) and clearsky radiative feedback parameters (α_{CS}) for each model and the multi-model mean, as the difference from hist-GHG values. (b) Difference of dS/dT (stability change per unit surface temperature change) from hist-GHG values.

4. Relating differences in feedbacks to stability changes

- Radiative feedbacks related to dS/dT differences in CMIP6 MMM, explaining differences across hist-aer, hist-GHG, and historical experiments
- Model spread large, but model differences are well-correlated in feedbacks and dS/dT
- HadSM3/HadAM3 experiments also follow trend

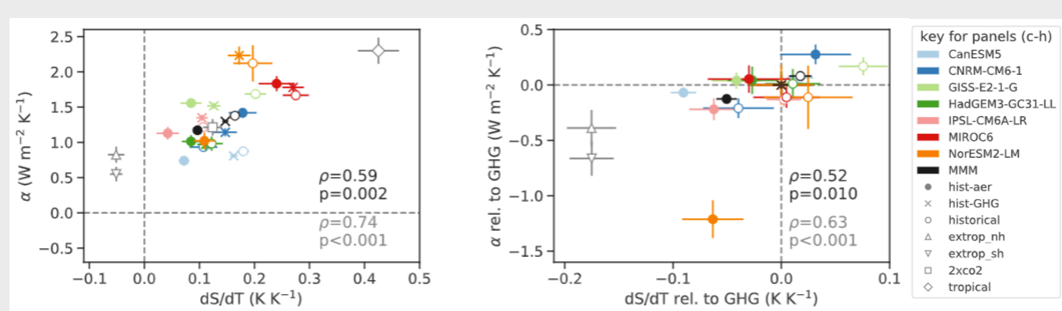

Figure 3. Allsky feedbacks against dS/dT, as absolute values (*left*) and with values relative to hist-GHG (*right*), with correlations across models shown by ρ (*black*: CMIP6 only, *grey*: including HadSM3 experiments)

5. Explaining differences in stability change

- Aerosol and NH extratropical forcing both cause shallow temperature change in NH compared to GHGs (with the opposite effect in the historical)
- By contrast, tropical forcing reproduces the air temperature change patterns of GHGs, even more pronounced
- This is related to deep convective regions being present in tropical regions, whilst these are absent in extra-tropics
- Thus, NH skew of aerosol forcing provides negative dS/dT contribution that explains the overall less positive dS/dT of aerosol vs GHGs

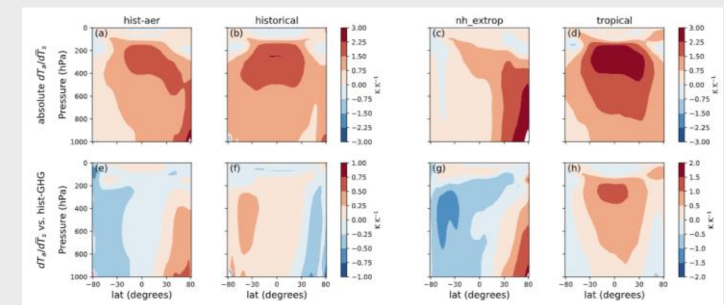

Figure 4. Zonal-mean profiles of air temperature regressed onto global-mean surface air temperature. Values shown are absolute (a--d), and relative to hist-GHG for CMIP6 MMM (e--f) or 2xCO2 for HadSM3 (g--h).

6. Conclusions

Do feedbacks depend on forcing agent?

- Yes for aerosols vs. GHGs, at least historically
- At least in some models, and in the MMM

What mechanism explains different feedbacks?

- Stability explains feedback differences, with enhanced stability de-amplifying warming
- Extra-tropical vs tropical forcing viable explanation of stability changes

What drivers explain differences in mechanism?

- Forcing patterns are different, with extra-tropical vs. tropical contrast
- Prescribed extra-tropical forcing recreates features of historical aerosol forcing

References

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[2] Becker & Wing, 2020, *Understanding the Extreme Spread in Climate Sensitivity within the Radiative-Convective Equilibrium Model Intercomparison Project*
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