Feedbacks, climate sensitivity and polar amplification insights from volcanic eruptions in model large ensembles

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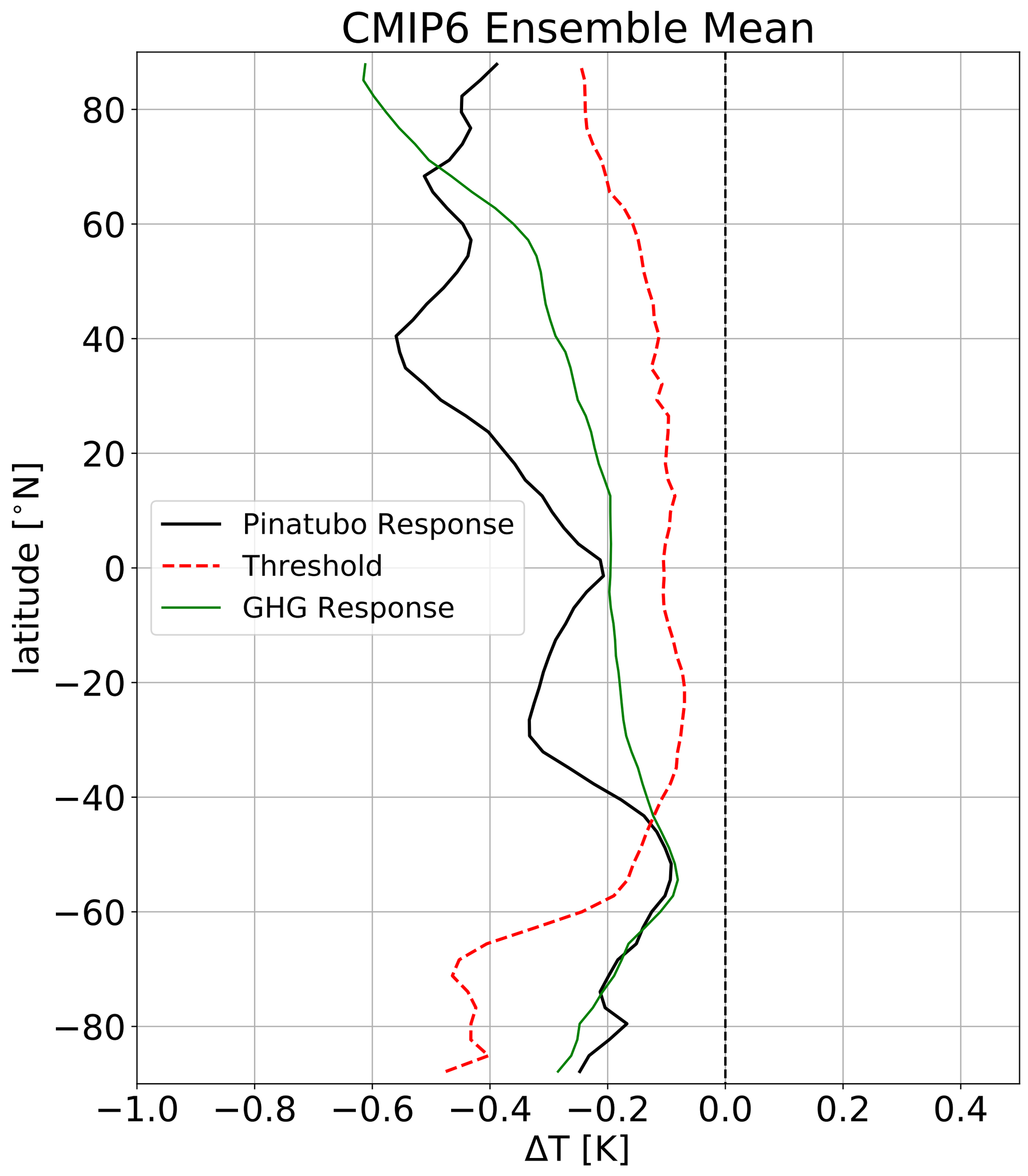
Motivation

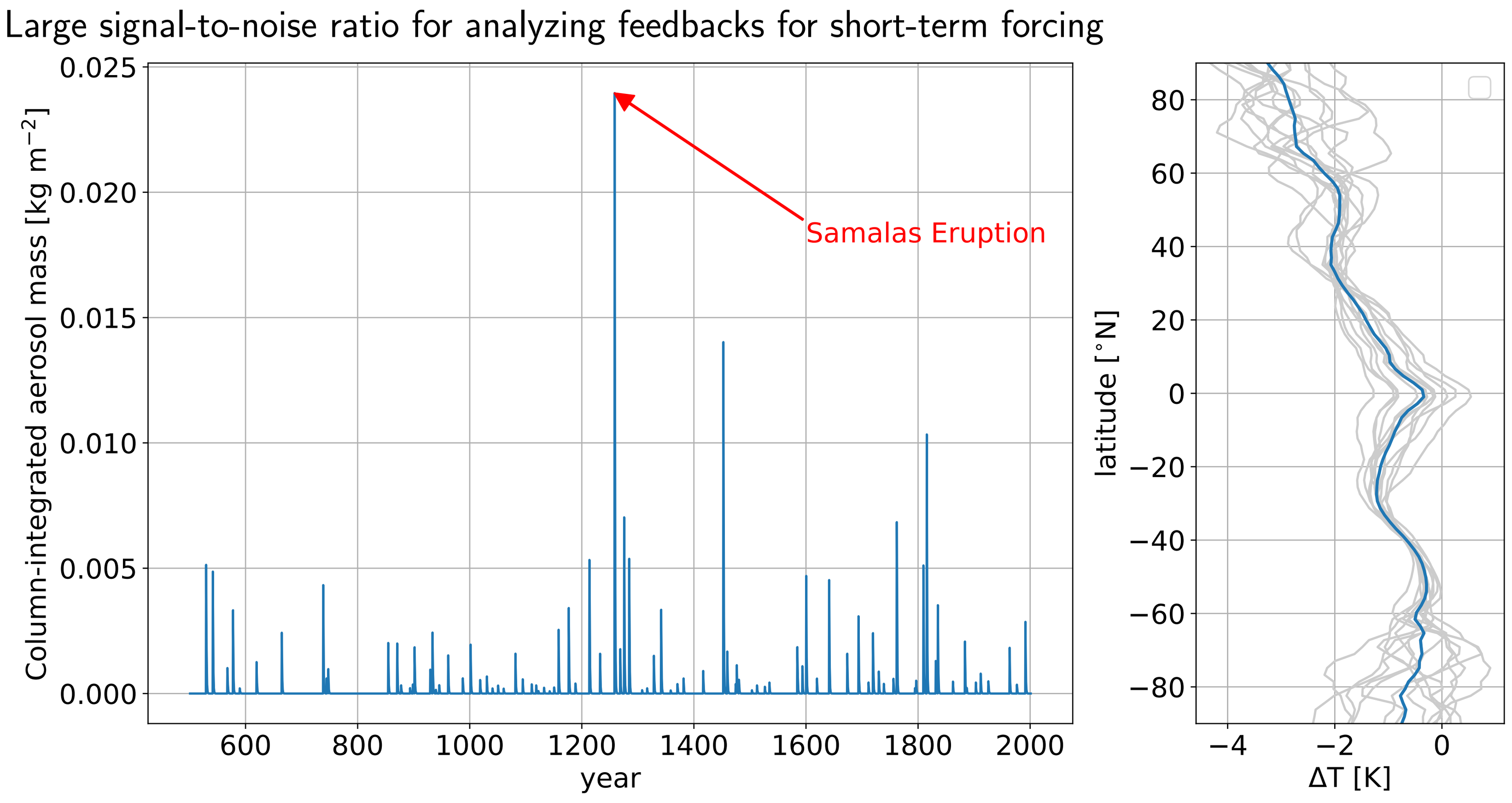
- Surface temperature response to large volcanic eruptions (Mt Pinatubo) is less polar amplified than the response to increased CO_2 [1]



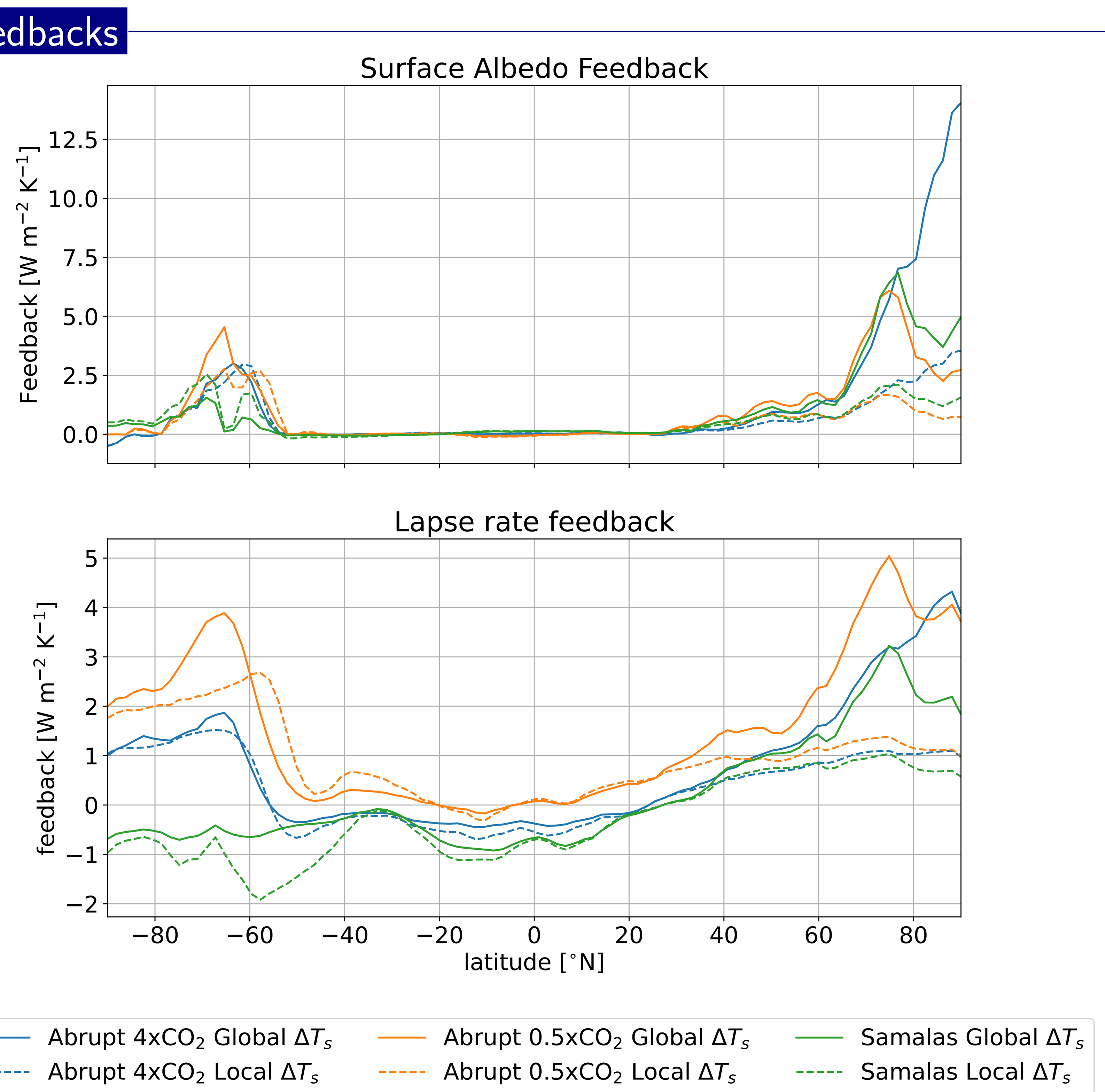
- We are interested in knowing why this is the case
- We expect less polar amplification with smaller forcing at high latitudes [2].
- Due to the pattern effect, this means we should expect a smaller climate feedback parameter and climate sensitivity in response to volcanoes compared to GHGs [3].

CESM Last Millenium Ensemble

- 13 ensemble members run with CESM1-CAM5 over the period 850 to 2005 with transient forcing [4].
- Many large volcanic eruptions. The largest (Samalas) was $\sim 9\times$ the size of Pinatubo.
- Large signal-to-noise ratio for analyzing feedbacks for short-term forcing



Feedbacks



- Smaller Arctic surface albedo and lapse rate feedbacks due to volcanoes than to increased CO2.
- Surface albedo also smaller in abrupt-0.5xCO2 runs, indicates it is likely due to sea ice
- Arctic lapse rate feedback difference due to different vertical structure of temperature change

Climate Sensitivity

- Bender et al. (2010) found a relationship between "volcanic sensitivity" and climate sensitivity in CMIP3 models [5].
- Volcanic sensitivity defined as the ratio between the time-integrated surface temperature anomaly and the time-integrated TOA net SW anomaly after the eruption.

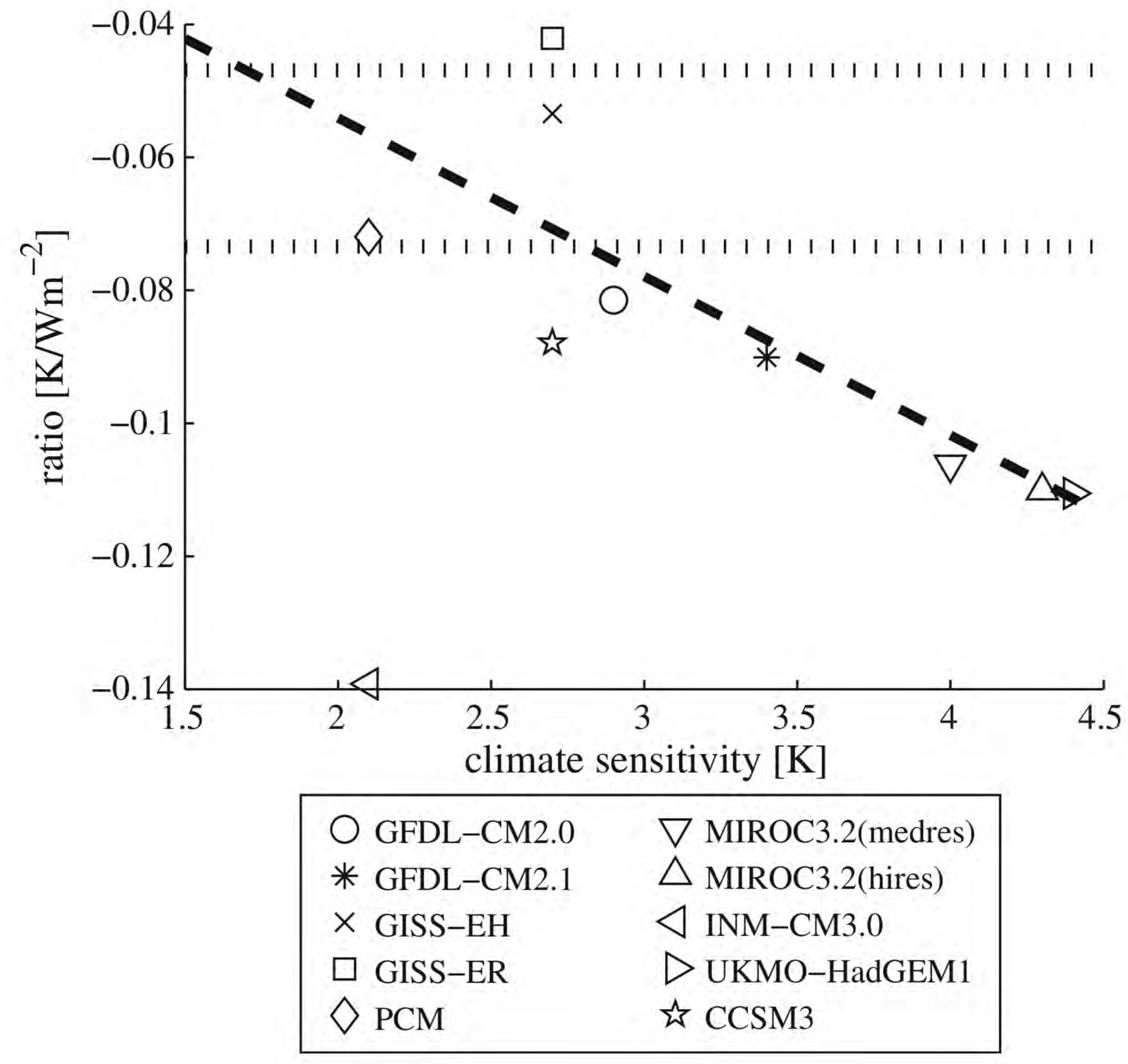


Figure 1. Volcanic sensitivity vs climate sensitivity from Bender et al. (2010).

- However, we find no such relationship with the much larger available multi-model ensemble of CMIP6 models (~500 ensemble members vs only 23 for CMIP3).

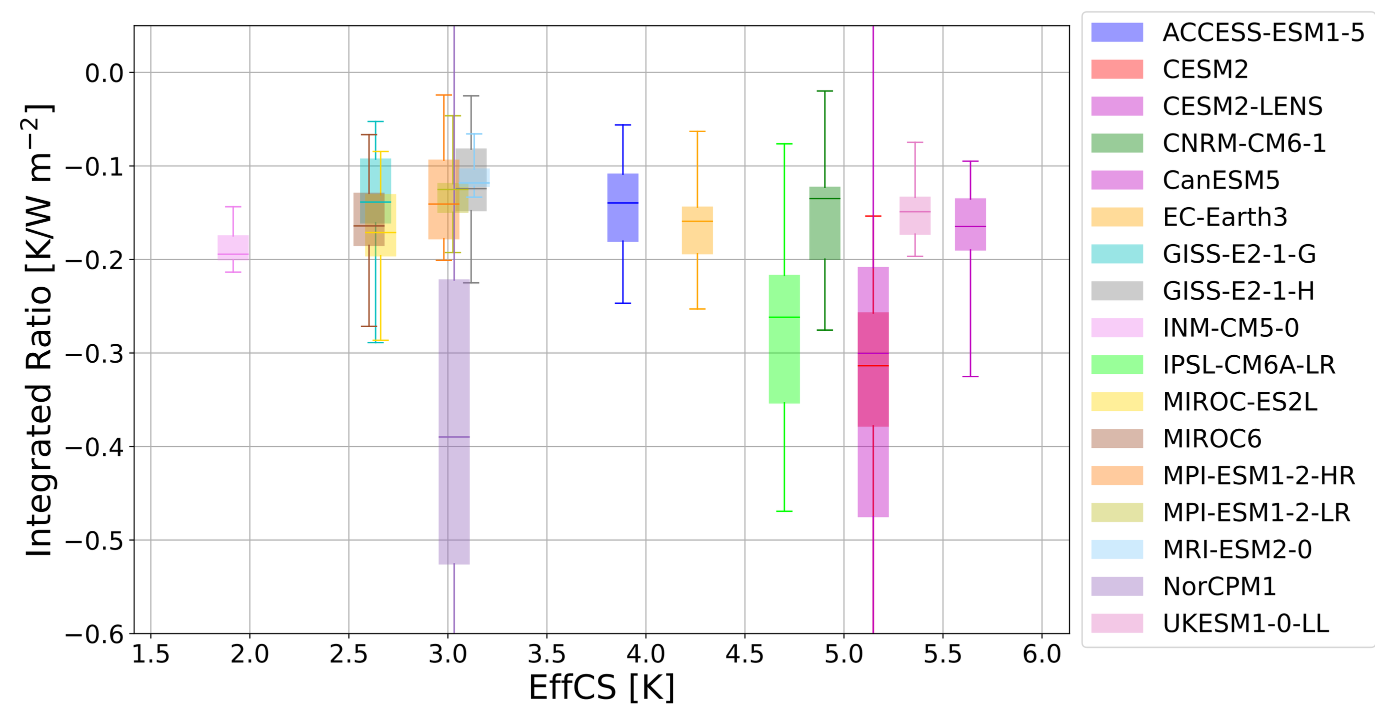


Figure 2. Same as above but for the CMIP6 models with at least 10 ensemble members in their historical simulations.

- If we randomly sample the same number of models and ensemble members as used by Bender et al. (2010), we find their result is due to statistical chance, because of their small number of models.

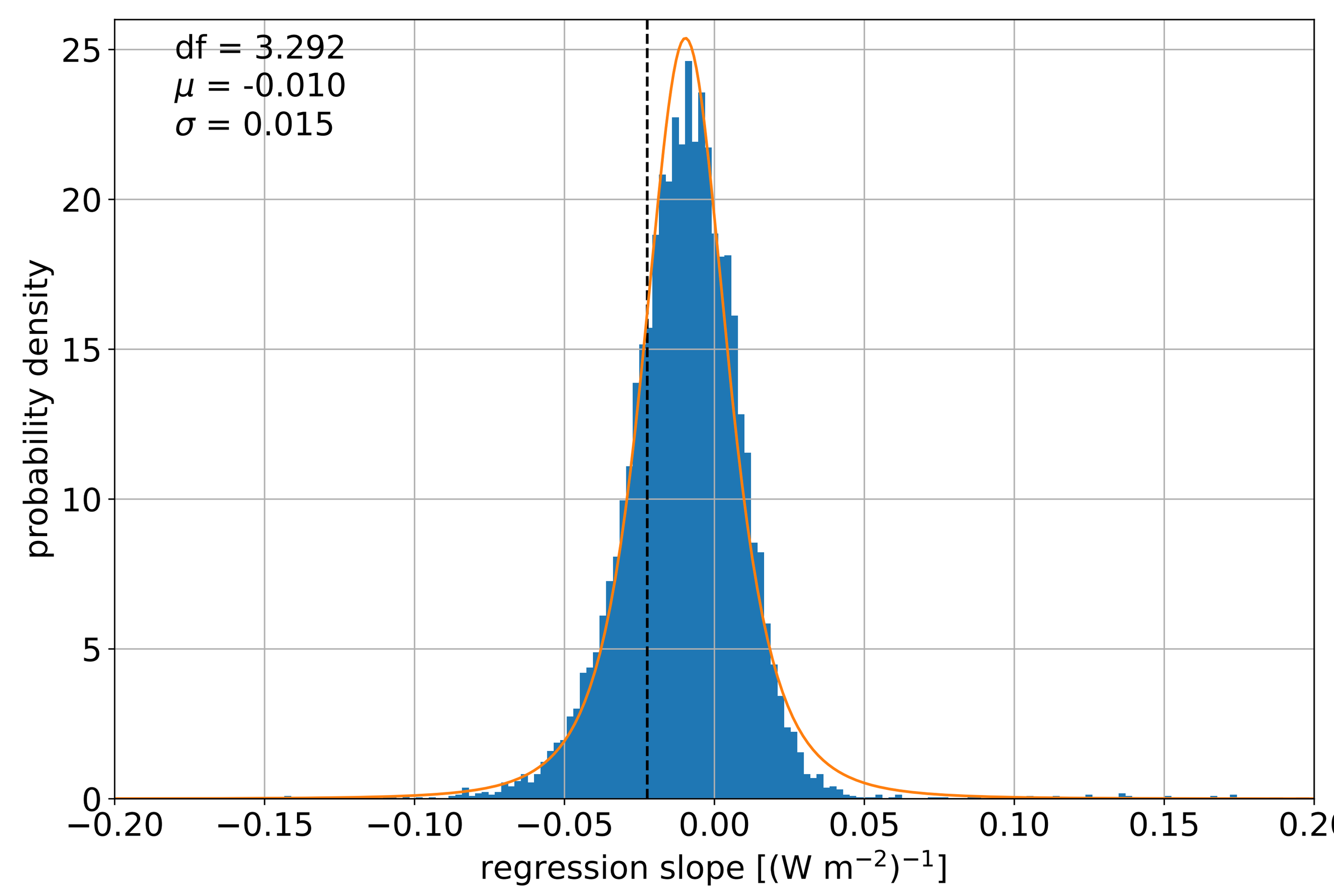


Figure 3. Histogram of regression slopes obtained by randomly sampling the same number of models and ensemble members as used by Bender et al. from the CMIP6 output. Black dashed line denotes the slope Bender et al. computed, and the orange line is a Student's t-distribution fit to the data.

Conclusions

- Climate response to large volcanic eruptions less polar amplified than the response to GHGs due to differences in feedbacks
- Response to volcanic eruptions not well-correlated to EffCS, in contrast to previous work, due to the much greater amount of model output now available

References

[1] A. G. Pauling, M. Bushuk, C. M. Bitz, *Geophysical Research Letters* **48**, e2021GL092558 (2021).
[2] M. F. Stuecker, *et al.*, *Nature Climate Change* **8**, 1076 (2018).
[3] K. C. Armour, C. M. Bitz, G. H. Roe, *J. Clim.* **26**, 4518 (2013).
[4] B. L. Otto-Bliesner, *et al.*, *Bull. Amer. Meteorol. Soc.* **97**, 735 (2016).
[5] F. A.-M. Bender, A. M. L. Ekman, H. Rodhe, *Clim. Dyn.* **35**, 875 (2010).

Acknowledgements

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