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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Tropical atmospheric circulation response to the G1 sunshade geoengineering radiative forcing experiment" *by* Anboyu Guo et al.

Anonymous Referee #1

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This manuscript is a valuable contribution to the geoengineering literature, as it provides a detailed assessment of the simulated tropical circulation response to uniform solar dimming in a suite of coupled climate models. The Hadley circulation does not return to preindustrial conditions in a climate with quadrupled carbon dioxide levels and reduced insolation (the G1 experiment). The authors attribute this result to changes in meridional temperature gradients rather than changes in static stability. The Walker circulation, by contrast, is largely restored to its preindustrial state in G1. The Introduction section effectively describes the many motivations for the study.

The novelty of this work lies in its assessment of the G1 experiment, as much anal-

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Discussion paper

ysis of the impact of elevated atmospheric carbon dioxide concentrations on tropical dynamics has been discussed previously (see references below). At present, the Introduction mentions a few studies on the latter subject (on page 3), but a more thorough review of the existing literature is warranted, both in the Introduction and the Discussion. This manuscript would be more effective if it were shortened so as to emphasize new knowledge; if the circulation changes in abrupt4xCO2 simulations differ from what is reported in the existing literature on the subject, this can be emphasized, but otherwise the geoengineering results should be brought to the forefront.

I have questions pertaining to the methodological choices described in Section 2.3. Why is the Hadley cell intensity based on such a broad latitudinal extent (to 40° S or N)? This extends beyond the tropics and includes the Ferrel cell. Additionally, the Hadley cell migration is not symmetric in the two seasons (the July-September cell extends further into the summer hemisphere than the January-March cell), so why is the Hadley cell intensity metric hemispherically symmetric?

Finally, throughout the paper it would be helpful to explicitly distinguish between robust results and results for which the ensemble mean is dominated by inter-model cancellation. For example, it is important to elaborate on this last sentence of Section 3.1 (line 253). Does the substantial inter-model spread undermine subsequent interpretation of the ensemble mean change?

SPECIFIC COMMENTS

The ENSO-related results could be included in the abstract.

Throughout the paper, starting in the abstract, the Hadley circulation changes are discussed in terms of “seasonal maximum northern and southern cells.” It would be clearer to discuss these together as the “solstitial Hadley cells,” or as “the JAS and JFM cross-equatorial cells.”

(lines 79-80) It is not entirely clear what is meant by this phrase: “and a similar response

of oceans versus land."

(line 84) Held and Soden (2006) are better known for explaining this P-E scaling, which is derived from the Clausius-Clapeyron relation and only valid over ocean (reference below).

(lines 108-110) This sentence is unclear: "The signal to noise ratio [. . .]."

(line 198-200) Are all 50 years used only for those measures that do not rely on sea surface temperature?

(line 213) Does the phrase "whole streamfunction" mean for all longitudes? Say that explicitly.

(line 237) Does mean state refer to annual mean state?

Labeling multi-panel figures would facilitate the discussion of results in the text.

(line 308) What constitutes a "good relationship?"

(line 312-314) Note that this was reported by Smyth et al. (2017).

(lines 321-344) This section can be made more concise by focusing on similarities or differences from previous studies on the subject (cf. major comment above).

(lines 339-340) Cite other studies which have noted that solar dimming results in an overcompensation of tropical circulation changes induced by global warming.

You might consider discussing all of the analysis of the Walker and Hadley circulation responses together, i.e. moving current Section 6.1 to follow current Section 3.2.

(lines 399-403) This section is confusing. "Monthly temperatures" in which region?

(lines 433-436) Why do you choose to analyze temperatures over Tibet if the general land-ocean temperature contrast is of interest? This choice should be justified, or the analysis modified. Are you considering surface temperatures? The methodology is not described in enough detail for the results to be reproduced. Additionally, there is an

extensive body of literature connecting inter-hemispheric temperatures and the Hadley circulation/Intertropical Convergence Zone, such as Broccoli et al. (2006), which can be referred to here.

(lines 445-448) Specify the location and season on which this is based. Are these near-surface potential temperature gradients?

(lines 468-470) The sentence "However only the eastern and western [. . .]" is confusing.

The analysis of the Walker circulation should be better framed. For example, He and Soden (2015) explain that weakening of the Walker circulation due to carbon dioxide forcing is mostly driven by the change in mean sea surface temperatures (SST).

(line 500) The second half of this sentence is unclear.

(lines 514-516) Rephrase this sentence for clarity: "But we observe [. . .] G1 forcing."

(line 545) Does "ocean heating" refer to warming sea surface temperatures or ocean heat uptake?

(line 548) Define "Rx5day extreme"

Figure 10: Is this based on annual data from El Nino years, or data from a particular season? In a few places in the paper it is not immediately clear what averaging periods and spatial domains are used for calculations.

TECHNICAL COMMENTS

(Line 10) capitalize "Earth"

(Line 25) "good correlations" should be rephrased more precisely

(Line 55) typically capitalized "Northern Hemisphere"

(line 29) "response to" should say "responses of"

(Line 63) “compliment” should be “complement”

(line 157) not a sentence

(line 349-351) This is not a sentence.

(line 542) “While under [. . .]” is not a sentence.

REFERENCES

*A sampling of the many studies examining the Hadley cell response to global warming:

Frierson, D. M. W. (2006). Robust increases in midlatitude static stability in simulations of global warming, Geophys. Res. Lett., 33, L24816, doi:10.1029/2006GL027504

Frierson, D. M. W., J. Lu, and G. Chen (2007). Width of the Hadley cell in simple and comprehensive general circulation models, Geophys. Res. Lett., 34, L18804, doi: 10.1029/2007GL031115.

Held, I.M. and B.J. Soden (2006). Robust Responses of the Hydrological Cycle to Global Warming. J. Climate, 19, 5686–5699, https://doi.org/10.1175/JCLI3990.1

Johanson, C.M. and Q. Fu (2009). Hadley Cell Widening: Model Simulations versus Observations. J. Climate, 22, 2713–2725, https://doi.org/10.1175/2008JCLI2620.1

Lau, W. K., & Kim, K. M. (2015). Robust Hadley Circulation changes and increasing global dryness due to CO2 warming from CMIP5 model projections. Proceedings of the National Academy of Sciences, 112(12), 3630-3635.

Lu, J., G. A. Vecchi, and T. Reichler (2007). Expansion of the Hadley cell under global warming, Geophys. Res. Lett., 34, L06805, doi: 10.1029/2006GL028443.

Seager, R., N. Naik, and G.A. Vecchi (2010). Thermodynamic and Dynamic Mechanisms for Large-Scale Changes in the Hydrological Cycle in Response to Global Warming. J. Climate, 23, 4651–4668, https://doi.org/10.1175/2010JCLI3655.1

Seidel, D. J., Fu, Q., Randel, W. J., & Reichler, T. J. (2008). Widening

of the tropical belt in a changing climate. Nature Geoscience, 1(1), 21-24. doi:http://dx.doi.org.ezproxy.princeton.edu/10.1038/ngeo.2007.38

Additional References

Broccoli, A. J., K. A. Dahl, and R. J. Stouffer (2006). Response of the ITCZ to Northern Hemisphere cooling, Geophys. Res. Lett., 33, L01702, doi: 10.1029/2005GL024546.

He, J., & Soden, B. J. (2015). Anthropogenic weakening of the tropical circulation: The relative roles of direct CO2 forcing and sea surface temperature change. Journal of Climate, 28(22), 8728-8742.

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