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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Hadley cell expansion in CMIP6 models" *by* Kevin M. Grise and Sean M. Davis

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We would like to thank the reviewer for taking time to review our manuscript and providing helpful comments. Based on the reviewer's comments, we have made a number of minor changes and clarifications to the manuscript. Detailed point-by-point responses to all comments are provided below, and the original reviewer's comments are provided in bold type.

The submission by Davis and Grise sounds at first like turn-the-crank research paper. Indeed, the analysis is a repeat of earlier work by the authors, only with some newer datasets (CMIP6 and ERA5). However, the authors do a commendable job of contrasting their results with their earlier work and under light of other

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recent studies. In doing so, the authors point out several outstanding questions, making this work a useful step forward. I have a few mostly-editorial comments.

We thank the reviewer for this recognition of our efforts to characterize, discuss, and interpret the CMIP6 results in light of previous findings.

Line 15-17: the sentence "First, both. . ., but this. . ." would be more clear as "First, while. . ., this. . ." to make it clear that "First" does not refer to the first clause, but to the second.

Thanks. Following the reviewer's suggestion, we have corrected this sentence to the following:

"First, while both CMIP5 and CMIP6 models contract the NH summertime Hadley circulation equatorward (particularly over the Pacific sector), this contraction is larger in CMIP6 models due to their higher average climate sensitivity."

Line 43 and 52: there's another "First" "second" list here, but it's not clearly introduced as a list, and it sounds like the list may continue afterward. "For example" and "In addition" might be better.

Thanks. We have changed "first" to "for example" and "second" to "additionally."

Lines 125-128: This is not the Hadley circulation boundary. If you believe the EDJ to be meaningfully related to the HC edge in the different ocean basins, you should state so, and somehow justify your belief.

Given the comments from Reviewers 1 and 2, we have eliminated the usage of the EDJ metric from the manuscript, as it does not directly correspond to the location of the Hadley cell edge (although it is highly correlated with it in terms of interannual variability and its response to climate change; see Waugh et al. 2018). We now use the USFC metric to quantify longitudinal variability in the tropical edge. The results are very similar over the Pacific sector, which is the focus of our discussion (see new Fig. 3 and Fig. S2). The new Fig. 3 is attached at the end of this comment.

Line 145: "drastic" is the wrong word; "dramatic" is better

Thanks. We have changed “drastic” to “dramatic.”

Line 166: Table 1 does not “support” the fact that the only significant differences occur during JJA. That fact doesn’t need supporting. But Table 1 helps explain the difference.

We have changed “is supported by” to “is consistent with.”

A more definitive way of explaining this difference would be to normalize the shifts by the respective sensitivities (or remove the component explained by the sensitivity) and determining whether the difference remains significant once the impact of sensitivity is removed.

In the SH, where the JJA Hadley cell edge shifts are all of the same sign and of a similar order of magnitude, the reviewer’s suggestion works well. If the SH JJA Hadley cell edge shifts are divided by the global-mean surface temperature increase in each model, the difference between CMIP5 and CMIP6 models is no longer statistically significant, supporting our argument in the text and confirming the reviewer’s idea.

In the NH, the JJA Hadley cell edge shifts are of varying sign (poleward and equatorward) and of varying orders of magnitude (near-zero to almost 10 degrees), so applying a simple normalization procedure is not straightforward to interpret (i.e., you are dividing large negative Hadley cell shifts by large positive climate sensitivities but you are dividing small negative, near-zero, and large positive Hadley cell shifts by smaller positive climate sensitivities). If we confine our analysis to only those models with equatorward Hadley cell edge shifts greater than 0.5 degrees latitude, if the NH JJA Hadley cell edge shifts in these models are divided by the global-mean surface temperature increase, the difference between CMIP5 and CMIP6 models is no longer statistically significant. However, this result breaks down once models with near-zero and poleward Hadley cell edge shifts are included.

We thank the reviewer for the suggestion of normalizing the Hadley cell shifts by global-mean surface temperature, but because it is not straightforward to apply in the NH, we choose not to include these results in the paper.

As the reviewer also suggests, one can also use linear regression analysis to remove the variance in the Hadley cell edge shifts associated with the variance in climate sensitivity across models, but this analysis can only be used to remove the variance associated with the climate sensitivity. It does not provide any information about the contribution of the climate sensitivity to the mean Hadley cell edge shift in CMIP5 and CMIP6 models, and thus it cannot be used to assess whether the mean Hadley cell edge shifts in CMIP5 and CMIP6 models are related to the difference in mean climate sensitivity.

One can, however, compare the linear regression fits between the global-mean surface temperature response and the Hadley cell edge shifts in CMIP5 and CMIP6 models. The linear regression lines have very similar slopes in both NH JJA (approximately -1.5 degrees latitude/Kelvin for CMIP5 and -1.25 degrees latitude/Kelvin for CMIP6) and SH JJA (approximately -0.3 degrees latitude/Kelvin and -0.2 degrees latitude/Kelvin from CMIP6), suggesting that the greater mean climate sensitivity in CMIP6 models contributes to the greater dynamical sensitivity during JJA in both hemispheres. This can clearly be seen in Fig. 2a for NH JJA, as the scatter of points from both CMIP5 and CMIP6 models generally falls along the same diagonal line from the upper left toward lower right.

Line 168: Fig. 2 vs Figure 2a

We don't understand the reviewer's comment here. The first sentence introduces Fig. 2 as a whole, whereas the second sentence discusses specifics only in panel a of Fig. 2. We believe that the text is correct as written. Additionally, per ACP guidelines, the abbreviation "Fig." is used when a figure is referenced within a sentence, whereas the word "Figure" is spelled out at the beginning of a sentence.

Line 289: “with forcing” would be clearer as “with a higher sensitivity to”

We apologize that our initial wording was confusing. We are actually not discussing the relationship with climate sensitivity here, but are instead referring to the difference between the greenhouse-gas only runs and the full historical runs. We have added a parenthetical note “(compare orange, black, and red lines in Figs. 5a-b)” to clarify this to the reader.

Line 346: “when which” should be “in which” or “during which”

We have changed “when which” to “at which.”

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2019-1206, 2020.

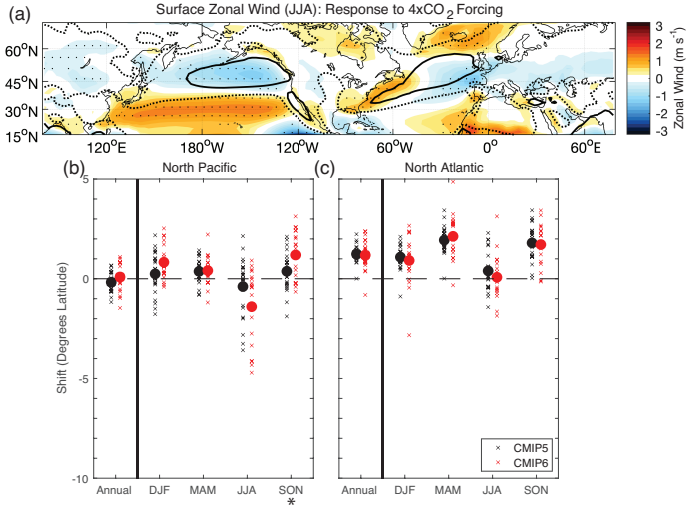

Fig. 1. Revised version of Figure 3

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