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Interactive comment on "The polar amplification asymmetry: Role of antarctic surface height" *by* Marc Salzmann

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Earth System Dynamics manuscript esd-2016-74: Salzmann, "The polar amplification asymmetry: Role of antarctic surface height"

reviewed by Timothy W. Cronin

Summary:

This paper uses a set of low-resolution coupled climate model simulations to address the mechanisms that underlie hemispheric asymmetry in polar amplification – or, why the Arctic warms more rapidly and more than the Antarctic. The major finding is that flattening Antarctica reduces the polar amplification asymmetry, largely through the role of increasing poleward atmospheric heat transport in the southern hemisphere

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that is linked to ice-albedo feedback just outside the south polar cap. Local feedback differences between north and south poles have mixed roles in altering the polar amplification asymmetry.

Overall, I found the question addressed to be important, the writing to be concise, and the conclusions to be mostly well-supported and novel. I do think, however, that there are a number of issues that require further clarification and discussion. I recommend publication if these can be addressed.

Major Comments:

1) One major issue is that the ocean circulation may change considerably between flat-AA and base setups, and it may not be in pre-industrial equilibrium in either case. A hint of this is seen in Figure 5, and a trace of its implications may also emerge in figure 10. How long was the model run for to get a stable "preindustrial climate" in both the flat-AA and base setups? If the ocean is not equilibrated – and I doubt it would be given that most runs appear to occur for ∼100-200 years and this is an order of magnitude less time than required for equilibration – how do we definitively interpret differences between flat-AA and base setups as being results of changes in terrain and not ocean transients? Some issues with this are hinted at in section 3.6, where southern hemispheric heat content changes are noted as large, and also in section 3.7, where the MOC starts to collapse in the 2xCO_2 run and leads to changes in Arctic temperature that may be purely due to internal variability rather than forcing or changes in topography.

2) I find the multiple layers of differences to make some figures, discussion, and notation very confusing. There are essentially three sets of differences used in this paper: a climate change difference (2xCO_2 – 1xCO_2), a hemispheric difference (Arctic – Antarctic), and a model setup difference (Flat-AA – base). Each of these is at some point annotated as Δ: in Figures 3-5 and 10, a single Δ means a climate change signal, in Figures 7 and 11, a single Δ refers to a Arctic-Antarctic difference, and in figure

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9 a single Δ refers to Flat-AA minus base difference. In the worst case, all three are used together in figure 12 as $\Delta(\Delta F)$, or the difference (flat-AA – base) between Arctic and Antarctic feedbacks (with feedbacks F being in turn a difference between 1x and 2x CO2 radiative fluxes). I would suggest using subscripts for all but one of these differences, e.g., T2x-T1x for climate change in response to doubling CO2, and FA-FAA for hemispheric difference, and reserving Δ for Flat-AA minus base, as it is least-easily subscripted (though F_ - Fˆ could serve here too).

3) The definition of "feedbacks" as changes in TOA radiative fluxes, un-normalized by surface temperature changes, complicates interpretation of findings in this paper for me. I am not sure what the basis is for this choice is, and I think it could be better explained if there is some strong reason for using these changes rather than the standard of feedbacks being normalized by temperature change – e.g., λ = (R2x – R1x)/(T2x – T1x) (units of W m-2 K-1). In Figures 6 and 7, especially, I find that use of changes in TOA fluxes rather than standard feedbacks convolutes changes in polar warming with changes in the true per-unit warming feedbacks λ. For example, do the Planck and lapse-rate "feedbacks" in Figure 6 change just because there is more warming in the Antarctic in the flat-AA case, or because each λ has also changed? Use of the conventional feedback metric normalized by surface temperature change would also allow for more straightforward comparison to previous work.

4) The reasons for the RAD re-runs are not made completely clear, and it is not clear where they are used and where they are not used. This is a particular issue around line 30 on page 6, where you say "the original coupled runs were chosen for this analysis" but then in the next paragraph, you say that the simulations behind figure 3 will be analyzed in more detail – but the caption of figure 3 says that they are RAD re-runs.

5) [Self-promotion disclosure!] Some work that I have been involved with recently has, I think, helped provide a better understanding of the high-latitude lapse-rate feedback. You might want to look at Payne, Jansen, and Cronin (2015), GRL, "Conceptual model analysis of the influence of temperature feedbacks on polar amplification" and Cronin

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& Jansen (2016), GRL, “Analytic radiative-advective equilibrium as a model for high-latitude climate”. Both papers attempt to develop a better prognostic understanding of the high-latitude lapse-rate feedback, which, as you note in section 3.5, is mostly connected to near-surface temperature changes being larger than mid- and upper-tropospheric temperature changes. Figures 3 and 4 of Payne et al (2015) are similar to your Figure 10, except that we focused on low-latitude/high-latitude differences and not polar asymmetries, and we were using simpler column models to get a sense of temperature structure changes. I have also done some preliminary work on polar amplification asymmetry due to surface height with a radiative-advective equilibrium model (nowhere near publication, so certainly nothing to cite!). If you plan to work on the subject more, it might be good to talk outside the review process, and potentially collaborate.

Other specific comments:

A) On page 5, lines 8 and 10 – what are the “respective polar circles”, exactly? It’s not obvious that you can choose 66.55 N and S when the model’s resolution is only T31 – so exact limits of integration and averaging should be noted more clearly.

B) I suggest combining Figures 1 and 2; it is difficult to compare the simulations to observations at present and an additional set of black lines in 1) should be completely readable.

C) Regarding the three time slices and standard deviations in Table 3 and p6, lines 17-27. I don’t understand why these three time slices were chosen, or what the % of warming difference explained by topography means, exactly. And how are the +/- standard deviations determined – based on three points (the means of the three time slices), or based on each year treated as an independent point?

D) In Figures 6 and 7: whether or not you stick to calling changes in radiative fluxes feedbacks or you decide to normalize them by temperature changes and make them true feedbacks, I think it would help to include changes in AHT and OHT convergences

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here, as well as storage if it is significant. Or, you could mention that the 'SUM' term in each plot adds up to the sum of changes in AHT convergence, OHT convergence, and storage. It surprises me that the changes in heat flux convergence would be so small relative to local feedbacks. I do appreciate your note on p8 L5 that the values should not be over-interpreted as heat transports vary rapidly near the margins of the Arctic and Antarctic caps.

E) Figure 10: The mismatch between the profiles and dots/crosses is confusing here. Why is there so much less change in the crosses in b) and d) than in the profiles at lowest-levels? Why is the red dot in c) warmer than the profile at lowest levels? And why are the base and flat-AA profiles so different in c)?

F) Page 8, paragraph around line 25: I suggest eliminating Table 2 – I found it more confusing than helpful – and relocating the paragraph from the methods section describing these simulations to this point in section 3.5 (paragraph from p4 L20-25). The information is not necessary when presented at the time in section 2, and will be more helpful in this section if the reader does not need to flip back to the earlier description.

G) Page 8 Line 34-Page 9 line 2, re: "weaker LR feedback in the flat AA model setup" – I thought Figure 6 showed the LR feedback was stronger in the flat-AA model setup? Do you mean that the LR feedback asymmetry is smaller in the flat-AA model setup (shown in Figure 7)?

H) Page 9, lines 3-9. I'm a little puzzled by these assertions and the choice to lump the Planck and LR feedbacks together. I agree that your sensitivity tests have shown that the lapse rate feedback is dominated by changes in surface temperature rather than atmospheric temperature, or that the "lapse-rate feedback" is a feedback related to how surface temperatures and near-surface temperatures change relative to the mid- and upper-troposphere (essentially, the lapse rate feedback relates to changes in the strength of surface inversions). Thus, it still seems meaningful to me to separate the lapse rate and Planck feedbacks, since the Planck feedback could be calculated

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given the model's control state alone, whereas changes in inversion strength are a complicated result of changes in many linked model processes. [Also, note: I do not see any references to Figure 11 in this section (or elsewhere). Perhaps the reference disappeared at the end of p9 L5? Figure 11 did not seem like the most compelling support for your argument; I think looking at each feedback by itself rather than their hemispheric asymmetry would make a stronger point]

I) Relatedly, on p 11, lines 1-4: I don't really follow this argument, as noted above. I also disagree with this assertion that there is no reason to separate the high-latitude Planck and lapse rate feedbacks. The reason for low-latitude separation is that we can calculate them separately, basically from first principles, if stratification follows a moist adiabat and we know the control-state climate – and further, that there is cancellation between water vapor and LR feedbacks in the tropics. That we don't understand the high-latitude lapse rate feedback fully seems to be a very good reason not to lump it in with a feedback that we do understand better (the Planck feedback).

Line-by line comments:

p1 L 6; p6 L13; p7 L10 – should be "led to" if in the past tense

p1, and then recurring: I am unsure of the correct style guidelines for capitalization of "Arctic", "Antarctic", and phrases containing these two terms. I have (perhaps) erred on the side of always capitalizing. Super minor issue, will presumably be fixed at the proof level, but I am interested in the "right" answer!

p 1 L19 – may want to put numbers on "substantially", e.g., "2-3 times as much as the global average"

p2 L4 – suggest rewording to "The focus in explaining arctic . . . has long been on the . . ." (rather than starting sentence with "For long")

p2 L9; p8 L17 – You could mention work from point 5) above at either of these locations.

p2 L26 – should be "water vapor feedback" (not just "vapor feedback")

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p2 L27 – should be “Antarctic” and “land-sea distribution”

p2 L28 – suggest changing “play a role for. . .” to “play a role in . . .”

p3 L19-21 – suggest changing “every second time step” to “every other time step” (as seconds are units of time

p4 L16 – suggest hyphenating “three-hourly”

p4 L21-22 – what does “73 hourly instantaneous model output” mean? (This looks like a typo to me)

p5 eqn 2 – use lower-case d’s in dλ dφ’ ? Also suggest using ‘a’ for Earth’s radius, as R has been used to indicate radiative fluxes

p5 L 16-18 – I believe I had heard, though I am not sure where from, that there is a small added ocean heat source in some variants of CCSM, to keep sea ice from growing too thick. This might contribute to your Arctic energy imbalance, though I am not sure about its magnitude – you might want to reassure the reader here by saying something about the size of the imbalance.

p5 L31; p6 L4 – suggest deleting “rather” in these sentences, as similar is already qualitative

p7 L7-9 – re: “Poleward OHT increased in the southern hemisphere and also slightly increased in the northern hemisphere” and subsequent sentence – Figure 5 seems to me to show a decrease in poleward OHT in the NH. . . are you showing the “original coupled run” results in Figure 5? (this ties to comment 4 above)

p7 L13 – No comma after “Both”

p7 L29-30 – The interpretation of reduced polar feedback asymmetry is complicated by the feedbacks being expressed as radiative flux changes rather than true feedbacks per unit temperature change (see point 3 above)

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p8 L3 – suggest changing to “was not directly affected by. . .”

p9 L 30 – Paragraph around here makes an excellent point about the semi-arbitrary extent of polar caps.

p10 L8, 12 – suggest hyphenating “half-hourly” “low-complexity”, and “high-resolution”

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