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Earth System Dynamics
Discussions

Interactive comment on "Enhanced warming of seasonal cold extremes relative to the mean in the Northern Hemisphere extratropics" *by* Mia H. Gross et al.

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*Note: RC=reviewer comment; AR=author response

RC: Review of manuscript # ESD-2019-36 entitled "Enhanced warming of seasonal cold extremes relative to the mean in the Northern Hemisphere extratropics". Gross et al. evaluate historical and projected changes in cold extremes across the Northern Hemisphere extratropics in a subset of CMIP5 models. The authors find that cold extremes are expected to warm substantially more than the seasonal mean. They attribute this difference to changes in advection during winter, and reductions in snow cover during fall and spring. The manuscript is fairly well written, but there are some

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instances where the text is repetitive or confusing. It features interesting analysis that is relevant to ESD and could be a useful contribution after some issues are addressed.

AR: Thank you to the reviewer for their very helpful comments and suggestions. Our responses are outlined point-by-point after the reviewers comment, and we believe once these changes are made, the readability of the manuscript will be improved, discussions are more relevant and added references contribute to strengthening the arguments put forward in the study.

Major Comments: RC: (1) Section 3.1: Given the weak pattern correlations I recommend changing the way in which these results are discussed. The authors should lead by describing the observed pattern and quantifying the mean across some given regions (e.g. hemispheric or continental). Second, they can discuss how well the models capture this on average (again quantifying results, perhaps with an ensemble mean value), then it makes sense to comment on the regional differences and the pattern correlations. For example, how much more have cold extremes warmed than the mean in observations and models across either the NH extratropics or EU vs NA (using regions in Fig. S1)?

AR: Thanks to the reviewer for their helpful suggestions on how to restructure this section. We agree that some substantial changes are needed to the way in which results are presented and how the section is structured. Firstly, we have decided that the pattern correlations are not an appropriate method for showing the similarities and/or differences between the individual models and HadGHCND as this coefficient is an average over the entire study region. Instead, we first take your suggestion and have decided to show the ensemble mean, which shows stippling for where there is both model agreement and agreement with HadGHCND. This allows us to then discuss similarities/differences by region. As per the reviewers suggestion, we first will discuss observational results, then these similarities/differences in the models. This then logically leads to discussing future projections based on those regions where there is model agreement.

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RC: (2) Baseline used for calculating future changes: Wouldn't it make more sense to compare 1982-2014 with 2070-2099 to evaluate future changes rather than using 1950-1981? The current definition used to calculate "future changes" combines both historical and 21st century changes in one. I recommend changing the baseline to the later historical period.

AR: Future changes are calculated for the last 30 years of data (2070-2099) relative to the first 30 years of data (1950-1979). We chose to do this to use the full range of data and compare to an earlier period in the historical period, however, we have also made plots of future changes relative to a more recent 30-year historical period, 1975-2005 (which end when the historical runs end in the CMIP5 models). Results using this later period are similar to those using the earlier historical period, though magnitude of positive excess change is generally around 1°C lower for the later period. We reason to use the earlier period as there is a clearer signal-to-noise ratio, but we understand there may be some confusion in the wording 'future changes' which might suggest we consider the changes starting from the present. This is clarified in the text at line 138 which states that "...'future excess changes' refers to excess changes between the mid-20th century and late 21st century.".

RC: (3) Presentation of results: There are a number of figures which can be improved or combined to better convey the authors main points. Figures 1-3 could be combined into one plot that shows the excess changes from HadGHCND and the CMIP5 mean for each season (as columns). A polar stereographic projection might be useful for this purpose. Individual model results could then be shown in the supplemental material or similarly as figure 2 if there are models of particular interest. If the authors agree that the CMIP5 mean is useful, I would also add it to Figs 4-6. Figs 7,10: Using the CMIP5 mean (or similar) would also be more informative than assessing the changes in an individual randomly selected model (CanESM2).

AR: Since we have decided to now show the ensemble mean, Figure 1 now combines Figs1-3 (multi-panel showing DJF, MAM and SON for both HadGHCND and the

ensemble mean). As per the reviewer's suggestion, we will now show the individual model results in supplementary material to highlight that the results are not affected by internal variability (in addition to an added supplementary figure which shows an example of multiple ensemble runs showing the similarities within one model). We will also show the ensemble mean for future projections now (which will become Figure 2). Further, as per the reviewers suggestion, we will now show the CMIP5 mean for Tadv, snow cover and albedo (i.e. current Figs 7,10) rather than showing CanESM2.

Specific Comments: RC: L14: Remove "The consequences of".

AR: This will be removed.

RC: L19: Remove "months".

AR: 'months' will be removed.

RC: L45-46: Remove second use of "in these regions".

AR: Thanks to the reviewer for noticing this. This will be removed.

RC: L54: Change "depending on the region and season" to "both regionally and seasonally".

AR: Thank you for this suggestion, the sentence reads much better with this change.

RC: L63: Remove "which are warming faster than the warm days" – this has already been established above.

AR: This will be removed.

RC: L74-76: Surface albedo feedback stemming from snow cover is strongest in spring not winter (see Fig 1c from Qu and Hall 2014). Furthermore, the timing does not only depend on large snow cover extent, but also insolation (which is very low in high snow cover months like December and January).

AR: The text here states that "the effect of snow cover on surface temperature is

strongest during spring. . .” (L77). The confusion here probably stems from the sentence before this, which states that ‘the surface albedo feedback from snow cover is more likely to influence winter months and early spring. . .”. We will also add a sentence here relating to insolation being low in winter (Dec-Jan) influencing the surface-albedo feedback from snow cover during these months. Thank you for the clarification.

RC: L85: Reword the first part of this sentence.

AR: The first part of this sentence can be re-worded to “Uncertainties related to biases within climate models are often related to ...”.

RC: L86: Change “capture” to “represent”.

AR: This will be changed.

RC: L87-88: This is a very broad statement. Either remove or be more specific about what is meant and explain how so. It is also unclear what is being “influenced”.

AR: This sentence will be amended as follows: “Evaluating the differences between different physics schemes in individual climate model simulations of snow cover, surface albedo and associated physical processes may help to increase the robustness in future projections of warming.”

RC: L143: This is repetitive - remove “daily data for”.

AR: This will be removed.

RC: L169-170: Remove “one by showing” and “the other by showing”.

AR: These will be removed for readability.

RC: L172: Remove “due to the number of figures”.

AR: This will be removed as it is unnecessary.

RC: L176: Change “that have” to “with”.

AR: This will be changed to ‘with’.

RC: L177: Define the regions with the latitude/longitude here.

AR: Coordinates will be added in parenthesis for both the North America and Eurasia region. Thanks to the reviewer for this suggestion.

RC: L186: Confusing wording. Change “Excess changes between recent decades” to “Historical excess changes”.

AR: Thank you for this suggestion, we agree this is confusing and that ‘historical excess changes’ is clearer and more succinct.

RC: L197: “Springtime show” – reword.

AR: This will be reworded to “During spring”.

RC: L210: Remove “between future and past decades”. This should be implied by the use of projected.

AR: Agreed. This will be removed.

RC: Figures 4-6, 10: all have colorbars with an unnecessary level of label precision. Increase the tick mark stride.

AR: These figures are being amended to show the multi-model mean now and we will ensure the label precision is appropriate.

RC: L214-215: Awkward wording. Change to something like this: “Cold extremes are projected to warm significantly more than mean temperatures across much of the NH extratropics.”

AR: Changing this sentence as per the reviewers suggestion is much better than the current wording, thank you.

RC: L215: Quantify these results in some way.

AR: This section is being re-written as we now show the multi-model mean instead of individual models.

RC: L243: Define what is meant by the "actual" change. I assume this is just the change in that variable, but the current wording is awkward and difficult to interpret.

AR: The term 'actual' refers to the average of only values of temperature advection on the 3 days prior to the cold extreme, as opposed to the "excess Tadv" (Tadv on extreme days – mean Tadv). We will add a sentence to the Methods section to explain that 'actual' refers to this for simplicity at line 174 – "For simplicity, we use the term 'actual changes' to refer to the seasonal mean calculated from values taken on the day the cold extreme occurs, or for the average of days prior to the cold extreme in the case of temperature advection." This indeed required clarification, thanks to the reviewer for pointing this out.

RC: L271: Change "high snow fall" to "seasonal snow cover".

AR: This will be changed.

RC: Figure 8: Fix cut-off MAM label, increase resolution of figure. The caption says this is the change in snow cover on the day of the extreme versus the mean annual snow cover, but in the methods, it says that the excess change is in reference to the change in the seasonal mean of a variable. Which is correct?

AR: Thanks to the reviewer for noticing this. The figure has been fixed and the resolution increased. Clarification is indeed necessary here. 'Annual' should be 'seasonal' here and this will be fixed in the caption.

RC: L300-301: Might be useful to state that the lack of snow cover changes in the coldest climates (e.g. Siberia) is due to the trade-off between increasing temperatures shortening the snow season and increased moisture holding capacity leading to greater snowfall. (e.g., Krasting et al. 2013 JCLIM, Mankin and Diffenbaugh 2015 Clim Dyn).

AR: Thank you for the information, we do think this is useful to add here with the sup-

porting references. We will add a sentence here as follows (after the preceding sentences which describe the lack of snow cover change in these regions: "... The lack of snow cover changes in the coldest climates, such as Siberia, is due to the trade-off between increasing temperatures that shorten the snow season and increased moisture holding capacity leading to greater snowfall in these regions (e.g. Krasting et al., 2013; Mankin and Diffenbaugh, 2015)."

RC: Remove "which is calculated using shortwave radiation fluxes" as this is already stated elsewhere.

AR: This will be removed.

RC: L334: But it is the DJF cold extremes that are of the greatest importance, right? Why not include this as well to be consistent with the rest of the paper?

AR: While it is true that cold extremes in DJF are the strongest, excess changes in SON/MAM are also strong and it is only these shoulder seasons that show this change in timing (in the current Figure 10). We will add a sentence to clarify why we do not show DJF here.

RC: L334-345: This point is slightly counterintuitive so I recommend adding more information to help the reader. Plot the historical DOY when cold extremes occur to add context to Fig 10. It might also be worth promoting some of the discussion material on this matter to help support this conclusion. Also, I am surprised that this timing would not be somewhat sensitive to internal variability.

AR: We think the confusion here (i.e. the counterintuitiveness the reviewer refers to) stems from using anomalies – where Figure 10 shows the change in timing of anomalously cold days that are relative to a mean annual cycle. When using absolute temperature values which are not subject to an annual cycle, such a change in timing is not evident. The change in timing shown in Figure 10 was also tested for other ensemble members, with all showing similar results indicating little internal variability within the

models. Because our main message here relates to the change in timing in the future, we do not feel it will add anything substantial to the study to show the timing during the historical period.

RC: L365-375: A new paper by Blackport et al. is highly relevant to this discussion (https://www.nature.com/articles/s41558-019-0551-4).

AR: This paper is indeed very relevant. We will add a sentence here regarding the greater influence of atmospheric circulation on mid-latitude cold winters, as opposed to the influence of reduced sea ice, as follows “However, atmospheric circulation is argued to play a more substantial role in influencing cold winters compared with Arctic sea ice loss (Blackport et al., 2019).”

RC: L408-409: Fix this comment on surface albedo feedback as recommended above.

AR: L408-409: We will reiterate here that the surface-albedo feedback is strongest in spring and that insolation is low in winter due to high snow content: “A change in surface albedo feedback, as a result of a change in snow cover, is more likely to influence cold days in early spring due to snow accumulation and low insolation during winter months.”

RC: L411-413: Reword this, removing “as simply the ratio between absorbed and reflected shortwave radiation”. AR: We will remove this part of the sentence which did not add anything to the discussion here.

RC: L418: Promote this material to the paragraph above.

AR: Thank you for the suggestion, we have decided to join this paragraph to the one above.

RC: L467: A number of studies have looked at changes in observed versus simulated snow cover (see Brutel-Vuilmet et al., 2013; Mudryk et al 2017). References listed in this review: Brutel-Vuilmet, C., M. Ménégoz, and G. Krinner, 2013: An analysis of present and future seasonal Northern Hemisphere land snow cover simulated

by CMIP5 coupled climate models. Cryosph., 7, 67–80, doi:10.5194/tc-7-67-2013. http://www.thecryosphere.net/7/67/2013/. Krasting, J. P., A. J. Broccoli, K. W. Dixon, and J. R. Lanzante, 2013: Future changes in northern hemisphere snowfall. J. Clim., 26, 7813–7828, doi:10.1175/JCLI-D-12- 00832.1. Mankin, J. S., and N. S. Diffenbaugh, 2015: Influence of temperature and precipitation variability on near-term snow trends. Clim. Dyn., 45, 1099–1116, doi:10.1007/s00382- 014-2357-4. Mudryk, L. R., P. J. Kushner, C. Derksen, and C. Thackeray, 2017: Snow cover response to temperature in observational and climate model ensembles. Geophys. Res. Lett., 44, doi:10.1002/2016GL071789.

AR: Many thanks for the suggested references for changes in observed snow cover versus simulated snow cover. We will add some additional information in both the introduction and discussion sections supported by these references. This information indeed fills some gaps that were missing in the submitted manuscript. Some context will be added to the discussion at line 426, and the Mudryk et al. 2017 paper is now cited at line 402, as well as in the introduction at line 87. We will also amend line 467 for future work suggestions as “Future work in understanding the physical mechanisms driving cold extremes would benefit in further evaluation of observational data of snow cover and wind against the model simulations used to project future changes”.

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