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Interactive comment on "Multi-components ensembles of future meteorological and natural snow conditions in the Northern French Alps" *by* Deborah Verfaillie et al.

Anonymous Referee #2

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This paper analyses the mean state and variability in historical and future snow conditions at a mid-elevation location in the French Alps. Analysis is based on output from a physical snowpack model (Crocus) driven by a regional historical reanalysis (SAFRAN) and a suite of historical and future RCM simulations. In situ observations from a nearby location are also used for comparison of the historical conditions.

The methodology used in the paper is novel and represents an improvement on previous studies. Results are generally well described compared to existing literature. However I believe there are several changes required and details to clarify before I can recommend final publication.

Specific Comments:

Table 1 obscures the fact that there are only 5 distinct GCMs simulations that sample natural variability. I think this should be pointed out explicitly.

Figure 2a-c: In the supplementary material for the RCP8.5 scenario there is a distinct change in the stddev as average snow depth becomes small. It's therefore unfair therefore to suggest that the stddev is stationary based on the RCP4.5 scenario. I think it would be fairer to show the RCP8.5 scenario in the paper and place RCP2.6 and 4.5 in the SI.

Figure 2d: The large relative contribution to combined model uncertainty arising from snowpack model multiphysics compared to RCM/GCM inter-model variability seems difficult to reconcile with plots 2a-c (I realize there is interannual variability in Figs 2a-c, while much of this signal is removed in the multi-annual average). Is it possible to present 15 year running means for the 13 RCM/GCM tracks shown in Fig 2c or at least for a representative subset of the 13 pairs along with Fig d (either in this same figure, or in a separate figure similar to how you subsequently separate quantile plots based on annual frequency data and multi-annually averaged data)? This may allow the reader to get a better sense of the relative spread in the ESCROC ensembles compared to the RCM/GCM inter-model variability. Further to this point — in the text there are several times that you refer to the relative fraction of uncertainty contributed by snowpack model multiphysics as ∼20%, yet this graph shows that is can be as high as 80%. Please justify the use of 20%. Is there a rationale for why the uncertainty due to snowpack model multiphysics is higher in the historical period, even though the combined model uncertainty remains fairly constant?

Figure 3 and 4: The quantiles from different RCPs overlap too much in these figures to discern one set of shading from the others. I suggest showing RCP8.5 only in these figures. The results from the other RCP scenarios are provided in tabular form in the main document which I think is sufficient (along with the plots of other RCPs in the SI).

Figure 3: Why do the SOD and SMOD for RCP8.5 begin to encompass summer months? Is this an error with the calculation?

P8.L15-21: Please clarify why you use a distance of +/- 1.37*sigma from the mean for the 17th and 83rd percentiles? Shouldn't the 17th and 83rd percentiles be 0.95 sigma away from the mean such that CV=1.9*sigma/mu?

P25.L28-29: Please rephrase in order to account for the relative component attributed to snowpack modeling errors in both future and historical periods.

P27.L10: This statement depends on the RCP scenario. It is not the case for RCP8.5.

P28.L15-17: Could there also be a change in the mean density of snowfall occurring at the location?

P29.L8-10: Please reword or justify the claim that snowpack modeling uncertainty is typically 20% when Figure 2d shows it can be up to 80%. I agree that it may have a smaller impact on trends.

P29.L11-17: The ADAMONT method was evaluated in a previous paper. Please be clear as to which aspects of these conclusions were accomplished in this paper. Further to this point, while you argue that your methodology is an improvement to previous studies that use delta change methods, your assessment of the results says that they, in fact, agree with these previous studies. Under what circumstances might you expect to see differences? Is it possible to provide a direct comparison between your methodology and a delta change method for this location or to highlight statistics that would differ between the two methods?

Technical corrections/Suggestions:

I find the use the phrase "annual-scale" a bit unnatural. I suggest using "annual indicators" as you occasionally do (P8.L15) throughout the paper.

Similarly, there are places in the paper where you might consider replacing the word

"variation" with "change", "response", "difference" or "variability", but I'm having trouble articulating a clear rule to follow in this. Variation is frequently reserved to specify a very small adjustment.

Title: "Multi-component ensembles. . .."

P1.L2: "This article investigates the climatic response of a series of indicators for characterizing annual snow conditions and corresponding meteorological drivers at 1500 m altitude in the Chartreuse mountain range in the Northern French Alps. "

P2.l30: "because they are newer. . .."

P3.L2-4. Please rephrase these two sentences to make the typical delta-change approach clearer.

P8.L15: "Moments of multi-year averages: A running average of annual indicator values is computed (typically with a 15 year sample window), for a given RCP and for each GCM/RCM pair."

P9.L1 "for 15-year windows around each future time period t and each RCP r" P9.L3: "i.e." in place of "e.g."

P10.L19: "It highlights the significant interannual variability in observed, reanalyzed and climate model datasets."

P11.L37: "which highlights the need for appropriate data synthesis methods". Please elaborate.

P21.L10: to widen

P23.L27: "By definition no performance metrics pertaining to annual variations can be computed between the adjusted climate output and either observations or reanalysis data, because the two are not designed to exhibit synchronous variations."

P25.L4: "independent from the time period for calibration of the ADAMONT adjustment method (1980-2011). . ..”

P25.L9-10: “or applying the final quantile mapping separately to rain and snow precipitation in order to mitigate detrimental interactions between temperature and precipitation (Verfaillie et al., 2017). . ..”

P25.L30: “Because the number of GCM/RCM model pairs was different for RCP2.6 (4) and RCP4.5 and RCP8.5 (13), we compared the statistics for indicators during the historical period based on the 4 RCP2.6 pairs alone, as well as the full ensemble of 13 GCM/RCM pairs.”

P26.L11: “similar statistics are found for these 4 model pairs as for the full ensemble of thirteen.”

P26.L24: I’m not sure what you mean by “snow-dry” seasons. Seasons without snow on ground or without snowfall occurring at this location at all?

P26:L26-28: “The decreasing SD trend is also combined with a decreasing SWE trend ($\sim$ -6 kg m-2 per decade for RCP2.6, -18 kg m-2 per decade for RCP4.5 and -35 kg m-2 per decade for RCP8.5 over the period 2030-2090, Table 4) and a decreasing trend in duration of STED5 (as in Marty et al. (2017a)), STED50 and STED100 (Table 5).”

P27.L33: “This is all the more relevant in that none of the GCMs used for this study. . ..”

P28.L6-8: “. . .in contrast to previous studies (Durand et al., 2009a; Pepin et al., 2015). This result may stem in part from the fact that although elevation dependent warming is generally maximal in the fall and springtime, our target period covers mostly wintertime. Alternatively, this low enhancement factor could be due. . ..”

P28.L26-28: “The multi-component ensemble framework makes it possible to account for the various sources of uncertainty and variability that affect future climate projections, some of which are neglected in both previous and ongoing climate change impact studies.”

P28.L28-32: Split into more than 1 sentence.

P28.L32-36: “The method defines a series of annual snow and meteorological indicators that represent various aspects of winter snow conditions. . ..”

P29.L21: “exhibit similar statistics at the interannual and multi-annual scale as the full 13-member ensemble, ...”

P29.L26: “but maintained interannual variability. . .. . . “ Rephrase.

P29.L28-29: “As assessed in this study, for this location, interannual variability is larger than inter-model spread for a given RCP scenario.”

P29.L32-33: “the latter leading to frequent occurrence of ephemeral or nearly snow-free conditions at the end of the century.”

P29.L25: “For example, the change in mean snow depth”

P30.L4: “this value changes very rapidly”: I dislike the wording that it changes "rapidly" since the changes on Figure 5 are quite linear (except for STED100). Please rephrase. I suggest something along the lines of "the magnitude consistently increases along with global mean temperature reaching reductions of 80% beyond 4°C of global warming.

P30.L8-10: “These locations may be investigated in the future, based on the methodological framework introduced here and the data available in the SAFRAN reanalysis for the French Alps and Pyrenees (Durand et al., 2009b, a; Maris et al., 2009).”

Figure 2 Caption: “c) Ensemble of Crocus model configurations driven by the 13 RCP4.5 GCM/RCM pairs; each GCM/RCM pair is displayed with a different color.”

Figure 4 Caption: “Ensemble spread in 15-year running mean ($\mu \pm \sigma$’) of all GCM/RCM pairs for each scenario (HIST, RCP2.6, RCP4.5 and RCP8.5), along with 15-year running means of observations (1960-2016) and SAFRAN-Crocus runs (1958-2016) at CDP, for: . . ..”

Figure 5 Caption: “Response of local meteorological and snow indicators to global warming level. Indicator response is computed as the difference of multi-annual means between end of century (EOC, 2071-2100), middle of century (MOC, 2041-2070), or beginning of century (BOC, 2011-2040) and the reference period (Ref, 1986-2005). Global warming level is computed as the difference in global mean surface air temperature between EOC, MOC or BOC and either the reference period (top axes) or the pre-industrial period (P-I, 1851-1880)(lower axes). Each point corresponds . . .. . . Warming levels of 1.5°C and 2°C compared to pre-industrial are shown with the vertical dashed lines. Regression lines are shown for the response at EOC, MOC, BOC or all three periods (ALL) (except for P). Mean values. . ..”

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