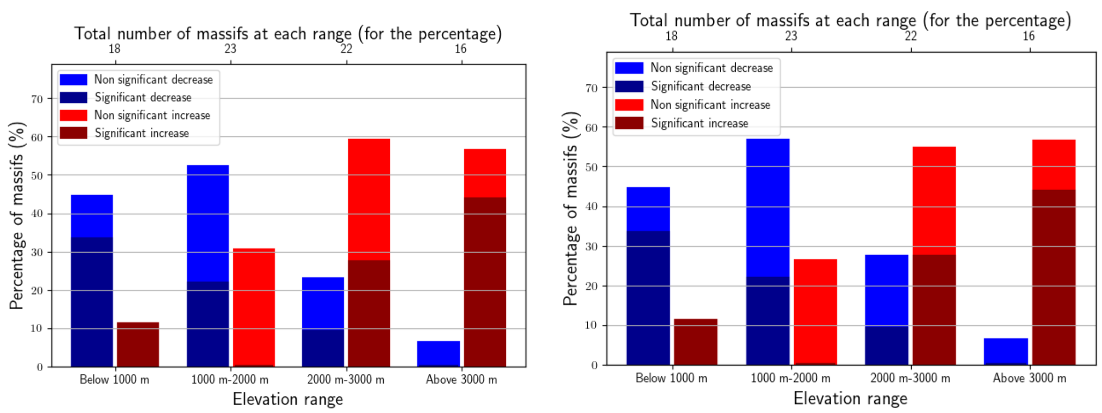
Suggestions from Referee #2

We thank Reviewer #2 for his/her useful questions and comments on our manuscript. Please find below detailed feedback to individual comments and questions.

Minor comments:

-The first comment is about the selection of the 100 yr return period, as targeted intensity of heavy snow event in this work. Perhaps authors should justify more why this recurrence (that involves very rare events) was chosen. I think that replicate some of the analysis (i.e. Figure 6) for a more frequent recurrent time (i.e. 5-10 yr) could give good information about the sensitivity of the results to the return period selection, and in case there are significant diferences the results of the paper could be more interesting for a management point of view. At least, I think this question should be discussed.

The 100-year return period was chosen because it is the largest return period considered in the Eurocode to build structures (Cabrera et al. 2021). We believe that this return period is the most familiar return period for non-experts as it corresponds to a centennial event. For smaller return periods (5-10 years), our results also apply. The Figure below provides results with a return period of 10 years and with a return period of 100 years, the overall distribution of increasing/decreasing trend for the 10-year return period remains the same as for the 100-year return period. The only noticeable difference is that for the elevation range 1000-2000m and for the elevation range 2000-3000 m, we observe that 1 massif shows an increasing trend for the return period 10 years, while it is decreasing for the return period 100 years.



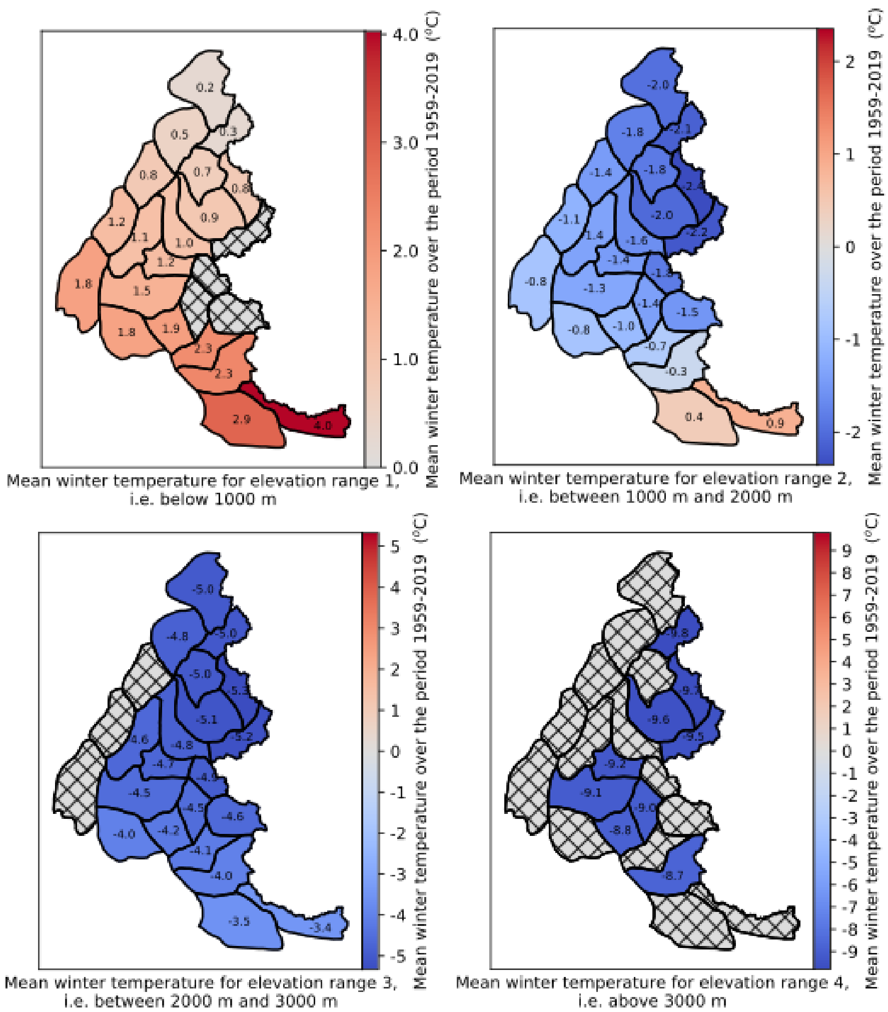
<u>Legend: Percentages of massifs with significant/non-significant trends in **10-year (Left) 100-year (Right) return levels of daily snowfall** for each range of elevation.A massif has an increasing/decreasing trend if the 10-year return level of the selected elevational-temporal model has increased/decreased.</u>

We will add the following sentence in the manuscript: “*We note that the sign and the significance of the trends (summarized with the percentages on Fig. 6) remain more or less similar for the trends in 10-year and 50-year return periods events.*” In an appendix section, we will add the equivalent of Figure 6 and Figure 8 for the 10-year and 50-year return level.

- Another question is that the assignation of existing trends to warmer climate or changes in precipitation intensity is discussed in a very qualitative way (based on some references) when this is a very interesting topic from a climate change perspective, as associated uncertainties of precipitation intensities are much larger than the ones for temperature warming. Perhaps simply presenting a map of temperature and 100 yr precipitation intensity during the snow season, and may be simple cross tabulation test could answer much of this question.

The works cited about changes in extreme precipitation over the Alps do not present in most cases their respectives study periods. They should be presented as trends on this parameter may change a lot depending on the selected period, and only those covering a similar time span than this study can be used as reference.

We understand that the main issue is that the works cited on changes in extreme precipitation over the Alps do not correspond to our study period, i.e. 1959-2019. Therefore, following the advice of reviewer #2, we present (see below) a map of temperature and 100-year precipitation intensity during the winter (December to February) obtained with the SAFRAN reanalysis, and spanning the period 1959-2019. For the temperature, we directly compute the mean winter temperature. For the changes of 100-year return level of winter precipitation, we follow the same methodology as our study.



Mean winter temperature for elevation range 1, i.e. below 1000 m

Mean winter temperature for elevation range 2, i.e. between 1000 m and 2000 m

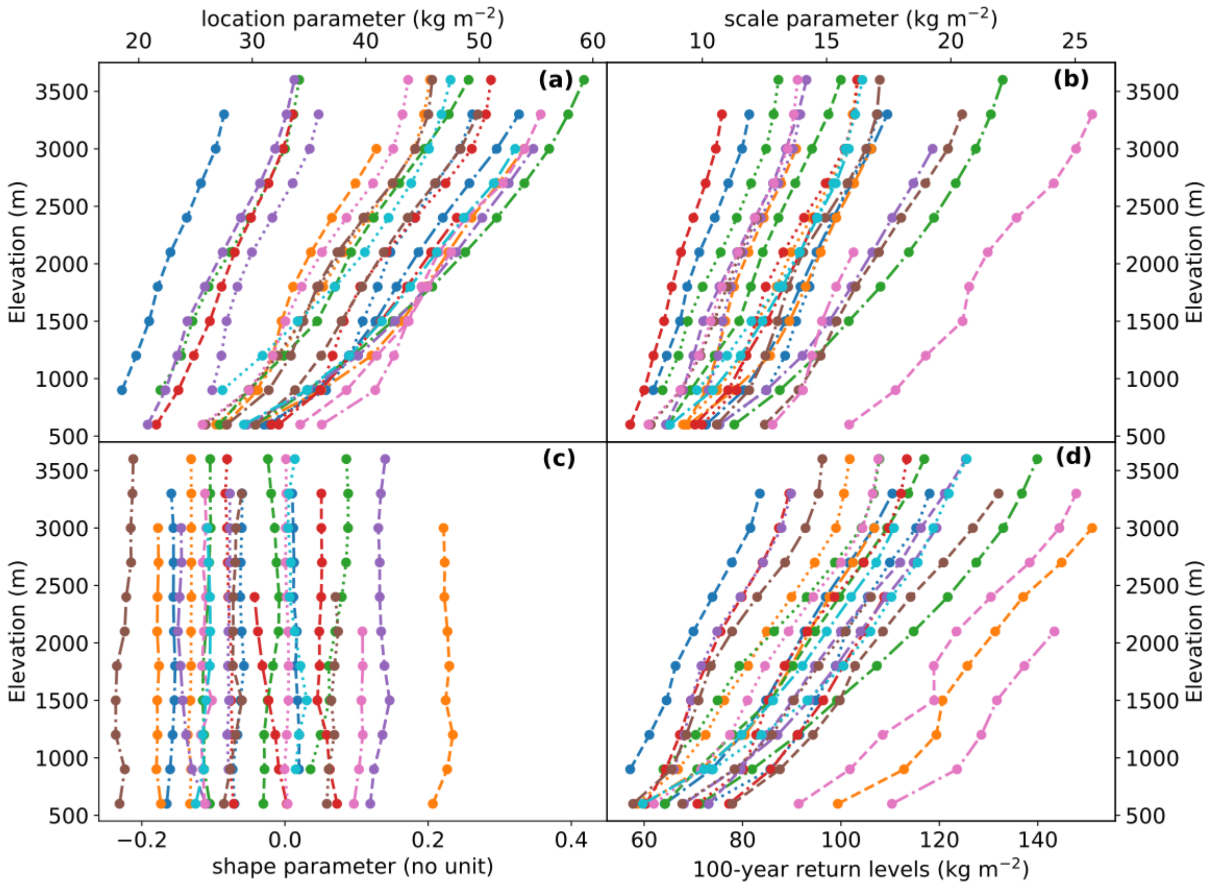
Mean winter temperature for elevation range 3, i.e. between 2000 m and 3000 m

Mean winter temperature for elevation range 4, i.e. above 3000 m

<u>Legend: Mean winter temperature averaged for the period 1959-2019 for each range of elevations. The mean temperature is written on the map. Hatched grey areas denote missing data, for example when one of the elevations in the range is above the top elevation of the massif.</u>

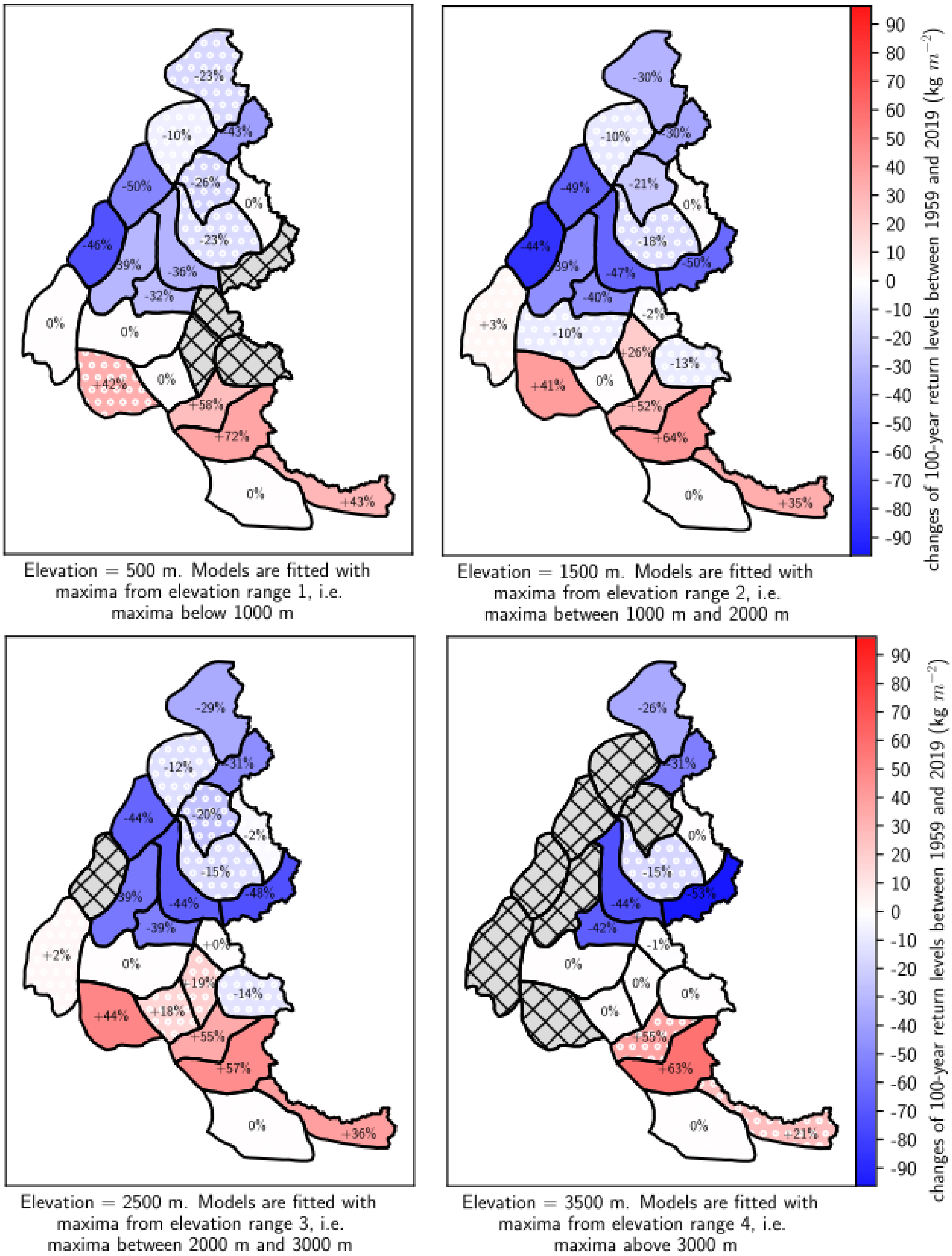
The temperature maps clearly show that in the French Alps “the north is climatologically colder than the south” for the 4 elevation ranges.

Then, for the 100-year precipitation intensity, we applied the same methodology as our study. Indeed, a preliminary analysis with pointwise fits indicates a linear parametrization w.r.t. the elevation for the location and scale parameters.



Legend: Changes of GEV parameters (a,b,c) and of 100-year return levels (d) with the elevation for the 23 massifs of the French Alps. GEV distributions are estimated pointwise for the **annual maxima of winter precipitation** every 300 m of elevation.

We observe a contrasted pattern for the total precipitation at all elevations. Above 2000 m, we observe that maxima often occurs in autumn (see answer to the next suggestion on the seasonality). We applied the same methodology on the total precipitation in autumn, and found the same contrasted pattern (not shown).



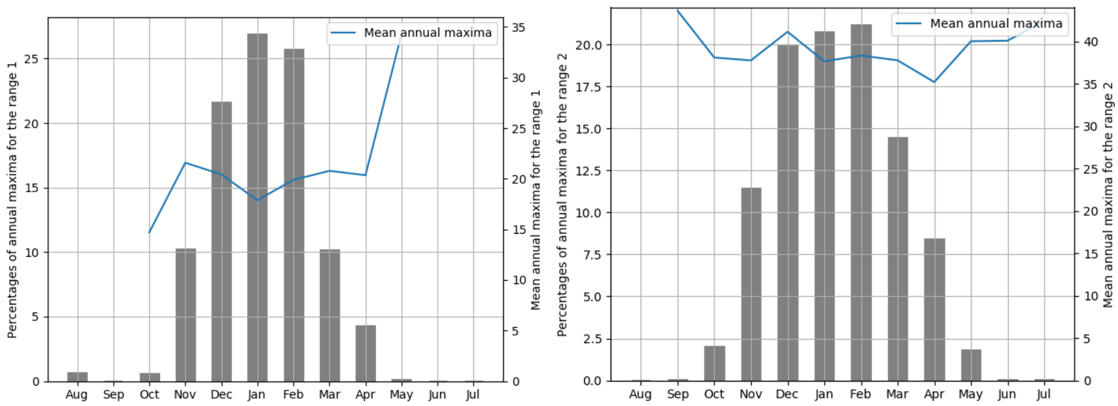
Legend: Changes of 100-year return levels of daily **winter precipitation** between 1959 and 2019 for each range of elevations. The corresponding relative changes are displayed on the map. Hatched grey areas denote missing data, e.g. when the elevation is above the top elevation of the massif. Changes of return levels are computed at the middle elevation for each range, e.g. at 1500 m for the range 1000-2000 m. Massifs with non-significant trend are indicated with a white-dotted pattern

To conclude, these analyses underline that the contrasted pattern of trends in 100-year return level of snowfall may result from the circulation patterns. In the revised manuscript, we will add an appendix section containing the two last figures, which justify the use of the same methodology to compute trends in 100-year return level of winter precipitation, and highlight at all elevations the contrasted pattern for trends in 100-year return level of winter precipitation.

- It would be also good to have an idea in which period of the snow season happen more frequently the very intense heavy snowfall events. The sensitivity of these events to climate change is supposed to be very different if they tend to happen in the coldest part of the snow season, or during the shoulder periods. This could be also a explanatory factor the the spatial heteregoneity shown between massifs.

In the following plots, we study the months when the annual maxima of snowfall occurred. We chose not to include this analysis in the revised manuscript, because we believe that it goes beyond the scope of this article.

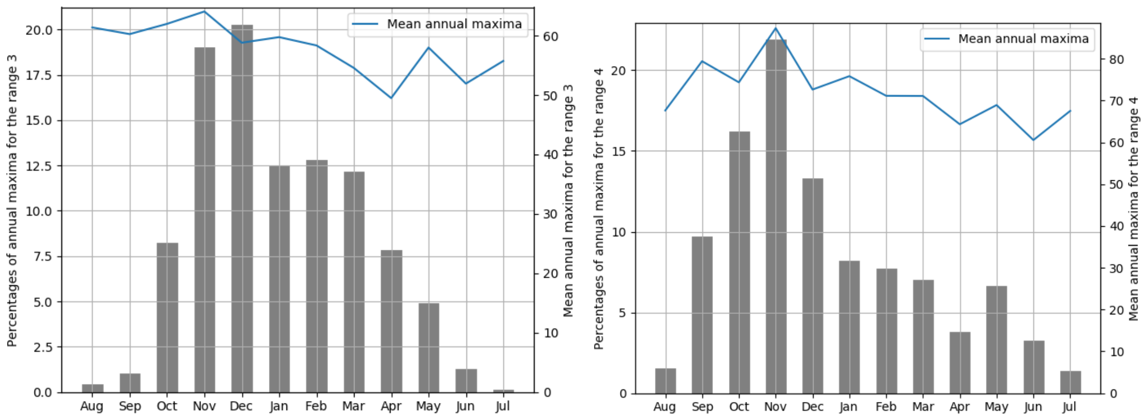
For the range 1 (below 1000 m) and for the range 2 (between 1000 m and 2000 m), we observe that the annual maxima are mainly located (>60%) between December and February, i.e. the coldest part of the snow season.



<u>Legend: Distribution of the month when the annual maxima of daily snowfall occurred for the period 1959-2019 for the range 1 (Left) and the range 2 (Right).</u>

For the range 3 (between 2000 m and 3000 m) and for the range 4 (above 3000 m) the months of maxima are more spread. For the range 3, maxima occurred between November and March (each month has at least 10% of the maxima). For the range 4, maxima occurred between September and December. In both cases, we note that most of the distribution of maxima is centered on the early winter period (November-December).

We note that for all ranges of elevation we do not find a large difference in terms of seasonality between the massifs in the north of the French Alps, and the massifs in the South of the French Alps.



Legend: Distribution of the month when the annual maxima of daily snowfall occurred for the period 1959-2019 for the range 3 (Left) and the range 4 (Right).

In conclusion, we find that below 2000 m, annual maxima of daily snowfall mainly occurs between December and February, while above 2000 m it mainly occurs between November and December.

- In line 25, and later in discussion, is mentioned that optimal temperature for heavysnowfall events is slightly below 0oC. Probably in Alps may be tru, associated to the humid arrival of oceanic/mediterranean air masses, but this is not generalizable worldwide (I guess that heavy sowfalls in Colorado or Hokkaid will happen well below 0oC). I would just clarify the sentence.

This optimal temperature interval for extreme snowfall is not specific for the French Alps but stems from physics theory provided by O'Gorman (2014). In the revised manuscript, we will reformulate the sentence as follows: "*Extreme snowfall stems from extreme precipitation occurring in a range of optimal temperatures slightly below 0ºC according to physics theory (O'Gorman, 2014).*"

- I agree with the other review that a stronger validation of the dataset would be desiderable, but I also wonder how to make it properly, as for my knowledge the best observations of snow in the region have been use to be assimilated in the SAFRAN-CROCUS. This difficults a comparison with observations. May be this question should be mentioned in methods or discussion section

We agree that this is a critical point which needs to be further discussed (see our response to the reviewer #1).

References

Cabrera, A. T., Heras, M. De, Cabrera, C., & Heras, A. M. De. (2012). the Time Variable in the Calculation of Building Structures . How, 1–6. Retrieved from http://oa.upm.es/22914/1/INVE_MEM_2012_152534.pdf

O'Gorman, P. A. (2014). Contrasting responses of mean and extreme snowfall to climate change. *Nature*, *512*(7515), 416–418. https://doi.org/10.1038/nature13625