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Interactive comment on "The European mountain cryosphere: A review of past, current and future issues" *by* Martin Beniston et al.

Anonymous Referee #2

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This is an interesting and ambitious attempt to synthesize recent research and future challenges in understanding cryospheric change in the European mountains, embracing the Alps (with a Swiss emphasis), Pyrenees, and Norway. The objective is of value, as a focused and integrative review paper that could inform and influence mountain cryosphere research in Europe.

I found the paper to be reasonably well organized and clear, with numerous grammatical errors but a logical thread. The authors succeeded in making this relatively inclusive. Examples are more illustrative than comprehensive in many places (e.g., concerning aspects of the glacier change or ecological impacts), but are reasonably effective and the whole topic cannot be fit into a single review.

But something is missing. I have trouble to be specific in my recommendations; if I

were to summarize, I would comment that: a) I did not learn anything new reading through this, and b) I was surprised to reach the end - I was still waiting for a synthesis of the present state of knowledge or some insightful discussion or analysis that did not seem to arrive. I appreciate that this is too general and vague a statement to be useful in a review comment. It may just be the dearth of new ideas that are needed to drive the field of study forward. The piece seems more reflective than innovative.

Some suggestions to add value could include:

- a stronger, more integrated synthesis of what is known about current and future cryospheric change in Europe; what has already been resolved by many studies to date, and what are the key knowledge gaps.

- European and more regional-scale maps and trend values (tables) of recent changes in snow, permafrost and glaciers, and perhaps also projected changes; right now there is discussion of all of this, but more on a case study basis, and it is difficult to infer general conclusions

- A section on elevation-dependent climate and cryosphere trends in the different regions might offer a good focus on a hot topic, providing a vehicle for integrative discussion and strategic (vs. sometimes ad hoc seeming) graphical additions to the manuscript. For instance, can changes in snow, temperature, precipitation, rock temperature, and glacier thickness be potted vs. elevation in Norway and the Alps? Integrating all available data.

- A separate section on 'grand challenges' for representing cryospheric change (observations and models) would collect and highlight some of these good ideas that are already in the text, and might offer a vehicle for additional ideas and a sense of triage/prioritization.

– Some additional specific comments, mostly minor:

p.4, ll 2-6, discussion of Alpine snow cover changes. Some things don't make sense as described. For instance, it does not seem reasonable that SWE and snow depth will decline while snow-covered area does not change. In winter perhaps, but spring and summer snow cover will surely decrease if there is a thinner snow pack.

Also the explanation of stable snow cover due to increasing Eurasian snow cover does not make sense; what is meant by Eurasian (does this include the Alps), and can the geography and atmospheric process(es) that connect the proposed links be more specifically explained? Is it still true, and generally accepted, that there has not been winter warming over the Alps or 'large areas of the northern hemisphere' since the 1990s? This seems surprising. Also not consistent with some of the narrative, e.g. p.11, l.14, discussion of warmer winters giving increased winter rainfall runoff.

p.7,l.4, "Alpsthe" p.7, l.18, propertie s p.7, l.20, annual mass balance highly sensitive to snow accumulation – I think this depends where

p.12, l.3, declining glacier area, really – it is the glacierized area that matters to basin runoff

p.13, l.14, statement about energy demand seems backwards – should it be that energy requirements are currently greater in winter than summer, I suspect?

p.16, l.16, are often p.16, l.25, grammar ("contribute solving") p.17, l.28, "of snow properties"

p.18, nice discussion of the uncertainties and challenges of spatial scale; I was left wanting though, for how to bridge local to catchment and RCM/GCM scales when it comes to observational validation at the larger scales. Some perspective and thoughts here would be welcome – what is needed to give e.g. SWE or snow hydrological datasets at the larger scales, for model validation?

p.19, l.14, out of curiously, what percentage of the European landscape is above 3000 m? Somehow I guess it is not much more than 1%, so I am curious how under-represented these high elevations are.

p.19, l.21 "are" crucial p.19, l.29, "has allowed a better understanding of" p.21, l.17 "are also a subject" p.22, l.21, "focus on" p.25, l.2, "built" p.25, l.13, "concepts"

p.25,l.30, I would say that it is also neglected often within the scientific community, esp. when it is a multidisciplinary study and we are using someone else's data (e.g. weather or hydrological data collected by another agency).

p.26, l.10, "reasons" p.26, l.17, "ecosystems"

p.26, Figure 8 discussion. Differences are shown in mm/day and the graphic is interesting. For context, is it possible to give a value of the average DJF and JJA precipitation for one or two high-elevation examples, perhaps in Switzerland – i.e. is a difference of 5 mm/day equivalent to 30%, 50%, 80%, etc? Some idea of the scaling would be helpful to assess whether the magnitude of differences is significant. Also, are these three datasets covering the same period? The Swiss-Italian border seems to show up prominently here. Is this related to altitude, or national measurement protocols? It might be interesting to make a plot of the precipitation difference vs altitude, at least for the central European subset of data. Norway might have its own story, but this is also worth a look.

p.26, Figure 9 could be better discussed as well. The figures show precipitation anomalies – is this the 'error' vs. observations? Against what observational dataset? Again, some idea of the scaling would be helpful, e.g. and average wet or dry bias of * % for a given region. Perhaps consider again plotting the anomaly vs. altitude. I would love to see some discussion of the processes involved in wet vs. dry biases in different models, while appreciating that this may be beyond the current scope. . .

p.26, l.34, "can provide adequate data for modelling atmosphere-cryosphere systems" – I think this is arguable – the biases over mountain regions are still huge with nested RCMs; processes here simply aren't resolved

p.27, l.5 "of climate changes are"?

Figure 5. Is the glacier runoff on this chart the specific runoff, i.e. mm/month per unit area of glacier cover? Or is it normalized over the full catchment? Probably the latter, given the values. In which case, the overall runoff reduction by end of century is less than I would have expected, given the dashed lines for the control period, especially for RCP4.5. Is it because there is some extra summer rainfall helping out, or are the deglaciated basins giving new lakes that help to reserve and release meltwater through the summer months? Is the latter process included?

Figure 8. Note in the caption that these are three different observational products, and also the time frame for each of these (is it the same, e.g., 1979-2014?)

Figure 9. These precipitation maps are expressed as anomalies: with respect to what? Please state in the caption.

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