***Response to CC#3***

*We thank the independent reviewer for the comments. We found them extremely useful for improving the manuscript. Here, our point-by-point response:*

DISCLAIMER: This review was prepared as part of graduate program course work at Wageningen University, and has been produced under supervision of Ryan Teuling. The review has been posted because of its good quality, and likely usefulness to the authors and editor. This review was not solicited by the journal.

This study looks at how the Italian Alps' snow depth and snow water equivalent have changed between 1967 and 2020. The study shows long-term trends and variability in snow cover using in situ measurements. In six macro-basins of the Italian Alps, the study examined snow depth and snow water equivalent (SWE). The findings show a considerable downward trend in SWE and snow depth. The average reduction of snow depth was 33%; the variations were greater at lower elevations (62% at 1000–1500 m) and smaller at higher elevations (30% at 1500–2000 m). SWE dropped on average by 32%, falling more precipitously at lower elevations (52% at 1000–1500 m) and less precipitously (28–29% at higher altitudes). According to the analysis, the data collected strongly suggest that the melting is impacted by global warming, which in turn has an impact on flood events, hydrological regimes, and water supply. Additionally, a change-point around 1988 was found by the study, which indicated decreasing snow depth and SWE in the decades that followed. The study produced a basic elevation- and time-based SWE model, which is a helpful tool for calculating the evolution of SWE in specific Italian Alps areas.

When looking at the overall relevance of the paper, the social relevance really stands out. As described in the introduction, knowledge about the snow depth and SWE is important for winter sports season prediction and can thus play an important role in the economic stabilization of the area during the increase in temperatures and thus snow melt.

The estimation of SWE based on snow depth is not a new concept M. Sturm (2010); however, it has not been done in this area. The unique parameters of the study area can give more accurate results for this unique set of snow depths. In addition, the reliability of the study is high because of the strong statistical analyses and background information supporting the claims and results found.

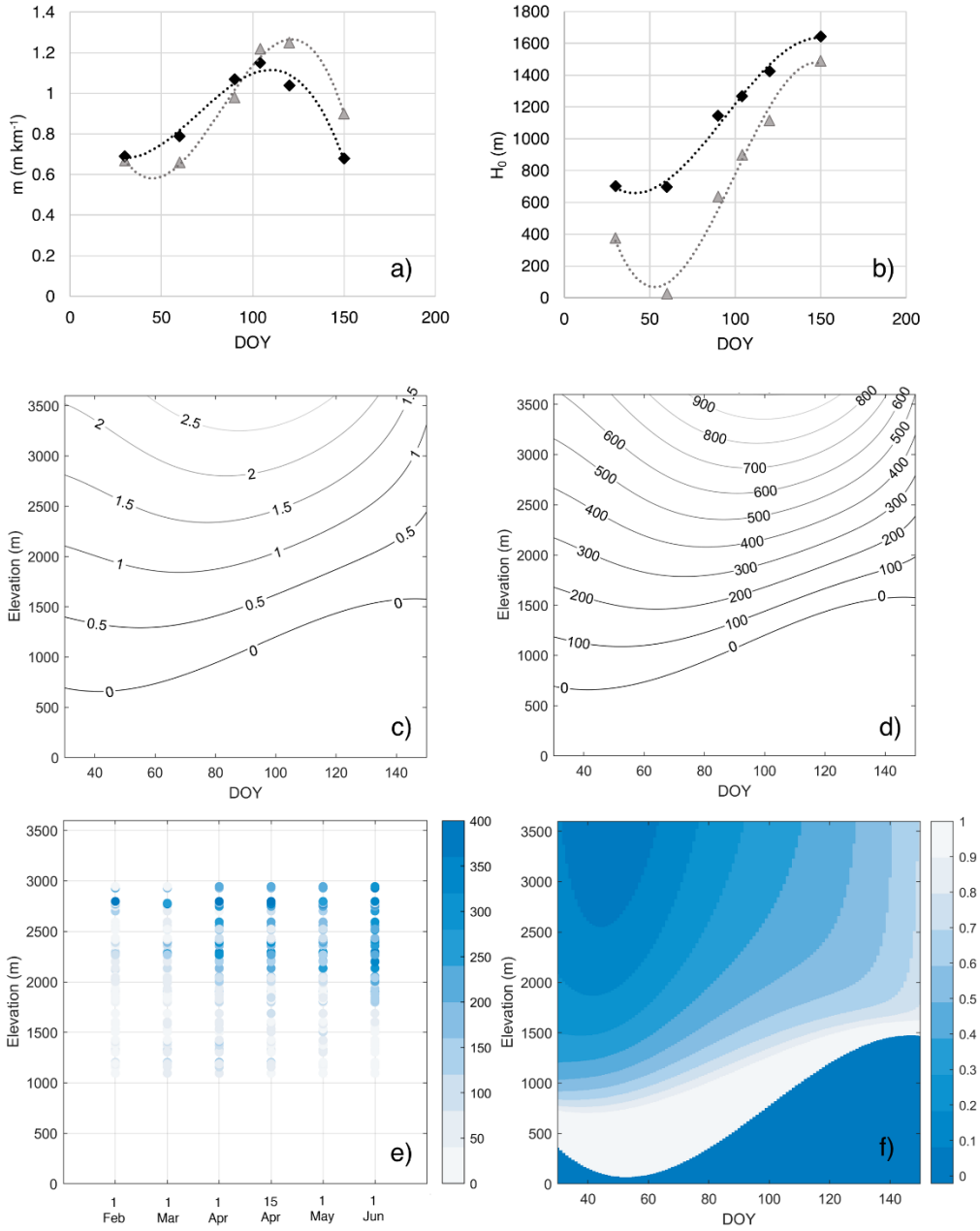
All in all, I think that the research is really valuable and well conducted. This paper is clearly worth being published after a few revisions on the following issues:

Major issue’s:

To start with issue (1): In the research, a model is made to determine the SWE (snow water equivalent) based on altitude and DOY (day of year). Although this model works quite well for some of the basins, for example, Oglio-Chiese-Sarca, this could not be the case for all other basins. As the paper already states, the R-squared value for this basin is the largest for Oglio-Chiese-Sarca. Since

the article claims this model works well to estimate the SWE, not only the best case should be used but also the basins that will probably give a worse estimate. Also, the paper doesn't touch on the potential estimation error of the SWE. The size of this error is an important factor in determining how well the model actually works and if it's worth using for future research and measurements. My suggestion would be to look more into the model errors and statistical significance of the model to really be able to tell how well this model works in estimating the SWE. It would help calculate the mean squared error and the confidence interval.

*R: Yes, thank you for this comment. We used your suggestions, pointed out also in other comments, to perform an error analysis of the model. We also presented the results for the first period and compare the results between the two subperiods. For the error analysis, we compared the modelled average SWE with the average measured SWE at each measurement site for each single measurement date over the two sub periods. We prepared a new figure, according also to the suggestions of other reviewers, combining Figure 13 and 14 and adding a panel containing the results of error analysis and a panel containing the comparison between the two periods.*



Major issue 2: The aim of the study is unclear. In the introduction, multiple issues are stated as well as reasons for the usefulness of the study. This, however, is not translated to the aim of the study nor to research questions. Moreover, the words: question or aim are not even used in the paper. This generates a lack of study direction throughout the entire paper, making the conclusion feel open-ended. My recommendation would be to add a research question in the form: technical problem statement, result of the problem, research question. This would give the paper a clearer outline that can again be followed in the conclusion. I also recommend using a signal word like aim to really make it clear what the aim is and to prevent confusion.

*R: Thank you for pointing this out. This lack of clear statements concerning the actual objectives of the research has been highlighted also by other reviewers. We expanded the introduction, including a paragraph clearly stating what are the objectives of the current research.*

*"In this study, we present a detailed long-term trends and variability analysis of snow depth and SWE measurements in a wide portion of the Italian Alps between 1967 and 2020. The first objective of this research is to quantify how snow depth and SWE has changed, evaluating trends, differences and change-points during the monitoring period using an independent dataset. The second objective is to establish elevation and seasonal dependencies of snow depth and snow density. A large dataset covering a wide area and spread at different elevations like the one presented here is suitable for such considerations and for fitting simple models able to describe those dependencies, with the aim of obtaining a climatological estimate of SWE. The third objective is to understand the links between meteorological variables with snow depth and SWE. In particular, we aim to better understand what are the weights played by temperature, precipitation and teleconnection indexes."*

*We agree that the introduction was confusing in defining the objectives. We also corrected the abstract, accordingly. We believe that the conclusions section summarizes the main findings obtained and, with the addition made in the introduction, we clarified the main contributions proposed in the paper.*

Minor issue's:

Minor issue 1: Figure 1 of the study area is not really helpful in understanding the study area, since it doesn't give a clear representation of the study; it is hard to see what basins are aggregated together. While it is clearly described in the text what basins are aggregated, it would be good to also show this in Figure 1. Furthermore, the different basins are visualized by the red lines (I think this is not specified in the caption nor text), however, I can only distinguish 11 basins, which is less than the 15 basins described in the text. Besides these points, the measurement points are quite hard to distinguish due to the contrast at a certain location with the elevation map. I recommend adding a different colored line to outline the aggregated basins, together with an explanation of the red line in the legenda or caption. Adding the basins (red lines) that are still missing, and finally changing the contrast of the elevation map to show the measurement locations more clearly.

*R: Thank you for this comment, it has been reported by other reviewers as well. Accordingly, we made some modifications in Figure 1 in order to be more representative and easier to read. We reported in the Figure the grouped basins only in order to avoid confusion related to an excessively fine basin disaggregation. The number of basin reported in the text was actually larger than the one in the figure because in the GIS we already grouped tributaries. With the new version of the figure there will be no confusion on the macro-basins as the only line present will be the boundary of each macrobasin. According to the suggestions of another reviewer we merged figure 1 and 2 to reduce the number of figures.*

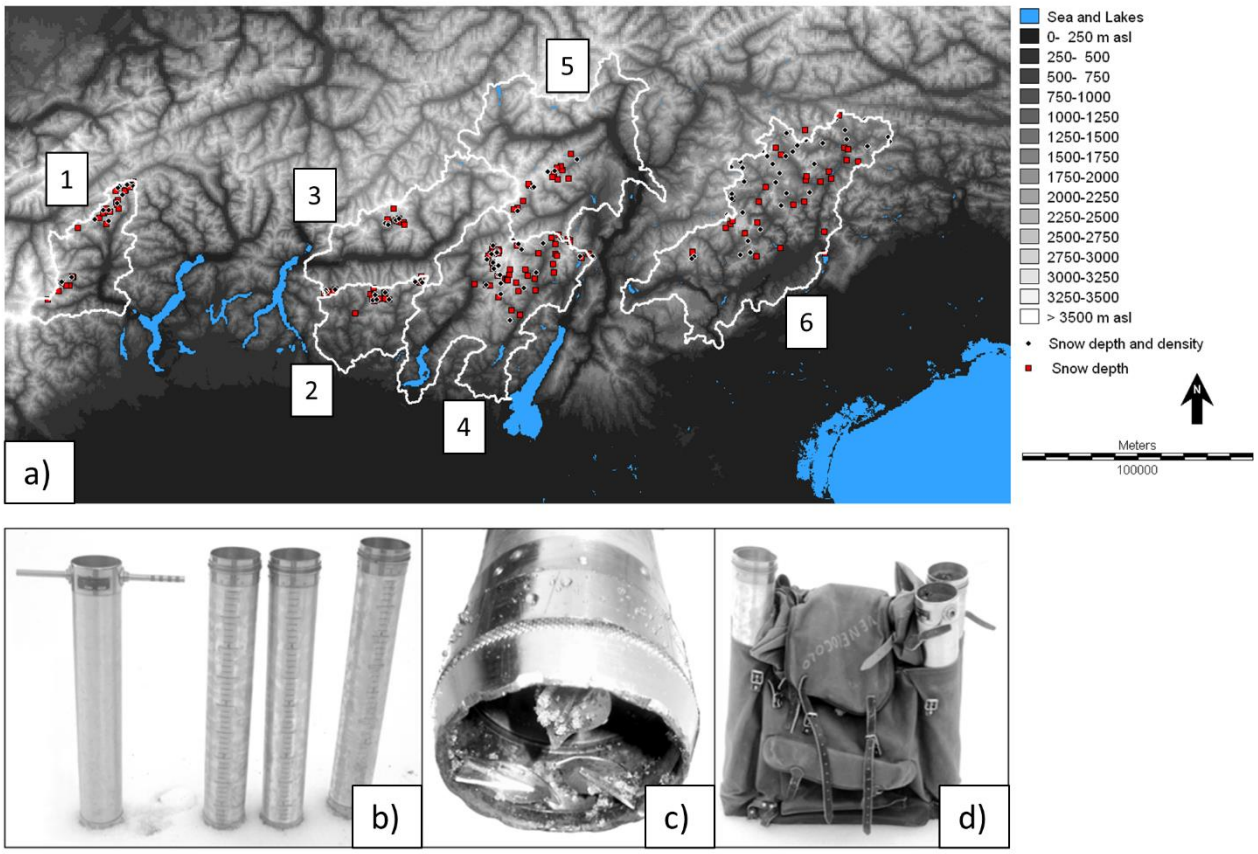



*Figure 1: a) Map of the research area. The individual basins are grouped in the six macro basins by number: (1) Toce, (2) Serio-Brembo, (3) Adda, (4) Oglio-Chiese-Sarca, (5) Adige and (6) Piave-Brenta. Locations of snow depth and density (black dots) and snow depth (white squares) are also reported. At the bottom, Photo of (a) CN2 type snow sampler and (b) detail of the cutting knife with the three internal fins and (c) the complete kit in its transporting bag.*

> Minor issue 2: In the conclusion, the recommendations for future studies are missing. This would be relevant to show the importance of the research when looking at potential innovation in this research area.

*R: We added a comment of possible future research linked with the use of the presented dataset at the end of the conclusion section: "Future research may consist in the utilization of analyzed data for the reconstruction of snow depth and SWE maps, within the targeted basins and possibly over a wider portion of the Alps, employing more sophisticated models, such as advanced machine learning techniques. Additionally, satellite data and remote sensing algorithms may provide valuable support in this context. These methodologies can be further validated leveraging the insights derived from the present dataset."*

> Minor issue 3: Line 401 stops mid-sentence, which keeps the paper with an incomplete result of the SWE model.

*R: Thank you for this comment, probably a copy and paste error lost in the formatting the manuscript. The completed phrase is "This model must be intended in a climatological way, as it has been conceived from average values over a time period of 27 years, and it can provide a simple yet useful estimate of the expected snow water equivalent at a given day of the year and at the specific altitude of interest, albeit*

*constrained by challenges related to knowledge of actual snowpack conditions at elevations exceeding 2500 m."*

Minor issue 4: The paper claims that T. Grünewald (2014) found a positive correlation between snow depth/SWE and elevation. This is partly correct; T. Grünewald (2014) found a positive correlation until a certain elevation. This is stated further down in the paper, but it might be good to also mention it with the earlier citation, since now it looks like a partly false statement.

*R: Yes, you are right. It is specified in Section 3.5 where we cite Grünewald (2014) when discussing the reliability of the climatological model until a certain elevation. We add a comment also at the end of section 2.6, as well, when discussing the altitudinal limitation. "Because of the scarcity of measurements above 2500 m asl, it is not easy to determine whether a maximum threshold is reached at higher altitudes. Moreover, Grunewald et al. (2014) found that snow depth increases with elevation until a certain level."*

Minor issue 5: In figure 5, the moving average triangle of the O-C-S and Toca have a different color scale. For comparing the different basin graphs, it would be helpful to make them the same.

*R: Yes, they have different color scale as they belong to two different elevation classes. Our choice was driven to have a sufficiently wide range of values to represent HS and compare two different dates (a vs b or c vs d) for the same elevation class in the same basin.*

Minor issue 6: Naming of locations is not constant. In the text, the full name of the locations is used. However, in Figure 12, abbreviations are used, for example: OC for Oglio-Chiese-Sarca (this abbreviation is explained in the caption). However, in tables 1, 2, 4, and 5, O-C-S is used without explanation. For easy understanding, I suggest making all abbreviations the same.

*R: Thanks for pointing it out. When changing Figure 12 to a Table we made the abbreviations consistent with the other tables.*

Minor issue 7: In the paper, multiple spelling and grammar errors can be found. For example, Line 54: 54-years period. I suggest reading it a few more times to get rid of these errors or using a grammar checker.

*R: Thanks! Corrected. We revised the paper to check for other typos and errors.*

References

Grünewald, T., Bühler, Y., and Lehning, M. (2014). Elevation dependency of mountain snow depth, The Cryosphere, 8(6), 2381-2394.

Sturm, M., Taras, B., Liston, G. E., Derksen, C., Jonas, T., & Lea, J. (2010). Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes. Journal of Hydrometeorology, 11(6), 1380-1394.