Reply to R3

This article presents a reanalysis of the snowpack conditions over the italian territory between 2011 and 2021. It uses a spatially distributed snowpack model (S3M) forced with gridded in-situ observations from automatic weather stations (AWS) and radar. The simulated snow depth is corrected by the assimilation of snow depth measured at AWS gridded thanks to a multilinear regression model and adjusted by satellite-based snow cover maps. The uncertainty of the reanalysis is estimated with Sentinel-1 derived snow depth (C-SNOW) and in-situ snow depth and SWE measurements.

This high-quality reanalysis will sure be useful for many applications. The article is well-written and seems comprehensive, covering most aspects of this work. The methods and results are well presented. I believe that the following points should be addressed by the authors before publication. Below are smaller suggestions and details to help improve the article.

> We appreciated all these suggestions, which we will welcome in the revised version of the manuscript. Please see below for our detailed response and planned changes.

The figures need improvement, especially figures 2 and 3. Each map needs a title. The axes should be labeled, a scale added. The colorbar choice often does not allow a clear reading of the maps. The colorbar legend is often too small and with too few labels. See detailed comments on each figure below.

> Changes to manuscript: Agreed, we will welcome all these recommendations.

Some data and methods information seems missing. I could not find which digital elevation model is used (what source, what resolution) or if the land cover is taken into account. It would be good to mention if the interaction between the snowpack and the vegetation, such as the forests, are considered.

> We used an Italian Digital Elevation Model as made available by The Italian Institute for Environmental Protection and Research, ISPRA. The Digital Elevation Model was originally at 20 m, which we resampled at 200 m using an averaging method. Land cover or snow-forest interactions are not taken into account by S3M Italy.
> Changes to manuscript: Agreed, we will include all points above in the revised manuscript.

Other reanalysis over the swiss, the austrian and the french Alps (Fiddes et al., 2019, Olefs et al., 2020, Vernay et al., 2021) are mentionned. Although the methods are largely different in each work, it would be interesting to compare the uncertainty of these works.

> Changes to manuscript: We will add a Discussion on this in the manuscript.

L2 "+" disturbing notation. I suggest using "over", ">" or just give the exact value. To be homogeneized in the text.

> Changes to manuscript: Agreed.

L9 "no mean bias" rather than "none"? (L421 as well)

> Changes to manuscript: Agreed.

L14 If ever the variability of the peak SWE date is available, it could be interesting to provide it.

> Changes to manuscript: Yes, this is available and will be included in the manuscript.

L25 "(Serreze et al., 1999; Skiles et al., 2018)" you might want to cite Li et al. (2017) in which the contribution of the snowpack to the runoff is indeed calculated. It seems like Serreze et al. (1999) only compared the solid precipitation amount to the total runoff and Skiles et al. (2018) cites Bardsley et al. (2013) for the 80% number.

> Changes to manuscript: We totally agree and will amend the manuscript as suggested.

L38 "lidar" in Deems et al. (2013), "Lidar measurement of snow depth : a review". To correct everywhere.

> Changes to manuscript: Agreed.

L38 "airborne lidar"? otherwise the list mixes methods (lidar, optic) and plateform (drone, satellite).

> Changes to manuscript: Agreed.

L47 and further in the text: what is a "dynamic model"?

> We used the term "dynamic model" to indicate digital replica of environmental systems, in this case snow and glaciers. To our knowledge, this complies with general jargon in the hydrologic literature.
> Changes to manuscript: We will replace "dynamic model" with "model", which is more general and less ambiguous.

L67 GlobSnow: maybe worth to mention that it is not available in mountain areas?

> Changes to manuscript: Agreed.

L91. A bit confusing with S3M, S3M Italy and IT-SNOW. Maybe add "the reanalysis IT-SNOW"

> Changes to manuscript: Agreed.

L100 "" => I was disturbed by this notation without letters. Maybe use "hh" instead?**

> Changes to manuscript: Agreed.

L100 Maybe precise the period covered by the inputs: is it only of the last hour?

> We generate inputs every hour, since S3M Italy has a hourly time step. For redundancy

reasons, and to fill potential gaps due to occasional malfunctioning and/or failures, every hour automatic procedures check the existence of inputs for the last 30 hours.

Changes to manuscript: We will add the above to the manuscript.

L108 RMSE of 1 mm, please provide the typical precipitation observed.

Changes to manuscript: Agreed.

L112 "spatialized" at what resolution?

Changes to manuscript: We will add resolutions in the main text.

L115 It would be very useful to provide the distribution of the temperature lapse-rate, even if supplement in necessary. This study from Navaro-Serrano et al. (2018) might help if you need to compare your temperature lapse-rate to similar regions.

Changes to manuscript: Agreed, as also recommended by reviewer 1 and 2.

L118 I would suggest rewording along "An unique estimate of the precision of these data is not available as the type of sensor installed varies from one region to another. The installation and the maintenance of the sensors..."

Changes to manuscript: Agreed.

L122 "remapped" quite vague. Cropped?

Changes to manuscript: Agreed.

L124 "each region to tailor" unclear. What is the exact meaning of "region" here? What is tailoring S3M?

In Italy, each administrative region (first-level administrative divisions of the Italian Republic) has civil-protection offices that have access to real-time outputs of S3M Italy. Each of these administrative regions may potentially ask for region-specific parametrizations.

Changes to manuscript: While the above was the intended meaning of *tailoring* in this context, we will remove that passage as it is superfluous information.

L128 "Sentinel-2"

Changes to manuscript: Agreed.

L129 How do you manage the overlapping images? Putting on top the most recent?

Changes to manuscript: Yes, exactly. We will specify this in the text.

L137. "Not shown". Could be added in supplement maybe?

Changes to manuscript: Agreed, we will provide such statistics as a supplement.

L146 Please provide the number of snow depth sensor.

Changes to manuscript: Agreed.

L151 "remapped"? unclear.

Changes to manuscript: Same as above, we will use "cropped" as suggested earlier.

L159. "For each time instant" not clear. Could be deleted.

Changes to manuscript: Agreed, this will be deleted.

L163 What happends if snow in SCA observation but not in S3M? "preserving" is a bit unclear, maybe use "leaving without snow..."?

Changes to manuscript: Correct, we will revise as suggested.

L170 "The duration"?

Changes to manuscript: Agreed.

L171 "1.3 h" give it in h and min.

Changes to manuscript: Agreed.

L172 "AM" a.m.?

Changes to manuscript: Agreed.

L184 Given the resolution, it seems like at least the last "57" can be dropped.

Changes to manuscript: Agreed.

L194 Some precisions about C-SNOW product would be welcome. First, it is only available for dry snow, that is accumulation period, isn't it? Second, some part of Italy seems not covered by C-SNOW (grey area in Fig. 1 of Lievens et al., 2019). Finally, is C-SNOW completely independant from IT-SNOW? C-SNOW was calibrated on snow depth from AWS.

Correct, C-SNOW is only available for dry snow. It is also correct that only mountain regions are covered by the product. Finally, the reviewer is right that some (but not all) snow-depth data from Italian AWS were used in developing C-SNOW, along with a variety of other snow-depth data from the Northern Hemisphere. In any case, C-SNOW remains the only, high-resolution and temporally dense remote-sensing product of snow depth that can be used to validate IT-SNOW across the Italian mountain ranges.
Changes to manuscript: We will add the above to the manuscript.

L211 "ASL" a.s.l.?

Changes to manuscript: Agreed.

L232 Is it not possible to make it "3.2 Results" and then sub-sections (3.2.n) for the different

data sources?

> Changes to manuscript: Agreed.

L235 how did you compute the RMSE? Between time-series at each pixel? Please write the MAD from Lievens et al. (2019).

> Yes, we computed RMSE between time-series at each pixel.
> Changes to manuscript: We will add the above and the requested MAD to the manuscript.

L243 Please provide values for the bias. A table summing all the statistics evaluation would be really helpful.

> Changes to manuscript: Agreed.

L248 Then there is little information brought by the comparison of IT-SNOW density with station density since the density is derived from snow depth and SWE and snow depth and SWE are also compared to IT-SNOW.

> This is correct, but at the same time we think it is important to provide error estimates for density given that this is one of the four data layers provided by IT-SNOW.
> Changes to manuscript: No change.

L253 Please provide bias values.

> Changes to manuscript: Agreed.

L284 "102 gauge stations"?

> Changes to manuscript: Agreed.

L294 "Again,..."

> Changes to manuscript: Agreed.

L306 "evalution results"=> "the results"

> Changes to manuscript: Agreed.

L307-309 Cut this long sentence int two.

> Changes to manuscript: Agreed.

L313 "peripheral"? geographicaly peripheral? The Alps are on the periphery of Italy but the station density is high...not clear.

> We meant areas that are at the periphery of the Italian territory. While station density in these regions may remain locally high, spatially distributed information like blended gauge-radar precipitation will have an inherently larger uncertainty (because of a lack of, e.g., available radar information outside the Italian territory).

Changes to manuscript: We will elaborate on the above in the manuscript.

L317 not clear if talking about the SCA of the Sentinel-2/MODIS product or from IT-SNOW.

Changes to manuscript: We meant SCA from satellites. This will be clarified.

L331-334 sentence is too long. To be cut.

Changes to manuscript: Agreed.

L334 "apriori appear"? please rephrase.

Changes to manuscript: We will delete "a-priori" here as it is confusing.

L336 "Thus, quantifying this uncertainty in still elusive at this stage." I dont understand where this conclusion stems from.

This conclusion stems from previous work, such as Magnusson et al. (2015) or Avanzi et al. (2016), showing that solving the energy balance is no key driver of model performance for snow bulk variables at daily scale.
Changes to manuscript: We will further clarify this point.

L336: "in"=>is

Changes to manuscript: Agreed.

L337 To move earlier in the description of the data or method.

Changes to manuscript: Agreed.

L344 "basic science"? Please reformulate.

Changes to manuscript: Agreed.

L348 I like the catchy quesions. However, "what is it doing?" is not so clear and it does not appear in the conclusion. Could it be deleted? I also suggest more detailed formulation "How much is accumulated in total? Where/how is it spatially distributed?"

Changes to manuscript: Agreed.

L353 1st

Changes to manuscript: Agreed.

L353 "(this finding is in agreement with a recent reconsideration of this conventional date, see Montoya et al., 2014)" get this sentence out of the brackets

Changes to manuscript: Agreed.

L364 "anecdotal data" unclear if they are data from IT-SNOW or non-scientific data.

> These data come from newspapers and/or other publications, as reported in the main text.
> Changes to manuscript: We will revise text here and remove the word "anecdotal".

L366 "150+ cm of fresh snow in 24 hours" give the date of this event.

> Changes to manuscript: Agreed.

Figure 2. Provide title in the figure for each subplot, next to (a,b,c). Provide more values for the colorbar of b and c. In a, is there no station with several type of measurements? Or are they hidden because points overlapp?

> Changes to manuscript: Agreed. We will also specify that some stations may host several types of measurements.

Make b colorbar symetric so that 0° is linked to the yellow color. In b, keep the same precision (14,8//-16,77) and meaningful values (-10,0,10...).

> Changes to manuscript: Agreed.

In the legend: "by S3M Italy and thus the IT-SNOW reanalysis" => "by S3M Italy to produce IT-SNOW." Confusing otherwise.

> Changes to manuscript: Agreed.

Scale is missing as well as xlabel and ylabel.

> Changes to manuscript: Agreed.

If you find a way to make all subplots fits in only one line, it would make better use of the space.

> Changes to manuscript: Agreed.

Figure 3 See comments for Figure 2 that can be applied here. For b, why is there a transparent area without data which is not of the colour of the NaN provided in the legend.

> Changes to manuscript: Agreed, we will revise the figure and the blank vs. NaN issue.

Figure 4 This figure is much more readable. Add xlabel, ylabel to the maps and make sure color scale is symetric centered on 0. Improve the colorbar (see above).

> Changes to manuscript: Agreed.

Figure 5 Suggestion for future figures: b and c would be better plotted with a heat-map or at least some transparency of the points.

> Changes to manuscript: Agreed.

Figure 8 Make the color scale continuous, it is really hard to read the map otherwise.

<u>Changes to manuscript</u>: Agreed.

References

Avanzi, F., De Michele, C., Morin, S., Carmagnola, C.M., Ghezzi, A., Lejeune, Y., 2016. Model complexity and data requirements in snow hydrology: seeking a balance in practical applications. Hydrological Processes .

Magnusson, J., Wever, N., Essery, R., an A. Winstral, N.H., Jonas, T., 2015. Evaluating snow models with varying process representations for hydrological applications. Water Resources Research 51, 2707 – 2723.