**The Cryosphere
Discussions**

Interactive comment on "Variability of snow depth at the plot scale: implications for mean depth estimation and sampling strategies" *by* J. I. López-Moreno et al.

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Response to "Variability of snow depth at the plot scale: implications for mean depth estimation and sampling strategies" by

J. I. López-Moreno et al. Anonymous Referee #1

We want to sincerely thank to reviewer 1 his constructive comments and suggestions to improve the quality of the work and increase the clarity of the presented ideas. As overall, his comments highlight the interest of the research but indicate a number of concerns mostly related with the extent of the dataset and the organization of the manuscript. We have followed the majority of the suggestions. Below, we explain in

detail the changes introduced to the manuscript and explain some questions which remained unclear to referee 1.

1- "In general, the topic of the paper is interesting and the conclusions may be useful in order to design a snow sampling strategy elsewhere. However it is based on a relatively limited range of data. . .."

Collection of data as presented in this manuscript is really difficult as each plot requires a very long time of work. The result was a total of 30 plots that reflects a wide variety of snow conditions in terms of snow characteristics (comparing surveys of February and April) and snow accumulation (as it can be deducted from Table 1 and Figure 2). From the observed data, I think that the hypothesis about the impact of local variability and spatial autocorrelation may affect our estimation on local snow depth is robust and gave us the guidance to design a next analysis based on a large amount of simulated datasets under different conditions. Such analyses allowed us to isolate the effect of local variability and spatial autocorrelation, as well as to test different sampling strategies to optimize our effort in further fieldwork surveys. This is why we think that the combination of observations with thousands of simulated series allow us to provide robust results about sampling design. Nonetheless at the end of the discussion section we recognize that specific numbers can vary according to specific characteristics of each site: "The aim of this research was not to provide guidance for sampling in other geographical areas, but highlights the usefulness of considering this type of analysis during the planning of snow surveys. Initial measurements of numerous snow depths at the plot scale can be used to determine the measurement variability of a location, and can help to decide how many samples should be taken to represent each survey point".

2- "The effect of different terrain surface characteristics is not touched, i.e. flat, scree, dwarf shrubs, boulders, surrounding topography influencing wind redistribution, etc. It is thus questionable whether the results are transferable / can be generalized"

The fact to not make reference to specific characteristics of terrain surface has been done intentionally, as it was not within the aim of our work. It is sure that terrain characteristics drive the spatial variability of snowpack at the scale in which we are working. However, when we go to measure snow, we do not know the characteristics of terrain surface beneath the snowpack, making impossible to take it into account in our sampling strategy. This is why we recommend conducting similar analyses in other areas, and we consider very interesting to reach "A better understanding of the factors that influence the spatial and temporal patterns of snowpack variability and spatial autocorrelation at the plot scale will aid efforts to obtain high quality snow datasets" (p. 1641, l-8-11 discussion manuscript).

3-The description of the field sampling should be moved from the introduction to the paragraph describing the data sets.

Accordingly to this recommendation we have removed the description of the dataset from introduction and it has been moved to the Section 2 (Datasets).

4. "Recursive random extraction" procedure should preferably be described in only one place.

Done

5. They should also better define the knowledge gap they are trying to fill. Perhaps the authors should reference some of the following articles where snow depth/snow water equivalent variability at the plot scale at least has been addressed.

We have modified a phrase in the introduction to say: "As autocorrelation decreases with the distance between sampling points, the sampling size, the distance between points and the sampling strategy (e.g. the spatial pattern of sampling) must be considered. In snow sampling these parameters are often decided subjectively rather than being derived statistically and very little literature can be found as guidance to increase the efficiency when sampling snow depth". We did a careful review of literature when

we wrote the manuscript, but there are really very few references dealing with the topic that we are addressing (i.e. publications of Deems and Trujillo). We have added the reference of Rovansek et al., 1993 to stress the necessity to find a balance between effort for sampling and the error of the resulted dataset. The reference of Sturm is really interesting, but we do not see well the direct relationship with this work, as his field surveys and objectives are very different to the ones presented in this work.

6- Page 1630, Line 9. I do not think that it is completely correct to say that wind influences the snowpack thickness randomly.

We agree, we have removed the word "random" from this phrase.

7- Page 1630, Line 20. It would probably be good to point out that the equation only is valid provided that the samples are independent.

We have modified the statement accordingly to the referee's suggestion: "If a variable does not exhibit spatial autocorrelation, the estimation error decreases as the sample size increases, and thus the average of a number of samples will better represent the ground truth than a single measurement".

8- Page 1630, Line 27. I thought that a spatial autocorrelation between individual samples might influence (1) the calculated sample mean in any direction, in either an overestimation or underestimation of the true mean, but (2) always in a too low estimated standard error of the sample mean. I might be wrong, in that case please correct me.

Spatial autocorrelation is not necessarily linked to a low standard error of the sample mean as you can have high values of variability in the sample under high levels of spatial autocorrelation, as we have shown in observed and simulated series. For instance, Figure 2 does not show any significant correlation between CV and range of the semivariogram.

9- Page 1631, Lines 8-25. Please state the aim of the study in more detail, like ob-

jectives or research questions, and move the summary of the study presented in this paragraph to appropriate places in the manuscript (for example the section describing the data sets).

We have added this paragraph to state clearly the objectives of the paper in detail: "The aim of this paper is to quantify the spatial variability of snow depth at a 10 m × 10 m plot scale, and to isolate the effect of the sampling size and strategy on the estimation of the mean under controlled conditions of snow depth variability and spatial autocorrelation. To address these issues two intensive snow depth sampling surveys were conducted in a Pyrenean mountain valley and a synthetic data set was constructed to assess the influence of the sampling size and strategy on the estimation of the mean under controlled conditions". The summary of the study has been moved to section describing the data sets.

10- Page 1632, Line 2. Should there not be a figure showing the study site? Figure 1 displays something different.

This was our mistake. We decided at the end to add a figure for the study site, as it does not provide useful information for interpreting the article and enlarge the manuscript unnecessarily. We have removed the mention to Fig.1.

11- Page 1632, Lines 12-14. The sentence sounds awkward to me, as if plots with irregular snow surfaces would have a known variability.

We have removed this phrase from the revised manuscript. It did not add valuable information, and it is obvious (from the comment) that may introduce confusion.

12- Page 1633, Lines 20-25. I do not understand why the method based on the random subsets would give a robust estimation of the standard error of the sample mean. Is not this estimate also influenced by the spatial autocorrelation? Please clarify.

We have simplified this phrase to avoid confusion. To extract random subsets of different sizes is a way to quantify how sample size affects to error estimation. We need to

repeat the process several times in order to ensure that the relation between sample size and error is robust. We hope that this part results clear in the manuscript, as it is important for understanding the results.

13- Page 1635, Line 19. It is not perfectly clear to me what "recursive random extraction" means. Please clarify or better avoid the term completely.

We agree with the comment, we have removed the term "recursive" to avoid confusion.

14- Page 1636, Lines 3 - 4. The sentence referencing to Figure 3 is difficult to understand

We have modified the sentence, we hope that now is clearer: "Figure 3 shows the mean, 25 and 75th percentiles of error for the 15 plots. Variability amongst analyzed plots informs that sample size may affect in a different manner to snow depth estimation at the plot scale".

15- Page 1636, Line 4 - 6. I think it might be better to say: "Figure 4(A) shows the average error as a function of both the sample size and the CV. Figure 4(B) displays the average error as a function of the sample size and the spatial autocorrelation (the range of the correlation length)."

We have changed it. Thanks for your suggestion.

16- Page 1638, Lines 2 - 18. This part is very interesting, and should perhaps be more emphasized throughout the study.

We have modified the abstract and conclusion sections to emphasize those findings in the manuscript.

17- The first half of the discussion deals mostly with the factors giving rise to variations in snow depth (which already have been frequently studied), and should be shortened. I would recommend that the second half, which deals with the actual scope of the study, should be extended. I would also consider giving more advices on how to design a

sampling strategy for different field sites.

We think that the different paragraphs of the discussion are explaining the main conclusions reached in the study in a coherent progression. Reviewer have shown a major interest for the section of the manuscript devoted to the sampling strategies, and probably this is why he would like that this issue would dominate in the discussion. We have decided not modify too much this section as we think that all part of the result section must be discussed, although we have introduced some changes according to the comments of the three referees. The final structure of the discussion is as follows: First paragraph is devoted to give a general overview of the manuscript; Second and third paragraph is devoted to discuss results and literature available about snow variability at the plot scale; the fourth paragraph discuss and review spatial autocorrelation of snowpack at the plot scale; and finally a long fifth paragraph is used to highlight the necessity to take multiple samples in a plot, and the implications of sampling strategy according to spatial variance and autocorrelation. In our opinion this structure is rather logical, although we are keen to introduce changes if any referee is not fully convinced.

18- Page 1640, Line 28 - Page 1641, Line 1. Please reformulate the sentence. It sounds a bit awkward to me.

We agree that the phrase needed to be reformulated. We think that now is more clear for the readers: "Overall, results suggests that snow sampling should prioritize the collection at least 5 snow depth measurements at a minimum 2 meters spacing to represent a 10 x10 meters plot sized area. The specific numbers presented here relating sample size and snow depth estimates are closely related to the topographic and climatic characteristics of the study area, and the specific plot size considered in this study".

19- Table 1. What coordinate systems was used? What different terrain surface characteristics; do the sites represent (except whether they are inside or outside forest openings)?

We have modified Table for indicating that coordinates are UTM. As it has been discussed before, we have not considered in detail specific terrain surface characteristics of each plot, as it is out of the main aim of this work. The work focuses on the impact of micro-scale snowpack variability and spatial autocorrelation on local estimation of snowpack. Obviously, differences in variability and spatial autocorrelation are driven by surface characteristics. However, when we conduct snow field surveys we do not usually know what exactly is beneath the snowpack and by hence we cannot use this information to know how many measurements we need for ensure the local representativeness. Sampling snow in the prairies, tundra, a forest or in a scree slope in alpine terrain will present different plot variability because the environment and the surface of the terrain is very difficult. This is why at the end of the discussion of the revised manuscript we state: "The aim of this research was not to provide guidance for sampling in other geographical areas, but highlights the usefulness of considering this type of analysis during the planning of snow surveys. Initial measurements of numerous snow depths at the plot scale can be used to determine the measurement variability of a location, and can help to decide how many samples should be taken to represent each survey point. This approach should improve the representativeness of the dataset. A better understanding of the factors that influence the spatial and temporal patterns of snowpack variability and spatial autocorrelation at the plot scale will aid efforts to obtain high quality snow datasets.". We hope that this point remains clear in the revised manuscript as it is very important to understand the main message of the paper and the methodological approach used in this study.

20- Figure 1. What unit was used on the horizontal axis?

The units are intervals of standardized snow depth (standard deviation units). It has been stated in the horizontal axis.

Thanks again for your helpful and constructive comments.

Please also note the supplement to this comment:

http://www.the-cryosphere-discuss.net/5/C784/2011/tcd-5-C784-2011-supplement.pdf

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