The Cryosphere Discuss., 5, C680–C687, 2011
www.the-cryosphere-discuss.net/5/C680/2011/


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.

**Anonymous Referee #2**

Received and published: 18 July 2011

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.

Anonymous review

July 16, 2011

The authors present an analysis of plot scale (10 x 10 m) spatial variability of snow depth. Data were obtained from two field surveys during which 121 equally spaced (1 m) depth measurements were made at fifteen plots characterized as either 'open' or 'forest gap' at two elevations in the Spanish Pyrenees. The spatial variability in each plot was then assessed by random sample. The authors found high variability of snow



depth at the measured scale; CV as high as 0.25. The authors generally attribute the observed differences to variability in terrain and surrounding vegetation coverage. The high variability at the plot scale has implications on sample design in that it affects both the required number and location of measurements to ensure that the mean of the samples minimizes the standard error. The authors conclude that the number of measurements depends on the degree of variation and the desired degree of accuracy. The authors acknowledge that most snow surveys are designed subjectively because neither the variance (or standard deviation) nor the autocorrelation of snow properties are known a priori, thus restricting an explicit evaluation of the effect of each factor on the optimal sample design required to achieve representativeness.

The authors then present a statistical methodology on synthetically derived snow depth fields to isolate and evaluate the influence of standard deviation and the degree of spatial correlation on the standard error of various sampling strategies. Results from 5 000 synthetic simulations each with 10 classes of standard deviation and four levels of autocorrelation (200 000 total simulations) showed that five measurements were sufficient to produce errors < 10 % under the highest level of simulated variability. With eight measurements, the error reduced to < 5% for more than 75 % of the simulations.

The authors' findings are significant in that they present results on a topic that is germane to snow science and has received relatively little attention despite a long history of global snow survey campaigns. The evaluation of the spatial variability of snow properties (e.g. depth) at scales relevant to streamflow prediction has long been conducted with statistical or (somewhat more recently) physical models. However, model accuracy is often 'validated' against field observations conducted in ways that lack statistical guidelines for capturing the mean (and variance) of the population within a known range of measurement error. The authors' evaluations of observed and synthesized snow depth fields provide interesting insight into appropriate survey design and recognition of uncertainty in measurements from a statistical perspective. While I believe the authors' methods are applicable to other datasets in other regions, it is not clear that the results can be used to guide survey design beyond the conditions used in the current study. The authors do acknowledge this concern in the current manuscript.

With these considerations in mind I recommend this manuscript for publication in The Cryosphere with appropriate authors' responses to General Comments and with the minor revisions recommended in the Detailed Suggested Corrections section.

General Comments

The limitation of such a study is that the results (reported error and number of samples needed for representativeness) may not be directly applicable to other regions. Furthermore, the authors only evaluate two months (January and April) of one snow season (significant melt was not observed between the two surveys). Additionally, field measurements at lower elevations were conducted in a forested environment, but no measurement plots were positioned beneath the forest canopy where interception and subsequent ablation might be expected to strongly govern spatial covariance of snow depth during the accumulation season. The authors' rough definition of the 'plot-scale' as being homogeneous in appearance could be elaborated upon. Do the authors have a sense for the influence of 10 x 10 m plot placement on their results of the range of the semivariogram? In other words, might the range actually be much greater if a slightly larger plot overlapped both vegetated and open areas? I believe this is a particularly relevant question as the 'plot' is expanded to the 'satellite pixel' scale (i.e. 30 x 30 m); pixels of which are not subjectively placed over 'homogenous' regions. The inherent system heterogeneity has implications on evaluation techniques of measurement uncertainty and state covariance required in many research and operational applications (e.g. data assimilation techniques).

Complex spring melt patterns might be expected to further complicate snow depth autocorrelation. While the consideration of sub-canopy plots may not change the authors' conclusions, it seems as if the field results presented are from periods and locations of relatively low plot-scale depth variability relative to what might be expected at other



times of the year (i.e. melt season) and in other parts of the catchment (i.e. sub-canopy forests). In this vein, the authors stop short of discussing survey design considerations when plot-scale variability itself is a significant variable both spatially and seasonally. A sentence or two about the dynamic nature of the variability (in space and time) might be helpful to identify pertinent future research objectives.

The authors present standard deviation values repeatedly in the text and figures that lack units. Include units with all appropriate variables.

Spell out common numbers under 10 throughout the manuscript.

The current structure of the manuscript has a substantial amount of the authors' methods described in the Introduction. I think this is acceptable, but the flow of the paper would greatly benefit from a succinct objective statement followed by a few science questions, which are later answered in the Discussion / Conclusion. The general methods (i.e. the last paragraph of the Introduction; page 1631, lines 8:25) could then follow the objective and science questions and would set the flow of the paper to then cover the detailed methods / datasets in section 2.

Detailed Suggested Corrections:

Page 1628, Lines 14-15: The sentence: 'The spatial autocorrelation of snowpack distribution can affect the local representativeness of snowpack.' is vague regarding the scale being considered. It doesn't seem to add much to the abstract. Consider removing.

Page 1629, Lines 7-9: The point about satellite data and aerial imagery seems out of place when the topic is variability of snow depth at the plot scale. To what snow depth products do the authors refer? Be explicit and include references.

Page 1629, Lines 26-28: Rewrite sentence for clarity. Current sentence suggests that field surveys are capable of 'considering'.

Page 1630, Line 6: Change: '. . .(i.e. areas in the order of . . .' to: '. . .(i.e. areas on the order of . . .’

Page 1630, Line 6: ’10 mˆ2’ is a typo., it should be 100 mˆ2 or 10 x 10 m.

Page 1630, Line 6: The authors need to be more clear and explicit in the definition of the ‘plot-scale’. Include references if available. The description of the ‘plot-scale’ as exhibiting ‘homogeneous characteristics’ is at odds with the last part of the sentence that states boulders, branches, and underlying vegetation are present within the plot scale. The authors likely mean that from the perspective of a surveyor the snow surface appears homogeneous, but that is not intimated in this sentence.

Page 1630, Line 9: Perhaps “seemingly random” effects of wind redistribution? Or “complex effects of . . .”.

Page 1630, Lines 12-14: Change, “. . . averaging the measurements over different locations within a plot.” to be clearer: “. . . averaging measurements made at different locations within a plot.”

Page 1631, Lines 10-11: Be consistent with unit inclusivity in context of areal descriptors: (10 m x 10 m) vs. (10 x 10 m) . . . check with Journal for correct use and maintain consistency throughout manuscript. Both are used in the current text. The consistency should also hold when stating a range of values (e.g. “. . . 4.7 to 10 m in April.”).

Page 1632, last paragraph: How were the specifications of the standard deviation classes and levels of autocorrelation derived? Were these values and ranges determined from the results of the field data analysis? Did the authors determine the values subjectively or objectively? Be explicit with your methodology in this paragraph as the specifics have significant implications on the results and conclusions.

Page 1634, Lines 1-4: Consider changing the measurement design descriptors from “a plus” to “ . . . a ‘+’ configuration . . .”. The symbol rather than its grammatical spelling is more similar to the ‘L’ configuration and emphasizes the point in a clearer fashion.

Page 1635, Lines 11-12: The sentence ending with “. . . statistically significant” is miss-



ing a period.

Page 1635, Lines 12- 14: Does the sentence, “ . . . the ANOVA test did not indicate a significant difference between the two environments.” refer to a difference in the mean snow depth between the two environments? Please clarify.

Page 1636, Line 7: It is my understanding that ‘loess’ is an acronym for ‘locally weighted scatterplot smoothing’, and should thus be explained as such and included in capital letters in the text. See (and possibly reference):

Cleveland, W.S. (1979). "Robust Locally Weighted Regression and Smoothing Scatterplots". Journal of the American Statistical Association 74 (368): 829–836. doi:10.2307/2286407

Page 1636, Lines 19-20: Shorten sentence to be more succinct: “In natural situations completely random sampling of snow is rarely achievable because of a variety of difficulties including variability in the distribution of snow-covered terrain.” Could be written as: “In natural situations completely random sampling of snow is rarely achievable because of a variety of difficulties including terrain complexity.”

Page 1636, Line 22: Again (and elsewhere) consider changing “plus” to “. . . ‘+’ configuration . . .”. And “L” to “ . . . ‘L’ configuration . . .”.

Page 1637, Lines 1-3: Regarding the sentence, “Both figures demonstrate . . .”; Be explicit in your reference to specific figures.

Page 1638, Lines 22-24: This sentence should be re-written, “To improve the accuracy of snowpack estimates, data for individual plots must be averaged from a set of replicate snow measurements within the plot.” to remove redundancy and clarify. “ . . . data from individual plots . . .”

“. . . data . . . must be averaged from a set of replicate . . . measurements . . .”. Is confusing as written.

Page 1639, Lines 22-24: In regard to the sentence, “An explanation for this relationship is that irregularities in the terrain are consistent in size, and thus their relative influence on the snow depth decreases as the snowpack depth increases . . .”

What do the authors mean by ‘consistent in size’? In what dimension(s)? Only the vertical? If the authors refer also to horizontal terrain patterns, are the patterns being adequately captured at the plot scale? Be specific.

Page 1639, Lines 22-24: in regard to the sentence: “In both surveys differences were found in the variability of plots in forest openings relative to those in open areas .” Be explicit and describe / reiterate the relative differences.

There is also an erroneous space before the sentence’s period.

Page 1640, Line 6 (and elsewhere): Check the Journals preferred citation method when including a citation within a sentence. “Holgram et al., (1998) recognized . . .”. The names may need to be italicized.

Page 1641, Line 1: Missing a period after “. . .a plot sized area”

Page 1647, Figure 2: Need to include symbol descriptors in caption or in a legend.

Page 1648, Figure 3: Describe the vertical lines in the caption or remove them.

Page 1649, Figure 4: Sub-figures are not of equal size and relative orientation as such the tick marks are not properly aligned. Y-axis tick marks are slightly offset between the two figures in A. (not a result of orientation but figure creation)

Page 1650, Figure 5: It seems like the authors set a benchmark error of 10 % in the text, and refer to 5 % error in the conclusions. Perhaps it would improve figure clarity if contour lines (5 %, 10 %) with labels were included indicating the standard deviation and sample size influence on these error benchmarks. Also, would the figure look better if 0 % error values were illustrated as ‘white’ instead of dark blue? This color is hard to distinguish from low (non-zero) error values.

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Interactive comment on The Cryosphere Discuss., 5, 1627, 2011.