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Discussions
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Interactive comment on "Orographic and vegetation effects on snow accumulation in the southern Sierra Nevada: a statistical summary from LiDAR data" *by* Z. Zheng et al.

Z. Zheng et al.

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Dear Dr. Sturm,

Thank you for reviewing the manuscript "Orographic and vegetation effects on snow accumulation in the southern Sierra Nevada: a statistical summary from LiDAR Data" by Zheng et al. Your comments were highly insightful and enabled us to greatly improve the quality of the manuscript. Please see our responses to your comments below.

Sincerely,

Zeshi Zheng

Responses to major comments

1. In this paper, the authors use airborne LiDAR data to assess primarily how the snow pack depth increases with elevation on the west side of the Sierras, and secondarily, how other factors (canopy cover, slope, aspect) affect the distribution of snow. The main conclusion (increasing snow depth with elevation to 3300 m) is not novel, nor is the basic technique of using airborne LiDAR to measure snow depth, but I suspect that what the authors have done is reach their conclusions regarding snow depth gradients using better and more comprehensive data than heretofore has been available. Unfortunately, the paper as written does not make clear what is novel and what is not in the study, and the paper suffers from too much detail in discussing secondary effects (slope, aspect, canopy), obscuring the main conclusions about elevation gradients. There is also a somewhat offhand attitude in the discussion of the choice of sites and why those might constitute an "upslope transect" along the western side of the Sierras. While the choice of sites may (or may not) have been chosen for the purposes of the present study, the paper would be improved if the authors were up-front in examining the choice of study sites, comparing and explaining why these sites can reasonably be used together. I think this approach works because storms come from the west, while the range runs north-south, thus the orographic lifting effect can be thought of as a two-dimensional problem. . ...but the authors need to explain and document this if it is true for the readers.

Response: Thank you for these observations, we have clarified what makes this research novel and we structured our findings into three main points, which are much clearer than in the original manuscript. For site selection, we could not do much about it because the sites were selected for multi-disciplinary investigation of the Southern Sierra Critical Zone Observatory. This is the only point-cloud data set currently available with snow-on and snow-off in the southern Sierra.

Changes in the manuscript:

(1) We now structure our findings to highlight three main take-home points:

a. The fraction of pixels for which Lidar measured snow depth in dense forest depends on the pixel size, or averaging area, used when processing the raw Lidar point cloud.

b. Other than elevation, aspect and slope also control the distribution of snow depths.

c. In mixed-conifer forest, for area under the canopy, the effect from canopy overwhelms effects from slope and aspect, in most sites, and the interactions between these features could be observed from the data.

(2) We changed the title to “Topographic and vegetation effects on snow accumulation in the southern Sierra Nevada: a statistical summary from LiDAR Data” rather than “Orographic . . .”. because orographic lift is one of the findings from the data set but not the current main finding of this paper.

(3) We rewrote our introduction as suggested and modified results and discussion in response to the specific comments.

(4) We added the rationale for using these sites for our analysis, in Section 2.1, page 8 line 152.

2. One other area of confusion needs to be improved in the paper: the authors introduce 4 linear models of increasing depth with elevation (or at least I think it is 4 models (Table 3)). What is the point of having 4 models? For large scale studies, wouldn't a single, averaged linear model be of more use? And if four models is what is needed, what is the use of these models? This part of the paper would be improved if the linear model was actually presented as a formula, and more care was taken in explaining how the residuals (Figures 6 and 7) were computed.

Response: We investigated the difference between using 4 linear models instead of using one (see attached figure #1), and they did not make much difference in terms of estimation bias. Using 4 individual models is slightly better because each catchment area has its own microclimate that could affect the snowpack. We have provided a

formula for presenting the model and a better explanation of calculating residuals.

Changes in the manuscript:

(1) A figure comparing use of using one vs. four models is added (Figure 9) and discussed in Section 4.2 (page 19 line 402)

(2) Equations for the combined 4 areas are added for the linear model (Equations 2-3).

(3) We added text in Section 2.5 (page 13 line 252) to clarify the calculation of residuals

3. Lastly, unless I missed it, there is no discussion of the accuracy of the snow depth measurements. . ..no check of the LiDAR results compared to ground measurements. I suspect the accuracy is order $\pm$10 cm, but the authors need to address this question.

Response: Addressed in the revised manuscript.

Changes in the manuscript: Text added in the last line in Section 2.3 (page 11 line 210) in the revised manuscript.

Responses to detailed comments

1. Abstract: I found this longer than needed and needless confusing. It seems like the first 7 lines were fine, then it bogged down in details that are not first order. For example, that canopy cover decreases from 80% to 0% with elevation is hardly a new result. Does it need to be in the Abstract? The last 7 lines make little sense until one reads the paper. I suggest deleting this or making clearer the meaning of the data.

Response: Abstract revised to meet with the restructured conclusions

2. Introduction:

Get right to it: this paper is not about ALL orographic systems....it is about the Sierras. Plunge in and talk about the current state of knowledge for the west side of the Sierras, and tell us what has been lacking in those data and how this study will fill that gap. On pages 4379 and 4380, you name the studies that have been done, but not what was found and why that information might be deficient. Tell us what the current numbers are for the snow gradients and why these numbers might be in error, then why your LiDAR data can help fix the problem.

Response: Thank you for your suggestions and we rewrote the introduction. Researchers have been successfully using regression trees or univariate regression to model the snow distribution on the west side of the Sierra. However, generally applicable regression coefficients could not be extracted from regression-tree models, and univariate-regression models do not account for the effect of additional topographic variables. And the relative importance of these variables has not been discussed. So the new three main points of the manuscript address these knowledge gaps.

Changes in the manuscript:

(1) Much of the introduction has been rewritten and we now introduce previous findings on snow distribution and knowledge gaps for the Sierra Nevada.

Page 4381, end of Introduction: It seems to me that the three state goals of the paper could be restructured a little differently and perhaps better. The prime goal could be the orographic gradient. In order to get that gradient, you have to deal with the other influences (slope, aspect, canopy), so you do. Also, there is a lot of discussion in the paper of canopy gaps vs. under-canopy snow. You should explain why knowing this is important (for example, is it to produce meaningful areal averages?).

Response: Now addressed please see main comment #1.

3. Section 2.1: Study Area: (see main comments). It is important that here you address why these areas were used, and why they can be used in concert. Looking at the map, they define a line parallel (rather than perpendicular to) the Sierras, which makes one a little suspicious. I was also struck by the differences in the areas. Two are nearly flat; Providence is almost below the rain line, and Wolverton has a huge elevation range. Without it, I suspect it would have been hard to reach the conclusions currently in the

paper. You need to explain why you have confidence in using these sites together. Also, add to Table 1 the mean elevation and elevation range for each site.

Response: Now addressed in Section 2.1 (page 8 line 151). These are the only point-cloud snow-on and snow-off data currently available for the southern Sierra. Another compelling reason to use them together is that the elevation range, after combining, covers from the rain-snow transition zone to above tree line.

4. Section 2.2: Data Collection. It states that met data was used to determine if it snowed during the 4 days of data collection. Did it?

Response: No, it did not. See section 2.2 (page 9 line 176).

5. Section 2.3: Data Processing: Define all acronyms. Page 4383. I ended up drawing a little sketch to clarify the various surfaces. Maybe it is worth adding such a figure. Also, a little more descriptive names might help. For example, why a "Surface Model". Why not a "Canopy Top Model" and a "Snow Surface Model? Finally, some discussion of snow depth accuracy is needed. See the new paper in The Cryosphere by M. Nolan, C. Larsen and M. Sturm for a detailed discussion of this topic.

Response: We followed standard convention for naming of acronyms please see http://neondataskills.org/remote-sensing/2_LiDAR-Data-Concepts_Activity2/ We also addressed the accuracy of the snow depth this time.

6. Section 2.4: Penetration Fraction: Perhaps I failed to understand this completely, par- ticularly the section on under-canopy vegetation. It seems like you are deciding that there is only one canopy (tree tops?) and if the laser gets below that canopy, you discount any shrub-like vegetation? Also, your test of the fraction seems incestuous. Did you test it against independent data?

Response: Because snow accumulates higher than most under canopy vegetation, over most of the domain, we assume that the snow would accumulate as it would in the open. There is no independent data to compare with at this spatial resolution.

Musselman et al., 2013 addressed this question and is cited (page 11 line 223).

7. Page 4384, Line 17: This statement (". . .elevation was selected as the primary topographic attribute. . . " confirms what is effectively true for the whole paper and is why I suggest revising the paper so that primary goal is clear, and treating canopy, slope and aspect as variables that need to be dealt with in order to clarify the main elevation control.

Response: Orographic effect is verified with the Lidar data. But the main contribution of the paper are the additional variables.

8. Page 4386, Line 8: Is the decrease in snow depth above 3300 m real?

Response: We believe this is a real effect probably attributable to exhaustion of perceptible water and/or wind redistribution. However because of the relatively small area above 3300 m, it is highly variable and difficult to draw general conclusions from Wolverton data set without support from other data. Explained in the manuscript as above on page 15 line 308.

9. Discussion, Page 4387, line 7: This "linear model" seems important, but nothing is said about its use. I assume it is used for water balance studies and the like, so it is important to have it as accurate as possible. You should explain why this model is important, and if developing a better model was a goal of the work. Also, why have 4 models? Why not a single, average model? Be sure to include the model as a formula so it is clear how it was done.

Response: We now present a single linear model that includes slope, aspect and penetration fraction for all four areas. Using 4 individual models is slightly better in predicting the snow depth. Either approach could be used depending on the site and question.

10. Discussion of vegetation effects, Page 4388: First, there are many types of vegetation. I think this section really refers to trees and tree canopies. Best to use more

precise nomenclature here. Second, it felt like you were trying to glean too much from the data. There is some interaction between canopy density and snow depth, so that the decreasing canopy density with height is convolved with the increasing depth with elevation. I wonder if it is really necessary (and supported by the data) to dissect this combined effect in too much detail? I also wondered about rain-on-snow, which is not discussed much. It must also affect the interception by the canopy.

Response: We acknowledge that there are many other factors that influence under-canopy snow accumulation. However we did find, by constraining the combined effect of slope and aspect to flatter terrain, that vegetation effects saturate above a certain elevation. Below that elevation, the increase of the snow depth difference could be explained by rain-on-snow and nonlinearity of snow depth increase with elevation. These points are now discussed in section 4.3 and shown in figure 10.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/9/C2324/2015/tcd-9-C2324-2015-supplement.zip

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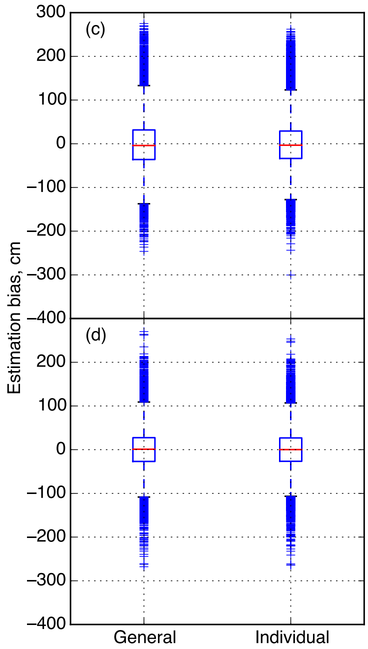
Interactive comment on The Cryosphere Discuss., 9, 4377, 2015.



(c)
(d)
300
200
100
0
−100
−200
−300
−400
Estimation bias, cm
General
Individual

Fig. 1.