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Interactive comment on "Independent evaluation of the SNODAS snow depth product using regional scale LiDAR-derived measurements" *by* A. Hedrick et al.

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General comments

1. *I do not understand the comment "it is paramount that no snow melt occurred between the survey dates in order to properly assess the snow depth component of SNODAS using LiDAR estimates alone." (p. 3150, l. 20-22). I can understand that snow accumulation is the primary phenomenon being examined, but why is it a problem if snow melt occurred during the 81-day span separating the measurements? In section 4 the integrative nature of the measurements is discussed (p. 3153, l. 21-24), and it does not seem to be an obvious problem if snow melt*

is another contributing process.

Response: What we were aiming to accomplish by analyzing the melt estimates of SNODAS was to rule out the melt routines within the energy balance model as a contributing factor of uncertainty in the context of this study. If we are confident that we know where melt occurred between the survey dates, then we can narrow down which processes control SNODAS uncertainty in different locations. The wording was incorrect for the draft, and we are rewriting the discussion of melt in the SNODAS description section to convey that the lack of significant estimated melt indicates that model representations of densification and spatial distribution of snow accumulation is more likely responsible for discrepancies

2. *SNODAS uses quantitative precipitation as its forcing, and assumes a constant bulk density for newly fallen snow. Therefore, SWE is the primary state variable produced by that system, while snow depth is derived as a function of SWE and snowpack density. This relationship is acknowledged (but with the positions of SWE and depth reversed) in the introduction (p. 3143, l. 14), but the following comment that "snow depth varies considerably more than bulk density over space" (p. 3143, l. 16-17) serves to diminish the importance of modeled snow density. However, this came back to me as I read the discussion of the in situ vs. SNODAS comparisons shown in Figure 5b (p. 3152, l. 14-19). SNODAS appears to underestimate snow depth when the observed snow is deep: is it possible that SNODAS overestimates compaction or initial density in these areas of high accumulation?*

   Response: It is true that model estimates of snow depth are likely more uncertain than SWE, especially for SNODAS, which is focused on maximizing accuracy of SWE estimates. Uncertainties in initial density and densification rates could certainly be the cause of the differences, and we now clarify this in the text. The high-resolution independent data available for this comparison study was snow depth from LiDAR, therefore this was the focus – however since the details of

SNODAS model physics were not available, it was difficult to conclusively determine the sources of the discrepancies. We will be changing the manuscript text to highlight the many possible causes of the differences, which certainly include initial density and compaction rate.

3. *I'm having a little trouble with the comparisons shown in Figure 8. Basically, the RMS difference between the in situ and LiDAR data is treated as a random error, but the data shown in Figure 6 depict a systematic error causing the datasets to differ, as discussed in section 4 (p. 3153, l. 3-18). I suppose the use of the RMS difference between the data sets means that neither is considered authoritative, and is a hedge against preferring one over the other. However, given that the LiDAR depths are systematically lower than the in situ depths, it seems more appropriate to treat the LiDAR data as negatively biased, and for example to depict the uncertainty associated with them as a more narrow range centered around a negative value. Perhaps this is not the ideal approach given that the difference between the two sets of observations seems somewhat proportional in nature (i.e., the slope of the line in Figure 6 is significantly less than 1.0), but further discussion of the choice to treat the RMS difference as a random error estimate seems warranted.*

   Response: Though Figure 6 does show a systematic underestimation by the LiDAR, we believe that the magnitude of the bias (5cm shallow sites – 15cm deep sites) is well within the noise of the LiDAR data in the first place. Additionally, the in situ measurements tend to undersample the variability of snow depths more and more as the mean snow depth increases, as shown in this modified Figure 6 below. If we really want to quantify LiDAR biases using the twelve HG sites, we would have to only consider the LiDAR measurements exactly at the probed locations due to the inherent depth variability at short length scales. However, the uncertainty of the reported manual measurement locations is ~7-10 meters due to the mapping-grade GPS receivers that were used at the time.

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The scale difference between SNODAS pixels and probe measurements is very apparent in Figure 5a, as they display a very low correlation. For a reason similar to the LiDAR/HG argument made above, the low correlation between SNODAS and HG stems from the undersampling of the HG surveys not only at the hillslope scale but at the regional scale as well. SNODAS does a good job of representing coarse regional scale patterns over very large areas, but naturally has difficulty with the hillslope and micro-scale variability that can have substantial effects on the timing of surface water input from snowmelt. The main point of Figure 5a (which will be combined with Figure 6 in the revised manuscript) was to show how difficult a task it is to evaluate such a large-scale snow model using sparse manual measurements, which up to this point has been the only technique available.

The slope of the best-fit line in Figure 6 can be explained by the undersampling of the manual measurements as the mean site snow depth increased. The point to point comparison was performed only after averaging all $\Delta LiDAR$ pixels in a 10m radius surrounding the reported in situ measurement location, resulting in the large support discrepancy that was alluded to in the text. An important point to clarify is that the available in-situ data was sampled for calibration and validation of the coincident airborne radar survey, and not to validate the LiDAR snowdepth estimates.

4. *The discussion for "region #1" (p. 3156, l. 5-19) suggests that SNODAS has failed to account for persistent snowpack sublimation in that region, which is certainly possible, even likely. However, the discussion implies that wind speeds that drive SNODAS and its simulation of snow sublimation are inaccurate because there are no nearby SNOTEL sites. I don't find this convincing. I don't see that the proximity of a SNOTEL would make any difference with respect to whether or not wind speeds are well represented in SNODAS forcing data in the area. Isn't it possible that observed wind speeds are assimilated into the forcings used by the*

SNODAS model, since it uses NWP analyses as its primary forcing data, and that many of these come from observation stations other than SNOTEL sites? Perhaps the winds are well represented, but the SNODAS model nevertheless fails to simulate the extent of snow sublimation occurring in the region.

Response: We will change this discussion of distance from SNOTEL sites, specifically, to distance from any station whatsoever. The North Park region is a very sparsely instrumented area and there isn't any other available forcing data to be found. The shallow snowpack combined with the sagebrush vegetation creates a surface that is likely much more rough than the SNODAS model assumes, and underestimates of sublimation due to underestimates of turbulence could certainly be the cause of differences, independent of the accuracy of the wind estimates. We will update the text to reflect this point.

5. *In the discussion for "region #3", why does sub-kilometer scale heterogeneity of snow distribution cause SNODAS to underestimate, and not overestimate, snow accumulation (p. 3156, l. 10-12)?*

   Response: The large sub-km snow depth variability was clear from the LiDAR high-resolution depth estimates, and the in-situ manual observations were in locations that were biased towards high depths. The large drifts contain a significant amount of the total SWE within a 1 km pixel, both due to the large depths, as well as the much larger densities. Large drifts tend to accumulate more snow in the down-wind sides, while their higher densities make their contribution to scouring less than similar topographic features. SNODAS may be underestimating total depth over 1km due to both lower estimated densities, as well as the higher snow deposition due to small scale wind distribution that is not considered in the model.

Interactive comment on The Cryosphere Discuss., 8, 3141, 2014.

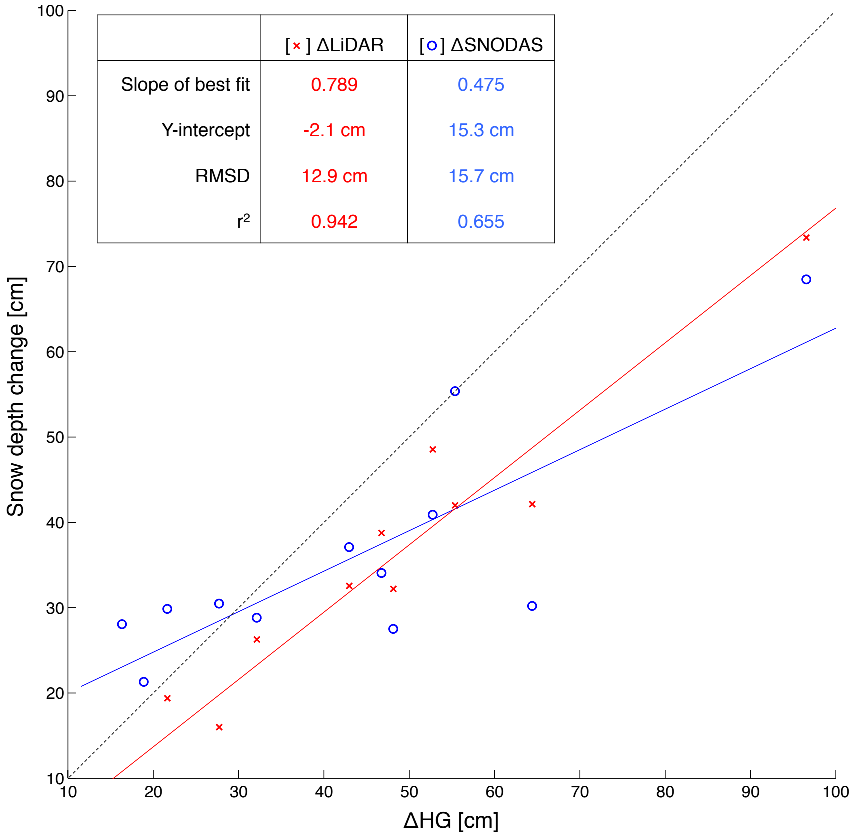

Fig. 1. Modified Figure 5, which combined Figures 5a and 6.