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The Cryosphere Discussions

Interactive comment on "Subgrid snow depth coefficient of variation within complex mountainous terrain" *by* Graham A. Sexstone et al.

Anonymous Referee #3

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Mountainous snowpacks accumulate deep snow and generally exhibit a large range in depth variability over short distances. Subgrid snow distribution is important for reliably simulating energy and mass exchanges between the land and atmosphere in snow covered mountainous regions. The authors attempt to use the snow depth coefficient of variation (CVds), as a metric of subgrid snow variability within complex mountainous terrain, as they feel that the current range of published CVds in this environment is quite variable and is not well parameterized. The objectives of the paper are to use high resolution LiDAR snow depth estimates recorded in the Front Range Mountains of north-central Colorado, over a 321 km2 study site to:

1) Determine the range of CVds values that are observed within varying grid resolutions throughout the study area

2) Evaluate the effects of mean snow depth, forest and topography characteristics on subgrid CVds

3) Develop a methodology for parameterizing CVds within complex mountainous terrain.

The authors fall short on achieving their objectives and/or provide evidence that their findings have already been well documented in previous publications.

1) The authors document that the range in mean CVds values decreases with increasing grid resolutions, which is not a novel result. They do point out that at 500 m there is very little difference in the range of CVds values with increasing grid resolutions >500 m and <1000 m. Their results also highlight a broad range in CVds values, which are as large (between 10th and 90th percentiles) as those currently presented in the literature and documented by Clark et al., (2011) – See specific comment PG 7 – Line 16-17 for details. The differing ranges and median CVds values for both alpine (non-forested) and subalpine (forested) mountainous environments also closely match those presented in Clark et al., (2011).

2) The authors evaluate the effects of mean snow depth, forest and topography characteristics on subgrid CVds values. They find that snow depth was the most important driver of CVds variability in both alpine and subalpine areas which are consistent with previous studies (PG 8 Line 32), which is not a novel result. The strong correlations between CVds (snow distribution) and vegetation parameters, wind exposure, and topography are also not new results, and have been previously well documented.

3) The authors develop two simple statistical models (alpine/subalpine) for predicting subgrid CVds from mean snow depth and topography/canopy information that can be used for parameterizing CVds at this site. However, as the authors state on PG 10 – Lines 1-10, analysis of subgrid snow variability across a greater geographical region (not limited to a single site), with differing snow regimes, using multiple years of data would be needed to improve the applicability of this parameterization for complex

mountainous terrain in general, which was the original 3rd objective .

The paper is well written and presented. The idea of using continuous, high resolution LiDAR data to better parameterize the CVds values in any environment is exciting, compared to the difficult and challenging task of conducting discrete in situ snow surveys. There is always some uncertainty associated with whether or not the discrete measurements will adequately capture the full range of CVds across the study domain. It is promising that the range of LiDAR derived CVds values observed in this study domain seem to match the results of many different in situ snow survey campaigns presented in Clark et al., (2011). It is also promising that the median LiDAR CVds values from this site agree well with the values defined by Liston (2004) for global modeling applications. These positive results highlight that past/present in situ snow survey methods seem to be adequately capturing the CVds values for mountainous environments. However, as the authors themselves highlight, LiDAR is a relatively new (and expensive) technology, and therefore existing LiDAR data are limited to small study domains, and typically of only a single snap-shot for a single winter season, or a very short multi-year time series. Therefore, developing methodology for parameterizing LiDAR derived CVds values that would be applicable to global snow classification using LiDAR data is not quite feasible yet.

Due to the lack of novel results, and the reasons discussed above, I cannot recommend publishing this paper in its current form. Major revisions, including a re-defining of objectives would be necessary. I feel that this paper should be rejected at this time.

Specific Comments:

PG 2 - Line 35-36: Please provide references for the common 1000 m resolution hydrologic and land surface models

PG 4 – Lines 24: TPI is calculated using three different scales (30 m, 110 m, 210 m – All three of these scales are relatively small – why did you choose these three options?). Typically, combining of small and large scale TPI allows for different landforms classes

to be identified. Was this completed? Or were only the raw TPI values used in this analysis? Only a single TPI correlation is presented in Table 1. Which scale of TPI was used? How different were the correlations between scales?

PG 4 – Lines 25-30: Move the description of the canopy density dataset (Line 28-30) to Line 25 when you state that additional forest canopy spatial datasets were also used. Please state who the author/source of the canopy density data is and what year they produced the map (produced by the Multi-Resolution Land Characteristics (MRLC) Consortium, based primarily on Landsat imagery from 2001-2011)

PG 4-5 – Lines 34-2: Awkward sentence. Please re-phrase or split into two sentences.

PG 5 – Line 2-3: Suggest changing to ‘ This study attempts to evaluate the subgrid variability of ds at a comparable grid resolution to a 1000 m grid resolution of an operational snow model (Carroll et al., 2006).’

PG 5 – Lines 3-4: I recommend that you add the description of developing the categorical variables alpine and subalpine (Lines 19-23) to the beginning of the site description to help explain the coloring and extent of the grids in Figure 1, otherwise when you first look at Figure 1 it is not clear on why the grids do not cover the entire LiDAR extent.

PG 5 – Line 5: How and why did you choose these particular grid resolutions to test (100, 200, 300, 400, 500, 750, 1000?)

PG 5 – Lines 31-36: If you deemed some variables unsuitable for parameterizing the snow depth CV and were excluded from the model testing, then simply remove all mention of them from the text (results and methods sections).

PG 6 – Line 19: Suggest changing to ‘increase in subgrid snow depth variability’

I would also suggest using a plot of change in snow depth data if available, rather than the niveograph of SWE. SWE may stay the same if density increases due to melt events (melt/re-freeze processes). Whereas snow depth always decreases during melt events. This paper is also concerned with parameterizing the snow depth coefficient of variation. (See attached Figure 1. taken from Dingman, 2002)

Reference: Dingman SL. 2002. Physical Hydrology Second Edition. Prentice Hall: Upper Saddle River, New Jersey

PG 6 – Line 21: Suggest changing to: 'snowpack melt conditions'

PG 7 – Line 5: Suggest changing to ' tended to increase with increasing grid size for all alpine study grids,'

PG 7 – Line 6: The 500 m resolution study grids had sample size of n=642 stated in the text. In Figure 1, the sample size is n=650.

PG 7 – Line 7: how did you define comparable? What thresholds did you use?

PG 7 – Line 11: insert reference to Figure 5 after providing median snow depth values.

PG 7 – Line 16-17: The snow depth CV values for mid-latitude tree-less mountains presented in Clark et al., 2011 Figure 2 (> 0.50 to < 1.5) agree with the range of snow depth CV values observed in this study for the alpine grids (0.61 to 1.57). The reported range of snow depth CV values for the subalpine (forested) grids (0.3 to 0.98) also fall within the range of reported Clark et al., 2011 values for the mid-latitude mountainous forest (0.10 to <1.0). Watson et al 2006 reported some very large CV values compared to all other studies, exceeding the max subalpine values found in this study ($\sim$1.75), however, the majority of their reported CV values were <1.0 agreeing with the results of this study. Therefore the range of observed CV values reported in this study seem to be already well documented for complex mountainous terrain.

PG 8 – Line 22-29: Liston's 2004 definition of nine different snow distribution categories and their typical snow depth CV values appear to agree well with the median CV values reported in this within this study. The reported range of CV values found within Clark et al., 2011 agree well with the values found within this study site (See comment for PG 7 – Line 16-17 above), and therefore it appears that CV values in complex mountainous terrain may already be adequately documented.

PG 9 – Line 5-9: Agreed. These two sentences describe future work that would be necessary to achieve objective 3 of this paper.

PG 10 – Line 7-10: Agreed. Future studies with multiple years of LiDAR measurements would be useful for achieving objective 3.

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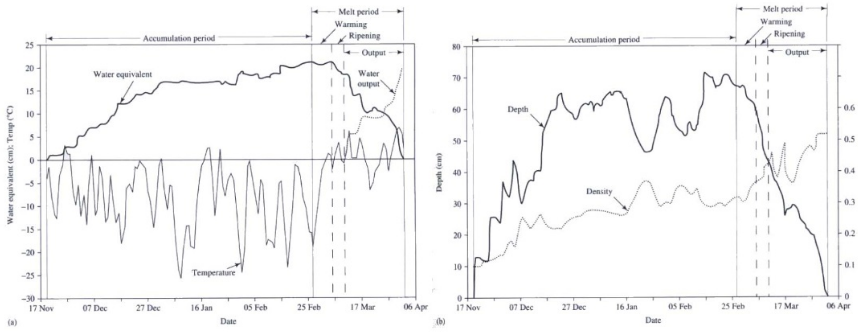

Dingman 2002, Figure 5-24

Fig. 1.