Response to review comments

Manuscript Number: **NHES-2020-302**

Submitted title: **Synoptic atmospheric circulation patterns associated with deep persistent slab avalanches in the western United States**

***We would like to extend our sincere thanks to the editor Yves Bühler and the two anonymous reviewers for taking the time to review and comment on our manuscript. Below you will find our responses to the general and specific comments provided to us. Note that we refer to line numbers referencing the modified and resubmitted document. Thanks again for your consideration and help bringing this manuscript to publication*!**

Comments from the editors and reviewers: (in plain text)

Responses from the co-authors (bold)

Reviewer #1 Responses

General Comments

The study builds on previous research and covers a novel approach to relate large scale weather patterns in early winter season combined with recent snowfall amounts to major and minor avalanche cycles with avalanches fracturing deep in the snow cover. These cycles are generally difficult to foresee and can cause considerable damage and loss of human lives. The study covers different climatic regions in western US and long data series. The analysis takes avalanche activity data with snow cover characteristics into consideration. The study is well organized and the paper well written. The results are valuable for the community in that it adds knowledge on the relationship of climatologic snow cover characteristics to avalanche activity. To underline the strength of the method and to put it into a forecasting perspective, I recommend to show and discuss in more detail the cases, when long- and short-term weather patterns are typical for deep slab avalanche cycles, but the cycle does not occur as well as on the advantages over a pure correlation with 72h storm totals. Furthermore, please consider are a few more small comments below

Thank you for these comments. We have provided additional details in the discussion as to how this method is of value for forecasting, and some additional information on how this reduces uncertainty for these types of events, over a 72hr storm total. The specific details are listed below. We have also addressed all of your comments below:

Introduction: Line 34: Please cite literature on avalanche formation in persistent weak layers for wet avalanches.

We added references to Baggi and Schweizer (2009), Marienthal et al. (2012), and Pietzsch (2009) to line 36 in the updated manuscript.

Line 57: Please also consider the work by Sturm, Holmgren et al. (1995) Climatic snowpack classification system; with classes for the seasonal snowcover according to stratigraphic and textural attributes

This paragraph is included to provide background relevant to synoptic climatology, which explicitly links atmospheric circulation to surface properties. The Sturm, Holmgren, and Liston (1995) snow cover classification paper is more closely related to the Mock and Birkeland (2000) paper, which uses meteorological variables (e.g. temperature, precipitation, rain events) to characterize different snowpacks, and does not fit into the synoptic climatology framework. The snowpack climatology classification system is relevant to this study, and we reference the Mock and Birkeland (2000) paper since it is more recent and more applicable to our study area (line 106 in the updated manuscript).

Study locations and methods: All study sites are ski resort, explain in more detail how disturbed/undisturbed the snow cover is by skiers and explosives, and how this has changed over time and how this may influence avalanche activity and avalanche size. Please show your definition of wet versus dry avalanche (where is the snow wet? – in the starting zone and/or path and/or deposition zone). How it it recorded? Deep wet avalanches are often correlated with first wetting of deep layers. Is this data available? Avalanche classification: Avalanche dynamic studies show, that the crown-depth but also the amount of erodable snow (new and old snow) in avalanche paths determines the dynamics and runout length of large avalanches. Hence, it is important, from where the measurements of the 72h storm totals are. Is there a difference in altitude of the location the measurement and the avalanche crown and/or the avalanche path? Please explain in more detail.

We added a more thorough description of the ski area record to the methods section (lines 116-126 in the revised manuscript).

We included a sentence with regards to the wet vs. dry designation (line 134 in the revised version). These records are used as part of a holistic approach to assess snowpack stability from an operational perspective. They can be recorder-dependent and do not necessarily involve direct measurements or a thorough examination of the avalanche. However, for reasons mentioned previously, they remain the most reliable and consistent record available in the US. Our classification process (described in section 2.4) minimizes the effect of this uncertainty by taking multiple metrics into account to identify large avalanches.

Discussion: Please discuss the reverse case in more detail, where typical long- and short-term weather patterns for deep slab cycles are present, but no minor or major deep slab avalanche cycles occurred. Please discuss the advantage of the presented method over simple correlation with 72h storm totals

We added a section on this the discussion (lines 518-528).

This method is not intended to replace any existing methods (i.e. weather, snowpack, and avalanche observations, test results, etc.). However, the tools we currently have available often leave a large amount of uncertainty in predicting the timing of these events. Our results should be able to reduce that uncertainty by providing another indicator of increasing likelihood. We added text (lines 576-585) with respect to incorporating our findings in a typical workflow already used by practitioners.

line 405: There is also subset -> There is also a subset line 436: wetter -> weather

Line 405 error fixed. Line 436 is intended to say wetter, referring to patterns with more precipitation.

We trust that the editor agrees that we have considered, and generally agreed with the vast majority of the peer review and editor comments provided for our submission. These review comments have greatly helped improve the clarity of the paper, and the narrative provided.

Kind regards

Andrew Schauer

(on behalf of the author team)

References used in this response:

Baggi, S., and Schweizer, J.: Characteristics of wet=snow avalanche activity: 20 years of observations from a high alpine valley (Dischma, Switzerland), Nat. Haz., 50, 97-108, doi: 10.1007/s11069-008-9322-7, 2009.

Marienthal, A., Hendrikx, J., Birkeland, K.W., and Irvine, K.: Meteorological variables to aid forecasting deep slab avalanches on persistent weak layers, Cold Reg. Sci. Technol., 120, 227-236, doi:10.1016/j.coldregions.2015.08.007, 2015.

Mock C.J., and Birkeland, K.W.: Snow Avalanche Climatology of the Western United States Mountain Ranges, Bull. Am. Meteorol. Soc., 87 (10), 2367-2392, doi: 10.1175\/1520-0477(2000)081<2367:sacotw>2.3.co;2, 2000.

Pietzsch, E.H.: Water movement in a stratified and inclined snowpack: Implications for wet slab avalanches, MSc thesis, Montana State University, Bozeman, MT, USA, 2009.

Sturm, M., Holmgren, J., and Liston, G.E.: A seasonal snow cover classification system for local to global applications, J. Clim., 8 (5), 1261-1283, doi: https://doi.org/10.1175/1520-0442(1995)008%3C1261:ASSCCS%3E2.0.CO;2, 1995.