To: Natural Hazards and Earth System Sciences
Reviewer 1
Re: Author Responses to Reviews of Manuscript (nhess-2021-193)
Date: 12-Nov-2021

Dear Reviewer 1,
Thank you for your positive feedback and constructive comments. We are addressing and incorporating your suggestions and look forward to submitting a revised manuscript. Our initial responses to your comments are in **bold** with revised text in red.
Sincerely,
Benjamin Hatchett

Summary The paper provides a visualization of the progress of snow water equivalent and simultaneously precipitation which allows to determine unset evolution and termination of snow drought this work contributes to monitoring and managing snow droughts the presented approach is an improvement to single date approaches. It also presents an implemented application of the approach in the western US snow monitoring (web tool). I think the approach is very useful and should be disseminated. I really appreciate the idea to not stick to a calendar day to define snow status but rather using the evolution and setting it in perspective to the long-term expectation to be able to define a drought. The paper is written clearly and has a logic structure, however I have some comments that the authors might want to consider before publication.

We appreciate your positive feedback!

I. Main comments

While I really like the proposed visualization using phase diagrams to simultaneously track snow pack and precipitation, I think the paper does not advertise the approach enough. The opportunities that are opened by using the phase diagrams to visualize could be even more clearly presented. That is in my opinion not because it is not written but because it is hiding a bit in the many ”side stories” in the paper.

For instance, now there is relatively much space given to the description of the web-based tool, which I would keep rather short to better present different opportunities these method offers beyond the application it already has in the web tool.

We appreciate the suggestion to further revise the text on the tool for brevity. Following the note below, we will add some additional discussion about how the tool can inform impacts of snow drought. This is a great suggestion as the goal of the tool is ultimately to support management as well as help researchers understand the temporal evolution of snow drought and its hydrologic impacts.

On this line, the authors could also clearer discuss, e.g., the impact of the snow evolution on summer low flows; is there a effect in summer at all?

Good suggestion, we will add additional text on these potential impacts for two of the areas

we use as case studies (the Nisqually River watershed and the San Juan Mountains).

Comment

Since not everywhere in the world there is such a snow measuring network like SNOTEL it would be good to put the comparison of station two gridded snow data a bit more in focus which makes this approach more interesting for areas without dense station network.

Very good point. While the purpose of our paper is not to do comparison with stations versus observations (this has been done by the University of Arizona group who developed the UA SWE product), we appreciate the reviewer's highlighting the need to apply this technique (and the snow drought concept) to poorly instrumented regions. We will add an example of this for the northeastern US using the UA SWE product operating under the assumption that if UA SWE performs reasonably well in the western US it should be at least reasonable for the eastern US. The northeastern US heavily relies on snow for recreation and ecosystem services, but does not have a long-term observational network like the SNOTEL network in the western US. In our revised manuscript, we plan to add a figure showing northeastern US spatial and a phase diagram for a standout snow drought year.

Comment

The authors might consider and discuss for which region regions of the world the presented approach might be a useful approach this is not everywhere the case because winter precipitation is the main driver off summer flow conditions (e.g., Jenicek et al. 2016).

Thank you for the suggestion. We will add text noting this limitation of our approach as not being ideal for regions or watersheds where precipitation, and not snow, is the dominant driver of summer flow magnitude and variability, such as identified in Jenicek et al. 2016. The northeastern US example above is a good location to highlight this, and we will think of other examples world-wide where this effect may play an important role.

Comment

How sensitive are the seven days longterm that are used to define the drought via quantiles should that be per calendar day or rather day of progress of the snowy season, i.e. day after start of season?

While developing the percentile windows, we tested three, five, seven, and nine-day windows (with the center date on the day of interest) and did not identify notable sensitivity to this window. As our goal was to remove seasonality (e.g., start of season versus peak snowpack) and still capture day-day variability, we settled on seven days as optimizing the removall of seasonality but also capturing variability by increasing the sample size. In our revision, we will provide a supplementary figure showing the lack of sensitivity.

To the reviewer's second point, we will also explore starting the trajectories on the calendar day once there is snow (rather than 1 Nov as we did in the initial submission). This may help avoid large jumps at the start of the season when snowpack can rapidly accumulate.

II. Minor Comments

Comment

L21 add that for some areas this very much depending on the climate see for example Jenicek et al. (2016) as opposed to Godsey et al. (2014) where that is true

Good point, we will add references to the western US and note this limitation in our discussion. New text:

In the western U.S., spring snowpack is an important predictor of warm season runoff for environmental flows and human consumptive use (Godset et al. 2014; Siirila-Woodburn et al. 2021). However, in lower elevation, humid summer climates, snowpack plays a lesser role in controlling summer hydrologic regimes, i.e., summer flow is less dependent on peak SWE (Jenicek et al. (2016).

Comment

L96 regarding the percentiles does this really reflect drought severity as it does for precipitation i.e. are the same range is adequate for snow data?

Great question. Percentiles are common way to track/identify drought. They normalize the anomaly, meaning it can be applied anywhere and offers a point of reference. Similar percentile-based numbers based on the drought categories identified by the United States Drought Monitor (USDM) have been used by other authors (e.g., Marshall et al. 2020, Siirila-Woodburn et al. 2021, Huning and Aghakouchak 2020), however no precise threshold has been identified for drought severity. Drought means different things to different people or systems. The drought categories identified by the United States Drought Monitor (USDM) is more of a rule of thumb intended to show where likely impacts will occur and based on stakeholder feedback.

As the purpose of our paper is tracking and monitoring snow drought with the intent of broad applications, we will add text highlighting this potential limitation and the need for future work to further constrain and identify meaningful percentile-based thresholds are by region.

Comment

L382/3that a drought onset is approximately at 85% of median snowpack should be made mentioned earlier in the article. **Thank you for the suggestion, we have added text to the introduction addressing this point:**

In addition, no clear definition for snow drought onset exists to our knowledge. For example, Hatchett and McEvoy 2018 used 80% of average SWE and Harpold et al. 2017 used below normal (average) SWE. Depending on the variability of snowpack accumulation, which varies by location and geographic region, snow droughts may occur across a range of percentages of average and are not easily comparable. This motivates the use of a percentile-based approach to facilitate regional comparisons.

Comment

Figure 2 left panel: I would suggest to put the annotations outside the plot and just add a line pointing at the labeled parts particularly under the left side of the plot it is very dense and is better readable outside the plot; right panel: Some of the text is hard to read consider larger font or darker color

Thank you for the suggestions. We have cleaned up the plot as suggested and agree it has improved. We are also adjusting the phase diagram plots following the second reviewer's comments and will include the new plots in our revised manuscript.

III. Technical comments by line (L) number

L9 add with before streamflow

Added "with"

L22 "in efforts of 89% of areas western United States" please reword not clear

Good suggestion, we apologize for the unclear statement. We have revised as follows:

"Snow water equivalent loss is projected to decline by 40-60% in the western United States (wUS) by end-century (Woodburn et al. 2021). For regions historically characterized by a seasonal snowpack, these declines are projected to reduce drought prediction skill (Livneh and Badger 2020)."

L23 change "will" to "are predicted to"

Change made, thank you.

L30 defined or not? maybe rather use roughly or about

Correct, "defined as". To make this more clear, we revised to: "defined as November–May".

L41 to be for varied user groups

Good catch, revised to: "...conditions **to** varied user groups..."

L44 allows to allow; "track their" referring to signals? Not clear

Thanks for noting this should be made more clear. We revised to:

"allow a user to track snowpack and precipitation evolution through the cool season or the entire water year (WY)."

L41-44 consider breaking the sentence into for better readability

Good suggestion. We broke this into two separate sentences:

"These challenges, and the need to communicate mountain hydroclimate conditions to varied user groups (e.g., the National Weather Service, natural resource managers and other decision makers Marshall et al. 2020), illustrate the need for easily-accessible, informative data visualization approaches. Ideally, these visualizations capture the signals of interest for decision-relevant contexts and allow a user to track snowpack and precipitation evolution through the cool season or the entire water year (WY)."

L46 remove also before demonstrate

Change made, thank you.

L58 add reference to Table 1

Table reference was added, thank you.

L64 What was the motivation to use this station? Why not one for each snow climate?

We selected this pair of SNOTEL and streamgage stations to use this region as proof of concept for sensitivity of runoff to varied snow drought conditions. We revised the text to point this out more clearly:

Last, we highlight an example of how snow drought conditions influence streamflow and to show how to link phase diagrams with hydrologic outcomes. To do this, we acquired daily streamflow for WYs 1943–2019 from the U.S. Geological Survey Gage 12082500, located on the unimpaired Nisqually River, near the Paradise, Washington SNOTEL site (Fig. 1b).

Figure 1: is it possible to push elevation legend bar down a bit?

Elevation bar has been moved down.

L68 add space before "Phase "

Space added.

L69 is → are

Change made, thank you.

L77 are → is

Change made, thank you.

L104 remove the before 31

This has been removed, thank you.

L 427 National Weather Service specify that this is for the US

We have clarified this, thank you.

Added References:

Godsey, S. E., Kirchner, J. W., and Tague, C. L.: Effects of changes in winter snowpacks on summer low flows: case studies in the Sierra Nevada, California, USA, Hydrol. Process., 28, 5048–5064,doi:10.1002/hyp.9943, 2014.

Jenicek, M., Seibert, J., Zappa, M., Staudinger, M., and Jonas, T.: Importance of maximum snow accumulation for summer low flows in humid catchments, Hydrol. Earth Syst. Sci., 20, 859–874, https://doi.org/10.5194/hess-20-859-2016, 2016.