Response to Referee #2:

The authors would like to thank you for the constructive and thoughtful comments. We have addressed all your suggestions, leading to a much improved and complete manuscript. The following comments are addressed in the sequence as they were asked. We also respond to each point and clarify the corresponding changes adopted in the revised manuscript. The original comments are copied from the report with a **bolded font in black**, and our answers are in blue. Manuscript changes are in ***bold italic***.

Thank you again for your time and effort in reviewing our manuscript.

Yours sincerely

Baoqing Zhang (on behalf of all co-authors)

Reviewer #2

The authors developed a global dataset of standardized drought indicators incorporating snow information. They first evaluated the indicator and then employed it for the drought temporal-spatial analysis across the globe. This is an interesting dataset for the drought analysis at the global scale. I have several comments as follows.

Reply: We appreciate the reviewer's comments and interest in our work.

General comments

Figure 1 In the box of hydrological drought. The advantage (green box) is "considers snowpack and water storage" and the disadvantage (red box) is "unsatisfactory performance over snow covered regions". What is the reason for the "unsatisfactory performance over snow…" if these indices already consider "snow pack"?

Reply: We would like to apologize for this vague description. We list three drought indices in the box of hydrological drought (i.e., SDI, PHDI, and SWI). The streamflow drought index (SDI) only requires monthly streamflow for its calculation. The Palmer hydrological drought severity Index (PHDI) requires monthly temperature, precipitation, and water-holding capacity of soils for its calculation. Thus, the SDI and PHDI have unsatisfactory performance over snow-covered regions because the input parameters of the two indices (SDI and PHDI) do not include parameters related to snow.

In the three listed indices in the box of hydrological drought, only the SWI (surface water supply index) considers snowpack in its calculation. Its input parameters include streamflow, precipitation, reservoir storage, and snowpack. Nevertheless, the SWI is basin-dependent by calculating at the basin level, and it is difficult to compare basins, not to mention at the grid level.

To clarify this vague description, we will update Table S1 in the supplementary material, which will clearly list the strengths and weaknesses of each drought index shown in Figure 1.

Figure 1 It seems the SZI addresses all the challenges of the indices mentioned in this figure. Is there any remaining disadvantage or limitation of SZI? Please clarify.

Reply: We agree with this comment and admit that the SZI can not address all the challenges of the indices mentioned in this figure. The SZI does still have some remaining disadvantages or limitations. Figure 1 is used to show our motivation and train of thought for the development path of the index. We thus did not put too much emphasis on the limitations of the SZI in the original manuscript. In general, there are two main limitations of the SZI. The first one is that its computation is more complex and difficult than the SPI or SPEI. Another limitation is that its calculation requires long-term climatic and hydrologic records, making it unsuitable for short-term drought identification and monitoring.

Following the comments, we will add the following information into the fourth paragraph of Introduction Section in the revised manuscript:

Additionally, there are two main limitations of the SZI. The first one is that its computation is more difficult than the SPI or SPEI. Another limitation is that it needs a long-term serial of hydrometeorological records, making it unsuitable for short-term drought studies.

Lines 133: "We evaluated the ability of the SZIsnow and SZI to capture different" It is generally hard for a single drought indicator to capture all types of droughts. Is the SZI designed to capture all drought types?

Reply: We cannot agree more with this comment. It is generally hard for a single drought indicator to capture all types of droughts. Indeed, it is essential to realize this challenging objective. This is because the impacts of droughts are significant and widespread, affecting many economic sectors and people at any one time. In addition, different types of droughts are considered to be interchangeable. Drought can convert from one type to another as it evolves in time and space. Nevertheless, different administrative departments nowadays employ various drought indices for drought management, leading to unaligned action plans against drought. Without alignment, there is likely to be considerable delay in action at the onset of drought in an area or region. Therefore, our study strives to design a drought index, SZI, to capture all drought types. Though it is challenging to develop a multitype index and our proposed index is not 100-percent perfect, our work is on the right track. In this way, different sectors of society can collaborate to synergistically fight against drought using a comprehensive drought index.

Lines 201-202: Here P and Psnow are used to define the water supply deficit. This equation is only applied in regions and seasons with snowfall, right? What about other regions (e.g., tropics)? Do you use a different set of equations to calculate SZI?

Reply: Our equation can be applied in regions and seasons with and without snowfall. For the regions without snowfall (e.g., tropics), the items relevant to snow in the equations are set to zero for the calculation of SZI_{snow}. For example, in the following equation, the $P_{snowfall}$, $\delta_j PSA$, and $\varphi_j PSM$ are set to zero when they are used for situations without snowfall.

$$\begin{cases} P = P_{rainfall} + P_{snowfall} \\ Z_{snow} = P - \hat{P}_{snow} \\ \hat{P}_{snow} = \alpha_j PET + \beta_j PR + \gamma_j PRO + \delta_j PSA - \varepsilon_j PL - \varphi_j PSM \end{cases}$$

This comment is an important reminder for our study. Following the comments, we will add some information into section 3.1 of the revised manuscript to explain how to calculate SZI_{snow} for regions and seasons without snowfall:

In addition, our equations can be applied in regions and seasons without snowfall. For regions without snowfall (e.g., tropics), the items relevant to snow in the equations of Table 1 are set to zero for the calculation of SZ_{Isnow}. For example, $\delta_j PSA$ (Equation 8), $\varphi_j PSM$ (Equation 8), and $P_{snowfall}$ (Equation 9) are set to zero when they are used for situations without snowfall.

Lines 244-245: Here the authors used SPI to evaluate the proposed index SZIsnow. SPI mainly reflects precipitation-related droughts. There may not be snow information in SPI (it does not incorporate snowfall, right?). How do we know a higher SZIsnow-SPI correlation reflects better performance of the proposed index? Please justify this.

Reply: The standardized precipitation index (SPI) uses historical precipitation records for any location to develop a probability of precipitation that can be computed at any number of timescales, from 1 month to 48 months or longer. The only input parameter of SPI is precipitation, which is the greatest strength of SPI. Precipitation is regarded as the sum of rainfall and snowfall during the calculation of SPI. Thus, the SPI considers the snow information, and it is reasonable to use SPI for the evaluation of the SZI_{snow}.

Lines 294-295: It seems the proposed index performs better for long-time scales. Any specific reason for this? Please clarify.

Reply: We agree with this comment that the proposed index performs better for long-time scales. There are mainly three reasons for its better performances at long timescales. Firstly, the magnitude of the accuracy of the moisture anomaly Z_{snow} (Equation 9 of Table 1) is small at a short timescale (e.g., 1-month). In comparison, the accuracy of Z_{snow} becomes relatively larger at a long timescale (e.g., 12-month) because the 12-month Z_{snow} on a certain date is an accumulative value by summing up monthly Z_{snow} of the prior 12 months. Accordingly, the improvement is more evident at a long timescale. Secondly, it usually takes a long time from the arrival of precipitation (rainfall and snow) to precipitation becomes different forms of useable water.

Precipitation infiltrates into the groundwater takes longer than it directly converts to overland flow. In addition, the snowpack accumulates in the cold season, and snowmelt drains into the soil or directly into the river channel in the warm season, which leads to a several-month to 1-year lag response in the soil wetness and total water storage variability. At last, long-term droughts always cause more widespread and severe consequences than short-term droughts. The capacity of the SZI_{snow} to identify and monitor long-term drought is the focus of our study.

Figure 6. This trend analysis for each grid is performed for the annual time series? Or for a season? Please clarify.

Reply: We performed the trend analysis for each grid in Figure 6 for the annual time series. Following the comments, we will provide a clearer caption and description for Figure 6 in the revised manuscript as follows:

Figure 6: Spatial distribution of the linear annual trend (changes per 50 years) in the SZI_{snow} during the period 1948–2010, at various timescales. The stippling denotes the trend being statistically significant at the 95% confidence level.

The spatial distribution of the linear annual trend in the SZI_{snow} over different timescales (i.e., 3-, 6-, 12-, 15-months) is shown in Fig. 6.

Figure 7 Any speculation for the low SZI and high dry areas during 1985-1990?

Reply: The SZI_{snow} employs precipitation amount (referred as $\widehat{P}_{snow}$) that is climatically appropriate for existing conditions to quantify the regional water demand. The moisture anomaly Z_{snow} is defined as the difference between the actual Precipitation (P) and $\widehat{P}_{snow}$, which is an appropriate indicator for regional water deficiency or surplus. In Figure 7b, we used Z_{snow}, instead of SZI_{snow}, to represent dry and wet conditions over a region. There is a negative correlation between Z_{snow} and dry areas. Thus, the high dry areas correspond with the low Z_{snow} during 1985-1990.