# Response to Reviewer

Dear reviewer,

We are very grateful for your recognition and encouragement of our work, and your professional guidance has provided us with new perspectives and ideas that will undoubtedly enhance the quality and impact of our research. We believe we have addressed all of the comments, and we feel our manuscript has become substantially stronger as a result of these improvements. Our point-by-point responses to your comments are listed below in black.

The manuscript presents a valuable contribution to the field of snow phenology by proposing a dynamic threshold method for snow phenology extraction in the Northern Hemisphere. The study effectively highlights the limitations of the traditional fixed threshold approach and demonstrates the advantages of the dynamic method in capturing the spatial heterogeneity and temporal variability of snow cover.

Response:

Thank you very much for your insightful and thorough evaluation of our manuscript. We greatly appreciate your recognition of our work.

**Main comments:**

1.The sentence "Our analysis further indicates that the changes in snow depth exhibits a significant shift around 10% of peak value across the Northern Hemisphere, marking the transition between the snow and non-snow seasons." need to clarity. I feel it's difficult to understand.

Response:

We apologize for our lack of clarity, which makes it difficult for readers to understand. This has now been corrected.

Our main approach is presented in Section 2.3 and illustrated in Figure 1. Specifically, after normalizing the snow depth data, we compute its first derivative and determine the percentage threshold based on the physical meaning of the first-order derivative. The first-order derivative represents the actual rate of snow accumulation and melting, with its extreme points indicating the maximum rate of snow change. When the first-order derivative equals zero (at the beginning and end of the curve, rather than at the maximum), it signifies that snow has either not yet begun to accumulate or has completely melted. The intermediate state between the maximum rate of snow change and no change corresponds to the onset of snow accumulation or the near completion of melting—this is the key phase we seek to identify for SCOD and SCED. Therefore, we define the extreme midpoint of the first-order derivative as the turning point of the snow curve. The percentage value at this turning point serves as the threshold required for our analysis.

To evaluate the generalizability of the percentage threshold, we perform calculations not only for the entire Northern Hemisphere and individual latitude bands but also at the grid-point level. The results for the Northern Hemisphere are presented in Figure 1, while those for different latitudinal bands are shown in Figure R1. The ratios consistently converge toward approximately 10%. When applying the same calculation at each grid point, we find that 73.05% and 82.65% of the two ratios fall within the 5%-15% range, respectively (Figure 5). Therefore, the final ratio is set at 10%. It is clear from the schematic in Figure 1 that below the 10% position of the curve, the curve is very flat. Above the 10% position, the curve changes rapidly.

Due to the word limit of the abstract, it cannot be interpreted in this way with multiple characters. We have changed this sentence in the manuscript for better understanding.

Line 11:

*After normalizing, the percentage snow depth curve turns significantly at the 10% position, marking the transition between the snow and non-snow seasons.*

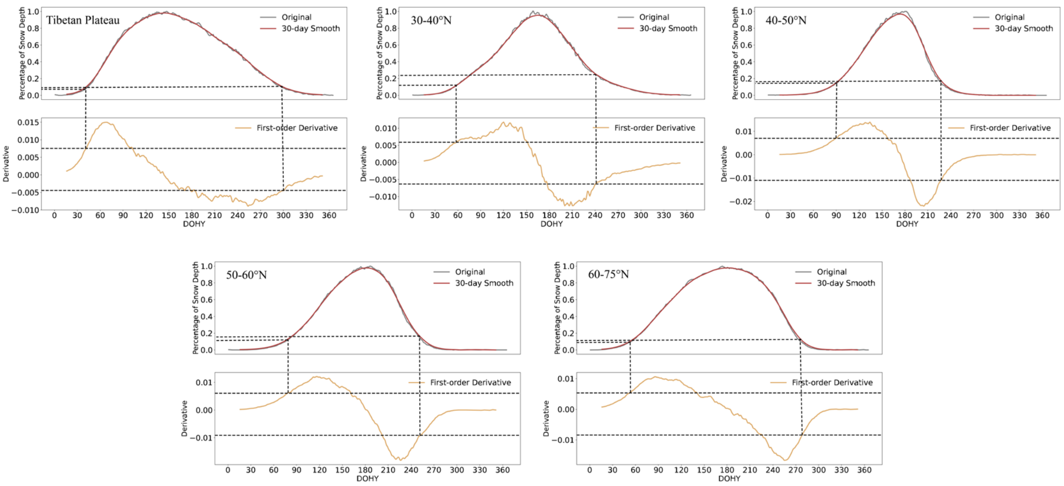


**Figure R1**. Schematic diagram of ratio results calculated at different latitudinal zones, including the Tibetan Plateau, 30°N–40°N, 40°N–50°N, 50°N–60°N, and 60°N–75°N. Similar to Figure 1.

2. The introduction could be more focused on the specific research gap addressed by the study. Could you rewrite it?

Response:

Thank you for your advice. Indeed, the introductory part of our manuscript has too much padding, and the specific research gap is told relatively little later. Therefore, we have abbreviated the background and detailed the problems in the field of snow phenology in the penultimate paragraph. The section of the manuscript on the specific research gap, which has been significantly altered, is shown below.

Line 53:

*Snow phenology was generally obtained through a two-step process in previous studies, i.e., identifying the presence or absence of snow in the grid based on a given threshold and calculating snow phenology indicators (Peng et al., 2013; Yang et al., 2019; Notarnicola, 2020). Various types of snow data are used to extract snow phenology, including SDs, snow cover fractions, and snow water equivalents, leading to possible differences in identified snow phenology (Chen et al., 2015; Guo et al., 2022). Additionally, most studies have employed a fixed threshold to extract snow phenology in different regions and years (Brown et al., 2007; Gao et al., 2011; Yue et al., 2022; Tang et al., 2022). The fixed threshold for snow phenology fails to account for the variations in snow cover across the NH. In fact, snow cover increases with latitude, with thick and stable snow cover at high latitudes and shallow and short-lived snow cover at middle and low latitudes, especially in the TP (Orsolini et al., 2019). In addition, the snow changes from year to year due to many aspects of the climate, and the regional snow cover trends exhibit a heterogeneous and non-linear response to its regional warming rate (Blau et al., 2024). Snow conditions are variable, but thresholds are always fixed, which can lead to inaccuracies of snow phenology. Therefore, employing different snow data and a fixed threshold will lead to uncertainties in extracted snow phenology. At present, it has been proven in the methods of extracting vegetation phenology that fixed thresholds cannot accommodate spatio-temporal heterogeneity, ignore inter-annual variations, and are not applicable to diverse* *vegetation types, among a series of other problems (White et al., 1997; Mo et al., 1997). However, this issue regarding snow phenology extraction methods has not yet received attention and resolution. In fact, the onset of the snow season is marked by the sustained accumulation of snowfall as ground snow, rather than being determined by a fixed threshold. We aim to propose a novel method that incorporates both spatial heterogeneity in snow cover and temporal variability to extract snow phenology, reducing the uncertainty associated with the fixed threshold method from a physical meaning perspective.*

3.If possible, could you add a sentence or two to explicitly state the research objectives and the main contributions of the study.

Response:

Thanks for your suggestion. We have added sentences to explicitly state the research objectives and the main contributions of the study.

Initially, we find that the method commonly used to extract snow phenology overlooks regional variability in snow characteristics and its temporal evolution. This limitation motivates us to improve the approach to enhance its accuracy and applicability. To support our argument, we first compare snow phenology results derived from different datasets to assess whether the fixed threshold used in snow evolution can reasonably capture the start and end of the snow season. After highlighting the shortcomings of the existing method, we aim to refine the method to achieve more accurate snow phenology extraction. Finally, we focus on the Tibetan Plateau, a region with unique topography and climate, to examine the generalizability and limitations of the new method.

In the manuscript, it is true that our objectives are not explicitly written, and they have now been added.

Line 68:

*We aim to propose a novel method that incorporates both spatial heterogeneity in snow cover and temporal variability to extract snow phenology, thereby reducing the uncertainty associated with the fixed threshold method.*

The main contribution of our study is the completion of our predefined objectives. At the end of the Conclusions and Discussion in the manuscript, we briefly summarize our main contributions of the study.

Line 413:

*In this study, we explore the spatial distribution of snow phenology in the Northern Hemisphere (NH) using several sets of satellite remote sensing snow data and multiple methods. A new extraction method for snow phenology is proposed in the NH, and the differences in snow phenology using the traditional and new methods are compared to evaluate the new snow phenology method.*

4.It would be helpful to provide a brief explanation of the rationale behind choosing the 30-day moving window for smoothing the snow depth data.

Response:

Thank you for your advice. In practice, the selection of a 30-day moving window is not of particular significance; its main function is to smooth the data, reducing noise and limiting the influence of random snowfall timing on snow phenology extraction. Snow changes are more stable and reliable on a monthly scale. To evaluate the impact of different smoothing windows, we calculate the dynamic threshold using percentage of snow depth derived from the first-order derivatives (see Methods) and illustrate the results in a line graph (Fig. R2). The snow depth percentage remains relatively stable when the smoothing window approaches 30 days. When the window is smaller than 30 days, the curve declines steeply, whereas for values exceeding 30 days, fluctuations are minimal. Based on this analysis, we adopt a smoothing window of 30 days. While slight variations in the window size do not significantly alter the results, a window that is too small amplifies noise, whereas an excessively large one may obscure valid information.

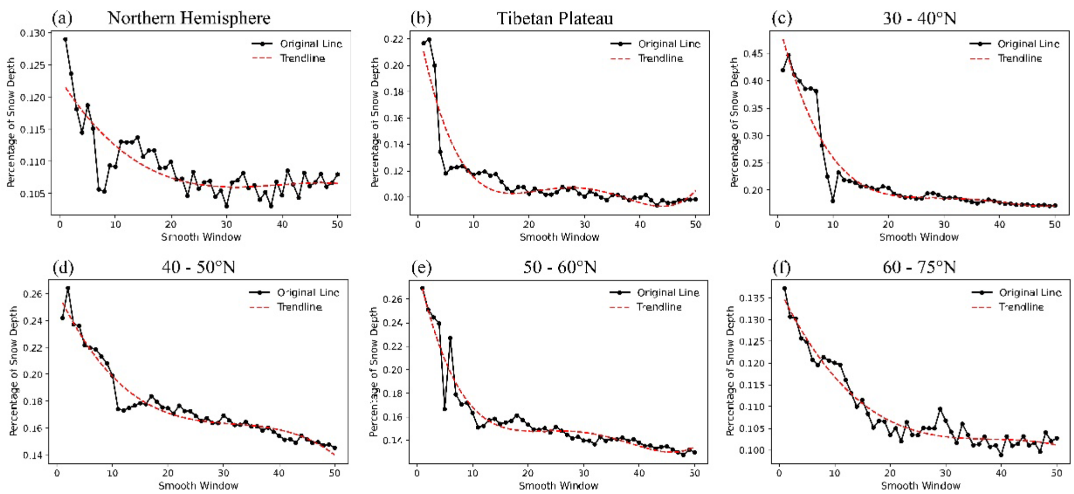


**Figure R2**. The relationship between the percentage of snow depth (dynamic threshold) and smooth window in (a) the Northern Hemisphere, (b) the Tibetan Plateau, (c) 30°N–40°N, (d) 40°N–50°N, (e) 50°N–60°N, and (f) 60°N–75°N. The black line is the original line, the black dot is the specific value for each year, and the red line is the trend line.

5.The conclusions clearly summarize the main findings and contributions of the study.

Response:

Thank you for your compliments. We have followed your suggestions and further improved the manuscript.