

Point-by-point reply on RC1

Black font = Reviewers' comments

Blue font = Response to reviewers' comments

Red font = Changes in the text of the manuscript

We thank the editor and reviewers for the valuable feedbacks on our manuscript. We have addressed all point-by-point reply below.

Overall Evaluation

This manuscript develops a fully integrated open-source Python toolbox (MSDT) for standardized snow drought assessment across yearly, monthly, and daily temporal scales. The authors integrate seven widely adopted snow drought identification algorithms, embed automated SWE data downloading, interactive geospatial visualization, and standardized NetCDF output within a graphical user interface. Global ERA5-Land datasets and three well-documented high-impact snow drought events are used to validate the toolbox performance. The work addresses a clear community gap: fragmented, non-reproducible custom scripts dominate current snow drought research, while no unified platform supports multi-method comparison. The modular software architecture, end-to-end computational optimization, and fully open code/datasets are significant strengths. Overall, this is a valuable methodological contribution to cryosphere and hydrological drought research, but one core issues about the computational performance require substantial revisions, alongside some minor textual, graphical and structural adjustments before acceptance.

Major Concern:

Computational performance benchmarks lack standardized hardware reference and scalability tests.

The manuscript introduces multi-layer computational optimization strategies for MSDT, but performance descriptions remain descriptive without standardized benchmarks.

1. No unified hardware environment is specified for runtime comparisons across yearly, monthly SWEI, and daily PDM modules. Readers cannot replicate or reference the reported efficiency gains.

2. Scalability tests are missing: the paper does not evaluate how processing time and memory consumption scale with spatial resolution (e.g., 0.25°, 0.1°, 0.01°) or temporal length of input datasets.

3. Revision request: Add a standardized performance benchmark table with clear hardware specifications, record runtime and peak memory usage for all three temporal modules under multiple spatial/temporal input configurations, and provide practical hardware recommendations for users running large-domain high-resolution analysis.

Response: We thank the comments for requesting standardized quantitative

performance evidence, which was mentioned by all three reviewers. The supplementary benchmarking attachment now reports all seven methods, temporal and spatial scaling, and lossless output compression.

All tests used the same Intel Core i9-12900K workstation (16 cores, 24 logical processors), 128 GB RAM, Windows 11 Pro, and Python 3.11.7. The full-domain inputs cover 20–84°N at 0.25° over 1980–2024 with the supplied extent mask. Annual methods and PDM use daily inputs, whereas SWEI uses monthly SWE. Each configuration was evaluated in three independent processes. Reported medians include input reading, calculation, compression and output completion; peak RAM is the maximum process resident memory.

The five annual methods required 124.6–319.3 s, with peak RAM medians of 1.76–27.11 GiB. SWEI required 117.3 s and 5.28 GiB using 3-month accumulation and empirical Gringorten plotting positions. PDM required 27.4 min and 28.45 GiB, producing 44 annual files totalling 7.38 GiB. Lossless compression reduced the tested output sizes by 88.2–98.2%, with identical decoded values.

The scaling tests cover 10-, 20- and 45-year records and regional grids at 0.25°, 0.1° and 0.01°. The finer regional grids are computational stress tests derived by nearest-neighbour replication, not native observations or demonstrations of full-domain high-resolution feasibility. Based on the measured peaks, 64 GB RAM is a practical planning recommendation for larger workloads, with headroom for the operating system.

For more details, please refer to Text S3 in the Supplement.

Minor Concerns:

1. Abstract & Introduction redundancy: The opening background repeatedly restates identical socio-environmental impacts of snow drought across two paragraphs. Condense repetitive literature summaries and tighten the narrative to highlight the core research gap (lack of unified multi-method toolbox) earlier.

Response: Thank you for the comment. We have condensed relevant sentences regarding the socio-environmental impacts of snow drought, and rewrite the first paragraph of Introduction as follows:

“Snow drought, characterized by anomalously low snow water equivalent (SWE) relative to climatological conditions, has emerged as a critical component of global change. Recent decades have witnessed a succession of high-impact snow drought events across the western United States (Harpold et al., 2017; Dye et al., 2023), Central Asia (Bair et al., 2018), the European Alps (Colombo et al., 2023), and the Hindu Kush-Himalaya region (ICIMOD, 2025), underscoring the global scope and increasing severity of this hazard. The growing prominence of snow drought are exerting important implications for natural and socioeconomic systems (Sturm et al., 2017; Henderson et al., 2018; Falk and Lin, 2021; Siirila-Woodburn et al., 2021; Han et al., 2025), attracting increasing attention from the research community.”

2. Typographical errors in figure labels: Multiple spelling mistakes appear in map captions, e.g., “Muti-year mean daily snow drought intensity” (Figure 5a) should be

“Multi-year”. The authors must systematically proofread all figure titles, axis labels and legends for spelling/grammar errors.

Response: Thank you for the comment. We have corrected the typo in Figure 5, and as suggested in Comment 9, we have also changed "SD" to "snow drought" in Figures 3 and 4.

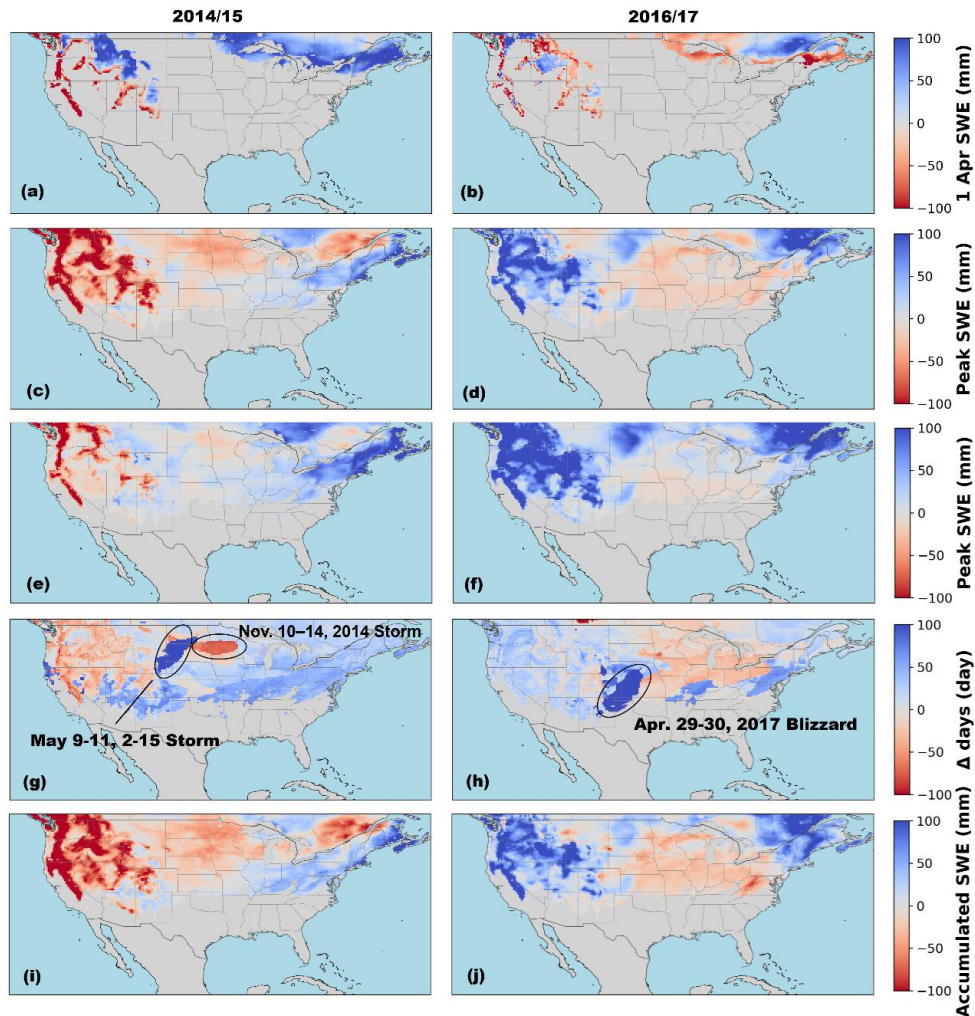
3. Ambiguous snow mask preprocessing workflow: Section 2.2 describes snow persistence zone filtering using MODIS and ERA5-Land thresholds, but does not clarify whether users can upload custom snow cover masks into MSDT. Explicitly state this customizable function in the text.

Response: Thank you for the comment. The method described in Section 2.2 is the approach used in this study to determine snow-covered area, but the MSDT system does not restrict this process. Users may refer to it or use alternative methods to define their own snow-covered areas, and optionally specify the Extent Mask in the MSDT program via an Excel file to reduce computational load. We have added relevant clarification in Section 2.2:

“The MSDT system does not restrict the method for identifying the snow-covered area. Users can use this as a reference or employ other methods to determine their own snow-covered area. Then, in the form of an Excel table (optional), they can specify the Extent Mask within the MSDT program to reduce the computational load.”

4. Figure annotation clarity: Circled anomalous regions in Figure 6g–h lack clear explanatory text linking peak SWE timing shifts to observed regional storm events. Expand the figure caption to connect visual anomalies to the cited National Weather Service records.

Response: Thank you for the comment. The original image has been modified and explanatory text has been added near the circled anomalous areas:



5. Hydrological year setting explanation: The tool automatically assigns winter periods for Northern/Southern Hemispheres, but the manuscript does not explain how users can manually override the default hydrological calendar. Add a short note on custom winter period configuration in Section 2.3.2.

Response: Thank you for the comment. We have added a note as follows:

“Meanwhile, users can customize the start and end months of the winter period. For the Northern Hemisphere, the end month is interpreted as a month in the following year, whereas for the Southern Hemisphere, it corresponds to a month in the same year.”

6. Missing severity classification metadata explanation: Table 2 lists output variables including `intensity\_flag` (drought severity level), yet the paper does not detail the default severity tiers for yearly/monthly/daily methods. Add a concise table summarizing severity thresholds for all seven algorithms.

Response: Thank you for the comment. Only three methods were used to classify the severity of snow drought. We have provided an explanation in Table S1 in the Supplementary Information:

Table S1. Classification schemes and flag values of snow drought intensity

Categories	Metric	Classification schemes and flag values
Point-in-time method (Yearly)	Accumulated SWE	$\left\{ \begin{array}{ll} \text{Light}(1), & 50\% - 25\% \\ \text{Medium}(2), & 25\% - 15\% \\ \text{Heavy}(3), & 15\% - 5\% \\ \text{Extreme}(4), & < 5\% \end{array} \right.$
Standardized index (SI) method (Monthly)	n-month accumulated SWEI	$\left\{ \begin{array}{ll} \text{Abnormally Dry}(1), & -0.8 - -0.5 \\ \text{Moderate Drought}(2), & -1.3 - -0.8 \\ \text{Severe Drought}(3), & -1.6 - -1.3 \\ \text{Extreme Drought}, & -2.0 - -1.6 \\ \text{Exceptional Drought}, & < -2.0 \end{array} \right.$
Phase diagram method (Daily)	SWE	$\left\{ \begin{array}{ll} \text{Abnormal}(1), & 30\% - 20\% \\ \text{Moderate}(2), & 20\% - 10\% \\ \text{Severe}(3), & 15\% - 5\% \\ \text{Extreme}(4), & 5\% - 2\% \\ \text{Exceptional}(5), & < 2\% \end{array} \right.$

7. Reference formatting inconsistency: Several journal article references use inconsistent abbreviation styles for journal names, and page number ranges are formatted unevenly. Standardize all citations.

Response: We have standardized all citations according to the publish rules of GMD.

8. The phrase “independent yet interconnected modules” should be corrected to “independent but interconnected modules”.

Response: Corrected.

9. The manuscript alternates between “snow drought” and “SD”. Please standardize.

Response: We are grateful to the reviewer for the comments. We have revised all “SDs” as “snow drought” in the manuscript.

Final Recommendation

The proposed MSDT toolbox delivers substantial value to the cryosphere and hydrology community, and the global/regional case studies effectively demonstrate its core functionality. The manuscript is promising but requires full addressing of all listed concerns. I recommend a Moderate Revision, and look forward a second round of evaluation.

Response: Thank you for your insightful comments and the time you've taken.