Response to Comments by Anonymous Referee #1:

Zhang et al. (2024) applied a uniform RIC threshold of 0.2 to identify ice-on and ice-off dates along the Yenisey River. Building on this approach, the authors introduce asymmetric thresholds to improve detection sensitivity and physical realism: the Break-Up Date (BUD) is defined as the date when RIC falls by ≥60% from the climatological winter peak (computed over December 1 to February 1), while the Freeze-Up Date (FUD) is set as the first date when RIC exceeds 30% above the ice-free baseline. However, the selection of these specific RIC percentages appears somewhat arbitrary. To strengthen the threshold justification, the authors are recommended to select hydrological stations with ground-based observations of freeze-up and break-up dates across different basins. A sensitivity analysis should then be conducted, comparing remotely sensed BUD and FUD derived from various RIC thresholds against these in-situ records. This would enable a more robust, data-driven determination of optimal RIC thresholds tailored to physical processes and regional variability.

Response:

Thank you for your meticulous review and constructive comment. We agree that the rationale for the asymmetric RIC thresholds should be stated more explicitly, and we have revised the manuscript accordingly.

First, we would like to clarify that the selected combination of thresholds is not arbitrary. Our asymmetric thresholding design follows the physically motivated protocol adopted by Podkowa et al. (2023), who used a minimum 40% decrease in river ice cover to identify breakup and a 30% threshold for freeze-up, explicitly noting that freeze-up is typically more gradual than breakup. Consistent with this rationale, we use different criteria for BUD (breakup date) and FUD (freeze-up date) to better reflect the distinct physical transition behaviors during ice ablation and formation.

Second, we identified and corrected an ambiguous phrasing in the original text. The manuscript previously stated that "RIC decreases by ≥ 60 % below the winter peak," which could be interpreted as a 60 % drop. This was a wording error only—the implemented code and all reported results use the intended criterion $RIC\ (t) \leq 0.60 \times RIC_{peak}$ (i.e., a ≥ 40 % decrease). We have revised the sentence to explicitly state that the selected, literature-based threshold

defines BUD occurring when RIC falls to ≤ 60 % of the climatological winter peak.

The corresponding revised text now reads as follows:

Building on this foundation—and acknowledging the rapid, sometimes abrupt nature of ice ablation versus the more incremental process of freeze-up—we follow an asymmetric thresholding criterion consistent with Podkowa et al. (2023) to improve detection sensitivity and physical realism. Specifically, the BUD is assigned as the first date when RIC falls to ≤ 60 % of the climatological winter peak (over 1 December–1 February); by contrast, the FUD is defined as the first date on which RIC exceeds 30 % above the ice-free baseline.

Third, beyond literature support and the above clarification, we agree that a sensitivity check against in situ records is valuable. In the manuscript, we already provided an empirical evaluation of the derived phenology against independent references, including (i) long-term in-situ station-based phenology compilations and (ii) an independent Landsat-based river phenology dataset. The current results yield MAEs on the order of ~10–11 days against in situ records (FUD/BUD) and ~10–16 days against the Landsat-based reference, supporting that the adopted thresholds produce reasonable, basin-consistent phenology.

In direct response to your suggestion, we conducted a concise sensitivity test by deriving phenology using (a) the asymmetric thresholds adopted in this study and (b) the uniform RIC threshold used by Zhang et al. (2024), while holding the same in situ reference records constant (Shiklomanov and Lammers, 2014; Shiklomanov, 2016). Using identical station observations, our asymmetric-threshold method yields MAEs of 10.8 days for FUD, 11.4 days for BUD evaluated against the "End of ice" record, and 8.4 days for BUD evaluated against the "Start of ice drift" record. Using Zhang et al. (2024)'s threshold, the corresponding MAEs are 12.9 days, 9.3 days, and 6.8 days, respectively (Figs. I and II). Overall, the two thresholding strategies produce comparable performance at the aggregated level, while the asymmetric scheme improves agreement for freeze-up in this test.

This sensitivity test suggests that phenology retrieval is robust to plausible threshold choices, while also underscoring that the resulting phenological dates should be interpreted with appropriate caution because the apparent error magnitude depends on the specific in situ event definition used. We have therefore strengthened the discussion of this comparability limitation

in the revised **"Methodological limitations."** section.

The corresponding revised text now reads as follows:

Methodological limitations. (1) We adopt robust, tractable thresholding for RIC retrieval and phenology detection. While practical, overly stringent thresholds risk missing thin or mobile ice, whereas permissive choices admit noise. The asymmetric thresholds adopted for phenology retrieval (following Podkowa et al., 2023) are intended to reflect different process rates, with breakup often rapid and abrupt and freeze-up generally more gradual. However, RIC-based dates capture footprint-scale areal transitions and may not align with station-based conventions, the resulting phenological dates should be interpreted with appropriate caution, as the apparent error magnitude depends on the specific in situ event definition used.

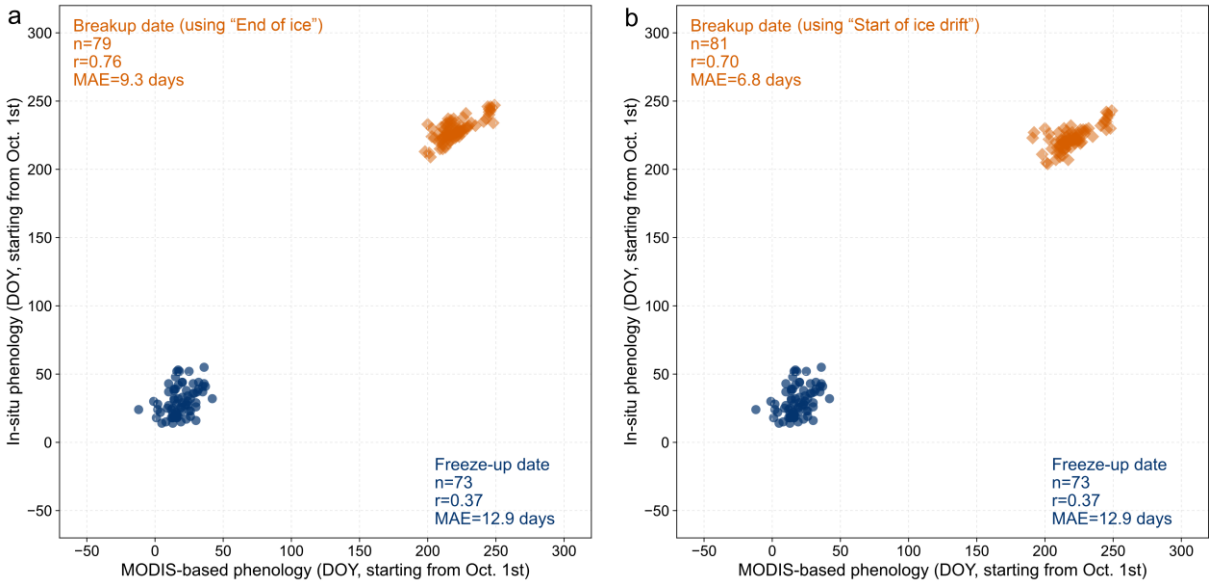

Figure I: Phenology validation against in situ records using the uniform thresholds applied by Zhang et al (2024).

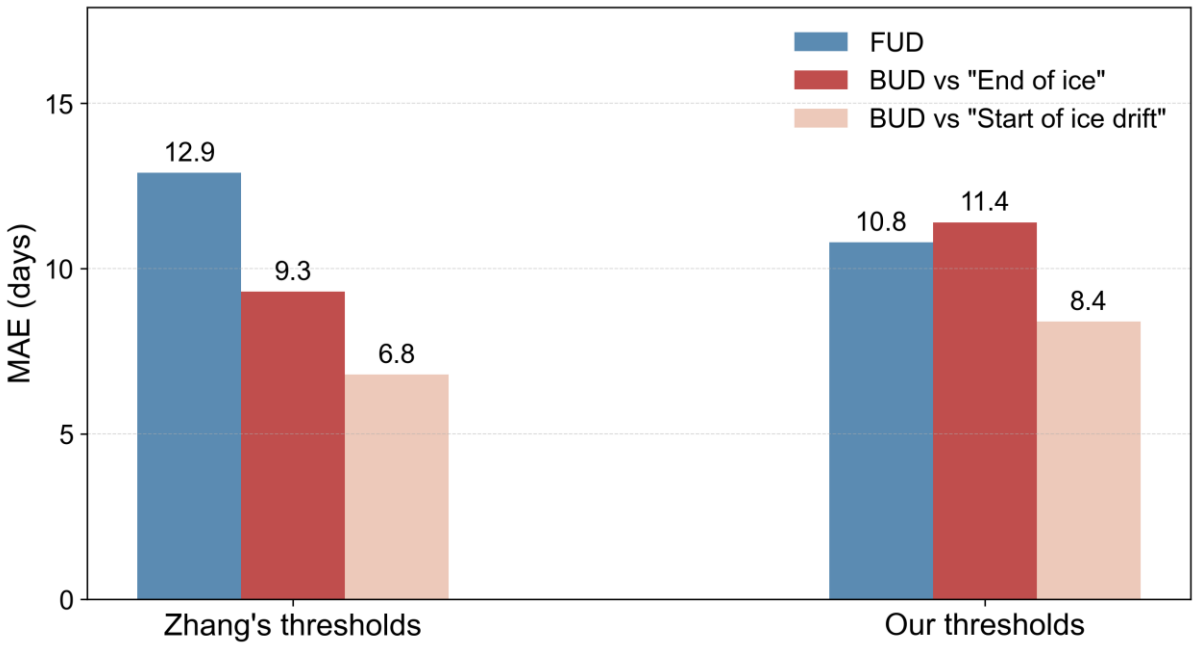

Figure II: MAE comparison between thresholding methods used by Zhang et al (2024) and this study.

References:

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Zhang, Y., Qiu, Y., Li, Y., Leppäranta, M., Jia, G., Jiang, Z. and Liang, W.: Spatial-temporal variation of river ice coverage in the Yenisei river from 2002 to 2021, J. Hydrol., 637, 131440, 2024.