

Response to Comments by Anonymous Referee #1:

The authors filtered the ‘Simplified GRWL Vector Product’ by the attribute ‘width_max’ $\geq 250\text{m}$, retaining only those river segments whose maximum mapped width (at mean discharge) exceeds 250m. This implies that, within each retained segment, portions of the river may still have actual widths less than 250m. Subsequently, the authors applied a 250m buffer on both sides of these segments, resulting in a fixed 500m vector polygon mask. For river reaches where the actual width exceeds 500m during ice period, this approach poses no significant issues. However, for narrower reaches (actual width $< 500\text{ m}$), the fixed 500m mask introduces considerable uncertainty. The buffered polygon not only encompasses the main channel but also extends into floodplain beaches and adjacent non-channel areas on both banks. In pre-freeze-up and post-breakup periods, snow accumulation is common on these non-channel areas. Since the Normalized Difference Snow Index (NDSI) cannot reliably distinguish between snow and ice, such snow-covered regions are likely misclassified as river ice. To address this limitation, the authors should quantitatively assess: (1) The proportion of analyzed river segments where the actual river width is less than 500 m; (2) The potential impact of this fixed-width masking on the accuracy of the final river ice concentration (RIC) estimates, particularly the risk of overestimation due to inclusion of snow-covered non-channel areas.

Response:

Thank you for your meticulous review and insightful comment. We would like to clarify that the purpose of applying a buffered river mask, rather than relying strictly on the stable reference channel geometry (“GRWL Mask”), is to better accommodate seasonal expansion/contraction of the active channel. We acknowledge that, under this approach, narrower reaches (actual width $< 500\text{ m}$) may exist and could introduce uncertainty, particularly through the inclusion of adjacent non-channel areas within the fixed-width mask. We have made supplementary analysis to address this limitation.

(1) Proportion of analyzed river segments with width $< 500\text{ m}$

To quantitatively assess the prevalence of narrower reaches, we further used the “GRWL Vector Product” (river centerlines) provided with the GRWL datasets, which include segment-level wetted width information (attribute ‘width_m’). We calculated the proportion of centerline

length with width_m < 500 m relative to the total analyzed centerline length for each river. We therefore relied on length-based statistics instead of polygon areas derived from the “GRWL Mask” raster, as exporting simplified river masks for Google Earth Engine (GEE) processing can inevitably alter polygon geometry and area, especially across large spatial domains with complex river morphologies and computational limitations.

Table S3 (in the revised **Supplement**) summarizes the results. Across the six rivers, the length-weighted proportion of narrower reaches is 12.0%, and the Mackenzie River exhibits the lowest proportion (7.2%). These results indicate that the majority of the analyzed river network corresponds to reaches whose widths are comparable to or exceed the effective 500 m MODIS mapping scale, while narrower reaches constitute a limited subset of the study domain.

Table S3: Summary of the river centerline length for the six major Arctic rivers in this study.

	Analyzed river segments length (km)	Narrower reaches length (km)	Ratio
Mackenzie	11,890.13	858.79	7.2%
Yukon	20,919.17	2,326.00	11.1%
Kolyma	19,152.67	2,081.93	10.9%
Lena	62,037.11	8,377.70	13.5%
Yenisey	57,836.47	6,377.58	11.0%
Ob	35,586.66	4,805.59	13.5%

(2) Potential impact of fixed-width masking on reported RIC

Regarding the potential influence of the fixed-width mask on the final river ice concentration (RIC), we would like to emphasize that introducing 3-km grid-cell partition from mapped results (500 m resolution) is to reclassify the potential cloud pixels and suppress noises (See details in Sect. 3.2.1). Under this framework, our reported RIC is defined as the fraction of mapped ice area within a 3-km grid cell. We acknowledge that during some periods, snow-covered banks included in the buffered mask may be mapped as “ice” as NDSI cannot fully distinguish snow from ice, thereby producing positive bias in the reported RIC for those narrower reaches.

To make this explicit, for narrower reaches the mapping uncertainty can be summarized in two conceptual cases based on whether snow is present on adjacent river banks. When bank snow

is absent, the inclusion of bank areas within the buffered mask does not systematically inflate mapped ice area, irrespective of river ice presence on the channel; under this condition, the “true” RIC—defined solely by ice within the watercourse—is expected to be consistent with the reported RIC. In contrast, when bank snow is present, snow-covered non-channel areas within the buffered mask may occasionally be misclassified as river ice, leading to a potential overestimation of mapped ice area and, consequently, the reported RIC. The maximum possible bias can therefore be bounded as:

$$\Delta RIC = RIC_{rep} - RIC_{tru} \leq \frac{A_{bank}}{A_{mask}}$$

where A_{bank} is the bank area (km²) inside the buffered mask that is snow-covered, and A_{mask} is the referenced mask area in a 3-km grid-cell.

Under a conservative worst-case assumption—(i) reach is narrow than 500 m, (ii) bank belt is fully snow-covered, and (iii) snow is entirely mapped as ice—the potential “bank belt” area introduced by buffering can be approximated geometrically. With a 250 m buffer applied on both sides, the additional bank-belt width is 0.5 km. For narrower reaches with total centerline length L_{narrow} (km), the maximum added bank area is:

$$A_{bank,max} \approx 0.5 \times L_{narrow}$$

Similarly, within a single 3-km grid cell, if the narrow reach intersects the cell with length l (km), the worst-case bank-belt area inside the cell is:

$$A_{bank,max,cell} \approx 0.5 \times l$$

the total valid river mask (with actual width of w in km) area is:

$$A_{mask,cell} \approx 0.5 \times (w + 0.5) \times l$$

and therefore the maximum absolute per-cell RIC inflation is bounded by:

$$\Delta RIC_{max,cell} \leq \frac{0.5 \times l}{(w + 0.5) \times l} = \frac{0.5}{w + 0.5}$$

In the most pessimistic configuration, i.e., $w \in [0.25, 0.5)$ over the entire reach, the resulting absolute inflation of RIC is estimated to be approximately 0.50–0.67. These values provide an intentionally conservative upper bound on the magnitude of possible positive bias in narrow-reach cells. In practice, the realized bias is expected to be smaller because (i) bank snow is spatially and temporally intermittent, (ii) snow-to-ice confusion is not perfect in all conditions, and (iii) the 3-km gridding and temporal smoothing procedures suppress isolated noise and reduce the influence of localized misclassification. Moreover, narrower reaches constitute only

12.0% of the analyzed centerline length (Table S3), limiting the overall spatial extent where this worst-case mechanism could apply.

We have added relevant analysis in “**Data uncertainty.**” module to the revised **Sect 6. Limitations and uncertainties** as well as in the revised **Supplement** document to quantitatively assess the RIC-related uncertainty and also explicitly clarified the river mask processing in the revised **Sect 2.2.1 Spatial reference data.**