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Title: A basin-scale mapping method for crevasse depth using ICESat-2: a case study on Greenland's Sermeq Kujalleq (Jakobshavn Isbræ)

Response to Reviewer #2:

Thank you very much for your careful review and constructive comments. We sincerely appreciate your suggestions, which have helped us improve the manuscript substantially. In response, we have carefully addressed all the comments and will revise the manuscript accordingly. The major revisions include additional comparisons with DDA-ice, clarification of the crevassed-region screening strategy, evaluation of the temporal representativeness of the 2019 observations, additional seasonal validation experiments, sensitivity analysis of key parameters, and improved quantification of depth uncertainties. We have also revised the related figures and descriptions accordingly. The detailed responses and corresponding revisions are provided below.

Main

1. Comparison and benchmarking against prior methods: The manuscript would benefit from more direct comparison against previously published crevasse-detection and depth-retrieval approaches. The density-dimension algorithm for ice surfaces (DDA-ice by Herzfeld et al.) would be the most directly comparable prior method, as this approach retrieves surface heights and crevasse morphology from the same ATL03 photon data and has been applied over the same Sermeq Kujalleq study region. A comparison against DDA-ice, even over a limited shared segment, would more convincingly demonstrate the added value of the proposed workflow and clarify where it improves upon existing ATL03-based methods.

Response:

Many thanks for this valuable suggestion. We agree that comparison with existing approaches is necessary to better demonstrate the advantages and added value of the proposed method. DDA-ice is an established ATL03-based algorithm that mainly focuses on photon denoising and glacier surface reconstruction (Herzfeld et al., 2017; Herzfeld et al., 2021). In comparison, our method includes not only photon denoising and surface reconstruction, but also candidate crevassed-region detection before detailed processing and automated extraction and depth estimation of

individual crevasses after surface reconstruction. Therefore, a direct comparison between the two methods is not entirely straightforward. Nevertheless, because DDA-ice is the most directly comparable existing ATL03-based framework, we conducted comparisons at the stages where the two approaches could be evaluated consistently. Specifically, we compared photon denoising performance and, for the final crevasse results, coupled the DDA-based reconstruction with the same crevasse extraction procedure used in our method to enable a consistent comparison of individual crevasse extraction, spacing, and depth estimates.

(1) Comparison of photon denoising performance

To ensure a direct and reproducible comparison, we selected the same ICESat-2 dataset used by Herzfeld et al. (2021) to demonstrate surface-height determination over the crevassed region of SKJI. Specifically, the comparison used ATL03 granule ATL03_20190511210825_06660305_002_02.h5, acquired along RGT 666 on 11 May 2019, and focused on the gt3l strong beam. As shown in Figure R1 and Table R1, both DDA-ice and the proposed method effectively preserve the dominant glacier surface signals and the bottom signals of most crevasses. Quantitative evaluation shows that the two methods achieve comparable precision values, with DDA-ice and the proposed method reaching precision values of 0.968–0.983 and 0.954–0.974, respectively. However, the proposed method achieves substantially higher recall values (0.855–0.886) compared with DDA-ice (0.508–0.548) across the three test segments. This indicates that, while both methods can effectively suppress noise photons, DDA-ice tends to remove more valid signal photons during denoising, particularly those associated with complex crevasse structures. As highlighted by the red boxes in Figure R1, noticeable differences occur along several steep crevasse walls. The proposed method generally preserves a more continuous distribution of sidewall photons, while DDA-ice shows partial loss or discontinuity of photons along some steeply inclined walls. This difference is mainly associated with the neighborhood configuration used in the photon density estimation. In our method, the orientation of the elliptical neighborhood is adaptively adjusted according to the local distribution direction of the photons, allowing the neighborhood to better follow inclined or near vertical crevasse wall structures. Consequently, photons distributed along these structures receive a higher and more representative local density response and are more likely to be retained during denoising.

The effect of the neighborhood geometry on photon density estimation was

examined in greater detail in our previous study (Chang et al., 2023), which is partly used in the denoising step of this study. In particular, Figure 12 in Chang et al., 2023 compared photon densities obtained using horizontal elliptical neighborhoods with different major-axis lengths and a direction adaptive elliptical neighborhood, while Figure 13 in Chang et al., 2023 further compared the proposed weighted-density formulation with DDA-based density estimates. These experiments showed that adapting the neighborhood orientation to the local photon distribution can improve the separation between signal and noise photons, particularly for inclined surface structures. The more continuous preservation of crevasse wall photons observed in the present comparison is therefore consistent with our previous analysis. This direction adaptive neighborhood represents an important methodological difference from the DDA-based density estimation and appears to facilitate more continuous preservation of steep crevasse wall signals in our method.

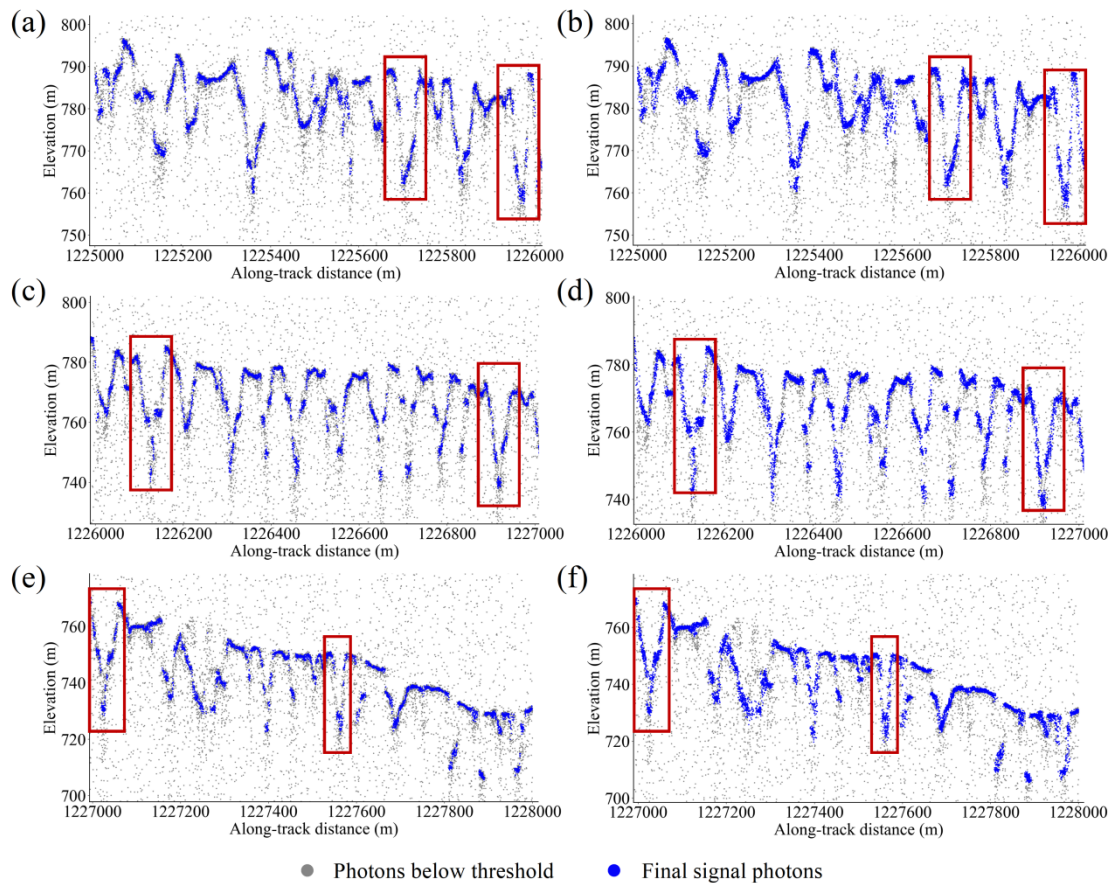


Figure R1. Comparison of photon denoising results between DDA-ice and the proposed method. Panels (a) and (b), (c) and (d), and (e) and (f) present three corresponding examples, where panels (a), (c), and (e) show the denoising results from DDA-ice, and panels (b), (d), and (f) show the corresponding results from the

proposed method.

Table R1. Quantitative comparison of photon denoising performance between DDA-ice and the proposed method across three test segments.

Test segment	Method	Precision	Recall	F1-score
Segment 1	DDA-ice	0.976	0.548	0.702
(Figure R1 (a) and (b))	Proposed method	0.964	0.886	0.924
Segment 2	DDA-ice	0.983	0.508	0.670
(Figure R1 (c) and (d))	Proposed method	0.974	0.855	0.911
Segment 3	DDA-ice	0.968	0.519	0.676
(Figure R1 (e) and (f))	Proposed method	0.954	0.884	0.918

(2) Comparison of crevasse spacing

We further evaluated the performance of the automated extraction of individual crevasses by comparing the extracted crevasse locations and spacing with the results reported by Herzfeld et al. (2021) for the same ICESat-2 segment. In their study, crevasses deeper than 20 m derived from the DDA-ice surface reconstruction were marked along the ICESat-2 track and matched with corresponding crevasse features in a SkySat image. Crevasse spacing was then calculated from these identified features, yielding a mean spacing of 81.37 m from DDA-ice and 81.25 m from SkySat imagery.

Using the same ATL03 segment, our method automatically reconstructed the surface profile and extracted individual crevasses without manually specifying their locations. To make the comparison consistent with Herzfeld et al. (2021), the crevasses used for the spacing calculation were selected according to the same correspondence shown in their Figure 8. In particular, the two adjacent depressions highlighted by the yellow box in Figure R2 (b) were treated as a single crevasse feature in the spacing calculation, consistent with the interpretation adopted by Herzfeld et al. (2021). The resulting mean crevasse spacing from our automated extraction was 78.28 m. Although the mean spacing derived from our method is slightly smaller, the overall spacing pattern along the track is consistent with those obtained from DDA-ice and SkySat. Differences in individual spacing values are expected because the identification of a crevasse edge can vary slightly with the

reconstructed surface morphology. In addition, as noted by Herzfeld et al. (2021), the SkySat and ICESat-2 observations were separated by approximately five months, during which glacier flow and crevasse evolution may have altered the positions and geometry of individual features. Therefore, exact agreement in spacing is not expected.

More importantly, this comparison demonstrates that the proposed method can automatically identify individual crevasses and provide their locations and geometric attributes directly from ATL03 photon data. The close agreement in the overall crevasse-spacing pattern with the DDA-ice and SkySat results provides additional support for the reliability of the automated individual-crevasse extraction. This automated extraction step represents a key extension of our method beyond photon denoising and surface reconstruction and enables the generation of individual-crevasse products for subsequent large scale analysis.

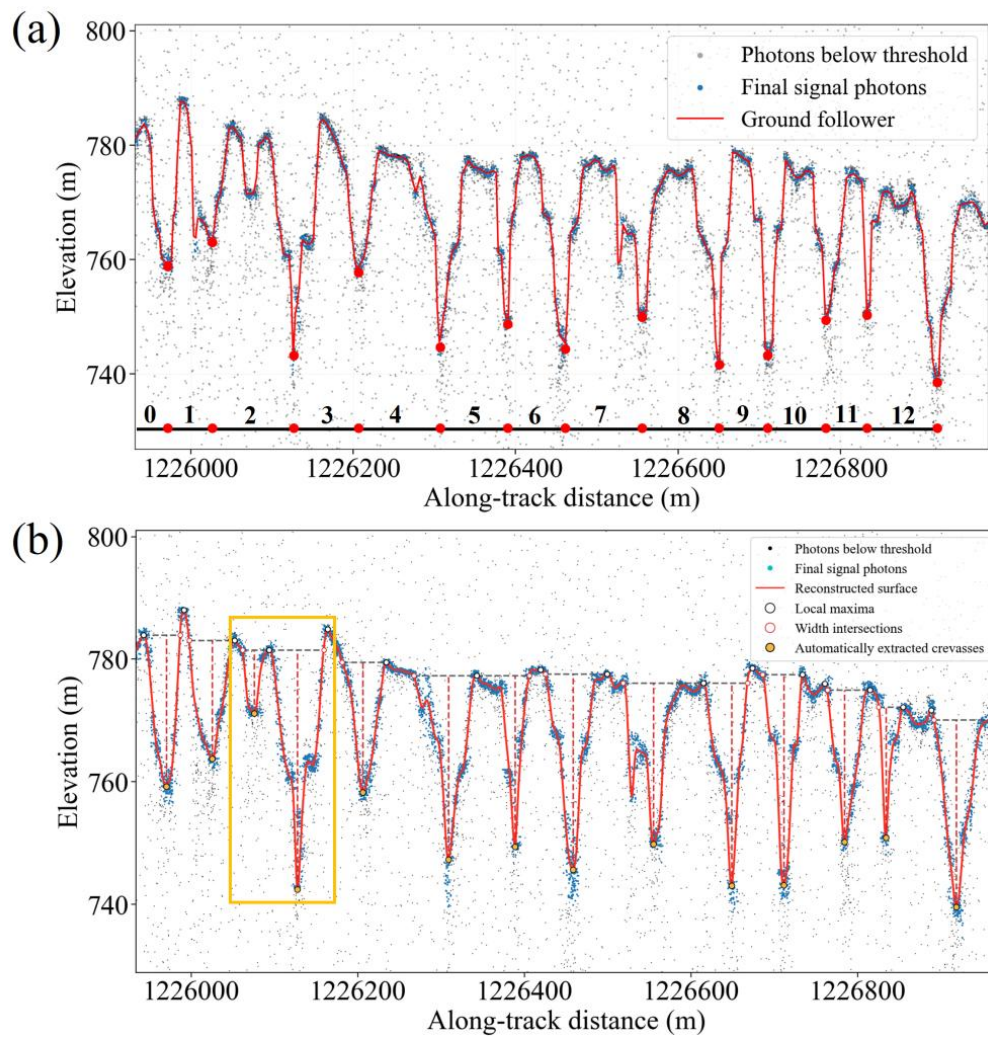


Figure R2. Comparison of crevasse extraction results between the proposed automated method and manually extracted DDA-ice results for the same ICESat-2

segment used in Herzfeld et al. (2021).

Table R2. Jakobshavn Isbræ crevasse spacing estimates from the proposed method, DDA-ice results (manually extracted), and SkySat imagery.

Segment	Ours (m)	DDA-ice (m)	Skysat (m)
1	60.4	59	58
2	109.6	106	108
3	70.7	82	83
4	108.4	106	120
5	81	82	83
6	79.6	76	79
7	98.8	100	100
8	96	94	113
9	61.8	65	71
10	56.3	71	58
11	41.2	53	42
12	75.5	82	58
Mean Spacing	78.28	81.37	81.25

(3) Comparison of individual crevasse extraction and depth estimation

To enable a further comparison with DDA-ice at the level of final crevasse extraction results, we coupled the DDA-ice photon processing and ground follower reconstruction with our automated crevasse identification and depth retrieval procedure. These results were then compared with those from our complete workflow for the same ATL03 segment. Figure R3 compares the resulting crevasse extractions from the DDA-ice reconstructed surface and from our reconstructed surface. Both workflows identified the same 14 major crevasses within the selected section, with very similar locations and depth estimates. As summarized in Table R3, the mean crevasse depth was 26.34 m for the DDA-based reconstruction and 26.81 m for our method, corresponding to a mean difference of only 0.47 m. The individual depth differences were generally small, indicating that both surface reconstruction approaches can provide consistent estimates of major crevasse depth when followed

143 by the same extraction procedure.

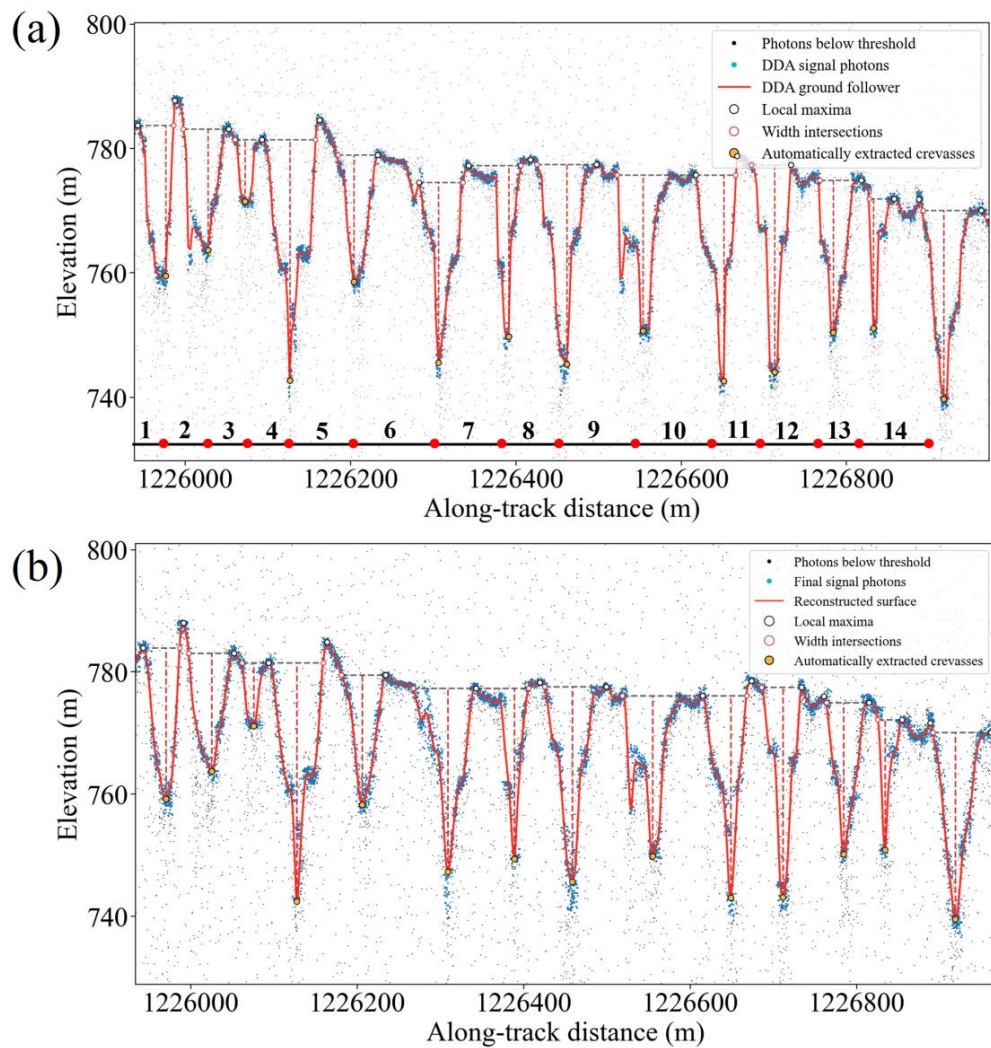


Figure R3. Comparison of individual crevasse extraction results from (a) the DDA-based reconstruction coupled with our crevasse extraction procedure and (b) the proposed method.

Table R3. Comparison of crevasse depth estimates between the DDA-based reconstruction and the proposed method.

Crevasse	DDA depth (m)	Ours depth (m)	Absolute depth difference (m)
1	24.16	24.73	0.57
2	19.48	19.32	0.16
3	9.96	10.43	0.47
4	38.70	39.10	0.40
5	20.41	21.23	0.82

Crevasse	DDA depth (m)	Ours depth (m)	Absolute depth difference (m)
6	28.97	30.04	1.07
7	27.54	27.98	0.44
8	32.18	31.99	0.19
9	25.06	26.31	1.25
10	33.19	33.12	0.07
11	33.32	34.41	1.09
12	24.53	24.79	0.26
13	20.85	21.38	0.53
14	30.39	30.55	0.16
Mean depth	26.34	26.81	0.47

To further examine the consistency of the two processing strategies under different acquisition conditions, we selected two representative ATL03 datasets: a winter weak-beam case acquired on 17 February 2019 (RGT 0780, gt1r) and a summer strong-beam case acquired on 10 August 2019 (RGT 0666, gt1l). For consistency with the preceding comparison, the DDA-ice photon processing and ground-follower reconstruction were coupled with our automated crevasse extraction procedure, and the resulting outputs were compared with those from our complete workflow. Because DDA-ice does not include the roughness-based candidate-region pre-screening used in our workflow, applying the full DDA processing chain to all ATL03 observations would require substantially greater computational effort. We therefore limited this additional comparison to these two representative cases.

Figure R4 compares the results obtained by coupling DDA-ice photon processing and ground follower reconstruction with our automated crevasse extraction procedure (left panels) and those obtained from our complete workflow (right panels). Panels (a) and (b) correspond to the winter weak beam case, whereas panels (c) and (d) show the summer strong beam case. Despite differences in season, beam strength, surface morphology, and photon distribution, the two processing strategies reconstruct similar overall surface structures and identify broadly consistent crevasse features.

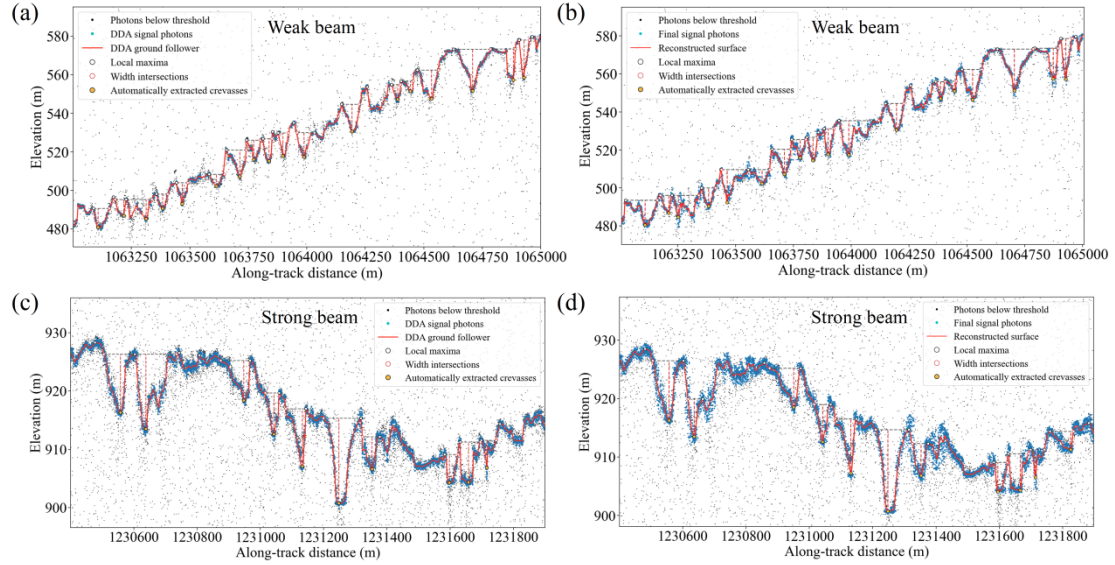


Figure R4. Comparison of crevasse extraction results under different seasonal and beam conditions. Panels (a) and (c) show the crevasse extraction results obtained by applying the proposed crevasse extraction procedure to the surface reconstructed by the DDA-based method, whereas panels (b) and (d) show the results obtained using the proposed method.

Overall, the comparison indicates that both DDA-ice and our method are capable of reconstructing crevassed glacier surfaces and providing consistent estimates of major crevasse geometry. The main contributions of our method relative to DDA-ice can be summarized in the following three aspects:

1) The roughness-based candidate region pre-screening limits the computationally intensive photon denoising and surface reconstruction procedures to areas with a high likelihood of containing crevasses, thereby reducing unnecessary processing over relatively smooth regions and improving the feasibility of basin-scale implementation.

2) The direction-adaptive elliptical neighborhood used in our photon density estimation better follows locally inclined photon structures and appears to facilitate more continuous preservation of signal photons along steep crevasse walls.

3) Most importantly, the reconstructed surface is further coupled with an automated individual crevasse extraction procedure, enabling the direct retrieval of crevasse locations, depths, widths, and other geometric attributes. DDA-ice provides a robust framework for photon classification and surface height reconstruction in crevasse regions, and not for automatically extracting crevasses, whereas the proposed method extends these capabilities toward automated generation of individual crevasse

products over large spatial scales.

2. Continuity of detected crevassed regions: It is unclear how non-contiguous detections are handled when defining a crevassed region. For example, if the roughness index remains near the threshold value along track but dips below t_a for short distances (e.g., 150–300 m), are these short segments still merged into a single overall crevassed region, or are they treated as separate regions? I generally had trouble understanding how the authors envision the crevassed region detection step, which I agree is a beneficial step for reducing processed data volumes, should be implemented across wider spatiotemporal scopes. For example, should crevasse-laden tracks be converted into a spatial mask with simplified geometric boundaries, and used to clip ATL03 along-track data? Or, would this step likely vary between years and varying degrees of temporal biases that it would need to be repeated for different study periods?

Response:

Many thanks for this insightful comment. We appreciate the reviewer's suggestion that the implementation details of the roughness-based crevassed region screening should be clarified. In the revised manuscript, we have further explained how candidate crevassed regions are identified and handled.

In our method, the roughness-based screening is conducted along each individual ICESat-2 ground track. After constructing the glacier trend surface using the extracted trend-surface photons, the roughness index is calculated for each interval between two neighboring trend-surface photons. When the roughness index of an interval exceeds the predefined threshold, that interval is identified as part of a candidate crevassed region. Consecutive above-threshold intervals are combined to form a continuous candidate crevassed region. To reduce the possibility of missing crevasses near the boundaries of these detected regions, an additional 300 m buffer is applied to both sides of each candidate region before subsequent processing.

For discontinuous detections, no additional spatial merging operation is applied in the current workflow. In other words, if the roughness index temporarily decreases below the threshold, the corresponding interval is treated as a separate segment rather than automatically merged with adjacent candidate regions. Therefore, the detected

regions are initially defined as a series of along track candidate segments rather than a continuous glacier-wide mask.

Regarding the application to larger spatial and temporal scales, the roughness-based screening step is designed as an efficient data-reduction strategy before detailed crevasse extraction. The output of this step is a set of along track candidate regions that can be used to filter ATL03 photons and reduce computational costs. Because ICESat-2 does not provide exactly repeat ground tracks between different years and glacier surface conditions may change over time, the screening step can only be taken as a reference for each observation period rather than directly taking as a fixed crevasse mask.

3. Temporal coverage and representativeness: More language is needed on the temporal distribution of the ATL03 acquisitions beyond simply restricting to the year 2019. The subplot in Figure 1b is helpful, but this likely reflects the temporal distribution of the full SKJI basin and not the smaller near-terminus areas later determined to be the crevassed region (less than 10% of the total basin area). Do the authors have a sense of the impact on temporal biases on results, and/or can justify why including all months is a more robust approach over, for example, targeting data in the summer months when the greatest area of bare ice is exposed? Relatedly, the crevassed-region detection evaluation was performed on a subset of 2019 data (January–March); it would help to explain why this window was chosen and whether it is representative of comparisons to the full-year product. I would suggest, at the least, also conduct a similar comparison for a subset of data during summer months when surface conditions are distinctly different.

Response:

Many thanks for this valuable comment. We agree that the temporal distribution of both ICESat-2 observations and the final extracted crevasses should be further clarified. To address this concern, we have added a monthly analysis of the ATL03 observations and the extracted crevasse numbers during 2019 (Figure R5). Unlike the previous temporal distribution shown in Figure 1b, which represents the coverage of ATL03 observations over the entire SKJI, the new analysis directly characterizes the temporal distribution of the final crevasse inventory. The results show that the

extracted crevasses are distributed throughout the year, although the number varies among months due to differences in ATL03 track availability and observation conditions.

The full-year ATL03 dataset was used to provide broader temporal and spatial sampling of the study area rather than restricting the analysis to a single season. Using observations from multiple months increases the number and spatial coverage of available ground tracks, thereby providing a more comprehensive basis for basin-scale crevasse mapping. Nevertheless, seasonal variations in surface conditions, snow cover, and photon quality may affect the extraction performance.

Regarding the evaluation of the crevassed region detection and subsequent extraction steps, the original assessment was conducted using ATL03 data acquired during January-March 2019. This period was selected because the repeat cycle of ICESat-2 is approximately 91 days, and a three month observation period provides relatively comprehensive ground track coverage over the SKJI, making it suitable for systematic evaluation of the proposed framework. However, we agree that the evaluation based on a single seasonal period may not fully represent the performance under different surface conditions. Therefore, following the reviewer’s suggestion, we additionally evaluated the proposed method using an independent summer dataset acquired during July-September 2019, when surface conditions differ substantially due to enhanced melting and increased bare-ice exposure. The results are summarized in Table R4. The comparison shows that the proposed framework maintains comparable performance between the winter and summer periods for both strong and weak beams, indicating its robustness under different seasonal observation conditions.

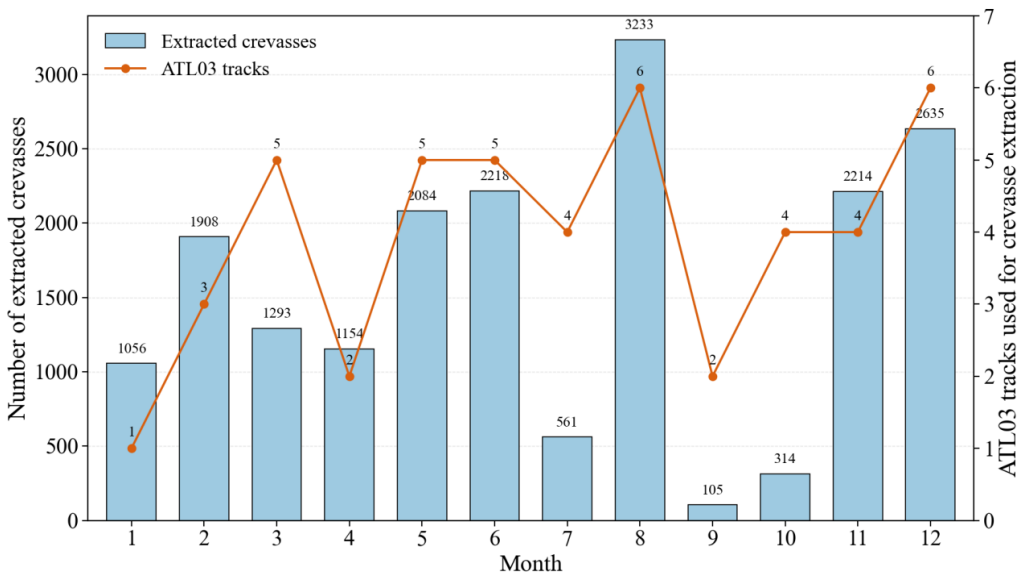


Figure R5. Monthly distribution of ICESat-2 ATL03 observations and extracted crevasses in the SKJI during 2019.

Table R4. Quantitative evaluation of the key steps of the proposed crevasse detection and depth estimation framework.

Time	Step	Weak beam			Strong beam		
		P	R	F_1	P	R	F_1
Jan-Mar	Crevasse region detection	0.896	0.955	0.925	0.922	1.000	0.960
	Glacier photon retrieval	0.958	0.850	0.900	0.984	0.879	0.929
	Crevasse extraction	0.846	0.880	0.863	0.877	0.912	0.894
Jul-Sep	Crevasse region detection	0.885	0.943	0.913	0.913	0.963	0.938
	Glacier photon retrieval	0.928	0.853	0.889	0.954	0.903	0.928
	Crevasse extraction	0.833	0.921	0.875	0.884	0.950	0.916

4. Uncertainty, bias, and descriptive statistics: The manuscript would benefit from further quantification of bias and uncertainty in some areas. For example, what is the sensitivity of the estimated crevasse depths to the outlier filter (i.e., how important is using a well-suited, region-specific and empirically derived threshold to algorithm performance)? In addition, I would suggest reporting sample/population descriptive statistics alongside the statistics describing the ATM–ICESat-2 crevasse-depth differences—for instance, the median crevasse depth derived from ICESat-2. It would also be helpful to express the reported depth differences as a fraction of the depth magnitude (e.g., is a 0.06 m difference ~1% of a ~20 m crevasse, or a considerably larger fraction of a shallower one?). This information is somewhat shown in Figure 8c, but would be helpful if the text provided these figures directly as well.

Response:

Many thanks for this valuable comment. We agree that the sensitivity of the density threshold and the uncertainty characteristics of the retrieved crevasse depths should be further quantified. In our method, the density threshold is used in the adaptive photon filtering procedure to distinguish potential signal photons from noise photons. Specifically, for each photon, the local photon density is calculated within an

adaptive elliptical neighborhood, and the threshold is determined based on the mean density of the selected photons with an empirical offset: $T = \bar{D} - 0.1$. where $\bar{D}$ represents the mean local photon density. This adaptive threshold allows the filtering process to adjust to local variations in photon distribution while retaining sufficient signal photons for subsequent glacier surface reconstruction and crevasse depth estimation. To evaluate the influence of the density threshold on the performance of crevasse depth retrieval, we conducted sensitivity experiments by introducing both small perturbations around the default value and larger deviations from the default threshold.

First, we evaluated the sensitivity of the retrieved crevasse depths to the density threshold used for photon filtering. Two types of sensitivity experiments were conducted. For small variations around the default threshold, the density threshold offsets were slightly adjusted (Figure R6, Table R5, and Figure R7). The results show that small changes in the threshold have limited influence on the extracted crevasse locations and estimated depths. Specifically, the median absolute depth differences relative to the default threshold were 0.09-0.21 m under different threshold offsets, and the maximum depth variation among individual crevasses was 1.42 m. These results indicate that the proposed method is relatively stable within a reasonable threshold range.

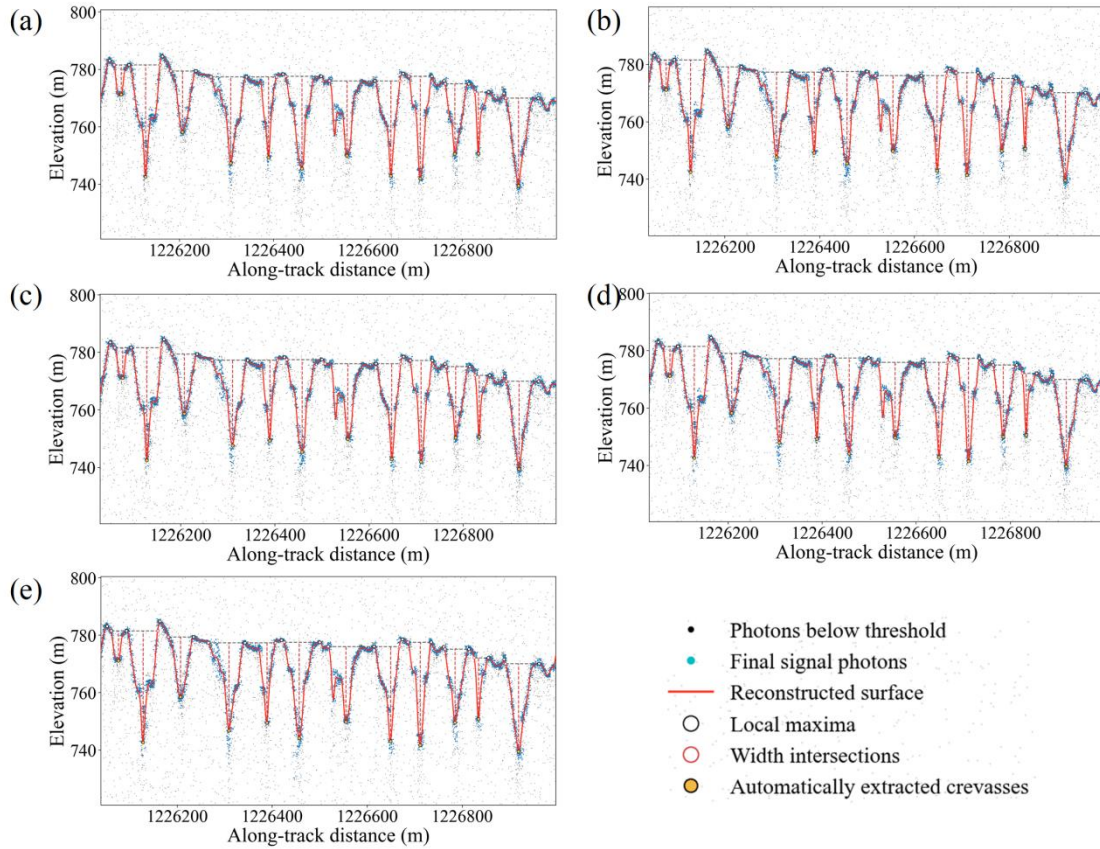


Figure R6. Crevasse extraction results under different density threshold offsets. Panels (a)–(e) correspond to density threshold offsets of -0.050, -0.075, -0.100, -0.125, and -0.150, respectively.

Table R5. Influence of density threshold offsets on retrieved crevasse depths.

Crevasse	-0.100 (Default)	-0.050	-0.075	-0.125	-0.150	Range
1	10.43	10.36	10.46	10.35	10.43	0.11
2	39.10	38.99	39.20	38.93	38.95	0.27
3	21.23	21.19	20.96	20.92	20.86	0.37
4	30.04	30.02	29.58	29.39	30.63	1.24
5	27.98	27.97	28.06	28.10	27.93	0.17
6	31.99	32.18	32.14	33.41	33.36	1.42
7	26.31	26.07	26.22	26.28	26.30	0.24
8	33.12	33.11	33.13	33.09	33.05	0.08
9	34.41	34.62	34.71	34.96	34.95	0.55

Crevasse	-0.100 (Default)	-0.050	-0.075	-0.125	-0.150	Range
10	24.79	24.44	25.31	25.14	25.57	1.13
11	21.38	21.51	21.53	21.53	21.35	0.18
12	30.55	30.55	30.52	30.31	30.64	0.33

Note: Crevasse numbers are assigned sequentially in the direction of increasing along track distance (corresponding to the crevasses shown in Figure R6).

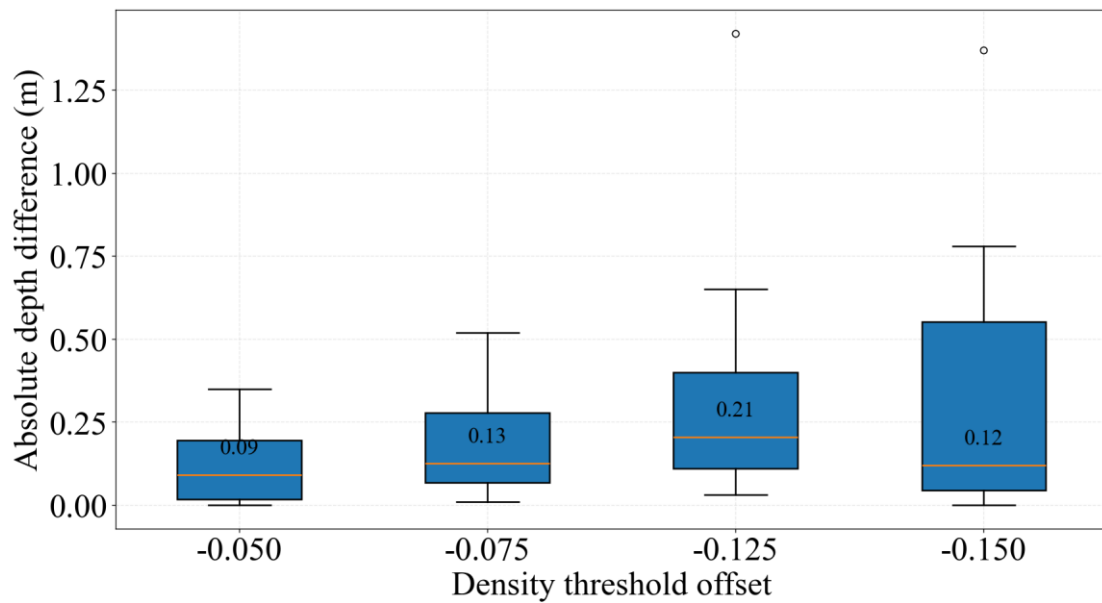


Figure R7. Sensitivity of retrieved crevasse depths to density threshold offsets. Absolute depth differences were calculated relative to the default density threshold offset (-0.100).

To further investigate the influence of substantial threshold deviations, we tested larger threshold offsets (Figure R8, Table R6, and Figure R9). The results demonstrate that the density threshold plays an important role when it deviates considerably from the appropriate range. For example, the median absolute depth differences increased from 0.33–0.57 m under moderate positive offsets (+0.1 to +0.5) to 4.18 m when the threshold offset reached +1.0. Similarly, negative offsets also introduced increasing uncertainties, with median depth differences of 0.85 m and 1.04 m for offsets of -0.5 and -1.0, respectively. The maximum depth variation among individual crevasses reached 22.22 m under extreme threshold settings. An excessively high threshold may remove useful signal photons and eliminate fine-scale crevasse structures, resulting in incomplete surface reconstruction and biased depth estimation. Conversely, an

excessively low threshold retains more noise photons, increasing uncertainty in glacier surface reconstruction and affecting the identification of crevasse boundaries. These experiments highlight that an appropriate density threshold is necessary to balance signal preservation and noise suppression.

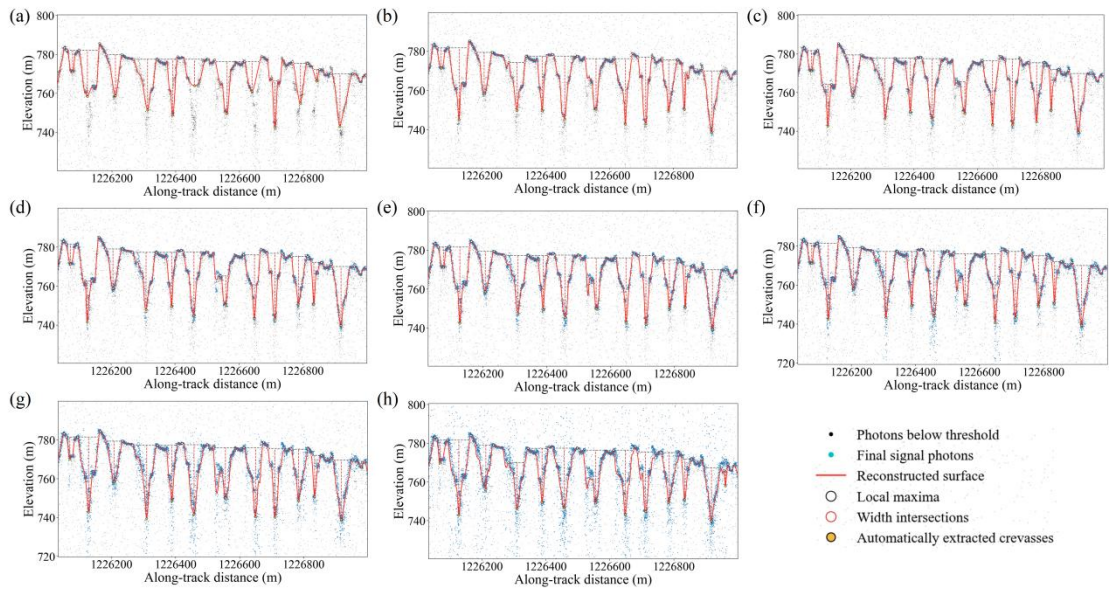


Figure R8. Crevasse extraction results under different density threshold offsets. Panels (a)-(h) correspond to density threshold offsets of +1.0, +0.5, +0.3, +0.1, -0.1, -0.3, -0.5 and -1.0, respectively.

Table R6. Influence of density threshold offsets on retrieved crevasse depths.

Crevasse	-0.1 (Default)	+0.1	+0.3	+0.5	+1.0	-0.3	-0.5	-1.0	Range(m)
1	10.43	10.20	10.67	10.39	11.06	10.44	11.38	11.89	1.69
2	39.10	21.09	21.84	36.69	23.65	38.98	38.73	38.83	18.01
3	21.23	20.33	20.88	20.71	21.12	21.17	20.99	23.00	2.67
4	30.04	29.50	31.55	24.61	25.94	33.90	37.82	23.82	14.00
5	27.98	27.98	27.82	27.81	28.69	27.86	28.74	27.96	0.93
6	31.99	32.79	31.35	32.15	13.61	33.34	35.83	30.94	22.22
7	26.31	14.97	16.58	25.69	26.74	26.27	25.91	27.35	12.38
8	33.12	32.78	33.15	33.48	15.31	35.17	35.62	33.32	20.31
9	34.41	33.70	34.09	33.95	23.65	34.04	35.55	30.81	11.90

Crevasse	-0.1 (Default)	+0.1	+0.3	+0.5	+1.0	-0.3	-0.5	-1.0	Range(m)
10	24.79	24.58	30.61	26.11	20.53	25.81	26.54	25.73	10.08
11	21.38	21.31	21.15	18.51	5.85	21.34	21.23	21.00	15.53
12	30.55	30.34	30.50	31.32	26.90	30.66	30.58	27.58	4.42

Note: Crevasse numbers are assigned sequentially in the direction of increasing along track distance (corresponding to the crevasses shown in Figure R8).

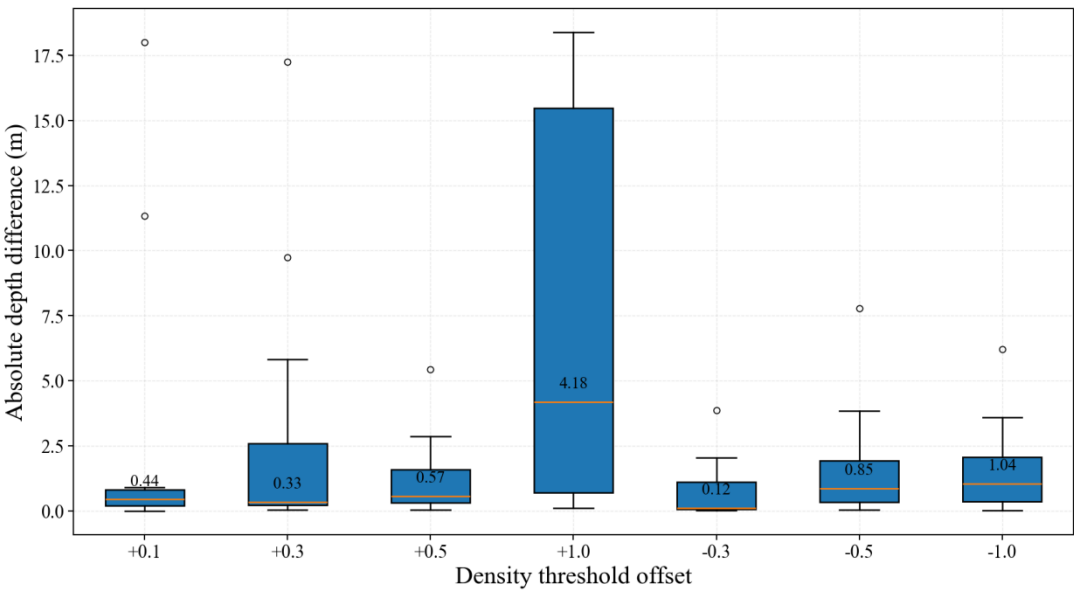


Figure R9. Sensitivity of retrieved crevasse depths to density threshold offsets. Absolute depth differences were calculated relative to the default density threshold offset (-0.1).

In addition, we have added additional descriptive statistics for the retrieved crevasse depths and quantified the depth differences relative to the crevasse magnitude (Table R7). Specifically, the statistical comparison shows that the median crevasse depth derived from ICESat-2 ATL03 is 9.55 m, with a 90th percentile depth of 14.08 m, while the corresponding values from ATM measurements are 9.79 m and 14.14 m, respectively. The comparison between the two datasets indicates that the median absolute depth difference is 0.67 m, and the 90th percentile difference is 1.35 m. When normalized by the corresponding crevasse depths, the median relative difference is 6.82%, increasing to 17.83% at the 90th percentile. These results provide a more comprehensive characterization of the uncertainty associated with the retrieved crevasse depths. In the revised manuscript, we have added these statistics to

Section 4.1.4.

Table R7. Comparison of crevasse depths derived from ICESat-2 ATL03 and ATM data.

Crevasse	ATL03 depth (m)	ATM depth (m)	Absolute difference (m)	Relative difference (%)
1	14.02	13.69	0.33	2.41
2	13.01	12.21	0.80	6.55
3	6.44	5.17	1.27	24.56
4	15.83	13.75	2.08	15.13
5	9.65	10.00	0.35	3.50
6	6.91	6.85	0.06	0.88
7	3.75	4.56	0.81	17.76
8	4.36	4.76	0.40	8.40
9	13.48	13.95	0.47	3.37
10	3.76	3.49	0.27	7.74
11	7.78	7.85	0.07	0.89
12	3.36	4.42	1.06	23.98
13	9.00	7.91	1.09	13.78
14	6.90	7.18	0.28	3.90
15	11.41	11.20	0.21	1.88
16	3.09	2.95	0.14	4.75
17	7.58	7.45	0.13	1.74
18	17.71	14.96	2.75	18.38
19	13.49	14.62	1.13	7.73
20	11.41	12.28	0.87	7.08
21	13.08	14.09	1.01	7.17
22	11.53	12.34	0.81	6.56
23	13.82	12.55	1.27	10.12
24	7.31	7.18	0.13	1.81
25	11.48	10.13	1.35	13.33
26	14.63	15.29	0.66	4.32
27	4.83	5.50	0.67	12.18
28	6.97	8.32	1.35	16.23
29	9.45	9.58	0.13	1.36
30	11.54	12.07	0.53	4.39
Median	9.55	9.79	0.67	6.82
90th percentile	14.08	14.14	1.35	17.83

Note: Crevasse numbers are assigned sequentially in the direction of increasing along track distance (corresponding to the crevasses shown in Figure 8c). Relative difference was calculated as $|D_{ATL03} - D_{ATM}|/D_{ATM} \times 100\%$.

Minor

1. Updated data citation: Please verify/update the in-text citations and bibliography with the version of the ATL03 product used in the study. For example, the current Version 7 user guide (found here: <https://nsidc.org/sites/default/files/documents/user-guide/atl03-v007-userguide.pdf>) provides the following data citation: which differs and Neumann, T. A., Hancock III, D. W., Robbins, J., Gibbons, A., Lee, J., Brenner, A., Felikson, D., Harbeck, K., Saba, J., Luthcke, S., Rebold, T., Reese, A., & Sutterley, T. (2025). ATLAS/ICESat-2 L2A Global Geolocated Photon Data (ATL03, Version 7). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. <https://doi.org/10.5067/ATLAS/ATL03.007> [Date Accessed]. The above reference is more recent than the citation provided in the bibliography (which lists a 2019 Neuman et al product). The bibliography's 2019 reference is also different than the one listed in the Data Availability section (which indicates a 2023 entry for the version 6 product).

Response:

Many thanks for this suggestion. We have verified the ICESat-2 ATL03 product version used in this study and confirmed that all analyses were conducted using ATL03 Version 6. Accordingly, we have updated the in-text data citation and bibliography entry following the official NSIDC data citation format for ATL03 Version 6: Neumann, T. A., A. Brenner, D. W. Hancock III, J. Robbins, A. Gibbons, J. Lee, K. Harbeck, J. Saba, S. Luthcke, and T. Rebold. 2023. ATLAS/ICESat-2 L2A Global Geolocated Photon Data, Version 6. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. <https://doi.org/10.5067/ATLAS/ATL03.006>. [Date Accessed].

2. Line 205 – Is there a citation that can be used for this 150 m threshold, or was this value determined empirically?

Response:

Many thanks for this comment. The 150 m neighboring range was not directly adopted from previous studies. Instead, it was empirically determined based on the

observed spatial scale of crevasse structures in the SKJI. We have clarified this point in the revised manuscript.

3. Line 280 – Consider adding a brief explanation of how the depth and width thresholds for crevasse detection were derived. Is this based on literature?

Response:

Many thanks for this comment. The depth and width thresholds used for crevasse identification were determined based on both previous studies and the morphological characteristics of crevasses in the SKJI. Specifically, we followed the identification strategy based on crevasse depth and width proposed by Wang et al. (2021), while adjusting the threshold values according to the crevasse geometries observed in SKJI. Compared with Antarctic crevasses investigated in previous studies, smaller and narrower crevasses are commonly observed in Greenland outlet glaciers; therefore, the thresholds were adapted to better represent the local crevasse characteristics. We have clarified this point in the revised manuscript and added the corresponding reference.

4. Figure 2 – Rotate the titles/text along the left side of the flow chart by 180 degrees for readability (consistent with the orientation used in other figures, e.g., Figure 3).

Response:

Many thanks for this helpful suggestion. We have revised Figure 2 to improve readability. Instead of keeping the titles as vertically oriented labels along the left side, we reorganized them as horizontal headings placed above each module, as shown in Figure R10.

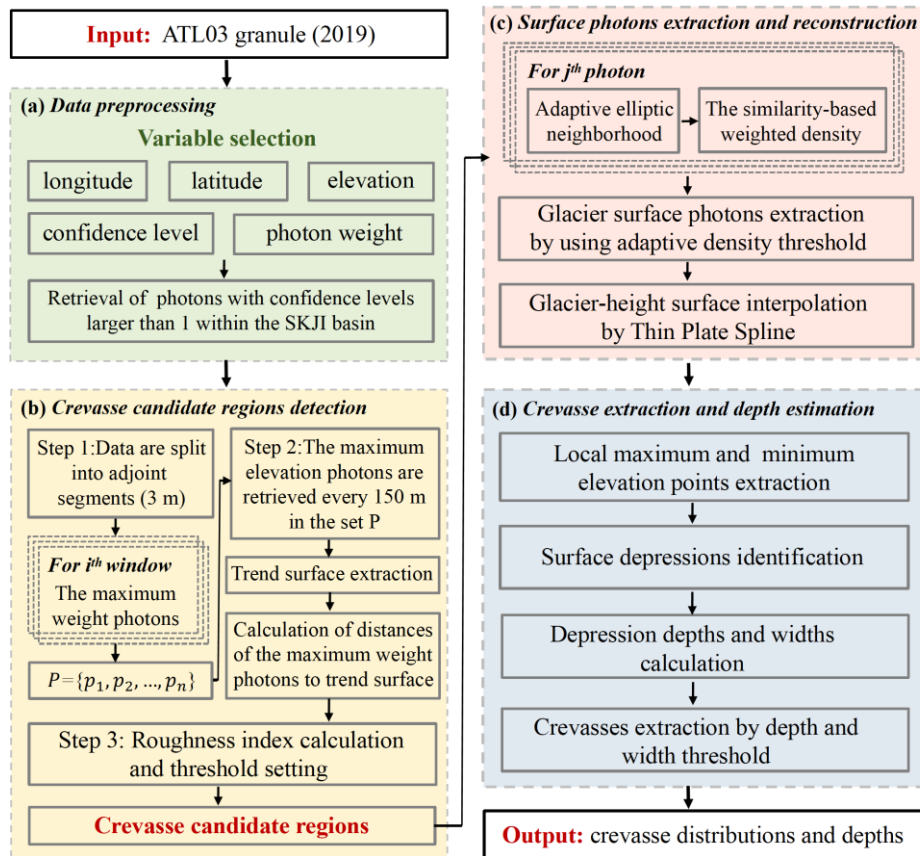


Figure R10. Flowchart of the proposed method.

5. Figure 4 – Consider making the underlying markers for the glacier-surface signal photons larger or more distinct so that they are more easily visible.

Response:

Many thanks for this helpful suggestion. We increased the marker size of the glacier-surface signal photons and enhanced their visual contrast relative to the background raw photons in the revised Figure 4, as shown in Figure R11.

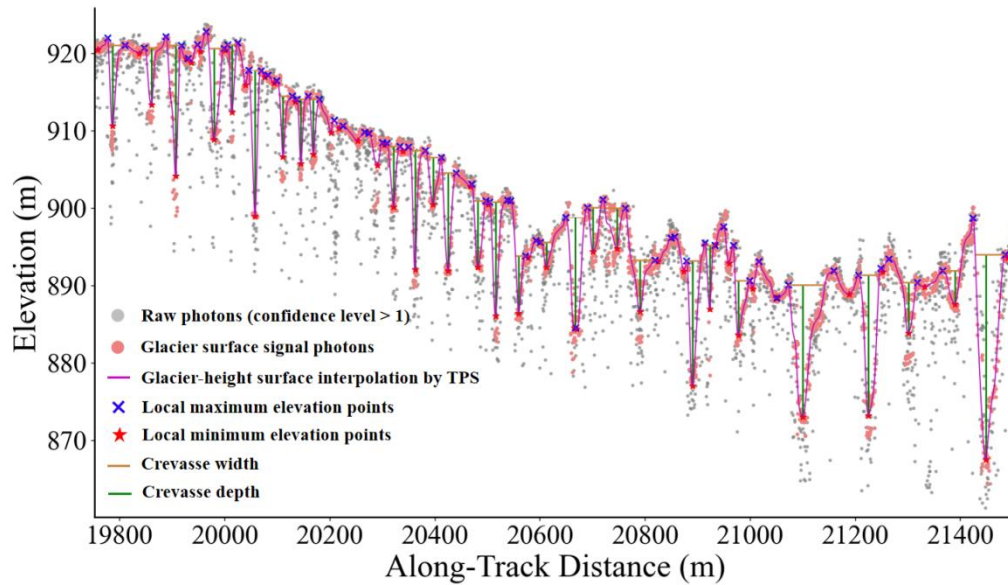


Figure R11. Illustration of glacier surface photon extraction, ice surface reconstruction and crevasse metric extraction.

6. Figure 5 – Consider including the equilibrium line, or the approximate snowline for January–March, in subplots 5a and 5b. Alternatively, overlaying the 600m or 900m elevation boundaries could also be useful to orient readers, as these elevation bands are discussed in results later in the manuscript.

Response:

Many thanks for this helpful suggestion. We have revised Figure 5 to provide a clearer spatial context for the distribution of crevasse candidate regions, as shown in Figure R12. Specifically, we added the approximate equilibrium line altitude (ELA, shown as the pink dashed line) and the 600 m and 900 m elevation boundaries in subplots 5a and 5b. The ELA was delineated based on the regional equilibrium line reported by Poinar et al. (2016), which was derived from RACMO2 surface mass balance estimates and represents the long-term mean ELA (1960–2011) in the SKJL.

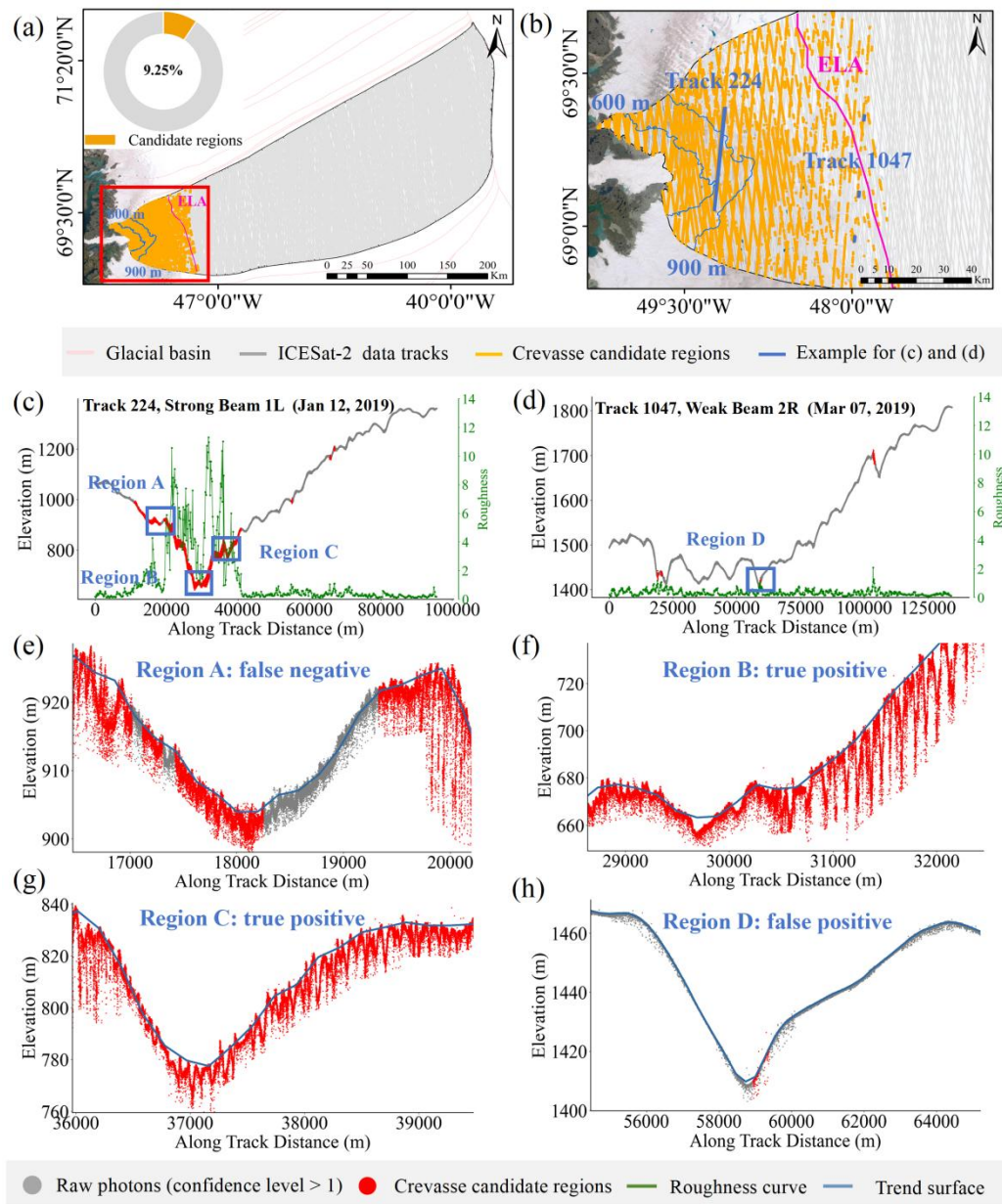


Figure R12. Evaluation results of crevassed region detection. (a) and (b) Extracted crevassed regions, where (b) is the red box in (a). (c) and (d) Results of roughness calculations and crevassed region detection for two beams. (e)-(h) Cases of crevassed region detection, where (e) shows a false negative, (f) and (g) show true positive, (h) shows a false positive.

7.Line 434 - 435 - Is there a typo here? Should 'estimate' instead read 'underestimate' ?

Response:

Many thanks for pointing this out. We agree that the original wording was not

474 sufficiently precise. Since ICESat-2 observations are distributed along sparse ground
475 tracks, the derived crevasse inventory may miss crevasses located between adjacent
476 tracks. Therefore, we will revise the sentence to clarify that our inventory likely
477 represents an underestimate of the true crevasse population.