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Assessment of SWOT for monitoring ice-marginal lake water levels in Greenland

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Key Points:

- SWOT was used to monitor water levels of ice-marginal lake around the Greenland Ice Sheet for the first time.
- The lake water levels monitored using SWOT and ICESat-2 are consistent, but SWOT can detect 1.5 times more ice-marginal lakes than ICESat-2.
- Due to the higher temporal resolution (< 21 days) of SWOT it could detect twice as many GLOFs as ICESat-2.

Abstract

The Surface Water and Ocean Topography (SWOT) satellite mission provides a powerful dataset for monitoring global surface water resources. However, its performance for monitoring ice-marginal lakes in Greenland remains unknown. Due to the scarcity of in situ measurements, this study evaluated the reliability of ice-marginal lake elevations derived from the SWOT Water Mask Raster Product by comparing to ICESat-2 lidar altimeter data. Results show that across 204 near-contemporaneous water level points for 110 lakes, the average deviation between SWOT and ICESat-2 was 0.03 m, with a root mean square deviation of 1.43 m, showing a good agreement. The higher temporal resolution of SWOT (<21 days over Greenland) enabled better monitoring of glacial lake outburst floods (GLOFs), with a 100% increase in the number of GLOFs detected compared to ICESat-2 between 2023 and 2024. These advantages make SWOT an excellent data source for monitoring ice-marginal lakes around the Greenland Ice Sheet.

Plain Language Summary

Satellite altimeters are widely used for monitoring water levels of ice-marginal lakes. However, previous altimetry missions (such as ICESat-2) primarily provided water level measurements along satellite tracks, yielding essentially one-dimensional observations. The launch of the Surface Water and Ocean Topography (SWOT) mission has introduced a new data source for monitoring water levels of global surface waters by enabling two-dimensional water level observations. This capability substantially increases the number of observable lakes, which is particularly important for remote, small-sized, and sparsely monitored regions such as ice-marginal lakes in Greenland. We evaluated the accuracy of SWOT elevations by comparing them with near-synchronous observations from the laser altimeter ICESat-2. We also investigated the factors influencing the accuracy of SWOT water level measurements, as well as the potential of SWOT for monitoring glacial lake outburst floods. Although SWOT was not specifically designed for ice sheet regions, it has strong potential to make significant contributions to the monitoring of ice-marginal lakes.

1 Introduction

Ice-marginal lakes around the Greenland Ice Sheet receive a portion of meltwater and constitute an essential and dynamic component of the terrestrial water volume (How et al., 2025). While some lakes have relatively stable water volumes (Dømgaard et al., 2024), others exhibit filling followed by sudden and large-scale water discharges otherwise known as glacial lake outburst floods (GLOFs), which can alter downstream geomorphology and ice flow velocities (Tomczyk et al., 2020; Kjeldsen et al., 2017). Under global warming, the extent and temperature of these lakes are projected to increase, exacerbating ice-front melting and increasing the risk of GLOFs (Zhang et al., 2024). Therefore, monitoring the water levels of ice-marginal lakes is crucial for studying changes of the Greenland Ice Sheet and climate change processes.

Satellite altimeters can obtain the water level of lakes over continental scales (Dømgaard et al., 2024; Yao et al., 2023). However, due to the dynamic nature of ice-marginal lakes, it is challenging to use satellite altimetry to monitor rapid variations in water levels due to the relatively low temporal resolution of the observations. For example, even the latest-generation satellite lidar altimeter, ICESat-2, has a temporal resolution of approximately 91 days (Smith et al., 2023). Furthermore, as satellite altimeters only obtain measurements along a narrow ground track beneath the satellite orbit, the spatial coverage and number of detected lakes are still limited.

The Surface Water and Ocean Topography (SWOT) satellite, launched in 2022, measures water elevation using radar interferometry and provides an alternative to satellite altimetry for monitoring global water resources (Fu et al., 2024). SWOT utilizes a wide-swath observation mode, enabling observations of 95% of lakes and rivers greater than 50–100 m in width, excluding Antarctica (Altenau et al., 2021). Furthermore, SWOT has a 21-day revisit period (Nickles et al., 2019), and due to its relatively dense orbit over the polar regions, observations of lakes at the ice sheet margins are typically more frequent. However, the validation and application of SWOT data have currently only been on non-glacial inland lakes, rivers and oceans (Archer et al., 2025; Andreadis et al., 2025; Girard et al., 2025; Kacimi et al., 2025; Larnier et al., 2025; Lichtman et al., 2025; Maubant et al., 2025; Nencioli et al., 2025; Patidar et al., 2025; Xiong et al., 2023). Ice-marginal lakes in Greenland are characterized by steep topography, the presence of floating ice, and small sizes, which are markedly different from those of typical SWOT validation sites, the performance of SWOT over polar water bodies remains largely unknown.

This paper provides the first evaluation of SWOT data to monitor ice-marginal lake water levels across Greenland. Due to the lack of in situ lake water level measurements, elevation data from the state-of-the-art lidar altimeter, ICESat-2, was used for comparison. Differences in spatial coverage and spatiotemporal resolution, and the factors influencing water level monitoring were analyzed. These results assess the performance of SWOT for ice-marginal lake water level monitoring and provide a preliminary reference for its future application over ice sheets.

2 Data and Methods

2.1 SWOT Data

The SWOT satellite is equipped with a Ka-band synthetic-aperture radar (SAR) (Fjørtoft et al., 2013) and uses Interferometric SAR technology to measure water elevations, with a 120-km swath at a temporal resolution of 21 days (Biancamaria et al., 2016). We used the SWOT Level 2 Water Mask Raster product in high-rate version (SWOT, 2024) from December 2022 to March 2025. This product was chosen because a recent validation of SWOT products demonstrated that this Water Raster product has the highest accuracy and can detect small (<0.2 km^2) water bodies (Maubant et al., 2025). Given the small size of some ice-marginal lakes in Greenland, the 100-m spatial resolution product was used. As this product also includes observations of mixed pixels (including both water and land), to ensure the reliability of the elevation data, only pixels with a water area greater than 80% (based on the 'water_frac' parameter in the SWOT dataset) were used. For each SWOT Level-2 Water Mask Raster product, a quality flag is provided for the water surface elevation of each pixel. Four classes are defined: good, suspect, degraded, and bad (corresponding to values of 0, 1, 2, and 3, respectively). Measurements flagged as suspect may contain relatively large errors, those flagged as degraded are very likely to contain significant errors, and measurements flagged as bad may be meaningless and should be excluded from further analysis. Here, using only good-quality observations (flag value = 0) over Greenland resulted in a small number of observation points for individual lakes. Specifically, a total of 506 lakes can be detected, with an average of 16 observations per lake. In contrast, using data with quality flags of both 0 and 1 results in 2549 detected lakes with an average of 59 observations per lake, nearly three times as many. A small number of observation points may result in a high proportion of potentially inaccurate observations. To account for this, observations with good or suspect quality (flag value = 0 or 1) were retained. As this approach introduced lower-quality elevation observations, an outlier detection method was used to eliminate possible observation errors by considering lake surface smoothness (see section 2.5). To eliminate the impact of SWOT sampling on lake elevation estimation as much as possible, the corresponding elevation data were retained only when 60% of the lake area (see section 2.3) was sampled.

2.2 ICESat-2 Data

Due to the lack of in situ lake water level measurements, ICESat-2 ATL06 data from December 2022 to March 2025 were used to evaluate the SWOT data. This product contains locations, surface elevations, and a quality indicator. Only high-quality elevations (i.e., atl06_quality_summary = 0) were used. A detailed algorithm for the ATL06 product can be found in Smith et al. (2023). Direct comparisons with kinematic GPS and static GNSS in Greenland have shown that ICESat-2 elevation estimates have a vertical bias of <1.0 cm and <6.0 cm precision (Pickell et al., 2025). ICESat-2 data was chosen because it offers the largest spatial coverage (up to 88°N), the highest temporal resolution (40 m), and the highest accuracy of any previous satellite altimeter, and has previously been used to study lake water level fluctuations of ice-marginal lakes in Greenland (Dømgaard et al., 2024). To ensure the lake water levels of the two satellites were comparable, the elevation data of both products were referenced to the WGS84 ellipsoid.

2.3 Lake Outlines

To obtain the satellite measurement points within lakes, an accurate and synchronized lake boundary is crucial. Here, we used the annual Greenland Ice-Marginal Lake Inventory from 2022 to 2023 provided by How et al. (2025). This dataset provides a continuous, high-precision inventory of ice-marginal lakes based on multi-source remote sensing data. It follows the 2017 Greenland Ice-Marginal Lake Inventory from the European Space Agency Climate Change Initiative (Wiesmann et al., 2021) and shares the same data structure and format. The dataset of How et al. (2025) includes over 3000 ice-marginal lakes larger than 0.05 km², each with a uniform lake ID. SWOT only covers up to 78 degrees, while the spatial coverage of ICESat-2 can extend to 88 degrees. The comparison was therefore restricted to areas south of 78 degrees, resulting in 2576 lakes. To ensure consistent temporal coverage, lake boundaries for 2024 and 2025 were derived using the method from How et al. (2025).

2.4 Lake attributes and topographic data

Lake characteristics, surrounding topography, and observation geometry were used to analyze their influence on the accuracy of SWOT-derived lake water levels. Specifically, we employed eight factors describing lake shape characteristics, including area, perimeter, etc. These factors were calculated from lake boundary data and characterize lake shape from multiple perspectives. Topographic variables include elevation, slope, and aspect. Elevation data were obtained from the ArcticDEM mosaics product at a spatial resolution of 100 m (Porter et al., 2023), from which slope and aspect were derived. Detailed descriptions of the corresponding parameter calculations are provided in Text S1 and Figure S1. In addition, we examined the relationships between water level measurement accuracy and the lake surface backscatter intensity, which was directly derived from from SWOT product, i.e., Sigma0 values).

2.5 Lake water level time series

Lake outlines were used to filter altimeter points and thus obtain lake water level measurement points. However, as the lake boundaries are derived annually, non-lake observation points may also be included due to lake area changes within a year. To obtain reliable lake water level observations, according to Dømgaard et al. (2024), an outlier detection method was employed to eliminate observation errors by considering lake surface smoothness. A detailed description of this method and a discussion of the associated thresholds can be found in Text S2, Figure S2 and Table S1.

To minimize the influence of lake ice cover on the water levels, we first searched for Landsat 8 images acquired within one week of the observation date (±3 days) with cloud cover less than 20%, and visually inspected whether the lakes were ice-covered. For observations without valid satellite imagery coverage, Sentinel-1 SAR data were used instead. Lake surface freezing reduces the radar backscatter coefficient (i.e., Sigma0), and therefore lake ice conditions can be identified based on systematic variations in lake surface Sigma0. Four examples that clearly illustrate the Sigma0 changes associated with lake freezing are shown in Figure S3, which demonstrates the feasibility of determining lake ice-on and ice-off dates. Here, the non-ice-covered periods for each lake were determined following the method described in Posch et al. (2024). Water level observations falling within the ice-free periods were retained, while those outside these periods were excluded. Four examples of final water level time series are shown in Figure S4, including sustained increase, cyclic variation within a single period, small-amplitude fluctuations, and large-amplitude variations.

Water-level time series were subsequently constructed to investigate temporal dynamics, and GLOFs for each lake—defined as a change in lake water level elevation greater than 10 m between consecutive time periods—were identified. We acknowledge that a fixed threshold might not be suitable for different lake depths; for example, 10 m could be a large change for a shallow lake, but a small change for a very deep lake. However, we focus solely on examining how differences in temporal resolution affect the precise detection of GLOFs, rather than directly comparing variations in water volume.

2.6 Evaluation strategy

The accuracy of SWOT was assessed by comparing lake water levels with those from ICESat-2. We restricted our assessment to lake water levels collected within three days of each other, yielding a total of 110 lakes and 204 elevation points. The mean difference (MD), mean absolute difference (MAD), root mean square deviation (RMSD), and correlation coefficient (*R*) were selected as evaluation metrics.

3 Results

3.1 Local-scale performance of SWOT

The spatial sampling of SWOT and ICESat-2 measurements for three examples of lakes of varying sizes are shown in Figure 1. Here, we compared the differences in raw elevations between SWOT and ICESat-2 along the ICESat-2 ground track. It should be noted that these water levels have only undergone an initial quality control based on the quality flags; no additional outlier detection procedures were applied. In Figure 1a, where the lake is surrounded by extensive ice and snow cover, surface elevations from ICESat-2 are more stable (with a standard deviation of 0.03 m), whereas those from SWOT exhibit noticeable fluctuations (with a standard deviation of 0.13 m). Similar patterns can be observed in lakes of comparable size (Figure 1b). However, the variability is reduced, with a standard deviation of 0.01 m for ICESat-2 and 0.03 m for SWOT. This indicates that larger variability of SWOT elevations may be related to the surrounding environment or observation time. In Figure 1c, we observe that ICESat-2 exhibits several pronounced high-elevation values, resulting in a relatively large standard deviation of 0.31 m, whereas SWOT shows a more stable behavior with a standard deviation of 0.05 m. These slight higher elevations from the ICESat-2 may be associated with the presence of floating ice on the lake surface. However, a temporal mismatch remains between the ICESat-2 observations and the available satellite optical image, making it difficult to conclusively establish this association. Overall, for both ICESat-2 and SWOT, the initial quality control procedures are effective in removing a portion of the apparent outliers. The mean bias between raw elevations from SWOT and ICESat-2 remains within 0.5 m.

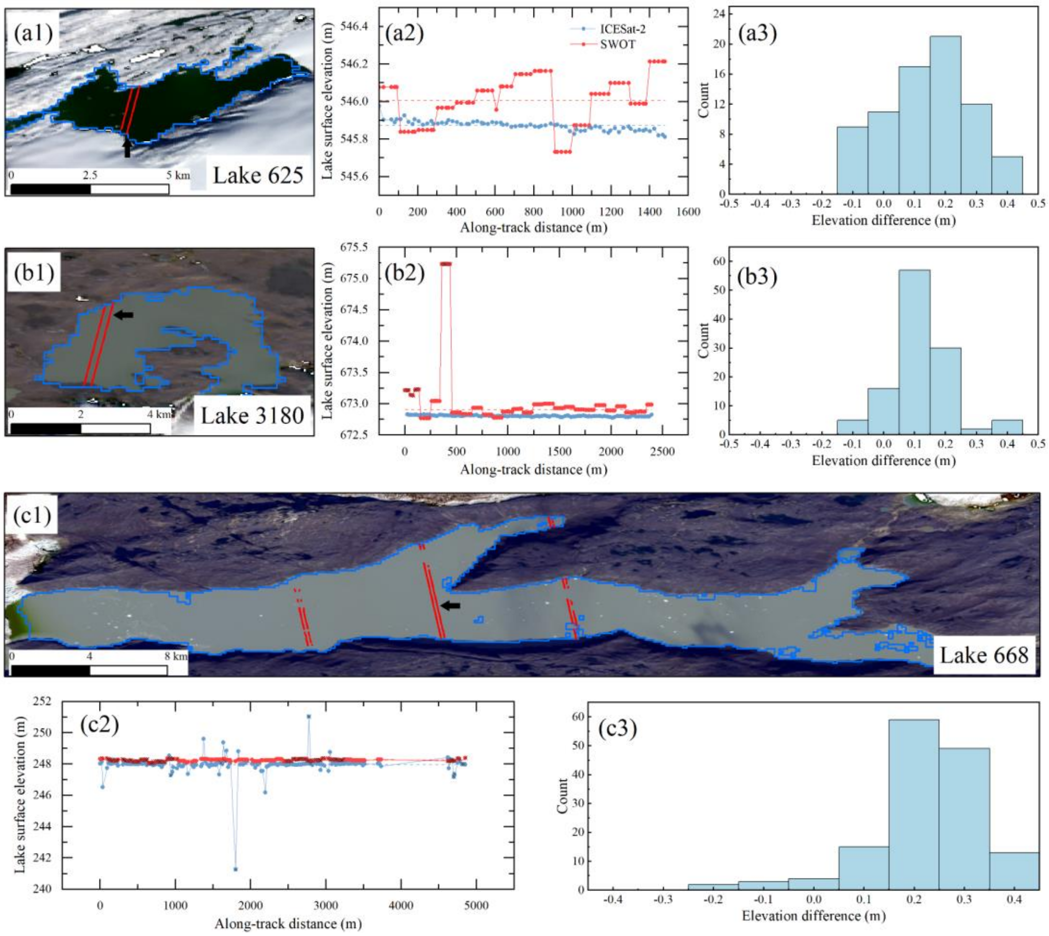

Figure 1. Examples of the spatial coverages of SWOT and ICESat-2 at ice-marginal lakes of different sizes, and comparison of lake water level elevations from SWOT and ICESat-2. (a) for Lake 625, (b) for Lake 3180, and (c) for Lake 668. In (a1)-(c1), the blue box indicates the coverage of SWOT, and the red dots indicate ICESat-2 measurement points. The background images are from Landsat 8 images. For Lake 625, ICESat-2: 2024-09-10, SWOT: 2024-09-10, Landsat 8: 2024-09-10; for Lake 3180, ICESat-2: 2024-10-29, SWOT: 2024-10-27, Landsat 8: 2024-10-27; for Lake 668, ICESat-2: 2024-09-17, SWOT: 2024-09-17, Landsat 8: 2024-09-17. The ICESat-2 tracks used for comparison are indicated by black arrows. In (a2)-(c2), the dashed lines represent the median elevations derived from all valid elevation values. The water levels identified as outliers based on the quality flags in the original product are indicated by cross marks. The related statistical results were computed after applying the quality flags, no additional outlier detection procedures were applied.

3.2 Assessment of lake water levels from SWOT

Based on 110 detected lakes (see section 2.6), we conducted an elevation comparison between SWOT and ICESat-2. These comparisons are widely distributed around the margin of the Greenland Ice Sheet, with variation in latitude or region (Figure 2). Results show strong agreement between SWOT and ICESat-2 lake water levels. The deviation ranged from -10 to +10 m, with 88% of the differences falling between -0.5 and 0.5 m (Figure 2a). The overall MD was 0.03 m, the MAD is 0.49 m, and the RMSD was 1.43 m. At the ice sheet basin scale, overall consistency is good across most basins, with the majority of the differences falling within ±0.2 m (Figure 2b). Specifically, the elevation differences between the two varied across different months (Figure 2c). The elevation differences are relatively smaller in summer (e.g., August) and larger in winter (e.g., December and January). A detailed discussion of the reasons for these differences can be found in Section 4.2.

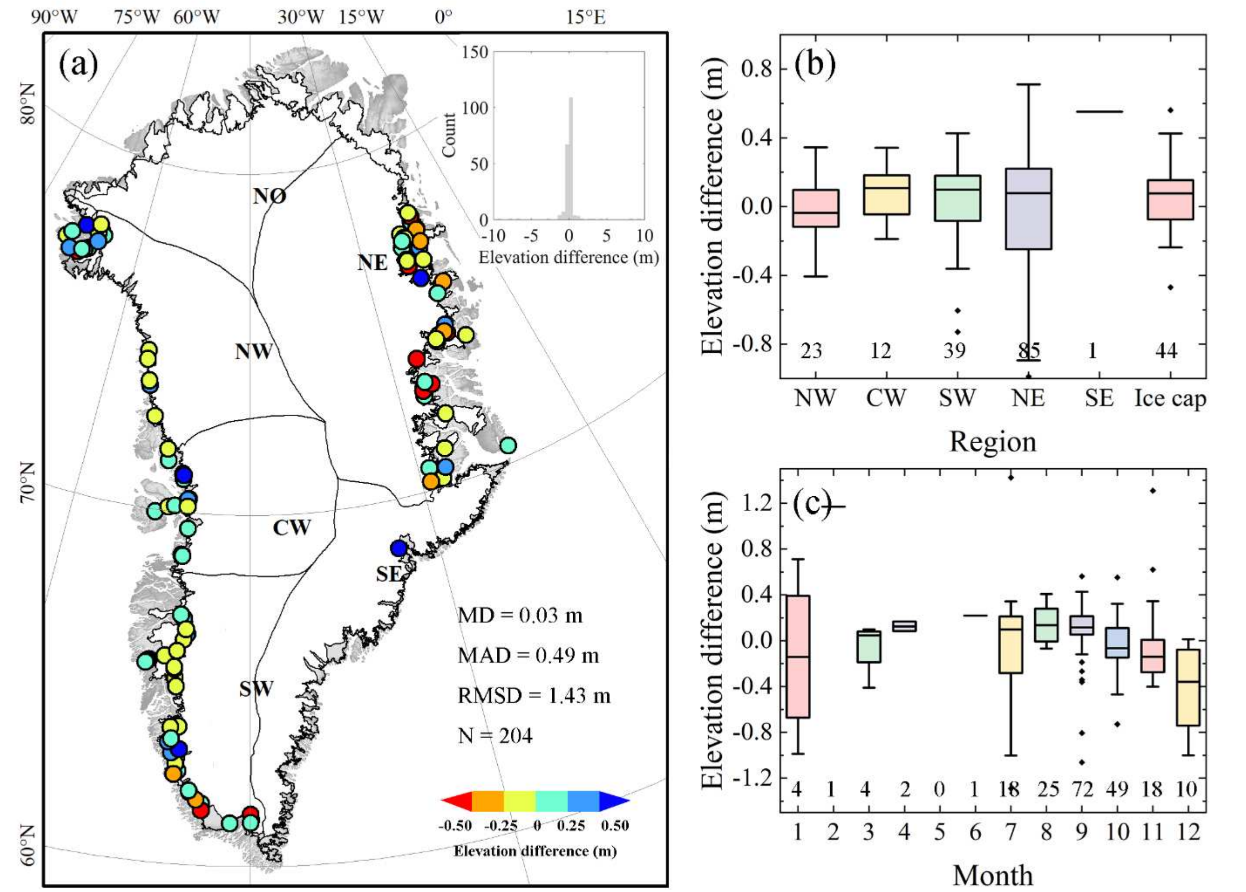

Figure 2. Differences between lake water levels derived from SWOT and ICESat-2. (a) Spatial distribution of lake water level differences at the lake scale, the inset panel shows frequency distribution of lake water level difference between SWOT and ICESat-2, (b) distribution of water level differences at the ice sheet basin scale, and (c) distribution of water level differences at the monthly scale. In (a), MD means median difference, MAD means median absolute difference, RMSD means root mean square deviation, and N means the number of matched observations. Black lines indicate boundaries of ice sheet basins and are labeled with corresponding names: South West (SW), Central West (CW), North West (NW), North (NO), North East (NE), Central East (CE), and South East (SE). In (b) and (c), the central line within each box represents the median, while the lower and upper bounds of the box correspond to the first and third quartiles, respectively. The whiskers extend to the most extreme data points within 1.5 times the interquartile range, and points beyond this range are plotted as outliers. It should be noted that there were no data points for May in (c). The number of water level measurement points in different ice sheet basins and months is also listed below.

4. Discussions

4.1 General performance

Here, we applied SWOT to monitor the water level elevation of ice-marginal lakes around Greenland. Of the 2576 ice-margin lakes (> 0.05 km²) south of 78°N (Wiesmann et al. 2021; How et al. 2025), SWOT detected 2549 (99%) of these lakes, while ICESat-2 detected 1736 (67%). The higher number of ice-marginal lakes observed using SWOT demonstrates the advantage of wide-swath technology. This ability also enables much denser elevation sampling compared with ICESat-2. When the number of lake water level points is low, there is a greater chance that fewer or even no points can be used (e.g., due to the quality of observations). Additionally, as the SWOT orbits are more densely distributed over the polar regions, the actual temporal coverage is less than the nominal 21 days (as frequent as three days at best). Of the 526 lakes observed by both SWOT and ICESat-2, we find that SWOT produces four times as many valid observations per lake as ICESat-2 in 2024 (Figure 3), significantly improving the frequency of ice-margin lake water-level observations.

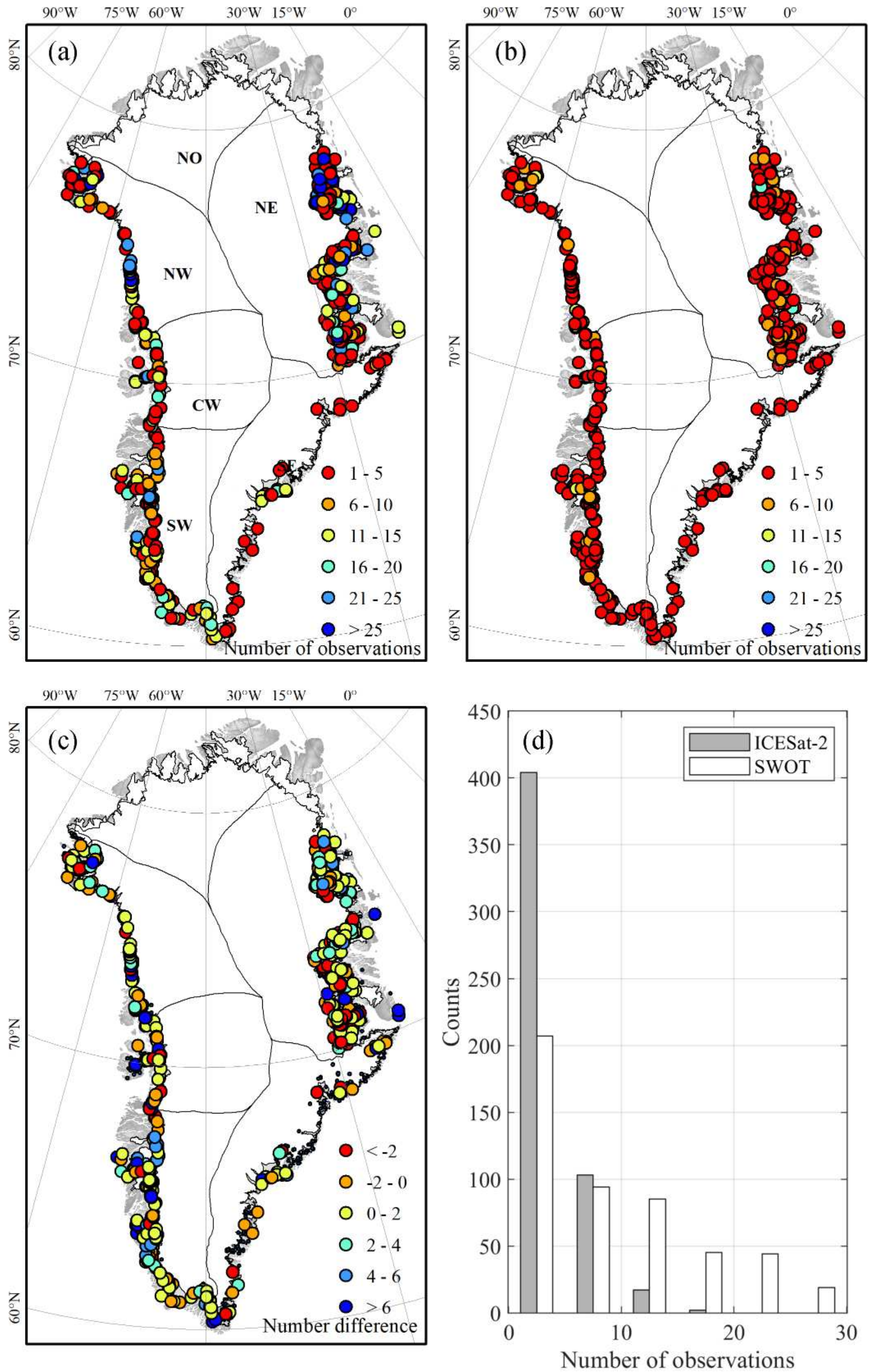

Figure 3. Number of observations of ice-marginal lakes observed by SWOT and ICESat-2 in 2024. (a) Spatial distribution of the number of observations for SWOT, (b) for ICESat-2, (c) the difference in the number of observations between SWOT and ICESat-2, (d) Frequency distribution of observations for SWOT and ICESat-2.

Dømgaard et al. (2024) used altimetry to detect water level changes of ice-marginal lakes on the Greenland Ice Sheet and found that, compared with existing historical databases, the number of detected GLOFs from 2003–2023 increased by 1200%. It should be noted that the temporal resolution of ICESat-2 used in their study is only 91 days, whereas the timescale of GLOF is often much shorter. Therefore, this number may still be underestimated. This process highlights the importance of high-temporal-resolution elevation data for monitoring GLOFs. Here, using a water level change threshold of 10 m, GLOFs from 2023 to 2024 detected by ICESat-2 and SWOT were compared. Water level time series for six lakes identified as having experienced GLOFs are also shown in Figure S5. These examples exhibit diverse behaviors, including stepwise increases, near-constant levels, gradual water-level rises after a GLOF event, and cases in which water levels show large-amplitude cyclic variations and remain stable for more than half a year before a GLOF event. A total of 37 GLOFs were detected by both satellites; ICESat-2 identified 14 events, whilst SWOT identified 30 events (Figure S6). Compared to previous satellite altimeters, SWOT enables continuous and spatially extensive monitoring of lake level changes, allowing early identification of potentially unstable lakes and supporting proactive GLOF risk assessment. It should be noted that the GLOF detection method used here may not unequivocally indicate a GLOF event. Automated GLOF detection based on SWOT data still requires further refinement in the future.

4.2 Sources of water level differences between SWOT and ICESat-2

The consistency of SWOT and ICESat-2 lake water level elevations is generally good (with a MD of 0.03 m). Here we compared the lake water level difference under different conditions of lake characteristics, surrounding topography, observation geometry and hydrology to analyze their potential influences. Overall, the largest lakes tend to have lower median differences than mid-sized lakes.(Figures S7a-b). This may be related to differences in the observation coverage of SWOT and ICESat-2. SWOT provides near-complete spatial coverage of lake surfaces, whereas ICESat-2 samples water levels only along satellite tracks. For smaller lakes, the spatial mismatch between the two observation types may be substantial. As ICESat-2 may sample only a limited portion of the lake, given the potential spatial heterogeneity of the lake surface elevations, this mismatch may result in larger discrepancies between the two water level estimates. For larger lakes, ICESat-2 is more likely to intersect the lake surface multiple times, providing a more representative sampling of lake water levels that is more comparable to SWOT. No clear relationship is observed between water level differences and other lake shape characteristics, including area-to-perimeter ratio, IPQ, Fractal, Reock, Schwartzberg and ratio of width and length (Figures S7c-h). In general, more complex lake shapes are associated with greater uncertainty in boundary delineation, which can introduce errors into water level monitoring. However, a series of quality control procedures (see section 2.5) were applied; as a result, lake shape characteristics appear to have no apparent impact on the SWOT water level accuracy.

Lakes at lower elevations tend to exhibit a wider range of water level differences, whereas no clear relationship with elevation is observed for higher-elevation lakes (e.g., above 340 m, Figure S8a). The effects of surrounding slope and aspect on water level bias are generally weak (Figures S8b-c). Although the incidence angle range of SWOT observations is relatively narrow (< 4°), a noticeable increase in water level bias is observed beyond ~2.7° (Figure S8d). As the incidence angle increases, radar backscatter intensity generally decreases, reducing the contrast between the lake surface and the surrounding environment. Under such conditions, elevation retrieval becomes more sensitive to phase noise and mixed-pixel effects. An increasing trend in median differences with increasing lake surface Sigma0 is observed, suggesting that SWOT measurements are also sensitive to surface scattering conditions (Figure S8e). For the number of effective observations within each lake, no clear relationship with water level bias is identified (Figure S8f).

With respect to hydrological factors, short-term water level variability may also contribute to water level bias. To keep a sufficient near-simultaneous SWOT and ICESat-2 observations, a 3-day temporal window was adopted for data matching. During summer, such a time window may encompass substantial water level changes, for example, associated with rapid meltwater inflow or GLOFs. To investigate whether rapid summer meltwater input influences the observed water level differences, we further restricted the temporal offset between the two datasets to within 1 day (Figure S9). Under this constraint, the overall consistency between SWOT and ICESat-2 improved. However, relatively large discrepancies still persist during winter, which may be related to extensive snow and ice cover surrounding the lakes. This may be partly because snow and ice cover during winter affect the reliability of elevation measurements near lake margins, e.g., it may affect the identification of valid SWOT pixels. In addition, a low radar echo level can affect the detection of water pixels by SWOT, either due to extremely smooth water surfaces or significant attenuation of the radar signal during propagation through rain (SWOT, 2024), thereby reducing the accuracy of elevation retrieval. Differences in the observation strategies of the two satellite missions may also contribute to discrepancies in the derived water levels.

4.3 Comparisons with related studies

Currently, SWOT data has been widely validated for non-glacierized lakes and rivers (Girard et al., 2025; Maubant et al., 2025; Patidar et al., 2025; Xiong et al., 2023), and these studies have highlighted SWOT's potential for observing small lakes. Compared with the evaluation of SWOT data in inland water bodies (such as mid- and low-latitude lakes and rivers), the accuracy of SWOT in ice-marginal lakes is relatively low. For example, Maubant et al. (2025) found that for widely distributed water bodies in Australia, SWOT achieved a weighted RMSD of less than 0.1 m; Wu et al. (2025) found that SWOT showed a MD of about 1 cm and a MAD of less than 0.1 m compared with ICESat-2 for lake water levels in Qinghai-Tibet Plateau; Lu et al. (2024) evaluated the accuracy of lake elevations of SWOT globally and found a MAD of less than 0.5 m, as well as a RMSD of less than 2 m. In contrast, for ice-marginal lakes, the MAD and RMSD were around 0.49 m and 1.43 m, respectively. This further highlights the differences in SWOT performance when monitoring ice-marginal lakes.

Our validation of SWOT over ice-marginal lakes in Greenland demonstrates that the satellite can reliably capture lake surface elevations even in challenging polar environments. This work provides the first systematic assessment of SWOT accuracy for small, ice-influenced lakes around the ice sheet, thereby extending the known applicability of SWOT in polar regions. By filling this observational gap, our study offers a meaningful contribution to polar hydrology research and enhances the foundation for future modeling and long-term monitoring efforts.

4.4 Limitations and future work

There are some limitations in this study. First, due to the lack of in situ water level measurements, SWOT-derived water levels are evaluated using near-simultaneous observations from ICESat-2. It should be acknowledged that ICESat-2 water level measurements also contain uncertainties, and therefore, SWOT has not been fully validated. Second, the analysis is limited to SWOT data from 2023 to 2025, a larger number of coincident water level observations would support a more detailed performance investigation. In addition, environmental conditions, such as the presence of icebergs or surrounding snow cover, remain difficult to quantify their impacts on SWOT elevation retrievals. Nevertheless, these limitations do not affect the main conclusions of this study, which demonstrate the overall reliability of SWOT for monitoring water level variations of ice-marginal lakes.

Future work is suggested to focus on strengthening data quality control, including further quantifying the influence of lake morphology, surrounding topography, and observation geometry on elevation retrieval, and developing targeted processing strategies to generate a high-quality SWOT water level dataset. Furthermore, the coordinated use of SWOT and ICESat-2 observations could provide higher observation frequency, enabling improved monitoring of both long- and short-term water level variability.

5 Conclusions

Here, we demonstrate the capability of SWOT for estimating lake water levels for ice-marginal lakes in Greenland. SWOT observes 99% of lakes in the study region, significantly outperforming the state-of-the-art lidar altimeter ICESat-2 (67%). Among 204 temporally-matched lake water level points from 110 lakes. The overall average deviation of lake water levels between SWOT and ICESat-2 was 0.03 m, with an RMSD of 1.43 m, demonstrating their high agreement. The higher temporal resolution of SWOT data offers an advantage in identifying GLOFs compared to ICESat-2, doubling the number of detected GLOF events over 2023-2024. Overall, SWOT offers advantages in observing ice-marginal lakes in Greenland, including more extensive spatial coverage, higher observation frequency, and comparable measurement accuracy. Future research needs to develop data processing algorithms tailored to the conditions of lake characteristics, surrounding topography, observation geometry, and to strengthen validation with ground-based and airborne observations, to improve the accuracy and reliability of monitoring in complex glacial environments.

Acknowledgments

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Conflict of Interest Statement

The authors declare there are no conflicts of interest for this manuscript.

Open Research

SWOT Water Mask Raster Product can be derived from Physical Oceanography Distributed Active Archive Center (SWOT, 2024); ICESat-2 ATL03 data can be obtained from Smith et al. (2023); The annual Greenland Ice-Marginal Lake Inventory can be derived from How et al. (2025). The original water level comparison data and the associated codes are available from Shen (2026).

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