Potential of SWOT Mission in Monitoring Taiwan Surface Water Dynamics

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Abstract:
The Surface Water and Ocean Topography (SWOT) mission, equipped with a Ka-band interferometric altimeter, has provided high-precision, wide-swath measurements of terrestrial water bodies and oceans since its launch on December 16, 2022. However, the accuracy of SWOT water surface elevation (WSE) data over small waterbodies still requires further evaluation. This study utilizes SWOT Level 2 LakeSP and Pixel Cloud (PIXC) products to conduct a time-series comparison with in-situ data collected from 14 reservoirs and 15 ponds across Taiwan. Through this comparison, LakeSP is found to capture temporal variations in water levels, with average root-mean-square errors (RMSEs) of 1.55 m for reservoirs and 1.21 m for ponds, and standard deviations (STDs) of 0.97 m and 1.02 m, respectively. With the application of a predefined water mask and a tailored processing workflow to extract valid PIXC data points, the accuracy was significantly improved, reducing RMSEs to 0.53 m and 0.15 m, and STDs to 0.30 m and 0.10 m for reservoirs and ponds. Additionally, detectability was enhanced, with the PIXC product successfully identifying water bodies as small as 11,992 m² (approximately 110 × 110 m)—substantially smaller than the original mission requirement of 250 × 250 m. These findings highlight SWOT strong capability in tracking seasonal water level dynamics and evidence its value for managing water resources in small and ungauged water bodies.

Keywords: SWOT, Inland water bodies, Elevation change

1. Introduction

Taiwan contains a wide range of inland water bodies, from large reservoirs to thousands of small aquaculture ponds, which are vital for water supply, flood control, and ecosystem services. Traditional monitoring methods remain limited in spatial coverage and frequency, highlighting the value of satellite remote sensing. The Surface Water and Ocean Topography (SWOT) mission, launched in 2022 by NASA and CNES, represents a major advance in global hydrological monitoring. Operating with a Ka-band Radar Interferometer (KaRIn), SWOT achieves centimeter-level vertical accuracy and provides 120 km wide-swath coverage with a 21-day revisit cycle, enabling consistent observations of rivers wider than 50–100 m and lakes larger than 62500 m². While recent studies confirm SWOT's accuracy over large lakes worldwide, its capability to monitor small inland water bodies remains less understood. This study evaluates SWOT Level 2 products—the Lake Single-Pass

(LakeSP) and Pixel Cloud (PIXC)—over small ponds in Taiwan ranging from 1,000 to 10,000 m². Water surface elevation estimates are validated against in situ data and analyzed through time-series consistency and size-dependent performance. Results provide critical insights into SWOT's potential for extending hydrological monitoring to ungauged small water bodies.

2. Methodology

For LakeSP, unreliable data were removed using a ±2 m threshold based on historical reservoir water levels (not applied to ponds lacking records). Polygons were adjusted by lake ID, transformed from geoid to ellipsoid height for consistency with in situ data, and area-weighted averaging was applied to reduce random errors. For PIXC, pixel clouds were first masked by reservoir/pond boundaries, then filtered by classes ("water near land" or "open water"), interferogram quality, and backscatter ($\sigma 0 \geq 16$). Outliers were further removed using an iterative interquartile range filter. Finally, tidal corrections (solid Earth, pole, and ocean load tides) were applied to derive corrected water surface elevations. Both processed datasets were then validated against in situ observations through time-series comparison.

3. Results/Findings

Across 14 reservoirs and 15 ponds, SWOT PIXC consistently outperforms LakeSP. For reservoirs, PIXC achieves average STD ≈ 0.20 m and RMSE ≈ 0.53 m, versus LakeSP's STD ≈ 0.97 m and RMSE ≈ 1.55 m; similar gains hold for ponds, where PIXC errors fall in the centimeter–decimeter range while LakeSP remains meter-level. The large gaps between LakeSP's non-robust (STD, RMSE) and robust (NMAD, MAE) metrics indicate substantial outlier contamination and unstable water-mask delineation. By contrast, the PIXC workflow—class/quality filtering, σ_0 screening, and de-outliering—yields tighter, more complete time series. However, correlation (CC) over ponds is less stable for PIXC, as small fluctuations in water level make CC highly sensitive to residual errors and limited sample sizes. Under SWOT observations, pond detectability increases with size, as shown in Fig. 1. PIXC outperforms LakeSP, exceeding 50% detection for ponds larger than ~20,000 m² and enabling reliable monitoring down to ~12,000 m² (~110×110 m), surpassing the original mission goal (~250×250 m).

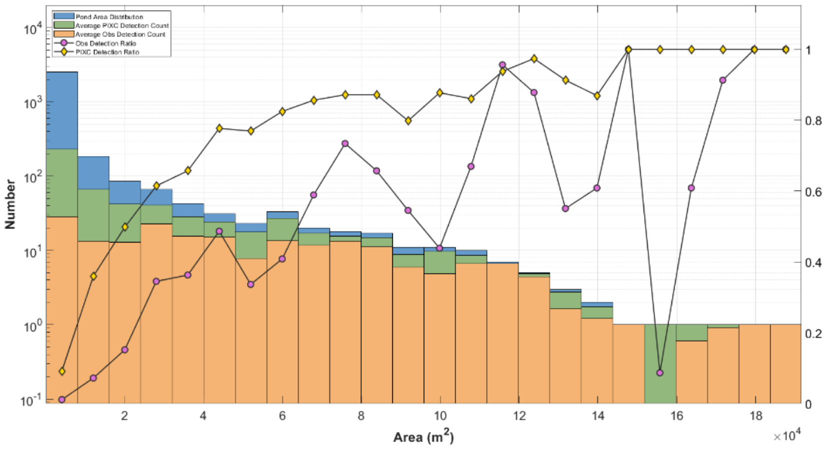

Figure 1: Trend of detectability in an order of pond size.

4. Conclusion

This study validates SWOT Level 2 products over 14 reservoirs and 15 ponds in Taiwan. The refined PIXC workflow reduces STD and RMSE to sub-meter levels and compensates for LakeSP data gaps, achieving reliable monitoring down to ~110×110 m, surpassing the mission's 250×250 m goal. SWOT shows strong potential for seasonal water monitoring, though further work is needed to address technical challenges and ensure stable, accurate observations for water resource management.

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