Accuracy Assessment of Multi-Temporal Intertidal DEM in Taiwan Using ICESat-2

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Abstract:

Taiwan's steep eastern terrain and gentle western slopes have shaped extensive sandy coastlines and numerous wetlands along the western shore. Situated in a subtropical region with variable climatic conditions, the coastlines are frequently affected by typhoons, tides, and coastal currents, resulting in continual shoreline changes. These factors highlight the importance of timely observation and analysis of intertidal zones. To capture such dynamic changes, this study utilizes Sentinel-2 multispectral imagery from 2018 to 2024 to reconstruct intertidal topography and applies ICESat-2 laser altimetry data to validate elevation accuracy. The objective is to identify the optimal time span for reconstruction and determine the most suitable temporal scale for intertidal monitoring in Taiwan.

The study area is located at the Dadu River Estuary Wetland. ICESat-2 ATL03 point cloud data from June 2020 to January 2024 were collected, with the lowest-tide observation used as the starting point for reconstructing intertidal topography across various time scales. A Modified Normalized Difference Water Index (MNDWI) was first applied to delineate the land–water boundary. Then, inundation probabilities were calculated and combined with tidal models to estimate elevation values. The reconstructed intertidal topography was validated using ICESat-2 elevation profiles. Results show that RMSE values across different observation periods range from 0.3 to 0.7 meters, with optimal accuracy achieved at the nine-month period. These findings demonstrate that the proposed method effectively evaluates reconstruction

performance across varying time spans and helps identify the optimal temporal scale for intertidal monitoring in Taiwan, offering valuable guidance for future wetland and coastal management.

Keywords: ICESat-2, Sentinel-2, Dadu Estuary, intertidal topography, time-series analysis

1. Introduction

(1) Background

Taiwan's steep eastern terrain and gentle western slopes have shaped extensive sandy coastlines and numerous wetlands along the western shore. Situated in a subtropical region, the island is frequently influenced by typhoons, tides, and coastal currents, which drive continual shoreline changes. These dynamic coastal processes highlight the importance of timely observation and analysis of intertidal zones, as they are essential for understanding environmental changes and supporting coastal management.

(2) Objectives

To capture these dynamic changes, this study integrates Sentinel-2 multispectral imagery to reconstruct intertidal terrain and applies ICESat-2 laser altimetry data for elevation validation. The main objective is to determine the optimal time span for reconstruction and identify the most suitable temporal scale for intertidal monitoring in Taiwan, while also enhancing the efficiency and reliability of terrain monitoring in highly dynamic coastal environments.

2. Methodology

(1) Study Area

The study area is the Dadu River Estuary Wetland in central Taiwan, where the intertidal zone can reach up to 4 km in width, offering a suitable environment for observing coastal dynamics in intertidal areas.

(2) Data Sources

Two primary datasets were employed in this study. Sentinel-2 imagery from 2018 to 2024 was used to reconstruct the intertidal DEM, while ICESat-2 ATL03 point cloud data from June 2020 to January 2024 were collected, with beams 1R and 2R from track 72 (September 25, 2022) serving as the reference for validation.

(3) Workflow and Method

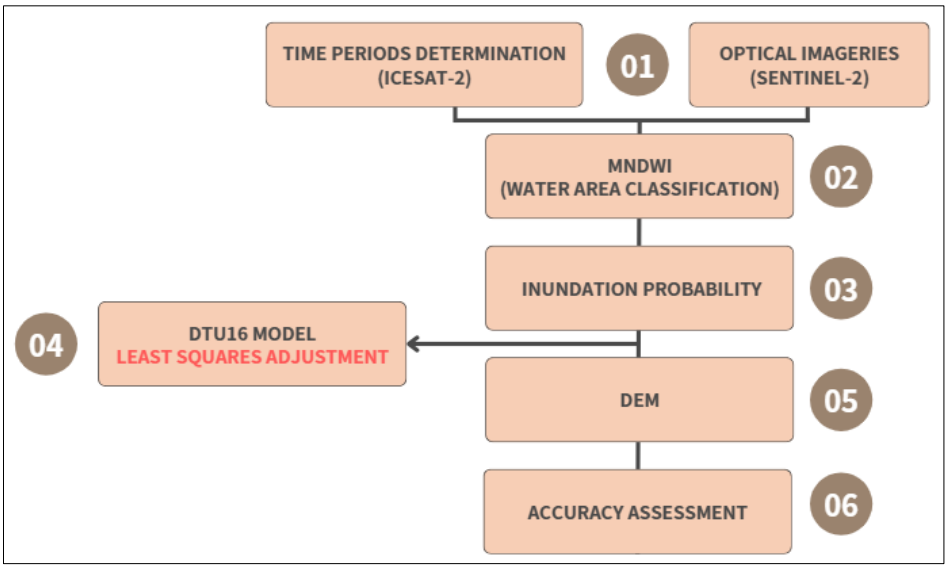

Figure 1 : The workflow of this study.

The method consists of six main steps (Figure 1):

A. Time Periods Determination: ICESat-2 observations at the lowest tide were selected as the reference point to define multiple temporal scales for reconstruction.

B. Water Area Classification: Sentinel-2 imagery was processed using the MNDWI to delineate the land–water boundary, with pixels > 0.1 classified as water and those ≤ 0.1 as land.

C. Inundation Probability: An inundation probability map was generated to indicate the frequency of inundation for each pixel. Pixels with probabilities > 0.95 were defined as permanent ocean, < 0.05 as permanent land, and intermediate values as intertidal areas.

D. Conversion from Probability to Elevation: Inundation probabilities were transformed into elevation using the DTU16 tidal model, and results were refined through least squares adjustment.

E. DEM Generation

F. Accuracy Assessment: The elevation of the reconstructed DEM was validated against ICESat-2 elevation data. Before the comparison, the 18.581 m geoid height (from the NLSC model) was removed to ensure both datasets share the same vertical reference.

3. Results/Findings

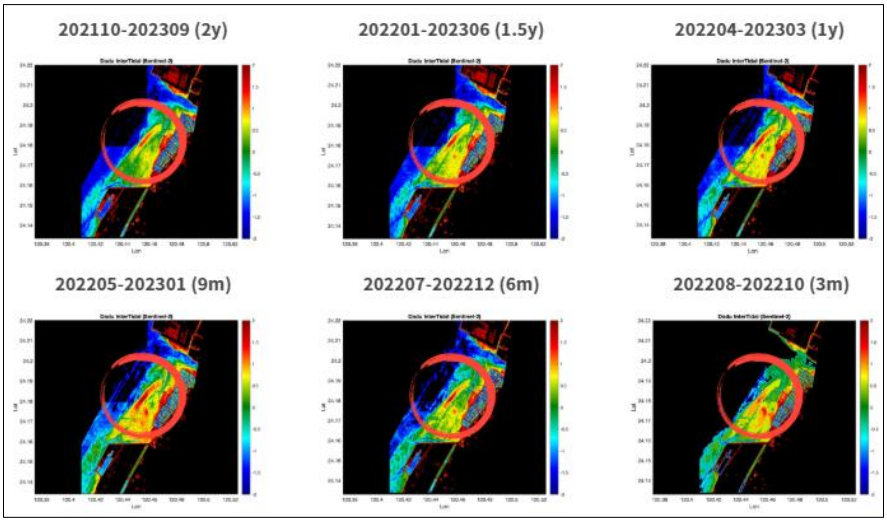

Figure 2 : Reconstruction results on different temporal scales.

Time Periods	2 years	1.5 years	1 year	9 months	6 months	3 months
Bias [m]	-0.37	-0.32	-0.22	-0.10	-0.22	-0.32
STD [m]	0.34	0.33	0.36	0.35	0.48	0.52
RMSE [m]	0.51	0.46	0.42	0.36	0.53	0.61
Correlation Coefficient	0.95	0.96	0.94	0.95	0.91	0.92
Number of images	68	49	35	27	22	7

Table 1 : Comparisons between Reconstructed DEMs and ICESat-2 data.

Reconstructed DEMs across different temporal scales showed clear spatial variations in intertidal sandbars, indicating a strong influence of observation length on reconstruction accuracy. Statistical comparison with ICESat-2 data revealed the lowest RMSE (0.36 m) at the nine-month scale. Longer periods produced larger errors due to dynamic coastal changes, while shorter periods suffered from insufficient imagery. Overall, a nine-month interval was identified as the optimal period for intertidal topographic reconstruction.

4. Conclusions

This study demonstrates that intertidal terrain can be effectively reconstructed using Sentinel-2 imagery, with ICESat-2 data providing validation of reconstruction quality across different temporal scales. The results show that RMSE decreases initially and then increases, with the nine-month interval achieving the best performance (RMSE = 0.36 m), which meets the 0.5 m accuracy standard.

For future work, this method will be extended to other wetlands in Taiwan to establish a representative observation period that supports long-term wetland monitoring and coastal management.