Crowd-Sourced Bathymetry Vertical Uncertainty Calculation per Sounding

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Keywords: Crowd-Sourced Bathymetry, Vertical Uncertainty Calculation, Tidal Reduction, Tidal Modelling, Hydrography, Ocean Mapping

Abstract:

Crowd-sourced bathymetry (CSB) data is becoming an increasingly valuable source of information for expanding hydrographic coverage in areas where traditional survey data is limited. However, the quantification of vertical uncertainty in CSB remains a critical challenge, particularly with respect to tidal reduction methods. Standard approaches commonly use nearest-neighbour Voronoi polygons to assign uncertainty from tide stations, but these methods often fail to account for regional tidal variability and the influence of observation period length on prediction uncertainty.

This study addresses these issues by evaluating three primary factors: uncertainties in tidal predictions, the influence of tidal observation duration and tidal propagation uncertainty. Observed and predicted tidal elevations for ten representative Canadian tide stations were analyzed using the UTide Python library (Codiga, 2011). Prediction accuracy was assessed via absolute and relative error metrics defined by Collins et al. (2011). To evaluate how observation duration influences uncertainty, tidal predictions were generated using datasets spanning durations from two weeks to one year. RMS prediction errors were calculated for each duration and compared against tidal range across stations. Linear regression was then applied to quantify how prediction error scaled with tidal range for each duration. This approach allowed the estimation of observation-length-dependent uncertainty values (σ_T) allowing estimation at stations lacking long-term observational records.

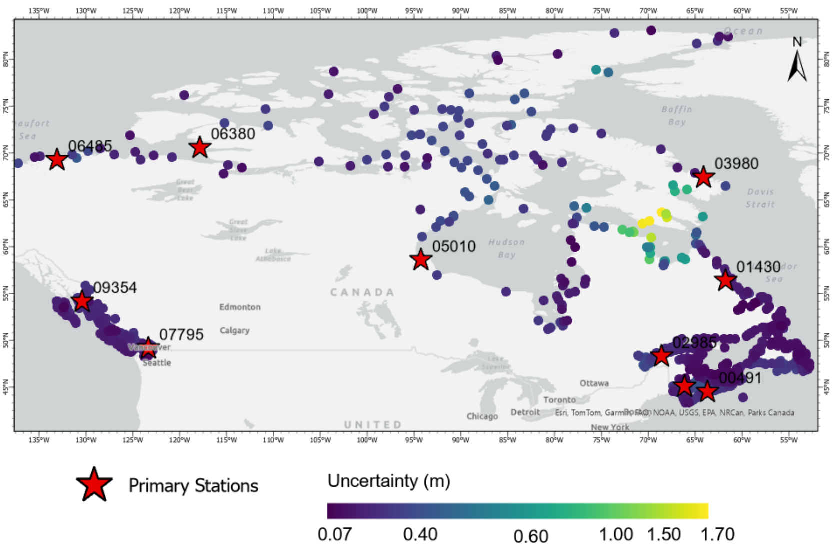

Figure 1 Vertical uncertainty results associated with tidal prediction across Canadian waters. Colored points represent calculated uncertainties at Integrated Water Level Stations (IWLS), with primary reference stations marked by red stars.

Total station uncertainty (σ_S) was calculated by combining prediction uncertainty (σ_P), initially calculated as relative error and converted to absolute uncertainty using tidal range R, and the duration-based uncertainty (σ_T).

Abstracts of the International Cartographic Association, 10, 209, 2025
32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada.
https://doi.org/10.5194/ica-abs-10-209-2025

The total uncertainty was determined using the following equation:

$$\sigma_S^2 = (R \times \sigma_P)^2 + (\sigma_T)^2 \quad (1)$$

Spatial assignment of these uncertainties utilized refined Voronoi polygons manually adjusted to account for coastal geometry, islands, and regional tidal variations for each analyzed station. The resulting total station uncertainty values across Canadian coastal waters are illustrated in Figure 1. The results demonstrated that vertical uncertainty is strongly influenced by both tidal range and the duration of observation data used in harmonic analysis. Shorter observation periods produced larger uncertainty values due to less stable tidal constituent estimation, whereas one-year datasets offered the most reliable predictions. Time-related uncertainty dominated in regions with shorter records, while prediction error was more prominent in areas with larger tidal ranges. Spatially, lower uncertainties were observed along sheltered coasts and stations with long-term data, while higher uncertainties occurred in areas with high tidal variability or limited records, particularly in Arctic and remote northern locations. These findings highlight the importance of integrating observation duration and regional tidal dynamics into vertical uncertainty assessments, enabling more reliable application of CSB data in hydrographic workflows.

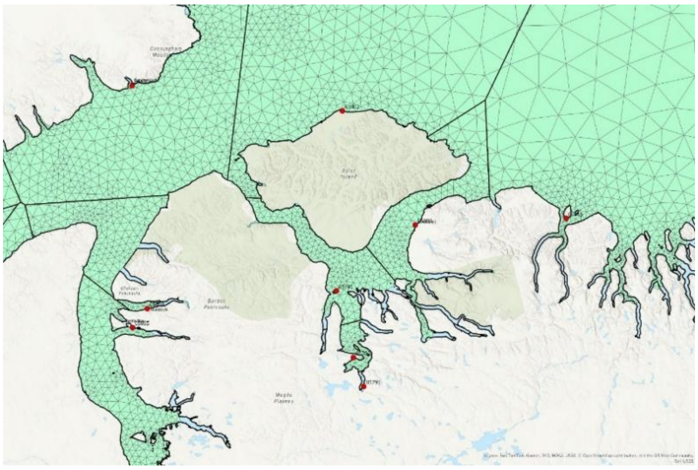

Figure 2 Comparison of Tidal model mesh and traditional Voronoi Polygons used for tidal propagation uncertainty analysis

In addition to calculating total station uncertainty, a second objective of this study was to evaluate tidal propagation uncertainty using numerical tidal models. This was assessed separately using traditional Voronoi polygons generated from all Integrated Water Level Stations (IWLS). As illustrated in Figure 2, these polygons cover broad areas where significant differences in tidal amplitude and phase can occur. To characterize this spatial variability and the resulting uncertainty from applying a single tidal prediction to data within the polygon, WebTide model grids were used to assign tidal model nodes to the nearest IWLS station. Within each polygon, nodes were classified as primary (nearest the IWLS station) or secondary. RMS differences between predicted tides at the primary node and each secondary node were computed to quantify propagation-related uncertainty (Collins, 2011).

This analysis revealed that even within a single station's influence zone, there can be notable tidal variability, particularly in regions with complex bathymetry or dynamic tidal conditions such as the Bay of Fundy. These results highlight the limitations of assigning uncertainty solely based on a single tide station and reinforce the need to incorporate regional tidal dynamics into CSB uncertainty frameworks. The results support the inclusion of dynamic tidal modelling, in combination with observation duration and tidal range, as essential components in improving the reliability of vertical uncertainty estimates for hydrographic and ocean mapping applications.

Acknowledgements
We thank the Canadian Hydrographic Service and Fisheries and Oceans Canada for supporting this research and providing data.

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https://doi.org/10.5194/ica-abs-10-209-2025