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Assessing the use of satellite derived bathymetry to simulate storm surge in New Zealand estuaries

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Coastal flooding events have become increasingly concerning worldwide in relation to climate change, due to the recent observation that they are growing in frequency and strength for many locations around the globe. In practice, predicting flooding events depends on understanding the contribution from the astronomical tide, wave run-up, fluvial discharge, vertical land motion, and changes in the sea level. In the specific case of estuaries, the bathymetric data are essential for predictions because the tidal propagation can be affected in terms of its amplitude and phase (timing) by the estuary's geometry (which can cause shoaling and choking) and bed-shear stress (which reduces energy due to its effect on friction).

There are many techniques to estimate topo-bathymetric data. One of them is in-situ surveys using echo-sounders, RTK or LiDAR devices. The advantages of these techniques are the high data quality and potential of good spatial coverage. However, they are usually expensive and more often than not area limited; for example, echo-sounding data collection is limited by the navigability of the estuary. To fill this gap, recent efforts have centred on estimating bathymetry from satellite images, a technique called Satellite Derived Bathymetry (SDB).

Existing SDB methods estimate the bathymetry using empirical formulas relating the relative reflectance of different spectral bands in each pixel to the water depth, where coefficients are evaluated using training data (Stumpf et al., 2003). These methods show a good approximation to measured data in open sea coastal areas; however, the method relies on light penetration to the seabed, and so there are limitations in its implementation for areas deeper than 25 m and in turbid waters such as enclosed seas, bays and estuaries.

Estimating bathymetry in intertidal zones can be more complicated using satellite methods because of the limitations of satellite coverage caused by the tidal dynamics. Recently, Google Earth Engine has shown innovation in the capacity to easily manage large geographical datasets, which has allowed global-scale studies in coastal science to evolve rapidly. Therefore, by combining recent SDB methods and the database of cloud cover, an extensive database for further developing bathymetry estimation using satellite images for estuaries on a large spatial scale can be accessed. Our current work is aimed at determining whether this database can be used to extract accurate intertidal bathymetric data from satellite imagery. The eventual goal is to use this SDB in numerical modeling of flooding events in estuaries.

Our method combines satellite images and local water level measurements and is composed of three steps, as shown in Figure 1. First, image pre-processing is done through the Google Earth Engine application (API) (Gorelick et al., 2017) in the Google Colab environment, querying images for a specific

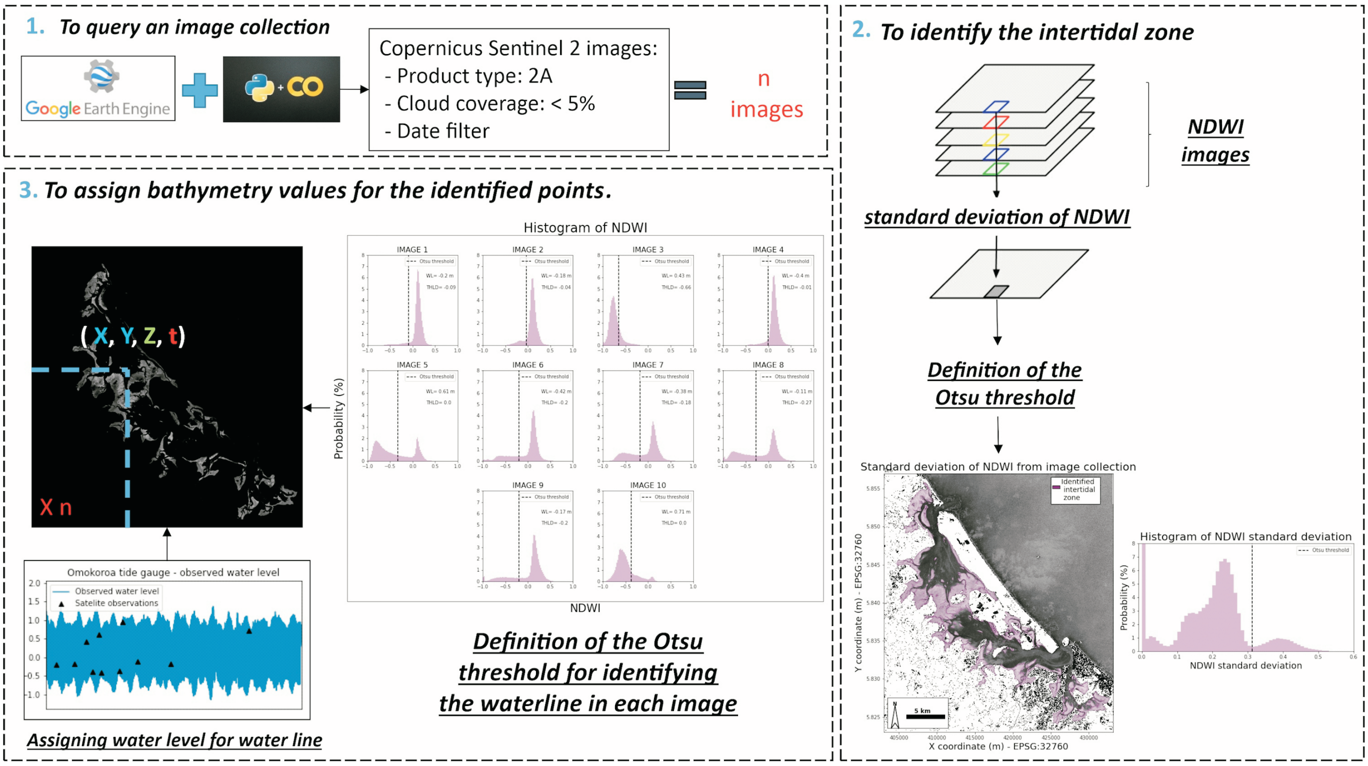

Figure 1: SDB method pipeline.

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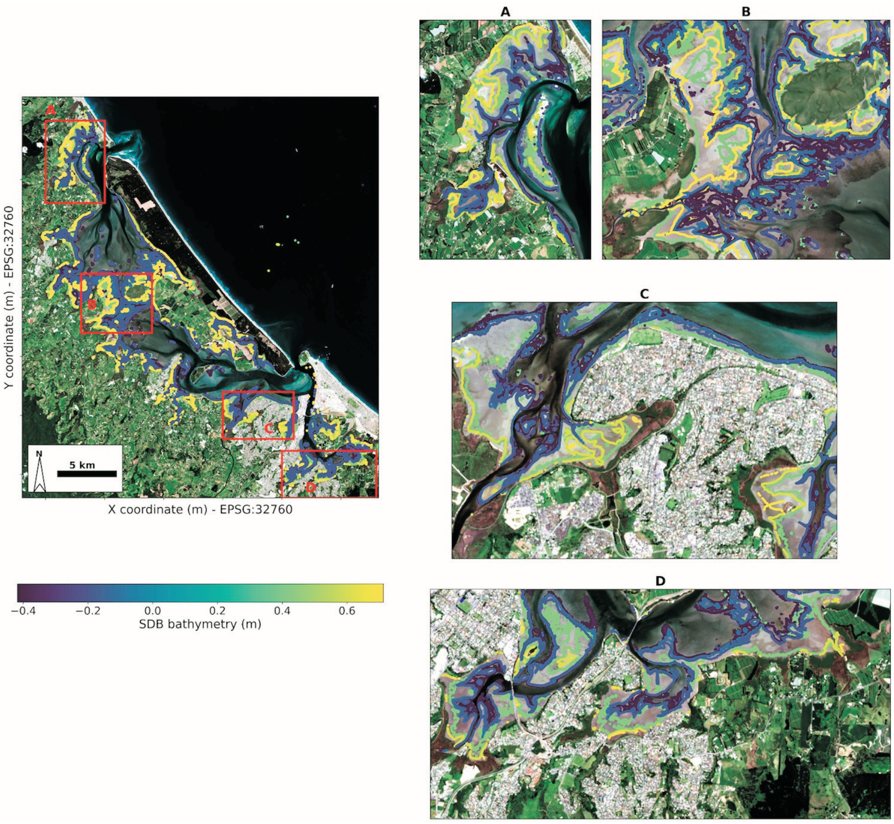

Figure 2: Samples of the SDB for intertidal zones created by analysing images collected at various tidal stages.

estuary in the Sentinel Copernicus database. Second, intertidal zone areas are identified using the Otsu threshold (Donchyts et al., 2016) on the standard deviation of the Normalized Difference Water Index (McFeeters, 1996) to locate the waterline:

$$NDWI = \rho_{green} - \rho_{swir} / \rho_{green} + \rho_{swir}$$

where ρ_{green} and ρ_{swir} are the green and shortwave infrared bands of Sentinel images respectively. The Otsu method works by defining the optimum threshold between two classes of data in the image distribution by finding the minimum value of the within-class variance. Third, we identify the boundary pixels between water and land (waterline) in each image of our collection inside the intertidal zone, and associate a waterlevel to the waterline using waterlevel observations from tide gauges.

The position of the waterline is defined using the algorithm Finding_Contours from the scikit.measure (Van Der Walt et al., 2014) python library. This function uses the Otsu threshold determined for every NDWI image distribution to extract the waterline contours. This contour extraction method uses the 'marching squares' algorithm (Lorensen and Cline, 1987) to identify precise contour boundaries in a two-dimensional array by linearly interpolating between adjacent pixel values. An example of the resultant bathymetry is shown in Figure 2. We validate the estimated bathymetry (gridded) for our test case (Tauranga Harbour), which has complete LiDAR coverage. The SDB is compared with LiDAR data available on the Land Information New Zealand (LINZ) website (https://data.linz.govt.nz).

The tidal wave in an estuary is not completely standing, and can experience deformations because of the estuary's geometry and bottom friction when propagating through enclosed areas, resulting in different tide amplitudes and timing (phases) over the estuarine domain. Moreover, the location of the detected waterline relative to the actual water line might vary with the tidal level (for example due to the change in the colour of the seabed associated with groundwater seepage at low tide). To ascertain whether it is necessary to take these factors into account, the derived bathymetry was assessed for any consistent biases identified by the statistical correlation between error and observed water level.

Once we have developed the best possible bathymetry estimation, using Tauranga Harbour as a test case, we can set up a hydrodynamic numerical model and compare the use of different bathymetry sources (e.g. high resolution survey data and SDB) in the simulation outputs, checking if there are significant differences between them in terms of the water level outputs. If these differences are not significant, this work will result in a dataset of estuary bathymetries for all New Zealand and allow the impact of present and future flooding to be assessed even in remote places of the country. Such a dataset could also help to evaluate biological, sedimentary and chemical processes in which tides and surges play an important role.

Preliminary results will be presented in the NZCS webinar series in January 2021 (see box below).

References

Donchyts, G, et al. (2016). A 30 m resolution surfacewater mask including estimation of positional and thematic differences using landsat 8, SRTM and OPenStreetMap: A case study in the Murray-Darling basin, Australia. *Remote Sensing*, 8(5). https://doi.org/10.3390/rs8050386

Gorelick, N, et al. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202, 18-27. https://doi.org/10.1016/j.rse.2017.06.031

Lorensen, WE, and Cline, HE (1987). Marching cubes: A high resolution 3D surface construction algorithm. *Proceedings of the 14th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH 1987, 21(4), 163-169. https://doi.org/10.1145/37401.37422

McFeeters, SK (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, 17(7), 1425-1432. https://doi.org/10.1080/01431169608948714

Stumpf, RP, Holderied, K, and Sinclair, M (2003). Determination of water depth with high-resolution satellite imagery over variable bottom types. *Limnology and Oceanography*, 48(1), 547-556.

Van Der Walt, S, et al. (2014). Scikit-image: Image processing in python. *PeerJ*, 2014(1), 1-18. https://doi.org/10.7717/peerj.453

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