Scalable real-time data assimilation with various data types for accurate spatiotemporal nearshore bathymetry estimation

Jonghyun Harry Lee, University of Hawaii at Manoa, jonghyun.harry.lee@hawaii.edu
Tyler Hesser, U.S. Army Engineer Research and Development Center, Tyler.Hesser@usace.army.mil
Matthew Farthing, U.S. Army Engineer Research and Development Center, Matthew.W.Farthing@erdc.dren.mil
Spicer Bak, U.S. Army Engineer Research and Development Center, Spicer.Bak@erdc.dren.mil
Katherine DeVore, University of Miami, krd57@rsmas.miami.edu

Immediate estimation of nearshore bathymetry is crucial for accurate prediction of nearshore wave conditions and coastal flooding events. However, direct bathymetry data collection is expensive and time-consuming, while accurate airborne lidar-based survey is limited by breaking waves and decreased light penetration affected by water turbidity. Several recent efforts have been made to apply interpolation and inverse modeling approaches to indirect remote sensed observations along with sparse direct survey data points. Example indirect observations include video-based observations such as time-series snapshots and time-averaged (Timex) images across the surf zone taken from tower-based platforms and Unmanned Aircraft Systems (UASs), while stationary LiDAR tower and UAS flights with infrared camera capability or imagery-based structure-from-motion (SfM) algorithms have been used to provide beach topographic data.

In this work, we present three bathymetry estimation tools for real-time nearshore characterization using different types of information. First, we present a spatio-temporal interpolation approach combining beach topography from infrared and direct sonar-based water depth data sets. The interpolation allows one to query the littoral elevation estimate at any time and space. However, such applications have been prohibited by the massive computational costs from data storage and large dense covariance matrix computation. In this work, we use the Fast Fourier Transform and Kronecker product to accelerate interpolation for which computation and storage costs scale linearly with the number of observations or the maximum grid number among 3D (i.e., 1D time x 2D space) directional grids. An example (Figure 1 (a)) took less than one minute with one CPU core on Google Cloud.

Second, the nearshore snapshot images can provide wave celerity information for bathymetry estimation through the well-known dispersion relationship or physics-based models. However, wave celerity may not be available over the entire area of interest during the image processing stage. Timex images can provide persistent regions of wave breaking over sandbars and at the shoreline so that one can create bathymetry profiles based on parametric forms like in Parametric Beach Tool (PBT). However, the accuracy of this approach highly depends on the assumption of the chosen parametric form as well as the accuracy of detecting sandbars and shoreline. Here, we present a rapid and improved bathymetry estimation method that combines image-derived wave celerity from cBathy and first-order bathymetry estimate from PBT in a statistical framework as shown in Figure 1 (b) in order to address some of the limitations in each of these approaches.

Lastly, we utilize a real-time batch-data model-based inverse modeling approach that can be performed during a UAS flight. In this approach, UAS-derived imagery through CBathy and SfM algorithms provide high-resolution wave celerity and beach topographic data on a single flight. pyPCGA, an open source python scalable inversion library, is then applied to estimate a snapshot of bathymetry and quantify its estimation uncertainty almost in real time with a nearshore spectral wave model STWAVE as shown in Figure 1 (c). Around 200 STWAVE model runs were required.

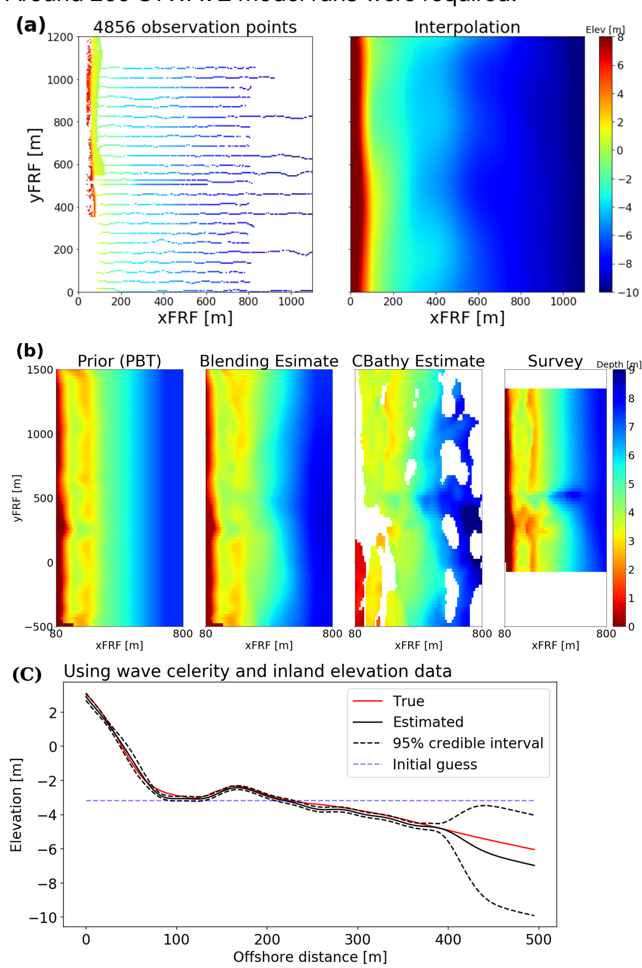

Figure 1 (a) spatial interpolation, (b) PBT+ celerity data inversion, (c) STWAVE with celerity + inland elevation