Using ICESat-2 to Characterize Coastal Ecosystems

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1. Introduction

Coastal seascapes (seagrasses, mangroves, coral reefs, tidal flats) support the livelihoods of over 3 billion people in 100+ countries and billions in revenue; offer protection from extreme weather events; provide 25% of the oceanic carbon pool and support 25% of global biodiversity. Despite this, the extent of coastal benthic ecosystems, such as seagrasses, are poorly quantified (Macreadie et al. 2019). The is particularly pertinent in tropical and developing nations and so called “Big Ocean States” (or Small Island Nations) which do not have the financial capacity to conduct extensive bathymetric surveys but depend upon coastal resources, to sustain their economies (Burke et al. 2001). Furthermore, the distribution of mangrove forest height is well known, but is derived from often static and outdated elevation data, particularly at the global level. With the increased availability of global elevation data (eg. TanDEM-X) ICESat-2 lidar data provides a means for measuring and calibrating estimates of canopy height.

2. Methods

Our aim was to evaluate the ability of ICESat-2 to characterize ecosystem structure in coastal environments. We used ICESat-2 to retrieve estimates of i) mangrove forest canopy height and aboveground structure and ii) bathymetry in shallow water environments. This utilized currently available ICESat-2 ATL08 and ATL03 data.

2.1 Coastal Forest Structure

We used existing accurate elevation datasets to assess the performance of ICESat-2 to estimate mangrove canopy height. Specifically, in Everglades National Park, Florida, 5 m NASA GLiHT CHMs and DTMs were compared against ICESat-2 ATL08 canopy height and terrain heigh, respectively. GLiHT height was extracted for each ICESat-2 ATL08 segment, as well as dominant mangrove type using an existing species map. Regression analysis was used to measure the agreement between the two height estimates. Furthermore, species data was used to assess the impact of variable mangrove structure on the accuracy of the canopy and ground height estimations.

2.2 Benthic Surface Retrieval

ICESat-2 ATL03 geolocated photon data were used to target sub-aquatic surfaces and were used to train 3 Sentinel-2 SDB models in the Google Earth engine cloud computing environment. The models of Stumpf et al. (2003) (CBS), Lyzenga et al. (2006) (CBL) and a Support Vector Machine (SVM) were trialed in Bermuda, Biscayne Bay in Florida and Gulf of Chania in Crete. Sentinel-2 composites were generated, using the 20th percentile of the composite data cube to remove effects, such as glint and waves. Sub-aquatic surface depths were calibrated following Parrish et al. (2019) to account for the refraction of the photons at the water surface.

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To validate these depth estimates we used a locally sourced NOAA bathymetric DEM, single beam sonar (SBS) data and independent ICESat-2 depths, dependent on availability at each location. The use of independent ICESat-2 data was used to demonstrate a wholly spaceborne approach for mapping nearshore coastal bathymetry.

3. Results

3.1. Coastal Forest Structure

We measured a strong agreement (r^2:0.94; Figure 1) between ICESat-2 ATL08 and GLiHT canopy height at everglades National Park, Florida. Mangrove trees were correctly characterized as taller mangrove types than scrub and shrub type mangroves. Less agreement was found between terrain height estimates, with mangrove types with increased aboveground structural complexity driving this disagreement.

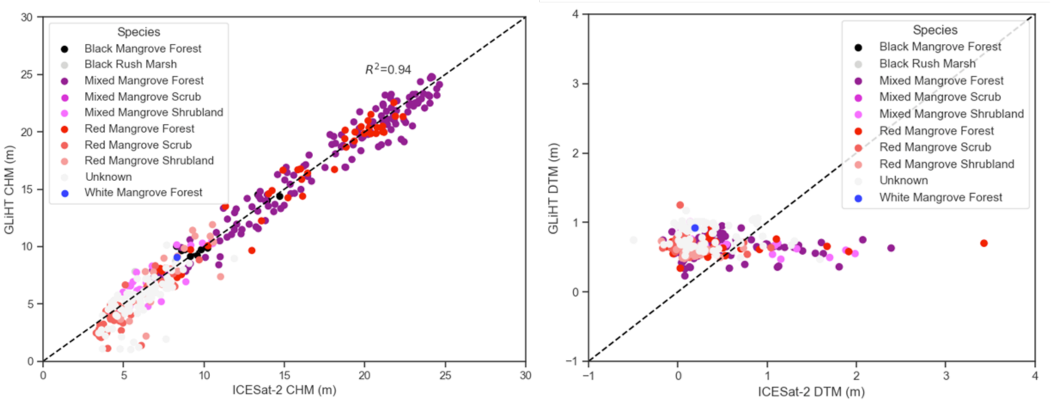

Figure 1. Left: Strong agreement between ICESat-2 ATL08 and NASA GLiHT CHMs, with forest type mangroves proving to be taller than shrub and scrub types. Right: Disagreement between ICESat-2 and GLiHT terrain heights, with mangrove forest types driving greater uncertainty.

3.1. Benthic Surface Retrieval

ICESat-2 ATL03 geolocated photon data was successfully used to train 3 Sentinel-2 SDB models at each of the study site locations, improving the spatial resolution (10 m) and detail over openly existing available data (Figure 2). The CBL method produced the most reliable SDB estimates at all sites. RMSE values of 2.62 m, 0.83 m, and 2.19 m, and MAE of 2 m, 0.65 m, and 2.02 m were calculated for Bermuda, Biscayne Bay, and Crete, respectively. The RMSEs of the CBL were approximately 10% of the maximum depth for the Bermuda (26 m) and Crete (22 m) models, but 17% for the Biscayne Bay model where the maximum depth was much lower (5 m). The R^2 of the models for Bermuda, Biscayne Bay, and Crete were 0.68, 0.79, and 0.83, respectively. The reference and the modeled depths of Bermuda were in good agreement between the depths of 11-17 m, whereas for the shallower Biscayne Bay it was between the depths of 1.2-3 m.

3.1. Discussion and Conclusion

In this study, we have demonstrated that ICEsat-2 is able to accurately characterize mangrove forest canopy height in a mixed species mangrove forest in Florida, validating its wider use in studies of mangrove structure and its potential use in biomass estimation. However, terrain height was found to be more variable, with mangrove type driving increased disagreement between the two measurements. This is interpreted to be due to the increased sub-canopy complexity of taller mangrove trees which may lead to false ground detections.

We also demonstrate the unique fusion of openly available ICESat-2 and Sentinel-2 data for retrieving openly available shallow water bathymetry DEMs, from coastline to island nation scales. We developed adaptive bathymetry estimation methods derived solely from space-borne observations over coastal waters in Bermuda, Biscayne Bay, and Crete at high-resolution and with low error. The high resolution of Sentinel-2 and ICESat-2 data allows us to map benthic variability in detail, improving upon freely available bathymetry maps. Our demonstrated method could enable the development of a global map of coastal submerged ecosystems, which continues to be a critical need of the Blue Economy community. This would be the foundation of global habitat accounting for currently poorly mapped subaquatic ecosystems as seabed morphology is a usual and helpful parameter in aiding underwater coastal habitat monitoring.

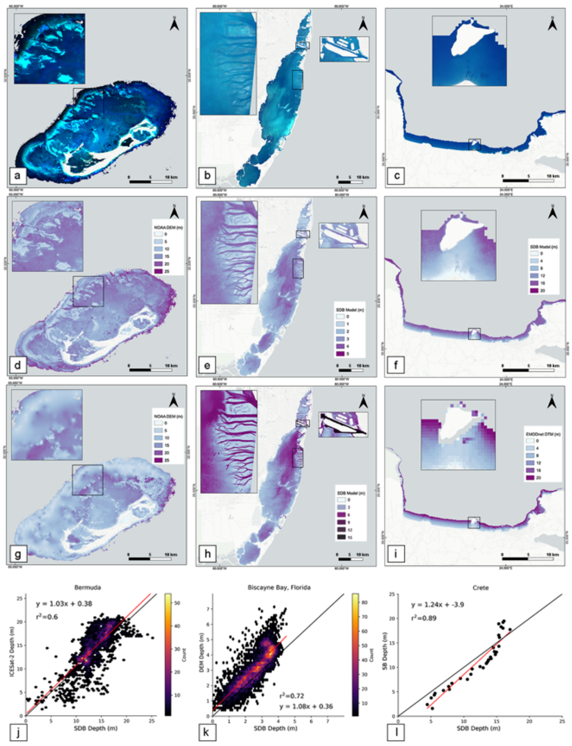

Figure 2. (a, b, c) Sentinel-2 RGB synthesis. (a) Bermuda: 53 L2A Surface Reflectance tiles, 597 km^2 (March 28, 2017 – April 20, 2020); (b) Biscayne Bay: 583 L1C Top-Of-Atmosphere tiles, 689 km^2 (January 1, 2015 – December 31,2019); (c) Crete: L1C 403L1C Top-Of-Atmosphere, 61 km^2 (January 1, 2015 – December 31,2019). (d, e, f) CBL Bathymetry SDB at Bermuda, Biscayne Bay and Crete. (g, h, i) NOAA DEM at Bermuda and Biscayne Bay and EMODnet at Crete, j, k, l) SDB-ICESat-2 depth comparison at Bermuda, Biscayne Bay and Crete.

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