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Evaluation of field-measured vertical obscuration and full waveform lidar to assess salt marsh vegetation biophysical parameters

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Local, high-resolution, accurate data sets are needed to support restoration and other management initiatives in coastal salt marshes, yet field collections of site-specific vegetation data is often impractical. In this study, a novel combination of full-waveform light detection and ranging (lidar) and field techniques for assessing the distribution of aboveground biomass throughout its height and its light blocking properties were investigated. Using new field methods, strong correlations were observed ($r > 0.9$) between subsamples' vertical biomass (VB), the distribution of vegetation biomass by height, and vertical obscuration (VO), the measure of the vertical distribution of the ratio of vegetation to airspace, for *Spartina alterniflora*. Also, it was found that simple metrics derived from the lidar waveforms, such as waveform width, can provide new information to estimate salt marsh vegetation parameters. The strong correlations between field-collected biophysical parameters and metrics derived from lidar data suggest that remote sensing methods can be used to estimate some vegetation biophysical parameters such as plant height and proportion of vegetation area (PVA) using smaller, more targeted field surveys. Future work will be needed to verify the extensibility of the methods to other sites and vegetation types.

1. Introduction

Salt marshes are important habitats providing valuable ecosystem functions such as fish nursery habitat, carbon storage, shoreline protection services, and others (Costanza, D'Arge, DeGroot, Farber, & Grasso, 1997). Therefore, coastal change, salt marsh inundation and adaptation caused by sea level rise are of great concern for scientists and coastal managers, who require timely methods to monitor impacts over short and long temporal periods (Brock & Sallenger, 2001). Advances in remote sensing technologies such as airborne light detection and ranging (lidar) for topographic/nearshore elevation surveys have led to more responsive, data rich, and accurate mapping of many terrestrial and aquatic environments including salt marshes (Argitas & Yang, 2006; Belluco et al., 2006; Chust, Galparsoro, Borja, Franco, & Uriarte, 2008; Hladik & Alber, 2012; Hladik, Schalles, & Alber, 2013; Lee & Shan, 2003; Marani et al., 2003; Schmid, Hadley, & Wijekoon, 2011).

Previous salt marsh lidar research has dealt mostly with discrete return datasets, which are readily available for many coastal areas but provide limited information about the structure of the vegetation (Hladik & Alber, 2012; Rosso, Ustin, & Hastings, 2006; Schmid et al., 2011). To compensate for a lack of information regarding the vegetation, additional research has been conducted using data fusion methods between discrete return lidar and hyper- or multi-spectral data to increase the contextual information available for analysis (Anderson et al., 2008; Dubayah & Drake, 2000; Hladik, 2012; Hladik et al., 2013; Millette et al., 2010; Schalles, Hladik, Lynes, & Pennings, 2013; Swatantran, Dubayah, Roberts, Hofton, & Blair, 2011). However, a relatively new capability in commercial, topographic lidar that offers promise for salt marsh vegetation mapping is the recording and analysis of full waveform datasets. Salt marsh vegetation with heights significantly less than the width of the transmit laser pulse typically show return waveforms that contain just a single peak (Fig. 1) (Parrish, Rogers, & Calder, 2014). Nevertheless, the waveforms may contain information that will assist in the analysis of vegetation. Specifically, the shape of the received pulse is expected to vary across the marsh as a function of the terrain and vegetation characteristics. An advantage to waveform shape-based metric analysis is that observable details, such as vegetation biophysical parameters, might be overlooked based solely on height-based metrics derived from discrete lidar datasets (Muss, Aguilar-Amuchastegui, Mladenoff, & Henebry, 2013). Additionally, waveform shape-based metrics may prove useful when there is no *a priori* knowledge of vegetation species distribution.

While a significant amount of work has been done on the processing of lidar waveforms to estimate surface characteristics (e.g., slope, and/or

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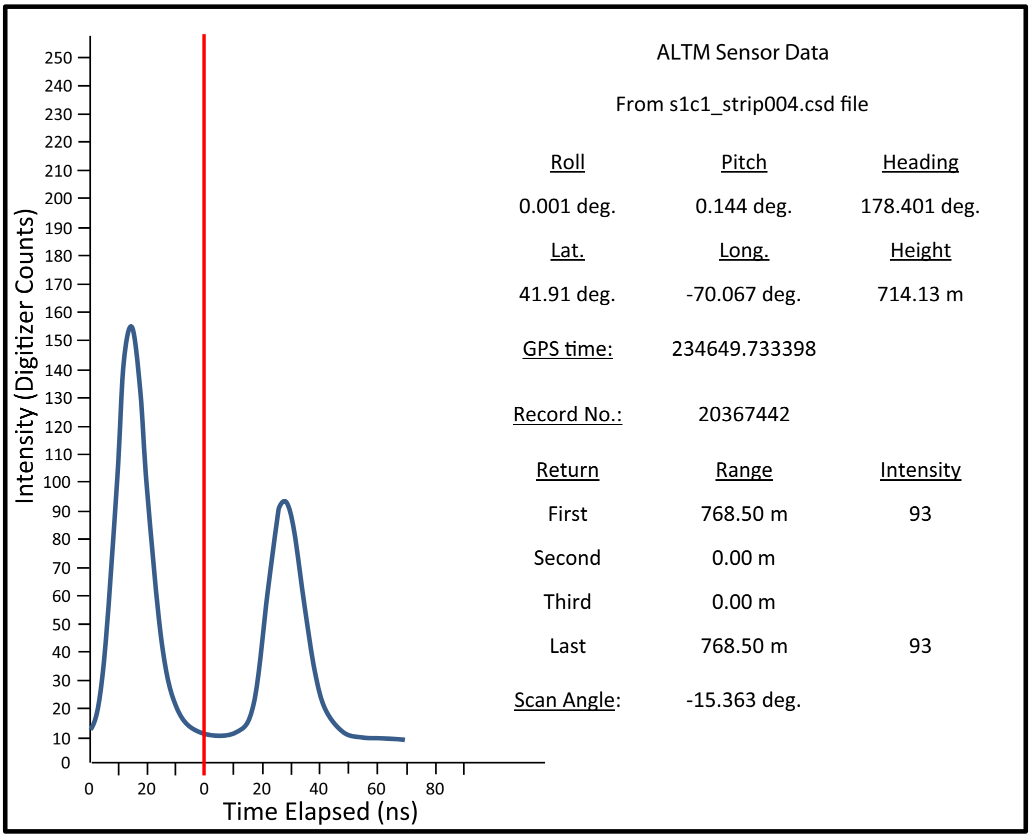

Fig. 1. Example of a typical transmit pulse (to the left of the vertical line) and return waveform (right of the vertical line) in a salt marsh (sample location GA3). Note that, although the return contains only a single peak, its shape may be influenced by the salt marsh vegetation, in which case there may be an observable relationship between shape-based metrics extracted from the waveform and vegetation biophysical parameters of interest.

radiometric properties) or forest biomass (Drake et al., 2002; Mallet & Bretar, 2009; Nayegandhi, Brock, Wright, & O'Connell, 2006; Wright & Brock, 2002), most of the methods discussed in the published literature involve sophisticated, computationally-complex signal processing approaches such as deconvolution (Jutzi & Stilla, 2006). To date, only a few studies have been conducted on the use of simple shape-based waveform metrics (Adams, Beets, & Parrish, 2012; Muss et al., 2013; Parrish et al., 2014) for estimation of biophysical parameters. The basic premise is that, since each salt marsh vegetation species should affect the shape of the return differently, by analyzing shape-based metrics it may be possible to extract information about the nature of the vegetation.

This study tests a novel combination of full-waveform lidar and field-based methods. The field techniques used were developed to extract vegetation characteristics from digital photography (Möller, 2006; Neumeier, 2005; Zehm et al., 2003) and were adapted for this lidar investigation. In research conducted by Möller (2006), vertical plant density was determined from digital photographs and related to roughness coefficients for water flow across the marsh. In this research, the vertical plant density and distribution were expected to have a measurable effect on the lidar pulse returns. Vertical profiles of salt marsh vegetation obscuration (VO) [%] and biomass by height (VB) [g/m^3] were investigated in their undisturbed growth position using in-situ digital photography. These data, along with other biophysical parameters collected in the field (including physical samples or those derived from photography), were used to examine relationships among the parameters and metrics extracted from lidar waveforms. The primary focus was on *Spartina alterniflora*, but other common and dominant salt marsh species were also included in the study. The hypothesis is tested that some simple waveform metrics such as waveform width, waveform standard deviation, and amplitude contain information that can assist in estimating salt marsh biophysical parameters such as vegetation height, stem density and biomass.

2. Methods

2.1. Study area and ecosystem description

The study sites comprised four mesotidal salt marshes (Hatches Harbor, Moors marsh, Pamet River marsh, and Great Island — Middle Marsh) on the protected bay coast of Cape Cod, Massachusetts, USA (Fig. 2), with field investigations conducted between July and August, 2010. This part of Cape Cod Bay exhibits a semidiurnal tide with a mean range of ~2.83 m (NOAA, 2013). All the marshes are largely low marsh dominated by *S. alterniflora* (smooth cordgrass) growing upon sandy substrata with typically a small rim of high marsh platform. Marsh sites were chosen based on their proximity to each other to maximize the data collected from a 40 km^2 lidar flight area, the availability of large stands of as many major marsh species as possible, and the ability to collect the field data within a specified time window around the July, 2010 overflight conducted by the National Center for Airborne Laser Mapping (NCALM). In general, wind conditions at the sites averaged 2.5–5.3 m/s (NNW) during most survey days, but occasionally reached up to 7.6 m/s. Multiple sample locations for each vegetation species type were collected to determine reproducibility of the results and investigate variability within each species type.

Hatches Harbor, a 2.2 km^2 (1.2 km^2 unrestricted with full tidal flow, 1 km^2 restricted with partial flow) salt marsh located at the eastern-most tip of Cape Cod, is one of the youngest marshes in the northeastern United States, due to the timing of the Provincetown