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Estimating the height of wetland vegetation using airborne discrete-return LiDAR data

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ABSTRACT

Several studies have been conducted to estimate wetland vegetation height using airborne LiDAR data. However, no studies have been conducted to explore the influence of vegetation cover on vegetation height estimation models. The objective of this research is to estimate vegetation height in wetlands with varying vegetation cover for further analyzing the effects of vegetation cover. First, we performed both linear and logarithmic regression analyses between field-measured heights and each LiDAR-derived metric in wetlands with different vegetation cover. Then LiDAR-derived metrics were combined through multiple regression analysis to estimate wetland vegetation height. The height estimates were finally validated by leave-one-out cross-validation method. The results showed that the logarithmic regression analysis performed better than the linear regression analysis in estimating wetland vegetation height for almost all LiDAR-derived metrics regardless of vegetation cover. The max height of LiDAR returns (H_{max}) provided the best agreement with field-measured heights in wetlands with high vegetation cover. In contrast, the strongest correlation was observed using the standard deviation of LiDAR heights (H_{SD}) for low vegetation cover. Results of multiple regression analysis indicated that the best model was based on H_{max} and 90 percentile height of LiDAR returns (H90) in wetlands with high vegetation cover, while the best model can be expressed as a function of H_{SD} and H90 for low vegetation cover. Therefore, our study concluded that vegetation cover is an important factor of vegetation height models. Additionally, our study will provide valuable guidance for field-measured data collection and vegetation height estimation using LiDAR data.

1. Introduction

Wetland vegetation is a core component of wetland ecosystems and plays an important role in the ecological functions of wetlands. The quantitative description of wetland vegetation structure characteristics is critical for sustainable ecosystem management and preserving biological diversity [1–4]. Vegetation height, one of the most important structural variables, is a key input required by wetland ecosystem models [3,5,6]. Therefore, it is essential to accurately estimate the height of

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wetland vegetation. Advances in airborne light detection and ranging (LiDAR) have made it a good data source for accurately estimating vegetation canopy height over large areas [7–10].

Over the past decade, many studies have demonstrated the capability of airborne discrete-return LiDAR data for forest height estimation [11–13]. LiDAR-derived metrics, such as the mean and max height of LiDAR normalized returns, have usually been used to estimate forest canopy height [9,14,15]. However, the estimation accuracy of these metrics derived from airborne discrete-return LiDAR data is usually limited in environments with short, dense vegetation for two reasons [16,17]. First, the laser penetration to the ground is greatly affected by dense vegetation, making terrain estimates and thus vegetation height estimates less accurate [18–20]. Second, airborne discrete-return LiDAR data provide limited information about vegetation vertical structure because they only record one return for each emitted pulse in areas with short vegetation [21]. Regardless of these limitations, a list of previous studies has proven that airborne LiDAR is a valuable tool for estimating short vegetation height across a range of vegetation species [14,22–24]. Simultaneously, these studies indicated that vegetation species has a substantial effect on vegetation height estimation models [14,20]. Both LiDAR-derived metrics and types of models varied greatly under environments with different vegetation species. For example, Davenport et al. (2000) indicated that the standard deviation of detrended LiDAR heights is the best predictor of vegetation height for agricultural crops [23], while Hladik, Schalles, and Alber (2013) showed that height metrics are more suitable for estimating vegetation height in salt marsh [25]. Kulawardhana, Popescu, and Feagin (2014) predicted vegetation height using a linear regression analysis in salt marsh environments [17], while Luo et al. (2015) reported that a logarithmic regression analysis performs better than a linear regression analysis in estimating the height of wetland vegetation [26]. Additionally, these studies also showed that vegetation height prediction models may be different even for the same vegetation species [22,25]. This situation may be caused by the different vegetation cover. However, no studies have been conducted to explore the effects of vegetation cover on the estimation models of vegetation height.

Therefore, in this paper, we aimed at estimating the vegetation height in wetlands of varying vegetation cover using airborne discrete-return LiDAR data to investigate the influence of vegetation cover on vegetation estimation models. To fulfill this goal, the following three objectives were used: (1) to conduct linear and logarithmic regression analyses of field-measured heights against each LiDAR-derived metric in wetlands with different vegetation cover, (2) to evaluate the combined use of LiDAR-derived metrics for height estimation through multiple regression analysis, (3) to assess the accuracies of wetland vegetation height estimates using the leave-one-out cross-validation method.

2. Materials and methods

2.1. Study area

The study area is located in Zhangye City, Gansu Province of northwest China (Fig. 1). The terrain of the experiment site is relatively flat, with a mean elevation of 1410 m above sea level. The dominant vegetation is reed (Phragmites australis), representing approximately 95% of all wetland vegetation, and there are a few other plant species such as Amorpha fruticosa L., Salix saposhnikovii A. Skv. and Lycium chinese Mill. The vegetation across the study area is short, and the maximum vegetation height is generally less than 2.0 m.

2.2. Airborne LiDAR data

The airborne discrete-return LiDAR data used in this study were from the "Heihe Watershed Allied Telemetry Experimental Research (HiWATER)" project [27] and were collected in July 2012 using a Leica ALS70 system. The nominal flying height was 1300 m above the ground level, and the average point density was approximately 6.7 points/m^2. Raw point clouds were processed to extract LiDAR-derived metrics in this study. Outliers were first eliminated using an elevation frequency histogram method [28].Then, the LiDAR point clouds were classified as canopy and ground returns using the adaptive triangulated irregular network (TIN) filtering algorithm embedded in the TerraScan software [29]. A digital elevation model (DEM) was finally created using ground returns with a grid cell size of 0.5 m. Additionally, the accuracy of the DEM was assessed using differential Real-time kinematic Global Positioning System (RTK GPS) points, and the mean error (ME) and root mean squared error (RMSE) of the DEM are 0.05 m and 0.12 m, respectively. Using this DEM, we can remove the influence of topography and obtain DEM-normalized LiDAR point clouds. The LiDAR-derived metrics were calculated based on the DEM normalized LiDAR point clouds.

2.3. Field measurements

The field measurements were conducted on July 11–13, 2012. There were a total of 208 sample plots, with a radius of 1 m, across the whole study area. Nine representative measurements of vegetation height were randomly collected within each plot, and the mean value of these nine vegetation heights was calculated and referred to as the reference height value of each plot. Table 1 shows the statistics of the measured vegetation height in the field plots. The geographic coordinate of each plot center was measured with high accuracy using a differential RTK GPS. Additionally, only the field plots in areas with