Multi-Scale LiDAR Assessment of Aquatic Vegetation Geometry for Hydrodynamic and Morphodynamic Modeling in the Lower Mississippi River

Introduction

Coastal erosion is a serious problem in Louisiana. Since 1932, the state has lost more than 4,800 km^2 of its coastal wetlands, with an additional erosion rate of 90 km^2 each year (Coastal Protection and Restoration Authority, n.d.). Wetlands sustain themselves through sediment retention (Clarke, 2002), in which the morphology and distribution of vegetation play a crucial role (Nardin & Edmonds, 2014; Xu et al., 2022). Aquatic vegetation reduces flow (Kouwen & Unny, 1973) and can facilitate retention of sediment (Abt et al., 1994), nutrient (Silvan & Vasander, 2004), and carbon (Fourqurean et al., 2012), mitigating coastal erosion and creating habitats for coastal life (Costanza et al., 1997). Laboratory experiments have shown that geometric parameters of vegetation elements and canopies, such as stem diameter (Zhao & Nepf, 2021; Tseng & Tinoco, 2024), frontal area density (Poggi et al., 2004; Tanino & Nepf, 2008), plant shape (Lightbody & Nepf, 2006; Liu et al., 2024) and flexibility (Luhar & Nepf, 2013; Rominger & Nepf, 2014), degree of canopy submergence (Zhao & Nepf, 2024; Park & Nepf, 2025), and patchiness (Follett & Nepf, 2012; Shan et al., 2020), dictate the flow and transport processes in vegetated areas. However, current hydrodynamic and morphodynamic models, such as Delft3D (Deltares, 2025), consider only part of the geometric parameters listed above. Proper parameterization of field vegetation geometry helps transition laboratory studies to numerical models that can predict hydrodynamic and morphodynamic processes and future evolution in coastal marshes. Improvements to these predictive tools are key to guide the design and revision of engineered and nature-based solutions in Louisiana's future Coastal Master Plan.

Remote sensing can capture the three-dimensional geometry of vegetation over large areas, providing spatially continuous coverage that would be impractical with ground sampling alone. In particular, drone-based and airborne LiDAR surveys yield high-resolution point clouds that resolve vegetation height (Luo et al., 2015) and canopy density (Lee & Lucas, 2007). Their laser pulses can penetrate gaps within the canopy (Véga et al., 2016), enabling separation of ground and vegetation returns and thus accurate estimation of metrics such as canopy height (Simard et al., 2011), vertical structure (Lovell et al., 2003), and patch morphology (Hong et al., 2024). In Winter 2022, an airborne LiDAR survey of the Lower Mississippi River (LMR) in southeastern Louisiana was conducted by the U.S. Army Corps of Engineers (USACE) and their contractors, resulting in a dataset with a laser pulse density of ~10 points per square meter, which can inform bulk parameters of canopy (e.g., canopy height and density) but not the element-scale details (e.g. stem diameter and plant shape). By complementing this dataset with higher resolution, low-altitude drone surveys and ground observations, the proposed project will bridge the gap to the finer metrics and provide a defensible pathway from LiDAR point clouds to model-ready vegetation drag fields, directly supporting more reliable planning and design of coastal restoration projects in coastal Louisiana.

Key Objectives

We attempt to answer the following questions:

1. Which vegetation geometric parameters (height, density, flexibility, patch metrics, etc.) can be robustly derived from the 2022 USACE airborne LiDAR?
2. How can drone LiDAR and quadrat sampling be used to calibrate and upscale these parameters to provide a coastwide mapping tool of vegetation geometry?
3. How can these parameters be translated into spatially distributed drag/roughness fields for Delft3D numerical models in the Lower Mississippi River?

Research Plan

Dr. Zhao plans to recruit a master's student to work on the proposed project, who will be co-advised by Dr. Allison. Both supervisors are involved in the Gulf Research Program's Mississippi River Delta Transition Initiative (MissDelta), which provides an established field program in the LMR and shared access to software, computing resources, and drone/LiDAR platforms but does not currently support a dedicated graduate student on this topic. The requested support will enable a dedicated student to pursue the distinct research objectives of this proposal while leveraging that existing infrastructure and reducing field-logistics risk.

First, using the 2022 USACE airborne LiDAR point cloud, the student will develop an algorithm to identify aquatic vegetation across a broad geographic scope, e.g., extending into the Barataria Basin to capture the full spectrum of deltaic marsh ecotypes. This workflow will visualize vegetation vertical structure and identify 3–5 candidate sites that coincide with CRMS stations and span a range of vegetation densities and marsh ecotypes. The student will implement a supervised classification approach that combines LiDAR-derived height statistics, intensity, and CRMS vegetation plot data to distinguish aquatic vegetation (marshes and macrophytes) from terrestrial vegetation (trees and upland species).

Second, in the field, the student will conduct drone-based LiDAR surveys over the selected sites at different heights (30 – 120 m) to determine the optimal flight height for resolving detailed vegetation geometry utilizing an existing system recently purchased by Tulane University. Evaluation metrics include point density in the canopy, success rate of resolving individual stems/small patches, and LiDAR penetration ratio. Ground sampling of vegetation will be made at specific quadrats (around 5 per site) within the drone-based LiDAR survey area, and statistics of the stem diameter, stem density, canopy height, and species type will be recorded for comparison with LiDAR data. Ground control points (GCPs) or high-accuracy RTK-GPS will be used in the drone imagery to ensure the ground truth aligns with the LiDAR images. Because the airborne LiDAR data was collected in winter, which represents the minimum vegetation resistance, the student will fly the drone in winter for validation, which helps to quantify the baseline roughness for understanding winter storms or periods of rapid flow when vegetation protection is weakest. If time permits, a summer drone and ground survey will be planned to capture the peak biomass, which allows the student to test whether there is a statistical link between the winter and summer scenarios and whether the winter airborne LiDAR can be used to predict peak drag in summer.

Third, vegetation metrics including canopy height, stem/canopy density (from LiDAR penetration ratio), and vertical structure (from voxelization) will be extracted from the airborne and drone-based LiDAR point clouds. To upscale fine-scale vegetation metrics from our drone LiDAR and quadrat plots to the 2022 airborne LiDAR domain, the student will fit statistical and tree-based machine-learning models (e.g., regression, random forest) that predict plot-scale canopy height and frontal area density from airborne LiDAR height percentiles, point density, and intensity-based texture metrics.

Finally, the resulting vegetation metrics will be converted to spatially distributed Manning's coefficient and/or explicit vegetation drag fields that can be incorporated into existing Delft3D-FM morphodynamic models of the LMR.

This project provides a comprehensive training platform for the master's student in remote sensing, coastal geomorphology, and hydrodynamic modeling. Under joint supervision of Dr. Zhao and Dr. Allison, the student will gain experience in LiDAR processing, drone mission planning, wetland vegetation sampling, and translating physical measurements into model inputs. Regular interaction with the MissDelta Initiative and CPRA collaborators will expose the student to applied coastal restoration decision-making.

Expected Outcomes

The student will finish a master's thesis and complete their degree in the Department of River-Coastal Science and Engineering at Tulane University, submit articles to peer-reviewed journals, present to CPRA and at national/regional conferences. The student will also publish the following products:

1. A documented workflow/code (MATLAB/Python) for processing multi-scale LiDAR for vegetated channels.
2. GIS-ready maps of vegetation geometry and derived drag coefficients along LMR reaches.
3. Parameter tables for Delft3D (e.g., from vegetation metrics to drag or bed roughness).

Mastery of these workflows ensures the student is prepared to support CPRA's predictive modeling and field data processing teams, facilitating a productive and technically rigorous internship placement.

Relevance to CPRA's Priority Research Areas

This project directly addresses the CPRA's mission to implement a comprehensive protection and restoration master plan by advancing the science of nature-based solutions and sediment retention modeling. Specifically, this research supports the 2023 Coastal Master Plan's objective to "use natural processes to promote a sustainable coastal ecosystem" by refining the hydrodynamic parameterization of aquatic vegetation, which is a critical driver of accretion in the Mississippi River Delta. By integrating multi-scale LiDAR data (airborne and drone) to quantify canopy geometry and drag, this work fills a critical data gap in current morphodynamic models like Delft3D. The resulting improved predictive capabilities will directly assist the CPRA in evaluating the efficacy of sediment diversions and marsh creation projects, and will refine forecasts of future marsh trajectories in the face of Relative Sea Level Rise (RSLR), ensuring that future engineering designs rely on accurate, field-validated representations of vegetation-flow interactions.