Nature versus humans in coastal environmental change: Assessing the impacts of Hurricanes Zeta and Ida in the context of beach nourishment projects in the Mississippi River Delta

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Contents of this file

Text S1. 3-D Models

The drone images, obtained via a digital 4 K/20 MP (RGB) camera, were treated using the Agisoft Metashape Professional v1.6.2. to generate 3D spatial data and orthomosaics with the support of planialtimetric GCPs (www.agisoft.com) (accessed on 7 May 2021). Orthomosaic images of 2019 and 2021 were used for the time series analysis. The software constructed a set of points in 3D space from all matched pairs between aligned photos. Erroneous points in the sparse point cloud were removed to improve the model's final geometry. This cleaned sparse point cloud was used as a reference to reconstruct a more detailed set of geometries known as the dense point cloud [6]. This dense and accurate 3D point cloud was manually classified with point spacings between 3 and 5 cm. The contrasts of colors and elevations of point clouds enabled the identification of points representing the vegetation cover and the sandy barrier surface. The points representing the sandy barrier surface were used to obtain a digital terrain model (DTM), which represents the substrate surface without the vegetation cover. A mesh of the sandy flat surface was then developed based only on the points representing the topographic surface of the terrain. This model was adjusted to the GCPs obtained by the field topographic survey. A digital surface model (DSM) representing the natural (trees and herbs) and built (houses and streets) features was also produced. The vertical differences between the GCPs and the DTM allowed a quantitative analysis of that model, following Equation (S1), as suggested by [6]:

$$Z_{dif} = Z_{DEM} - Z_{grd} \qquad \text{(S1)}$$

where Z_{dif} = the vertical differences, Z_{DEM} = the Z value of the 3D dense point cloud, and Z_{grd} = the Z value of the Ground Control Point. The vertical differences (Z_{dif}) were lower than 10 cm, indicating a vertical margin of error of ± 10 cm for the 3D models. The horizontal differences (latitude and longitude) were <0.71 m (Table S1, Supplementary Material). The differences between the latitude/longitude data obtained by the Trimble Catalyst GNSS receiver in the GCPs and drone surveying have been attributed to the lower accuracy of the drone GPS compared to the Catalyst GNSS receiver. In contrast, elevations based on aerial photogrammetry of drones present high vertical accuracy. The final digital terrain model was adjusted using the GCPs' planimetric values. Considering the X_{dif}, Y_{dif}, and Z_{dif} values, margins of error were estimated at ± 0.076 m^3 and ± 0.15 m^3 for the volume calculations based on drone and Lidar data (vertical and horizontal accuracy of 15 and 100 cm), respectively.

An elevation grid for the ground was obtained based on the mean dense point cloud to minimize the effects of vegetation and seasonality on the drone and Lidar surveys. Vertical features were referenced to NAVD88. The shoreline position and dune crest were defined as the mean high tide water elevation (higher level of the intertidal zone) and the maximum surface elevation, respectively, as identified by cross-shore profiles. Sediment volumes were measured according to the elevation grid generated for each drone and Lidar survey, relative to a baseline defined as the mean sea level (0 m). Cut-and-fill volumes were calculated within a selected area using Global Mapper software version 18. Volumetric calculations were performed by dividing the area of interest up into small, rectangular pieces following a uniform grid and then calculating the sum volume of the small 3D rectangles (Volume = Height * Pixel Size) between the terrain models and the cut surface [6]. Two fences along the dunes were used as a common reference in the drone images to delimit the target zones: Zone 1, which was part of the supratidal and the sandy intertidal flat under the action of currents and waves; Zone 2, which was part of the supratidal area; and Zone 3, which was part of the supratidal and the intertidal flat behind the coastal barrier. In addition, Global Mapper generated a vertical profile along a specified path using loaded planialtimetric datasets. A spatial and temporal sequence of these profiles shows the dune crest dynamics and the coastal morphology in three dimensions with the most pronounced vertical variations recorded along a beach barrier. Eight planialtimetric profiles, identified by the red lines in the figures, were developed to record the coastal morphology changes in a temporal sequence. Seven profiles are cross-shore transects that start landward of the dune ridge and end at the shoreline (perpendicular to the shoreline). The locations chosen for each cross-shore transect have a wide spatial representation of the intertidal and supratidal zones of the studied coast (Fig. 1&4). One longshore profile follows the top of the dune ridge line (parallel to the shoreline) of the year of each digital terrain model (Fig. 4&5). Planialtimetric cross-shore profiles were used for sediment volume analysis, while planimetric cross-shore transects were used for measuring shoreline and habitat changes.