Using LiDAR to Assess Storm Damage Caused by Hurricane Sandy

The Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX) was tasked to perform LiDAR surveys and change assessments in the aftermath of Hurricane Sandy. The US Army Corps of Engineers (USACE) organized a large mapping effort with the goal of collecting LiDAR data for all impacted USACE project areas within a two week time frame between 11 and 24 November 2012. USACE requirements for data encompassed the Atlantic shoreline from NC to MA. USACE leveraged the JALBTCX partnership among the USACE, the U.S. Naval Oceanographic Office Airborne Hydrography Program, the National Oceanic and Atmospheric Administration (NOAA) National Geodetic Survey, and U.S. Geological Survey's (USGS) Coastal and Marine Geology Program to coordinate post-storm data collection in order to most effectively use the limited funds available for the effort.

USACE used its capability at JALBTCX, 3 industry partners, and leveraged USGS LiDAR data collection efforts to meet requirements for time-sensitive data collection over such a large geographic area. JALBTCX focused on New York and New Jersey requirements, while Magnolia River, Fugro EarthData, and Woolpert focused their efforts on Massachusetts and Rhode Island,

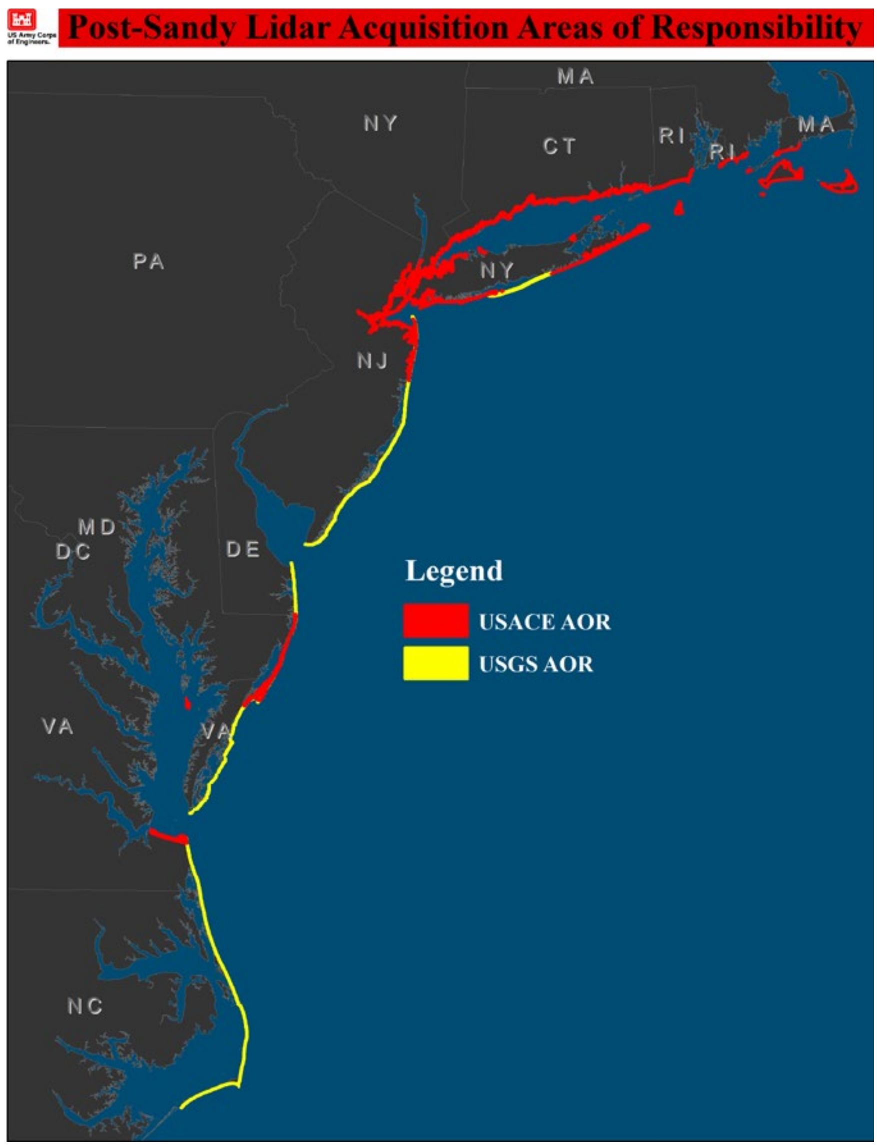

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Figure 1: USACE requirements for post-Sandy topographic LiDAR data extended from North Carolina to Massachusetts.

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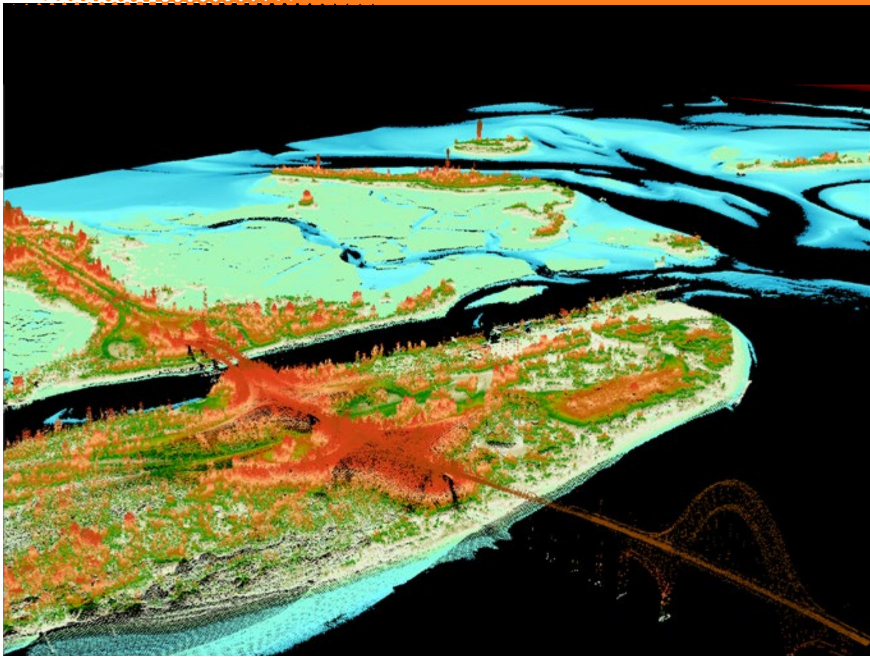

Figure 2: Bathymetric and topographic LiDAR data collected by JALBTCX in the Gilgo Beach area of Jones Beach Island.

Connecticut, and Eastern Long Island and Maryland and Virginia, respectively. The USGS Coastal and Marine Geology Program used its Experimental Advanced Airborne Research LiDAR-B (EAARL-B) to survey the New Jersey coast immediately before and after Hurricane Sandy. USGS also used industry partner Woolpert to meet requirements on Fire Island, New York, and PhotoScience to conduct aerial LiDAR surveys of the Delmarva Peninsula and coastal North Carolina. Figure 1 shows the extent of the collaborative post-Sandy LiDAR data collection effort. The USACE and USGS collaborated on specifications in advance of data collection to assure a consistent post-storm collect, regardless of agency or contractor. The data were collected at 1-m postings, 12.5 cm RMSE vertical accuracy, and during the low tide cycle.

JALBTCX collected over 500 square miles in the impacted areas of New York and New Jersey using its in-house capability called the Coastal Zone Mapping and Imaging LiDAR (CZMIL). CZMIL is the third generation airborne coastal mapping and charting system developed for JALBTCX. It was first fielded for operations in summer of 2012, and the post-Sandy data collect was its first use in hurricane response mapping. CZMIL was specifically designed for coastal mapping based on over two decades of operations of JALBTCX bathymetric LiDARs. CZMIL is a blue-green LiDAR sensor capable of penetrating the water surface, which allows for measurement of underwater topography. Because of its bathymetric LiDAR heritage, CZMIL is a waveform resolving LiDAR on both land and in water. It also has a segmented detector array such that each 2-m diameter laser footprint yields seven LiDAR waveforms on land and in water. On flat ground and in water, elevation measurements are spaced 0.7m apart. The current processing system allows for discrimination of up to 31 distinct ranges from a single waveform. With the segmented detector array, that means a single laser shot can yield up to 217 elevation measurements in 2 square meters in areas of high variability, like vegetation.

Design characteristics that make this system well-suited for coastal mapping include high laser power, short laser pulse-length, and a large, circular scanning prism. The large field-of-view afforded by the circular prism, with the high laser power and hand-selected photo-receivers work together to improve the capability of the system to measure depths in turbid water, which was one of the main design criteria for the system. CZMILs large, rotating Fresnel prism scans laser pulses in a circular pattern on the ground and water surface. The circular scan improves probability of penetrating breaking waves and of detecting objects in the water column by providing a forward and backward look into the water with a single pass. It also reduces building and tree shadow that occur with single-look systems. The short laser pulse length improves ranging accuracy on land and in water. Current processing techniques give the capability to range targets that are only 10 cm apart. Figure 2 shows an example of the data collected by JALBTCX for this mission in the Gilgo Beach area of Jones Beach Island, the easternmost Long Island barrier island surveyed by JALBTCX. The bridge at the lower right is the Robert Moses Causeway from Jones Beach Island to Fire Island. Each dot is an individual elevation measurement, and the dots are colored by elevation where tan, green, red, and brown are elevations on land, roads, buildings, and vegetation, and blues are depth measurements.

The New York and New Jersey areas assigned to JALBTCX were extremely challenging for airborne operations at CZMIL operational altitudes because of their proximity to JFK, LaGuardia, and Newark airspace. Most JALBTCX flight operations occurred at night due to the volume of air traffic during the day, because many of the desired survey areas were located in the approaches to these 3 major airports. Figure 3 shows the green laser cone and circular scan made by the rotating Fresnel prism over the World Trade Center in Manhattan. Other challenges for this work, and post-hurricane work in general, are access to GPS monuments for GPS control, access to fuel and accommodation, and for bathymetric LiDAR in particular, water clarity. In the passage of a major storm, it often takes several days for flood waters to runoff and the wave climate to calm so that the water is clear enough for successful depth measurement using bathymetric LiDAR. In this case, the improved performance envelope offered by CZMIL allowed for collection of bathymetry even in post-hurricane, winter conditions, in areas where previous generation bathymetric LiDARs failed to detect depths due to water clarity even during non-storm conditions. For the topographic LiDAR sensors deployed for this effort, challenges included waiting for the cloud deck to rise sufficiently for the higher altitudes that are most efficient for those systems, and coordination with low tide for greatest coverage of the coastal zone, since they cannot see below the water surface.

To accommodate the requirement for quick data turn-around, JALBTCX staff processed data 24 hours/day. Each night's data collection was processed to classified LAS and preliminary bare earth DEMs were delivered by ftp within 24 hours. Contracted topographic LiDAR data were delivered in preliminary LAS files within a week of data collection. Data collected for USGS were also available within days of collection. Final classified LAS and bare earth DEMs were delivered by all providers before Christmas.

In addition to airborne data collection, JALBTCX was tasked with pre- and post-storm change analysis. The JALBTCX mission is airborne operations and research and development in airborne LiDAR bathymetry and airborne coastal mapping and charting. Its primary operational program for the USACE is the National Coastal Mapping Program (NCMP). The NCMP was started in 2004 to provide the regional, re-occurring elevation and imagery data necessary to support management of USACE coastal projects on a watershed scale. Though the data are regional in scope, the airborne LiDAR and imaging technologies used for collection assure that they are also suitable for management of individual project components like jetties, navigation channels, breakwaters, beaches, and dunes. In addition to providing information on the physical characteristics of the coast, the data also provide quantitative information about the environment within which our projects exist, like the density and spatial distribution of sea grass and dune vegetation, and the distribution of wetland species. The goal of the program is to collect new LiDAR bathymetry and topography, high-resolution aerial photography, and hyperspectral imagery data for each portion of the US coast every five years, depending on sensor availability and funding.

JALBTCX surveyed the Sandy-impacted areas in 2005 and 2010 as part of the NCMP. The new data collected by JALBTCX and USACE industry partners were compared to these pre-event data to quantify the impact of the storm to the beaches and USACE coastal navigation and storm damage reduction projects. Pre-storm bare-earth DEMs from 2010 were subtracted from post-storm bare-earth DEMs to produce a difference layer. The difference layers were masked to encompass only the

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Figure 3: CZMIL laser cone and circular scan at the World Trade Center site. The blue-green laser is in the visible portion of the electromagnetic spectrum and is especially visible at night when there is no solar background.

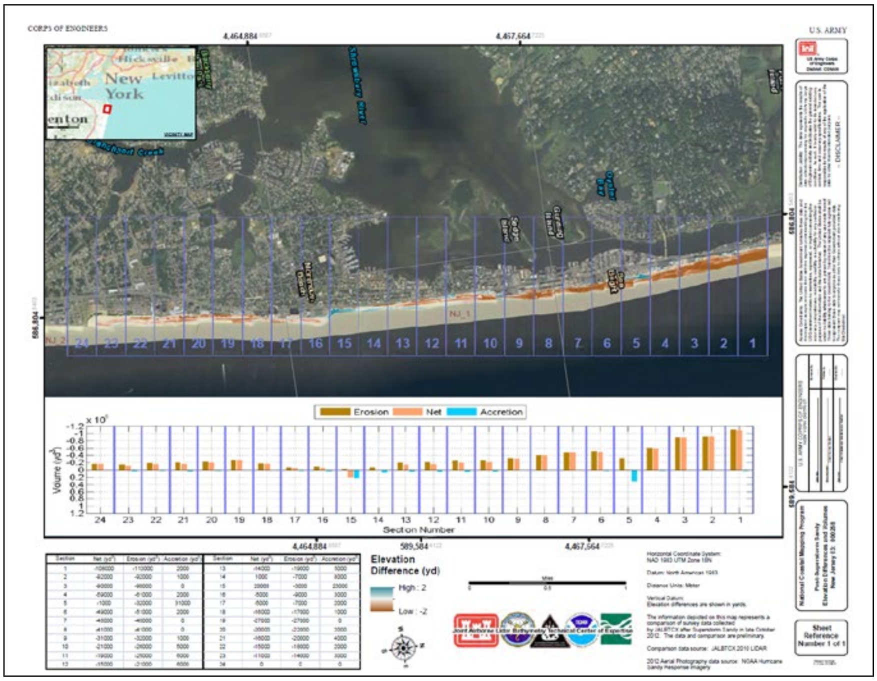

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Figure 4: JALBTCX preliminary change detection product near Sea Bright, New Jersey. The brown and blue overlay near the shoreline indicates where erosion (brown) and accretion (blue) have occurred. The graph and table give quantities of sand volume change.

beach areas. Volumes of erosion and accretion, and net volume change were computed from the masked difference layer in 1,000-ft alongshore segments. These volumes are key pieces of information used by USACE engineers to determine the cost of restoring USACE coastal storm damage reduction projects to their pre-storm condition.

Figure 4 shows an example of a preliminary change detection product for a section of the New Jersey coast. The top pane shows aerial photography overlaid with a brown and blue layer near the shoreline that indicates where erosion (brown) and accretion (blue) have occurred on the beaches. The intensity of the color is an indicator of the amount of change for an area, where dark browns and blues indicate over 2 m of elevation change. The bottom panel is the quantity of change that has occurred for each 1000-ft alongshore section of beach, where erosion is brown and accretion is blue and the net volume change is the narrow peach-colored bar for each section. This product quickly shows the pattern of change (erosion/accretion) for this area and the volumes quantify how much sand was lost to the beaches as a result of the storm. USACE uses these numbers to quantify the amount of sand lost to projects, which is a key component in developing a request for funds to restore USACE projects to pre-event condition. A preliminary version of this product was delivered two days after completion of the New York and New Jersey surveys. JALBTCX is currently working with the final post-storm bare earth DEMs to produce final volumes for USACE engineers to incorporate into their plans.

Though the goal of the USACE post-Sandy effort was to collect topographic LiDAR data for change detection, these data are widely available for other uses. As the USACE leveraged USGS LiDAR data collection post-storm for their requirements, USGS will use their own data and those data collected for USACE to produce elevation difference maps from the first-return digital surface models. This type of comparison can help characterize the nature, magnitude, and spatial variability of hurricane-induced coastal changes, such as beach erosion, overwash deposition, and island breaching, over the large impact area of Hurricane Sandy. Examples of this type of comparison can be seen at http://coastal.er.usgs.gov/hurricanes/sandy/LiDAR/.

Final products from the USACE post-Sandy LiDAR data collections are currently available to the public for point cloud visualization and download through the USACE GRiD at its Cold Regions Research and Engineering Laboratory. The USACE and USGS data have also been uploaded to the USGS Hazard Data Distribution system for emergency responders and will be available to coastal managers, scientists, and the general public through NOAA's Digital Coast and incorporated into the USGS National Map.

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