



JALBTCX Coastal Mapping for the USACE

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Abstract

The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) provides spatial data to support the U.S. Army Corps of Engineers (USACE) National Coastal Mapping Program (NCMP) and hurricane damage evaluation and response. The NCMP was designed to provide topographic and bathymetric elevation data with accompanying digital, geo-referenced imagery to USACE District engineers and scientists. The data support monitoring and maintenance of federal navigation and shore protection projects, and regional sediment management. The main source of these data is the CHARTS system, which is owned by the U.S. Naval Oceanographic Office and operated through the JALBTCX. The NCMP leverages other federal entities' funding, equipment, and mapping programs to efficiently provide these data to the USACE, and avoid duplication of coastal mapping initiatives.



Résumé

Le JALBTCX (Joint Airborne Lidar Bathymetry Technical Center of Expertise ou « Centre expert technique mixte de bathymétrie Lidar aéroportée ») fournit des données spatiales à l'appui du NCPM (National Coastal Mapping Program ou « Programme national de cartographie côtière ») de l'USACE (Army Corps of Engineers des USA) ainsi que pour l'évaluation des dommages provoqués par les ouragans et des réponses devant être apportées. Le NCMP est conçu pour fournir des données sur les élévations topographiques et bathymétriques ainsi que sur l'imagerie numérique géoréférencée ; ces données sont destinées aux ingénieurs et scientifiques du District USACE. Ces informations contribuent à la supervision et à l'actualisation des projets en matière de navigation fédérale et de protection du littoral, ainsi qu'à la gestion régionale des sédiments. La principale source de données est le système CHARTS qui appartient à l'« U.S. Naval Oceanographic Office » et qui est exploité par l'intermédiaire du JALBTCX. Le NCMP influence d'autres organismes fédéraux du point de vue du financement, des équipements, et des programmes de cartographie afin de fournir avec efficacité ces données à USACE, et pour éviter la duplication des initiatives en matière de cartographie côtière.



Resumen

El "Joint Airborne Lidar Bathymetry Technical Center of Expertise" (JALBTCX) (Centro Técnico de Pericia Conjunta de Batimetría por Lidar Aerotransportado) proporciona datos espaciales para apoyar el Programa Cartográfico Costero Nacional (NCMP) del Cuerpo de Ingenieros del Ejército de EE.UU. (USACE) y para efectuar una evaluación y dar una respuesta a los daños ocasionados por los huracanes. El NCMP fue creado para proporcionar datos de elevaciones topográficas y batimétricas acompañados de imágenes geo-referenciadas digitales a los ingenieros y científicos del Distrito USACE. Los datos apoyan la gestión y el mantenimiento de los proyectos de navegación federal y de protección de la costa, y la administración de los sedimentos a nivel regional. La fuente principal de estos datos es el sistema CHARTS, que es propiedad del Servicio Oceanográfico de la Marina de EE.UU. y que está manejado a través del JALBTCX. El NCMP tiene influencia en la financiación de otras entidades federales, de equipo y programas de cartografía, para proporcionar eficazmente estos datos al USACE, y evitar una duplicación de iniciativas cartográficas costeras.

Introduction

The U.S. Army Corps of Engineers (USACE) investment in airborne Lidar bathymetric technology began in 1986 with the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) program at the Coastal Engineering Research Center (CERC, now the Coastal and Hydraulics Laboratory) in Vicksburg, Mississippi. SHOALS was designed to augment existing USACE hydrographic survey capability by providing fast, accurate hydrographic surveys along the 40,000 km of federally maintained navigation channels (Lillycrop and Banic, 1993). The program was designed to develop airborne Lidar bathymetric technology, prove its application, and transition the mapping capability to the survey industry so that it would continue to be available to the USACE beyond the life of the SHOALS program (Miles et al. 1994).

The original SHOALS system, now referred to as SHOALS-200 (the laser pulsed at 200 Hz), was built by Optech, Inc. of Toronto, Ontario, and field tested in March 1994 (Lillycrop et al., 1994). Subsequently, SHOALS-200 flew projects for the USACE, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Naval Oceanographic Office (NAVOCEANO), demonstrating its capability to provide hydrographic survey data for navigation channel and shore protection project monitoring, to support numerical modeling, for nautical charting, and as part of emergency response to hurricanes (Lillycrop and Brooks 1996, Lillycrop et al., 1997). In 1996 the SHOALS program was transitioned from the USACE research and development organization at CERC to operational USACE at the Mobile District through the creation of the Airborne Lidar Bathymetry Technical Center of Expertise (ALBTCX).

ALBTCX owned the SHOALS system, contracted its operations, and continued research and development in airborne Lidar for the USACE. Mounted between the skids of a Bell-212 helicopter, SHOALS-200 surveyed projects throughout the USACE, extending its utility by providing successive surveys at project sites (Irish and Lillycrop, 1997) and expanding surveys beyond the immediate project components: authorized channel, navigation structure, constructed dune, or constructed beach profile (McClung 1998, McClung and Douglass, 1999). The SHOALS data enabled project scientists and engineers to monitor change at high spatial resolution and accuracy, and understand the relationship of the

coastal project with the adjacent shorelines and shoreface (Mohr et al., 1999).

In 1998, NAVOCEANO joined the USACE to form the Joint ALBTCX (JALBTCX). Its mission is to perform operations, research, and development in airborne Lidar bathymetry and complementary technologies to support the coastal mapping and charting requirements of the USACE, NAVOCEANO, and most recently (2002) for NOAA. In late 1999, Optech, Inc., upgraded SHOALS-200 to a 400Hz laser, and the SHOALS-400 began flying regional scale surveys from a Twin Otter (Wozencraft and Irish 2000, Wozencraft et al. 2002a). The most significant of these were the 2000 and 2001 surveys in the Hawaiian islands. The USACE, NAVOCEANO, the U.S. Geological Survey (USGS), and NOAA, all provided funds for the mapping of six islands: Hawaii, Maui, Lanai, Molokai, Oahu, and Kauai. The data were collected to a common standard designed to support the activities of each contributing group. The USACE used the data for storm wave run-up modeling, NAVOCEANO and NOAA required the data for nautical charting, and the USGS used the data as part of their coral reef mapping initiatives. The USACE further exploited these data to evaluate navigation channels and coastal structures, and as a baseline for regional sediment management (West and Wiggins, 2000).

The success of the SHOALS program, and customer demand for more Lidar and complementary airborne data like aerial photography, led JALBTCX, through a Navy contract, to specify development of the next generation of SHOALS airborne Lidar bathymeter (Wozencraft, 2002). The Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system was initially composed of the first Optech Inc. SHOALS-1000T9, an integrated Lidar system with a 1kHz bathymetric laser, a 9kHz topographic laser, and a DuncanTech (DT)-4000 digital RGB camera (LaRocque et al., 2004). In 2005, CHARTS was upgraded to include a 3kHz bathymetric laser, a 20kHz topographic laser, and an Itrics Compact Airborne Spectrographic Imager (CASI)-1500 (Figure 1, Wozencraft and Millar, 2005). The following sections describe how JALBTCX has used the CHARTS system to support USACE activities, specifically the National Coastal Mapping Program and hurricane response surveys. JALBTCX research and development activities, from CHARTS improvements to new system development are outlined in the final section.

USACE National Coastal Mapping Program

USACE Headquarters funds its National Coastal Mapping Program (NCMP) to support construction, operation and maintenance activities in the coastal zone, like navigation and flood protection projects. With the Lidar and imagery data provided by CHARTS, USACE project managers can monitor project components at engineering scales. CHARTS capability to provide engineering scale data, on survey scales as great as 1:200, over large areas, gives project managers the further benefit of managing projects with regard to regional sediment processes.

Through the NCMP, JALBTCX is providing support to several national initiatives, including the USACE National Shoreline Management Study (NSMS), the Integrated Ocean Observing System (IOOS), and the coordinated federal response to assessing hurricane impacts. The NSMS was authorized in the Water Resources Development Act of 1999 under Section 215c (USACE, 2006). The study presents the first opportunity for the USACE to reexamine the status of the Nation's shoreline since its last assessment 30 years ago. NSMS results will provide a baseline for Federal shoreline management actions in the foreseeable future. The technical basis and analytical information derived from NSMS will be useful in developing recommendations regarding shoreline management, including a systems approach to sand management that considers natural processes of sediment movement along the

entire coast, and the impacts of human activities on these processes. The NSMS study team will also recommend roles for Federal and non-Federal participation in shoreline management. To aid NSMS, JALBTCX produces a shoreline vector from NCMP data as a standard product for measuring and monitoring the condition of the coast.

In the President's response to the Ocean Commission Report, coordinated ocean and coastal mapping was identified as an on-going effort. JALBTCX and the NCMP are heavily engaged in the Interagency Working Group for Ocean and Coastal Mapping (IWG-OCM) as one of the four co-leads. The goals of the IWG-OCM are to: coordinate needs, planning, and operations; develop data acquisition, data, metadata, and product standards; develop new mapping technologies and capabilities; and establish processing, distribution, and data product portals. The initial efforts center on federal agencies, but the group is open to non-federal participation. The JALBTCX is participating in IWG-OCM initiatives and aiding the organization while the NCMP is providing data and survey opportunities.

Over the past two North American hurricane seasons (2004 & 2005), numerous storms have caused significant damage to the US coasts. JALBTCX has worked with other federal agencies, namely NAVOCEANO, the USGS Center for Coastal and Watershed Studies, the National Aeronautical and Space Administration's Experimental Airborne Advanced Research Lidar (EAARL) Program Office,

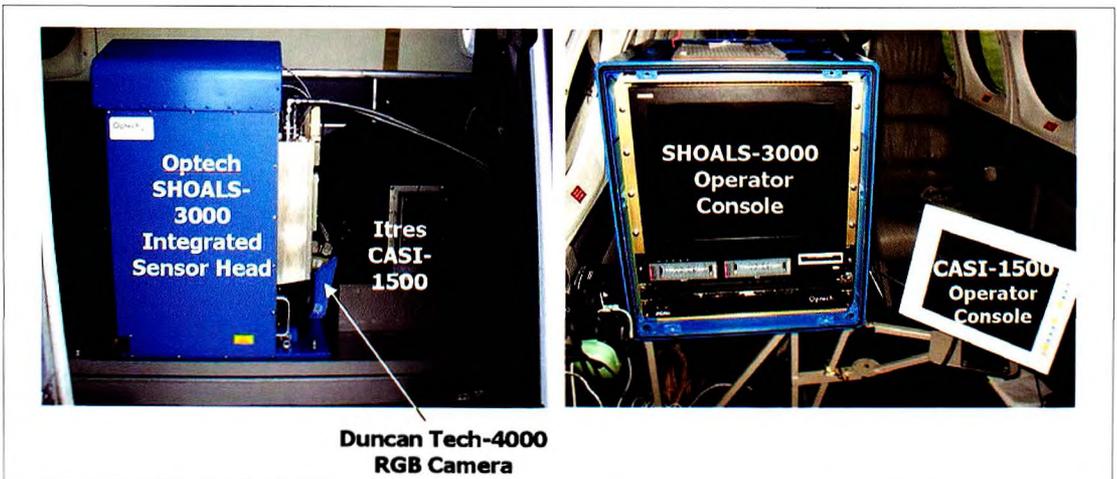


Figure 1: CHARTS sensor suite and operator consoles. The photo on the left was taken looking in through the door of the aircraft. The photo on the right was taken looking toward the rear of the aircraft, just aft of the pilots' seats.

and NOAA's National Geodetic Survey and Coastal Services Center, to collect regional surveys following each major event. These data have been collected and rapidly disseminated to coastal managers to support damage assessments, reconstruction of navigation and shore protection projects, and modeling and coastal processes studies.

CHARTS completed the opening field season of the (NCMP) on the Gulf of Mexico coastlines of Mississippi, Alabama, and Florida, and the Atlantic coast from Miami to the North Carolina/Virginia border in early summer 2004. The USACE funded CHARTS surveys on the Alabama and Florida Panhandles and Florida's east coast following the 2004 hurricane season (Wozencraft and Millar, 2005). The post-storm data, used together with the NCMP data, supported over \$200 million of construction to restore 16 coastal projects to their pre-storm condition prior to the start of the 2005 hurricane season.

Since its 3kHz upgrade field test completed on 6 July 2005, CHARTS has flown hyperspectral demonstration projects in Florida and New England and has surveyed areas impacted during the 2005 hurricane season. During this time, data for the NCMP was collected from Virginia to New York by contract through Fugro Pelagos, who own and operate a SHOALS-1000T9. Fugro will complete the survey from Connecticut to Maine beginning in summer 2006. The two-month 2006 field season for the NCMP also begins in summer 2006, in Erie, Pennsylvania. This year's work includes the U.S. shorelines of Lake Erie, Lake Huron, and the eastern shoreline of Lake Michigan. CHARTS will deploy to complete this data collection.

The JALBTCX continues to develop new information products from the data it collects. In addition to bathy/topo ASCII XYZ and digital RGB orthomosaics, all data collected in 2005 were delivered with bathy/topo data in LAS format, 1-m ArcGIS grids, an NAVD88 shoreline, bare earth grids, and building footprints (Wozencraft and Millar, 2005). Two new products are images of seafloor reflectance at 532 nm and the CASI hyperspectral

imagery. Grids of seafloor reflectance are created using Optech, Inc.'s SHOALS Ground Control System and Optech International's Rapid Environmental Assessment extension to ENVI. The estimates of seafloor reflectance are extracted solely from the bathymetric waveform as described in Tuell et al. 2005. The CASI hyperspectral imagery is processed to orthomosaics using Ires processing software. Examples of these two products are shown in Figure 2 for data collected as a demonstration at Portsmouth Harbor, New Hampshire, USA. Data produced by the CHARTS and SHOALS-1000

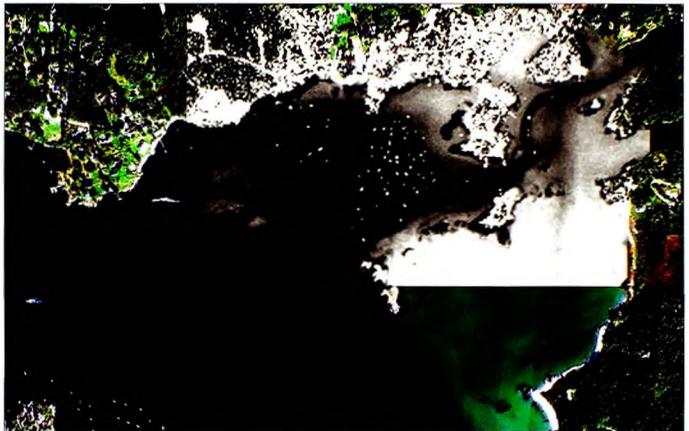


Figure 2: Two new products from the CHARTS system. The color image in the background is RGB extracted from 36 bands of hyperspectral at-sensor radiance from the CASI-1500. The black and white overlay is seafloor and land reflectance computed from the green Lidar waveforms.

systems for the NCMP meet the accuracy requirements published by the USACE for topographic (USACE 1994) and hydrographic surveys (USACE 2002), and by the International Hydrographic Organization for nautical charting (IHO 1998), with notable exceptions including structure deformation monitoring and IHO Special Order Surveys. Field test reports of the SHOALS-1000 and CHARTS 3kHz upgrade (Optech 2004, LaRocque et al. 2005) present the results of comparisons between the Lidar instruments and a sonar survey collected by NAVOCEANO in the months prior to the SHOALS-1000 field test in fall 2003. The sonar survey was referenced vertically using data from a nearby tidal gauge. The sonar data were shifted vertically to the ellipsoid using values from the published geodetic and tidal benchmark sheets. The Lidar surveys were referenced vertically to the ellipsoid using standard carrier-phase GPS processing techniques.

The JALBTCX identified areas in the sonar data with

relatively low relief for Optech to use in their comparisons. Steeply sloping reefs and highly variable hard bottom were not selected. There were nine and eleven comparison areas for the SHOALS-1000 and CHARTS 3kHz upgrade field tests, respectively. Depths for the comparison areas ranged from 7 to 40 metres. The Cross Check Tool in the Fledermaus software suite was used to perform the analysis. This tool compares each Lidar depth to a 5m average gridded surface of the sonar survey. For the comparison it was assumed that the sonar surveys represent the true bottom depth and contain no error.

The field test reports present mean differences and standard deviations between the sonar and Lidar surveys by flight (day) for each depth area. These statistics demonstrate that both systems produced depths accurate to 30cm at 95% from 7 to 25 metres, then transitioned to 50cm at 95% as depths increased to 40m. For both Lidar instruments the topographic elevation accuracy for both the red and green lasers was 15cm at 95% over a flat parking lot. The 95% confidence values were computed from tables of field test results in the following way. For each depth area in flight a 95% confidence value was computed by adding the absolute value of the mean difference to 1.96 times the standard deviation. A weighted mean 95% value was then computed for each depth area over all flights, with weighting based on the number of points in each comparison.

2005 Hurricane Season Response Surveys

The 2005 hurricane season brought Hurricanes Dennis, Katrina, Rita, and Wilma to the U.S. Gulf Coast, and Hurricane Ophelia impacted the entire Eastern seaboard of the U.S. from Portland, Maine to Miami, Florida. CHARTS data support the response of many federal, state, and local agencies to the 2005 hurricane season: the USACE, the Federal Emergency Management Agency (FEMA), the USGS, the Florida Department of Environmental Protection, NOAA, and the Interagency Performance Evaluation Taskforce formed by the USACE to provide scientific and engineering perspectives about the performance of the New Orleans hurricane and flood protection system during Hurricane Katrina. The data have also been released to several univer-

sity groups and engineering consultants to quantify storm impacts to coastal areas.

JALBTCX collected or contracted Lidar and RGB imagery data in response to three storms: Dennis, Ophelia, and Wilma. CHARTS data were collected both before and after Hurricane Dennis on the Alabama and Florida Panhandles. The Hurricane Dennis data collections were sponsored by the USACE, USGS, and FEMA. Fugro Pelagos was contracted to extend NCMP mapping from Virginia south to Miami, Florida, in response to Hurricane Ophelia. CHARTS will survey the west coast of Florida in response to Hurricane Wilma prior to its Great Lakes deployment. USACE Headquarters funded collection of Lidar, RGB, and hyperspectral imagery following Hurricane Katrina to serve as a baseline for recovery of mainland, barrier island, lake, and bay shorelines of designated areas of Louisiana, Mississippi, Alabama, and the Florida Panhandle.

Hurricane Dennis

Two days after the completion of its 3kHz upgrade field test, on 8 July 2005, CHARTS was sent to the Alabama and Florida Panhandles to collect a pre-storm condition survey in Dennis' expected impact area. Following landfall, a post-storm condition survey was collected in the same area, plus for federal projects to the east of this area in Bay and Walton counties, Florida. In addition to collecting survey data that customers used for determining storm damage, the JALBTCX computed sand volume losses for Bay and Walton counties in Florida to support USACE reconstruction efforts. Technicians computed the differences between surfaces created from the Post-Ivan data collected in November 2004 and the Post-Dennis data collected in July 2005 using the SHOALS Toolbox (Wozencraft et al., 2002b). Post-Ivan data were used as the pre-storm condition because the pre-Dennis survey did not extend this far east. The differences were converted to volumes with the same software package.

For the USACE Panama City Beach Shore Protection and Flood Damage Prevention Project, volume computations showed a surprising net gain of 300,000 3^m material within the project limits between the storms. Further, the accretion had a spatial component. That is, the ends of the project, near the Walton County shoreline on the west and St. Andrew's

Inlet on the east showed accretion, while the middle of the project eroded. Consultation with project engineers revealed that sand was being placed on the beach prior to Dennis' landfall in preparation for the 2005 hurricane season. Specifically, about 700,000 m² had been placed over 7km at the western end of the project, and 1.5km at the eastern end of the project. Areas where sand placement had been completed showed apparent accretion in the survey comparison, while areas where sand placement had not been completed prior to landfall, showed erosion. In actuality, the entire project had eroded. The actual change within this project was a net loss of 400,000 m³, the difference between the placement volume and the result of the survey comparison.

Mississippi and Alabama barrier islands at the request of USGS for comparison with their pre-storm Lidar data.

New operational constraints were implemented to ensure collection of good hyperspectral imagery. To achieve optimal illumination of ground features, and reduce shadows that might fall on features of interest, missions were flown only within 3 hours of solar noon. This limited daily flight time to six hours. A five hour aircraft flight duration and a GPS PDOP spike precluded the use of the entire six-hour operational window as defined by solar conditions. Survey time was often limited to only 3-4 hours per day. Typical, Lidar-only operations consist of nine 5-hour flights per week.

Post-Hurricane Katrina

The Post-Hurricane Katrina surveys mark the first large-scale acquisition of CASI-1500 data undertaken by the JALBTCX. Three collection schemes were devised for the collection of hyperspectral data with concurrent topographic Lidar, based largely on desired coverage and spot density for the topographic laser data. Topographic Lidar were collected with 100% coverage in areas where more dense topographic Lidar data had already been collected. As such, these areas were primarily hyperspectral projects and included: the shoreline of Lake Pontchartrain, Mobile Bay shoreline, and the Mississippi Sound shoreline.

For these projects, the plane flew at 1000m resulting in a Lidar spot density of 1.5m. Figure 3 shows an example of hyperspectral data collected along the Mississippi Sound shoreline near Ocean Springs, Mississippi. Topographic Lidar at 100% coverage were also collected for the New Orleans levees, the Mississippi River Gulf Outlet, and the levees along the Mississippi River south of the city. For these projects, the plane flew at 700m, resulting in a Lidar spot density of 1m to facilitate engineering measurements of the levees. The final scheme applied to data collection was 200% coverage at 700m altitude, resulting in an average Lidar spot density that was less than 1m. This was applied at Grand Isle, Louisiana, which had not been surveyed in the past by either the USGS or USACE, and to the



Figure 3: RGB extracted from 36 bands of CASI-1500 hyperspectral data collected near Ocean Springs, Mississippi, following Hurricane Katrina. Areas where there are houses, but no FEMA blue roofs, are areas where storm surge inundated the coast and either destroyed homes completely or made them unlivable.

Survey coverage rates were also impacted by the requirement that the pilots fly as slow as possible to achieve on-ground resolution of 1m for the hyperspectral imagery. The CASI-1500 is a programmable sensor that can collect up to 288 bands of spectral data, and can produce imagery with pixel resolutions as small as 20cm. However, there is a trade-off between spectral and spatial resolution. On-ground resolution is entirely dependent on flight speed and the integration time of the CASI-1500. Integration time is dependent on the number of spectral bands collected. To collect 36 bands of hyperspectral imagery, the integration time is 16ms. At near stall speed (125 knots) this results in 1m imagery. For comparison, 72 bands of spectral data result in 2m images, and 12 bands of

spectral data result in 50 cm images.

Bathymetric Lidar data were collected for one area, the 300km of shoreline between Fort Morgan Peninsula in Alabama to Panama City Inlet in Florida. This is the only area in the post-Katrina survey where water clarity would support successful bathymetric Lidar operations. The collection was defined as a typical NCMP mission: 1km offshore (or to laser extinction if that occurs closer to shore) with the bathymetric Lidar and 500m onshore with the topographic Lidar, both accompanied by RGB imagery. CASI data were not collected for this area.

Data collection began 10 October and was completed 10 December. During these two months, the following data sets were collected: 1 terabyte of raw

hyperspectral data, 54 gigabytes of raw bathymetric Lidar data, 160 gigabytes of raw topographic Lidar data, 37 gigabytes of RGB imagery in JPEG format, 99 megabytes of raw GPS groundstation data, and 24 megabytes of raw GPS/IMU aircraft data. In the final stages of processing, the Lidar data occupy 1 terabyte of disk space, while the hyperspectral data occupy 1.5 terabytes of disk space.

An example of Lidar and CASI data collected in an impacted area of New Orleans is shown in Figure 4. This is around the 17th Street levee failure. The bright white area (Figure 4 (b&c)) is a sand repair to the levee. In the RGB (Figure 4(b)) imagery, the flooded area east of the canal looks brown when compared to the area west of the canal, where vegeta-

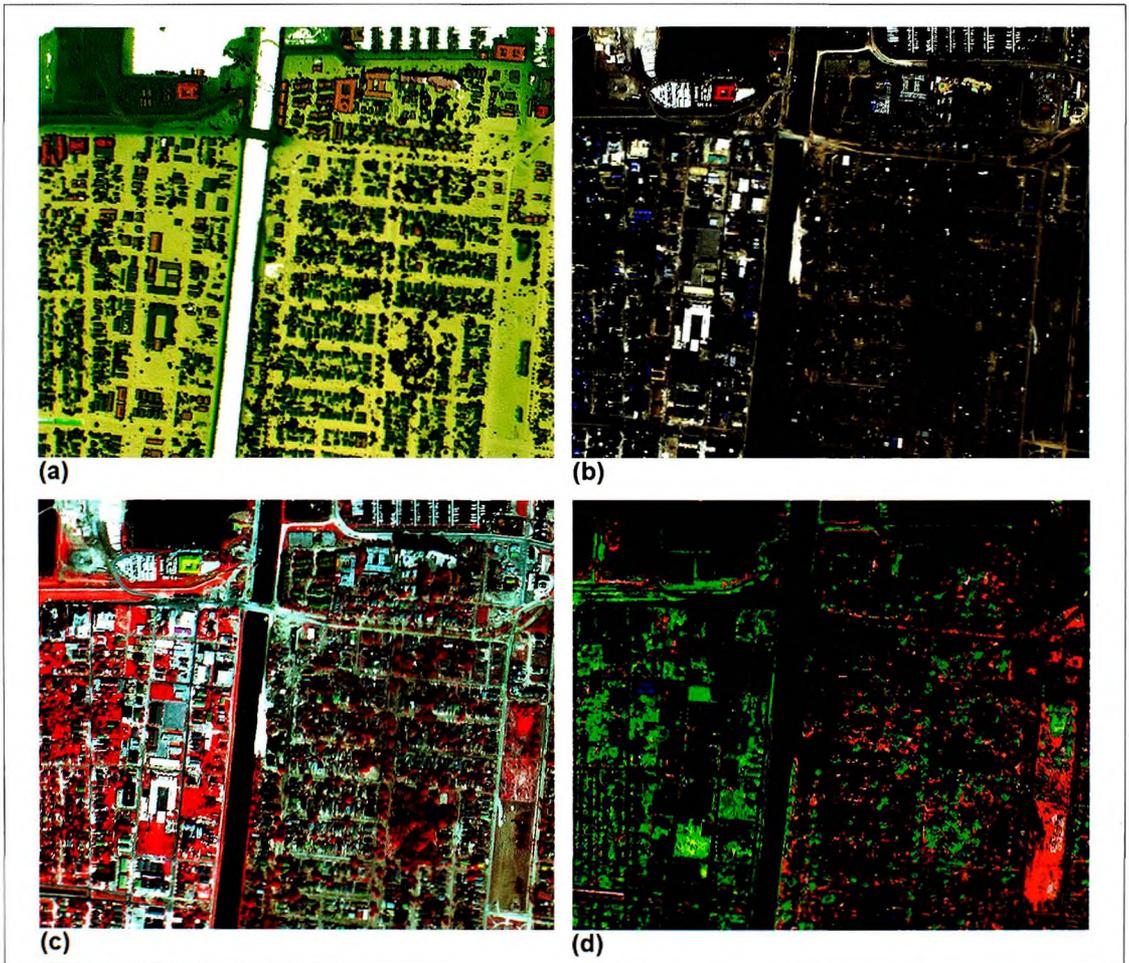


Figure 4: CASI-1500 data collected near 17th Street Canal levee failure. (a) 1-m surface created from CHARTS topographic Lidar data, where elevation increases from tan to green to red. (b) RGB extracted from the hyperspectral imagery. (c) Color IR image extracted from the hyperspectral data. (d) Classification of the hyperspectral imagery where green is healthy vegetation, orange is inundated vegetation, and blue is FEMA blue roofs.

tion remains green. In the Color IR image (Figure 4(c)) extracted from the hyperspectral imagery, healthy vegetation shows as bright red and stressed vegetation looks more muted. A classification of this imagery is shown in Figure 4(d). This classification was created in ENVI using a supervised classification method called the spectral angle mapper.

Research and Development

JALBTCX research and development supports and leverages work in government, industry, and academics to advance airborne Lidar and coastal mapping and charting technology and applications. Initial stages of development for a next-generation airborne coastal mapping and charting system are underway. The new system will retain the current depth detection capability of the CHARTS system, but will have improved depth accuracy, be capable of operation in a broader range of water conditions, and provide better characterization of seafloor and water column properties. New receiver technology can increase sounding density and improve target detection capability, or provide a multispectral detection capability.

In the course of work for designing the new sensor, CHARTS design and software algorithms will be evaluated and improved where practicable. Development of a total propagated error model for CHARTS will enable survey engineers to apply the Combined Uncertainty and Bathymetry Estimation (CUBE) algorithm (Calder 2003) more rigorously. Current implementation of the CUBE algorithm in CHARTS data processing uses a constant error estimate for a survey in absence of a model that will provide error estimates for each depth measurement based on the errors associated with each CHARTS system component. Further development of Lidar waveform processing techniques will provide additional water column parameters that can improve the bottom reflectance measurement. Sensor fusion algorithms will advance from pixel-level classification to classification of groups of pixels as features.

Conclusions

JALBTCX provides Lidar elevation data and digital imagery at engineering accuracies on a regional

scale to support project monitoring, regional sediment management, and hurricane damage evaluation and response. These data are provided by a combination of in-house survey capability through the CHARTS system, and surveys contracted to Fugro Pelagos, who own and operate a SHOALS-1000T9 Lidar system. Both of these systems have proven accuracy capabilities that meet the standards set by the engineering and nautical charting communities. JALBTCX is involved at a national level with coordination of data collection activities to reduce duplication of effort between agencies. JALBTCX is currently contracting the initial stages of work toward a new sensor for airborne coastal mapping and charting. CHARTS data processing will be improved as part of this effort, as a major goal for the new system is increased automation of existing algorithms. JALBTCX provides the airborne coastal mapping and charting community a source of information for emerging customer requirements, funding, and current research.

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