USACE National Coastal Mapping Program and the Next Generation of Data Products

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***Abstract*-The U.S. Army Corps of Engineers (USACE) has been monitoring coastal change for decades. Each coastal district has the duty to maintain the federal navigation channels to insure safe passage for commercial and private vessels. In addition to these navigation channels, monitoring coastal change and regional sediment management rank high in both importance and financial expenditures. Acoustic boat surveys have been and will continue to be a viable way to accomplish these goals. For the past 15 years these surveys efforts have been assisted by the Joint Airborne Lidar Bathymetry Technical Center of eXpertise (JALBTCX). The JALBTCX has in-house survey capability using the U.S. Naval Oceanographic Office's Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system. The CHARTS system collects bathymetric lidar, topographic lidar, RGB imagery, and hyperspectral imagery. CHARTS is mounted on a Beech King Air 200 which provides a platform capable of surveying the federal navigation projects and the areas between to support regional sediment management.**

In 2004, USACE Headquarters funded JALBTCX to map the sandy shoreline of the continental U.S. on a recurring basis. This mapping effort falls under the National Coastal Mapping Program (NCMP). In addition to the NCMP, JALBTCX performs emergency response surveys following natural disasters. Since 2004, JALBTCX was surveyed after every category 2 (or greater) hurricane that makes land fall within the U.S. As the survey capabilities increase it becomes more difficult for the local engineers to process the large volumes of data and the demand for analysis ready products became a necessity. JALBTCX took on this challenge and is currently delivering a suite of products to meet the needs. With the addition of new sensors, JALBTCX has also been able to develop new data fusion products to assist in monitoring the engineering, economic, and environmental changes to the coastal zone.

I. INTRODUCTION

The U.S. Army Corps of Engineers (USACE) Joint Airborne Lidar Bathymetry Technical Center of eXpertise (JALBTCX) is funded by USACE Headquarters to collect lidar, RGB, and hyperspectral imagery along the coastline of the contiguous United States. This effort falls under the National Coastal Mapping Program (NCMP) and provides Corps Districts throughout the U.S. with a complete series of data products designed to meet their coastal engineering and research needs. The in-house survey capability utilizes the coastal mapping and charting system Compact Hydrographic Airborne Total Survey (CHARTS). CHARTS is the U.S. Naval Oceanographic Office program name for an Optech, Inc. SHOALS 3000T-H. CHARTS comprises a 3-kHz bathymetric lidar, a 20-kHz topographic lidar, a DuncanTech DT4000 high-resolution digital camera, and a Compact Airborne Spectrographic Imager (CASI)-1500, fig.1 [1]. In addition to the in-house survey capability, JALBTCX has the ability to contract data collection efforts to various commercial survey providers. The elevation and imagery data are used singly and in conjunction to provide a variety of GIS data products that are used to support management of coastal sediments and can be used to support management of coastal environmental resources.

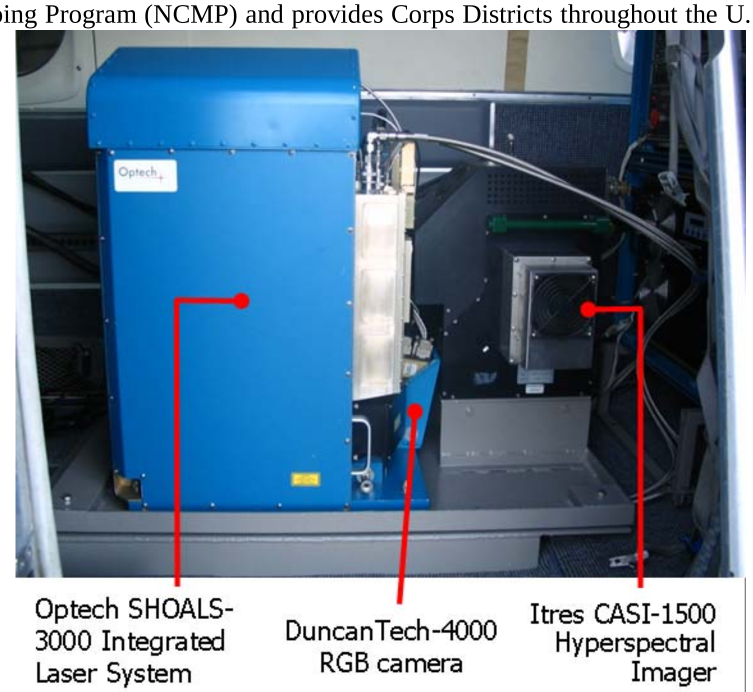

Fig. 1 Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system.

With the in-house survey capability and contract support, the JALBTCX can provide rapid response for emergency assessment surveys. This has been demonstrated with multiple post-hurricane surveys, the most notable would be after Hurricane Katrina in 2005 and more recently following hurricanes Gustav and Ike in 2008. The post-Gustav and Ike surveys were carried out using our commercial contract service provider, 3001 Inc., A Northrop Grumman Company.

In addition to the operational aspect, JALBTCX is also dedicated to the advancement of the data types to generate higher level products. These higher level products are generally referred to as data fusion products. The newest data product developed at JALBTCX incorporates the topographic lidar and hyperspectral imagery to produce a basic land cover classification. Funding for this development was funded by both USACE Headquarters and the USACE System-Wide Water Resource Program (SWWRP). Using an unsupervised decision tree classification routine, the data are segmented into a total of 14 classes which include high vegetation (>6m), medium vegetation (0.5m-6m), low vegetation (<0.5m), tall structures (>2.5m), low structures (<2.5m), roads, bare ground, and water. This product was the initial phase to fuse the topographic lidar and hyperspectral data and is currently being evolved to generate land use maps and mask layers to speed up traditional spectral classification algorithms.

II. National Coastal Mapping Program

In 1994, the U.S. Army Corps of Engineers Engineering Research and Development Center (ERDC) transitioned the research project Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) into operations at the USACE Mobile District. The initial mission supported monitoring of the ever changing navigational channels. It is the responsibility of the USACE to maintain these federal navigation projects at a safe depth for mariners. This is accomplished by dredging, erecting jetties, and break waters in and around tidal inlets. As the technology improved, the speed of collection increased and the cost per survey mile decreased. It soon became feasible to use SHOALS as a tool to map the coast on a regional scale to assist in the generation of regional sediment management decisions. The first regional sediment budget survey, Regional Sediment Management Demonstration Program (RSMDP) in 2000, was performed along the Alabama Coast and Florida Panhandle that demonstrated this capability [2]. Then in the summer of 2004, JALBTCX started the NCMP's regional surveys to support all of the USACE coastal district's regional sediment management. The first cycle of the NCMP will be completed during the summer of 2010.

III. Emergency Response Surveys

Since the inception of airborne surveying it has been demonstrated time and time again that these platforms can mobilize and survey areas unreachable by conventional survey methods or complete the survey in a fraction of the time. Majority of the surveys performed by SHOALS and CHARTS occur prior to a hurricane's land fall or shortly after the hurricane has pasted. For the JALBTCX, these surveys date back to Hurricane Opal in 1995 and most recently following Hurricane Gustav and Ike in 2008. Hurricane Gustav made land fall on the 1st of September in the Louisiana marsh south of New Orleans. 12 days later on the 13th of September the powerful category 2 Hurricane Ike ravaged the south east Texas coast along Galveston Island and the Bolivar Peninsula. Many surveys following these storms focused their efforts on the more populated areas and possible navigational hazards in and around Houston and Galveston, TX. JALBTCX contracted a survey effort with 3001 Inc. that spanned from Freeport, TX (40 miles west of Galveston, TX) to the mouth of Mobile Bay, AL. The inland areas of the Galveston Bay Complex, Lake Sabine, and Bay St. Louis were also included in the survey limits. The entire survey limits are shown in fig. 2 with the

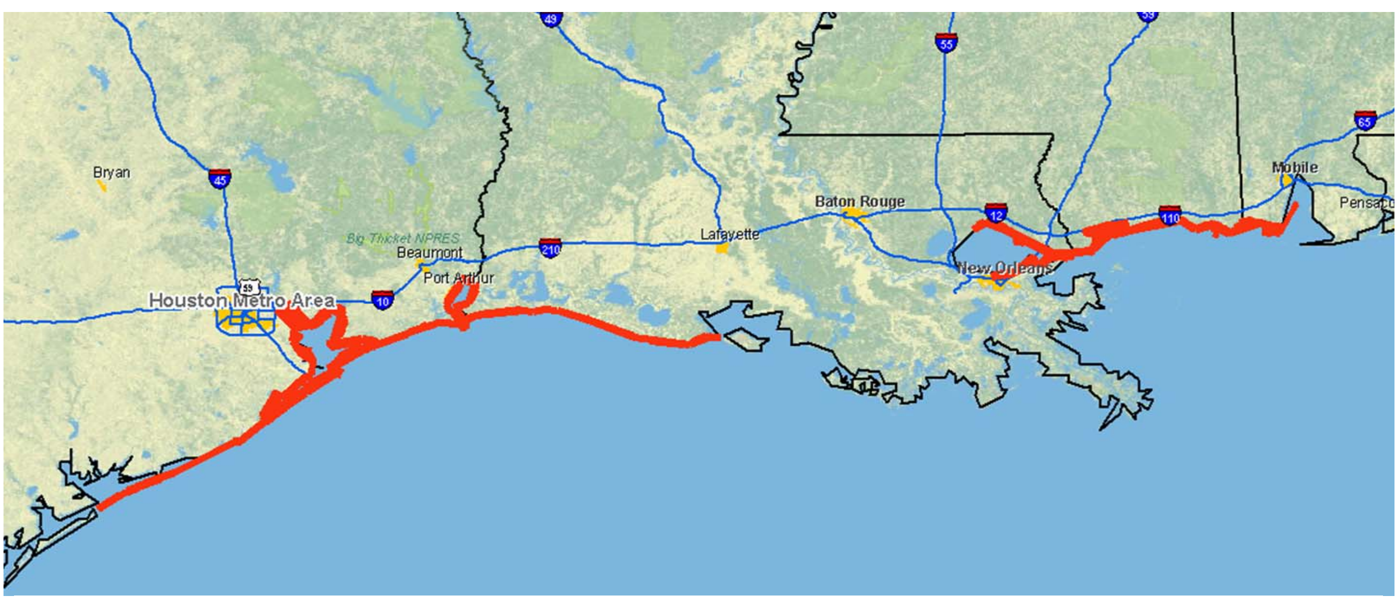

Fig. 2 Post Gustav and Ike survey limits shown in red.

flight lines in red. This vast stretch of coastline encompassed all areas impacted by both of these storms. Due to the questionable water clarity along these areas only topographic lidar, RGB imagery, and hyperspectral imagery have been collected. This effort consisted of 528 lines with 7710 km of total flight line distance. There were 8.1 billion topographic lidar shots, 38,544 RGB images, and 942 GB of hyperspectral imagery collected. Fig. 3 is an oblique view of coastal Biloxi, MS showing the topographic lidar point cloud (A) and the orthorectified RGB imagery overlaid onto the lidar surface (B).

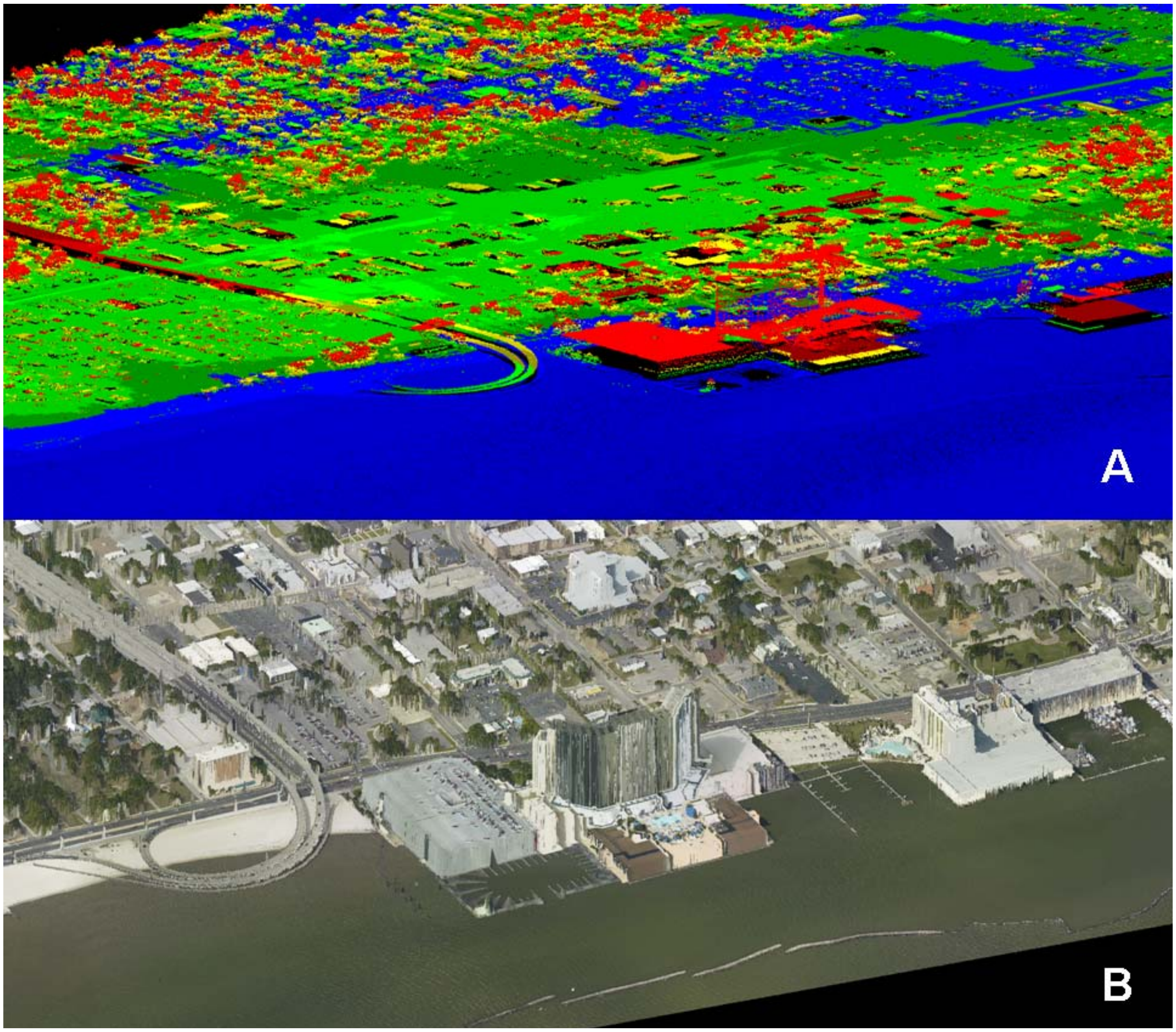

Fig. 3. Oblique view of coastal Biloxi, MS. A – topographic lidar point cloud B – RGB imagery overlaid onto lidar surface

IV. DATA PRODUCTS

A. Standard Products

The first data products generated by SHOALS and CHARTS were (and still are) vector point cloud data in ASCII or LAS files. As the systems improved and acquired larger datasets, our end customers were unable perform analysis due to the sheer volume of information the computer had to process. The need for analysis ready products was realized and started JALBTCX into product generation and development. Majority of the analysis for regional sediment management occurs in a Geographic Information System (GIS) environment. The first GIS compatible product deployed was a 1m raster grid containing bathymetric and topographic lidar data. The grids are generated by making a Triangulated Irregular Network (TIN) surface then extracting the grids values from the TIN surface. With the upgrade to the CHARTS system, a RGB camera was integrated to support decision making during the data editing and cleaning process. These images were then exploited through orthorectification and mosaicking the individual frames into 5km along shore mosaics. In the subsequent years, JALBTCX has implemented more evolved products that include North American Vertical Datum of 1988 (NAVD88) zero shoreline and bare earth extraction which has paved the way for bare earth 1m grids, building footprint delineation, and a classified LAS point cloud. Fig. 4 shows examples of data products, A – Bathymetric and Topographic 1m Grids, B – Bare Earth and Bathymetric 1m Grid, C –

Orthorectified RGB Mosaic, D – Land Cover Classification. In addition to the in-house JALBTCX product development, there has also been development by Optech International to calculate the absolute seafloor reflectance from the SHOALS bathymetric lidar waveform. These reflectance values are generated for each laser pulse and then made into a raster seafloor reflectance map using a TIN algorithm similar to the standard 1m grid produced from the elevation data. Optech International is developing methods that utilize these grids to calculate spatial statistics (rugosity, mean, variance, etc.) which enable them to classify the seafloor with an 85% accuracy. These techniques will be incorporated into the JALBTCX product flow within the next 2 years.

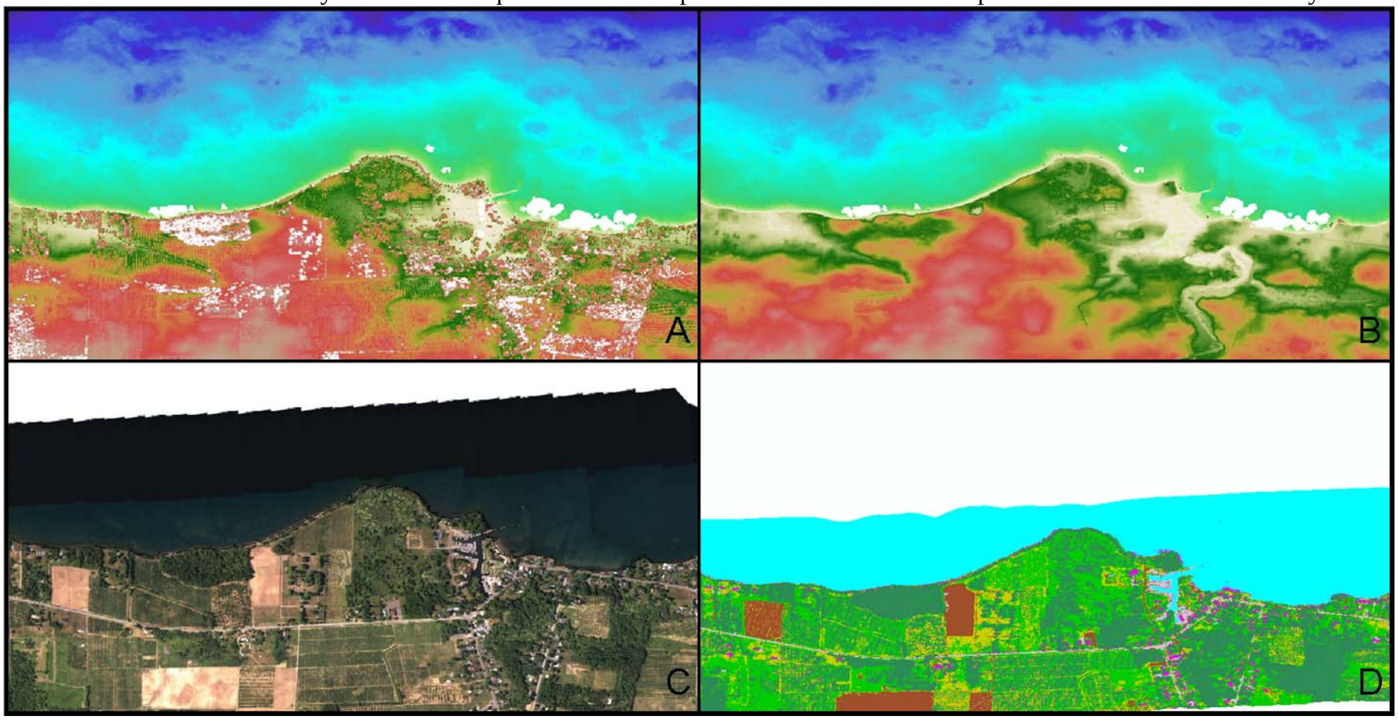

Fig. 4. Example data products. A – Bathymetric and Topographic Lidar 1m Grid, B – Bare Earth and Bathymetric 1m Grid, C – Orthorectified RGB mosaic, D – Land Cover Classification

B. Data Fusion Products

Combining data types to improve existing data products or to develop new products is not a new idea. The first data fusion effort combining hydrographic lidar and hyperspectral imagery date back to 1994 at the SHOALS field test in Sarasota Bay, FL. It successfully demonstrated that SHOALS depths could be used to normalize the hyperspectral imagery then enhancing the classification results [3]. One of the problems with data fusion is the different data types are often collected on multiple platforms and on different dates or times. These factors can make it difficult to correlate similar parameters needed to leverage one data type from the other. Not to mention the costs involved with operating on multiple platforms or performing additional flights. The integration of JALBTCX's multiple sensors allows all data types (bathymetric lidar, topographic lidar, RGB imagery, and hyperspectral imagery) to be collected simultaneously. This simultaneous collection technique ensures that all sensors have the same inertial navigation solution and affects from the environment.

With Optech International conducting research to fuse the bathymetric lidar and hyperspectral imagery at the signal level [4],[5], JALBTCX still had the need to generate informational products from the topographic lidar and hyperspectral imagery. This data fusion approach used the topographic lidar grids, bare earth grids, and the hyperspectral reflectance mosaics. Each data type was pre-processed using the manufacture's proprietary software. The grids and mosaics both have a 1m spatial resolution but they each needed to be cropped to have the same amount of rows and columns in the image. This now enables the lidar grids to be used as additional bands to the 36 bands of hyperspectral imagery. The software package ENVI was selected for manipulation of the hyperspectral imagery due to its suite of powerful built-in classification routines. One of these routines is a decision tree classifier that can be tailored to a specific set of input parameters. Decision tree classifiers work by asking a series of yes or no questions that segments the image scene at each level.

The decision tree built at JALBTCX uses a series of 13 equations to classify the images into 14 classes. It starts by finding all of the image pixels in the hyperspectral image where every band is equal to 0 and classifying them as the "No Data" class. Sometimes there are extremely bright objects in the image that saturate the pixel value and render them useless. These pixels are removed by detecting pixels with very high or very low reflectance values and classifying them as "Saturated Pixels". Next the land and water pixels are separated by using the Normalized Difference Vegetation Index (NDVI) equation. This equation uses a near infrared band (NIR) at 738 nm and a red band (RED) at 624 nm [6]. This equation is shown in (1),

$$NIR - RED \,/\, NIR + RED = NDVI\ value. \qquad (1)$$

The pixels that have a NDVI value less than -0.05 are then classified into the "Water" class. Even though the sensors are all collected simultaneously they each have their own collection limitations and do not always have the same amount of coverage. The areas of no data in the hyperspectral image have already been removed but the 4^{th} level in the decision tree removes the pixels that do not have any lidar coverage. This is accomplished by finding any pixels in the topographic lidar images that have a null pixel value and classify these pixels as the "No Lidar" class. Step 5 utilizes the NDVI equation, (1), to separate out the vegetation pixels from the non-vegetation pixels. To indicate a vegetation pixel, the NDVI value greater than 0.30 is used. The non-vegetation pixels are then split by determining the height above ground. The height above ground is calculated by differencing the topographic lidar image from the bare earth image. A threshold of 1.0 m is used to differentiate between structures and non-structures. The structure pixels are then classified as "Low Structures" and "Tall Structures" using a height above ground threshold of 2.5 m. The non-structure pixels are segmented into "Roads" and "Bare Ground" classes by performing a band ratio between the 852 nm and 472 nm bands. This band ratio determines the slope of the spectral signature and any spectra with a slope less than 2.0 is deemed to be part of the "Roads" class. All other non-structure pixels are therefore placed into the "Bare Ground" class. The vegetation pixels are also separated using their height above ground. Currently 3 vegetation height categories are being used but they can be configured differently if specific species identification is desired. The vegetation height classes are short grass (<0.5m), brush, shrubs, short trees (0.5m-6m), and tall trees (>6m). Each of these vegetation height classes are segmented again by comparing a red band (662 nm) to a green band (564 nm). If the green band is greater than or equal to the red band than the pixel is classified as "Green Vegetation" and all others are classified as "Brown Vegetation." Fig. 5 is a graphical representation of the decision tree classification process.

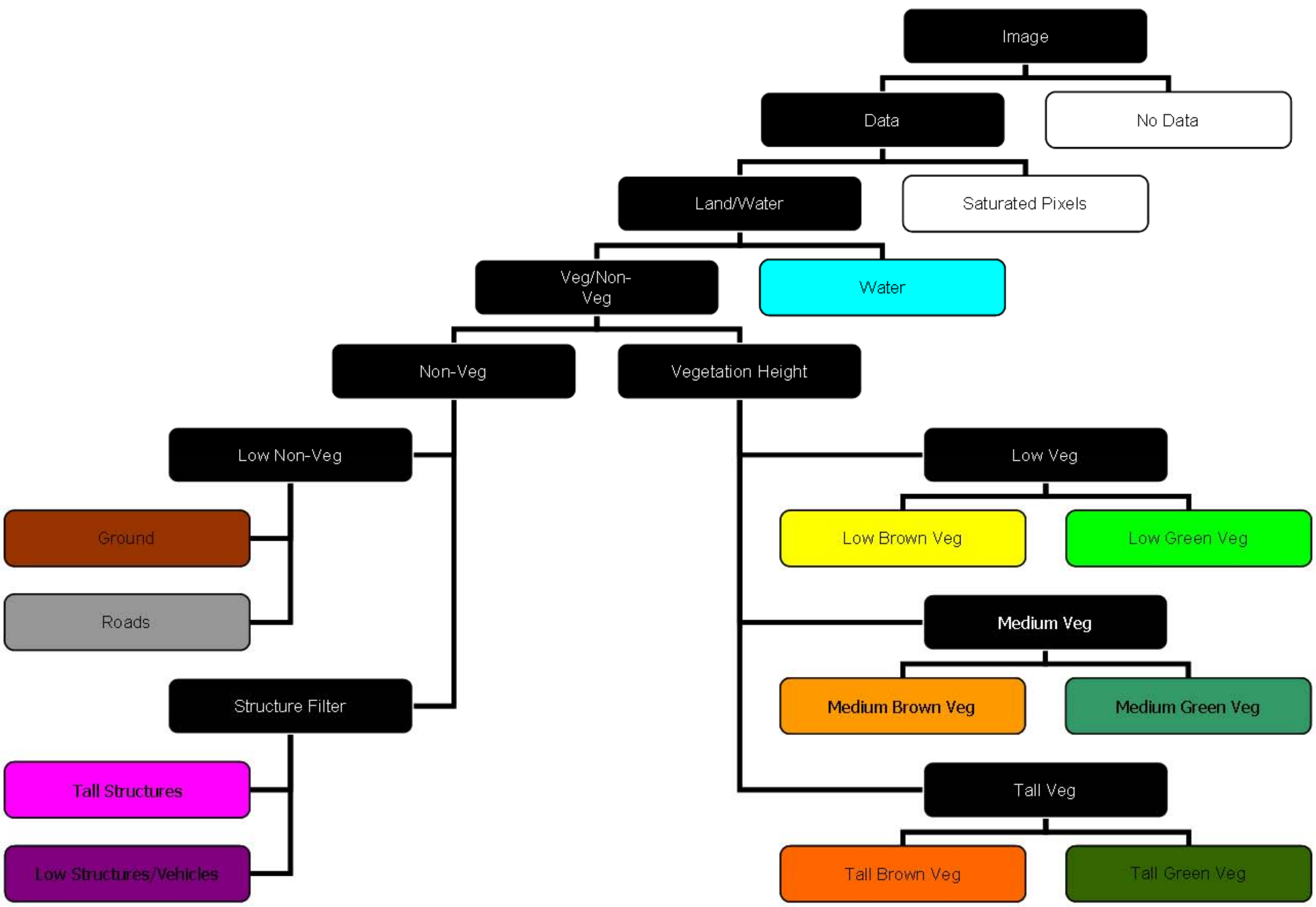

Fig. 5. Graphical representation of the land cover classification decision tree process.

This classification method has recently been put into production at JALBTCX starting with the NCMP collection effort from 2007. Its fast run time and minimal user input make it a reliable and consistent classification tool. An added benefit to this technique is that various lighting conditions with in the same mosaic have no affect on the output classification image. These various lighting conditions can be caused by cloud cover, multi-day collections, and a changing sun angle during the flight. For areas where more specific classifications are needed, these basic land cover classes can be used as mask layers to focus additional algorithms on the needed pixels. This classification routine has been utilized for temporal analysis of the Lake Pontchartrain shoreline after Hurricane Katrina. Using lidar and classification images the physical and environmental changes can be quantified for each individual class [7]. Fig. 6 are graphics of the lidar images (top) with accretion and erosion overlays and the classification images (bottom) for 2005, 2006, and 2007. Future work to evolve this classification is planned by generating land use maps that delineate wetlands, neighborhoods, industrial areas, agricultural areas, and forested areas.

Fig. 6. Temporal data analysis - Top images are lidar elevation images with accretion (green) and erosion (red) overlaid. Bottom images are the land cover classification images for each year.

ACKNOWLEDGMENT

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