RAPID RESPONSE, RECOVERY, MITIGATION AND DAMAGE-ASSESSMENT (R^3 MD) FOR HURRICANES AND NATURAL DISASTERS

Ramesh L. Shrestha[1], Craig Glennie[2], William E. Carter[3], Vipulanandan Cumaraswamy[4], Keh-Han Wang[5] and Kyle Strom[6]
[1]PI NCALM director, Hugh Roy & Lillie Cranz, [2]Co-PI Assistant Professor,
[3]Research Professor and Senior Research Engineer, [4]Professor and Director of CIGMAT & THC-IT,
[5]Professor, [6]Assistant Professor
3605 Cullen Blvd, Room 2011, Houston, TX – 77204 – 5059;
Phone: 832-842-8882; Fax: 713 743 0186; email: rlshrestha@uh.edu

ABSTRACT
The capacity to understand, prepare for, adapt to, and one day predict natural hazards such as Hurricanes in the Gulf Coast region will require integrated research, education, and long term data collection and analysis programs to amass the necessary information and build the critical analytical skills. Texas legislature took a major step forward by approving and creating Texas Hurricane Center (THC) at University of Houston (UH) few years ago to address rapid response, recovery, mitigation and damage assessment caused by Hurricanes and natural disasters. It has provided a step forward to attract talented researchers to the UH to stimulate research focused on coastal dynamics, and develop workable interfaces between the academic community and the governmental agencies charged with preparing for and responding to natural disasters on local, state, and regional levels.

INTRODUCTION
During 1980 - 2009, hurricanes and tropical storms caused the deaths of 2,601 and more than 367 billion dollars in property damage in the US, including 200 billion dollars in Texas and Louisiana alone. Damage to the Nation's oil production and processing facilities, heavily concentrated along the hurricane prone Gulf coastline has immediate economic repercussions across the nation, and severe damage to the refineries could rapidly degrade the nation's defense capabilities.

In order to fully understand the science and hazards associated with the regional coastal dynamics inflicted by hurricanes and other associated events, high-resolution topographic and hydrographic data are critical. In collaboration with the NSF National Center for Airborne Laser Mapping (NCALM), the Texas Hurricane Center at UH proposes to utilize its unique suite of airborne sensors, i.e. full waveform NIR and Green airborne bathymetry LiDAR, CASI 1500 hyperspectral imager, and 60Mp DIMAC aerial camera, having a combined value of more than $2.5 million, to collect time series geospatial data sets every year for the entire Texas Coast to monitor coastal environment and ecological systems due to Hurricanes and storm events. In the event that the Texas coast is struck by a hurricane, the affected area should be re-mapped as soon as it is safe to fly, to facilitate rapid response, recovery, mitigation and damage-assessment. These topographic and bathymetric measurements that permit large scale documentation of the coastal zone at centimeter levels (Shrestha et al., 1999), should be augmented by satellite radar altimeter, and Interferometric Synthetic Aperture Radar (InSAR) to measure water level changes, and SAR to classify inundated areas in the coastal wetlands and estuaries.

The vast majority of hurricane studies is conducted by federal agencies (NOAA, USG, NIST and US Navy). The National Science Foundation (NSF), the largest funding source for academic research, provided only $7 million dollars (11%) for hurricane research and $57 million (89%) for earthquake annually (NSF Board, 2007), although the damages by these two catastrophic events tells just the opposite story. We believe that this is due to the fact that the Hurricane community has yet to make its case to advance an agenda for Hurricane research. This is quite evident by the fact that almost every major university in the nation has academic research and education program in earthquake, but there is not a single university that offers a comprehensive education and research program in Hurricanes.

HURRICANE THREAT TO HOUSTON AND TEXAS

Densely populated areas, such as Houston, TX, the 4th largest city in the nation, the energy capital of the world, with the largest petrochemical industry, largest medical center in the world, and the second busiest port in the nation will continue to be impacted by hurricanes and flooding from storm surge and heavy rains. Many believe that a slight change in direction of hurricane Ike's landfall over Galveston Island, Texas in September 13, 2008 would have resulted in the loss of thousands of lives and a catastrophic economic damage to the region. History suggests that a hurricane such as the one in 1900, which killed over 8,000 people in Texas, would be capable today of far greater damage and loss of life if it were to directly strike Houston. It is not when a major hurricane is going to strike Houston and its surrounding areas, but what kind of damage and death a major storm is going to inflict when it comes. Texas must be prepared with the best available tools and resources to minimize the unthinkable outcome.

The potential for massive property damage and loss of life each hurricane season makes it imperative that aggressive efforts be taken to mitigate the impact of hurricanes on human life, property, and the natural environment. There is a lack of consolidated effort, particularly in the academic community, to advance hurricane research effort, and the Texas Hurricane Center at UH is poised to play that role by filling the void in Hurricane research by establishing a world-class research center, facilities and education program.

UNIQUE INFRASTRUCTURE AT UH FIR HURRICANE RESEARCH

NSF National Center for Airborne Laser Mapping (NCALM) — NCALM, funded by the National Science Foundation (NSF), and a joint collaboration between University of Houston (UH) and the University of California (UC), Berkeley, provides research quality airborne laser mapping and imaging data for the scientific community (Shrestha et al., 1999; Slatton et al., 2007). In January 2010, NCALM relocated to UH with significant support to purchase additional airborne and terrestrial topographic/hydrographic sensors, as well as to hire 7 new faculty members in three departments (Civil & Environmental Engineering, Electrical & Computer Engineering, and Earth and Atmospheric Sciences) to develop a multi-disciplinary graduate research program in Geosensing Systems Engineering (GSE). UH is investing millions of dollars to secure the next generation hardware and software required to advance the frontiers of geosensing for geosciences, hydrographic sciences, ecology and coastal mapping.

UH owns and operates a multitude of remote sensing equipment and has the expertise that is unrivaled for collection of a dataset of unprecedented accuracy and spatial resolution for advanced characterization of the near shore and littoral zones of the Texas coast. The centerpiece of the UH program is a twin-engine Cessna 337 airplane, instrumented with a suite of state-of-the-art sensors having a total value of over 2.5 million dollars, including:

1. Optech GEMINI 167 kHz full waveform Near IR Topographic LiDAR,
2. Optech Aquarius Airborne Bathymetry LiDAR,
3. Itres CASI-1500 Airborne Hyperspectral Imager, and
4. Digital Aerial Camera (DiMAC 60 Mega-pixel).

Collectively, this imaging system is referred to as the airborne Geodetic Mapping Systems (GeMS, Figure 1). At present, this is the only such system owned and operated by an academic institution anywhere in the world. Airborne GeMS makes it possible to map hundreds of square kilometers of coastal area in a few hours, providing 3D points with sub-meter scale and sub decimeter level vertical accuracy, to scientific researchers and the public (Shrestha et al., 1999; Carter et al., 2007).

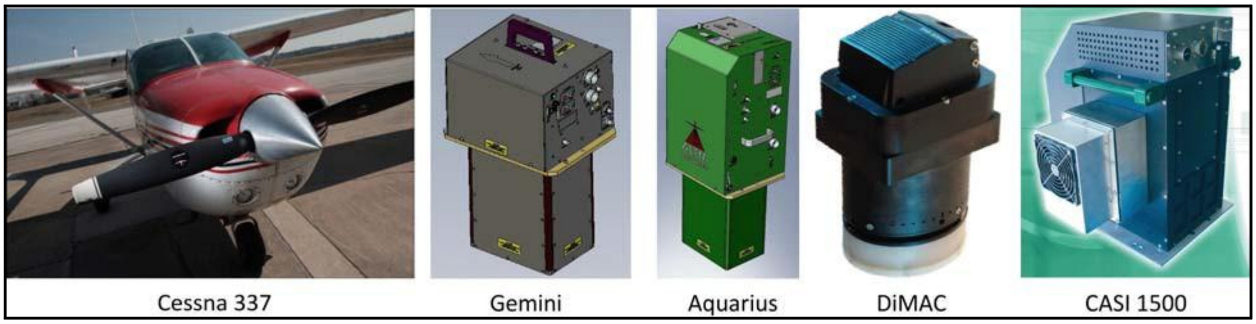

Figure 1. Geodetic Mapping Systems (GeMS): (1) Cessna 337 Twin Engine Aircraft, (2) 167 kHz GEMINI LiDAR: 4 stops and intensity, vertical accuracy 4 - 7 cm, point density 6 - 20 per sq. meter, (3) 70 kHz Green Laser sensor head for bathymetry: vertical accuracy 5 - 10 cm, point density 5 - 10 per sq. meter, (4) 60 mega-pixel Forward Motion Compensation (FMC) DiMAC Aerial Camera: Pixel resolution 6 - 8 cm, (5) 288 bands CASI 1500 Hyperspectral Spectrometer: pixel resolution 30 cm to 1 m (Total UH investment: $2.5 million).

Multi-Disciplinary Graduate Research Program - University of Houston has taken an aggressive role to fill the void in Hurricane research. It has already invested millions of dollars to provide base support and create a multi-disciplinary graduate research program in Geosensing Systems Engineering (GSE). As mentioned before, one of UH's major accomplishment has been to bring the NSF National Center for Airborne Laser Mapping (NCALM) to UH in 2010. From the two original 2 faculty members in 2010, GSE program has already grown to 5 faculty members and we plan to hire additional 2 by Summer 2012. Two new graduate degree programs, i.e. MS and Ph.D. in GSE and Sciences have been developed and proposed to UH. Anticipated approval of both degrees by the State is Fall 2012.

GEO-SPATIAL OBSERSATION FOR HURRICANES

Time Series Geo-spatial Data for the Texas Coast — Observational data are the foundation for any research and/or application to provide vital information before, during, and after hurricane impact (Maidment et al., 2007). We propose to collect high resolution data for the entire Texas coast annually prior to the start of hurricane season using GeMS to monitor the coastal dynamics covering an approximate area of 3,250 square kilometers (see Table 1 for breakdown). The approximate proposed arae to be mapped is shown in Figure 2. In an event of a hurricane, the GeMS system will be deployed immediately to re-map the hurricane affected area. All data will be made available to the public immediately which will provide much needed data sets for the behavior of natural processes such as, storm surge, flooding, coastal erosion, environmental damage assessment, emergency management, and evacuation.

Table 1. Summary of Geodetic Imaging of the Texas Coast

Annual Mapping	**NIR LiDAR +**	**Bathymetry**	**Hyperspectral**	**Total**
Area (km^2)	2,600	650	3,250	3,250
Number of Mapping Days	30	15	15	60
Instrument On Time (IOT, hrs)	89	28	49	166
Total Flying Time (hrs)	208	43	49	300
Number of Points (Billion)	40	5	N/A	45
XYZ & Intensity Points/sq. km.	10	8	N/A	
Points/(1 m x 1 m) area	10	8	N/A	
Vertical Accuracy (cm)	5 - 8	5 - 8	N/A	
Horizontal Accuracy (cm)	20	20	100	

The topographic LiDAR data acquisition is normally optimal during the winter and early spring months when the vegetation biomass is low as this improves the probability of detecting the true "bare earth" ground surface under a vegetative cover. In general, the turbidity of the near shore water in the Gulf of Mexico is also lowest during the early springtime (Shideler, 1978), which is optimal for bathymetric LiDAR collection. Given these constraints, the LiDAR (topography and bathymetry), aerial pahotography, and hyperspectral acquisition will be carried out in the first quarter of each year. Table 1 shows the anticipated annual data acquisition summary.

GEMINI Near IR Topographic LiDAR — The GEMINI LiDAR system is a near infra-red (NIR) sensor which provides up to 4 discrete returns stops for each laser pulse up to as many as 167,000 pulses per second (pps), and simultaneously digitized waveforms for as many as 125,000 pps. The discrete and waveform data contain complementary information regarding the density and distribution of vegetation and the 'bare earth' terrain such as the ones shown in Figure 3. The discrete returns (up to a maximum of 4, the first three and last, from each shot) are based on automatic registration of return pulses using a constant fraction discriminator within the sensor electronics. Discrete events are recorded only when the signal passes from a low level across a threshold level, and generally record the time when the pulse reaches half its peak value. As a result, return signals that have complex waveforms caused by closely spaced object surfaces are recorded as single events. In contrast, the wave-form digitizer records a discrete 1 GHz sample of the entire backscattered laser energy which allows post mission analysis of complex waveforms. This post-mission analysis often allows the improved detection of the terrain surface under low lying vegetation, such as that typically found in coastal areas.

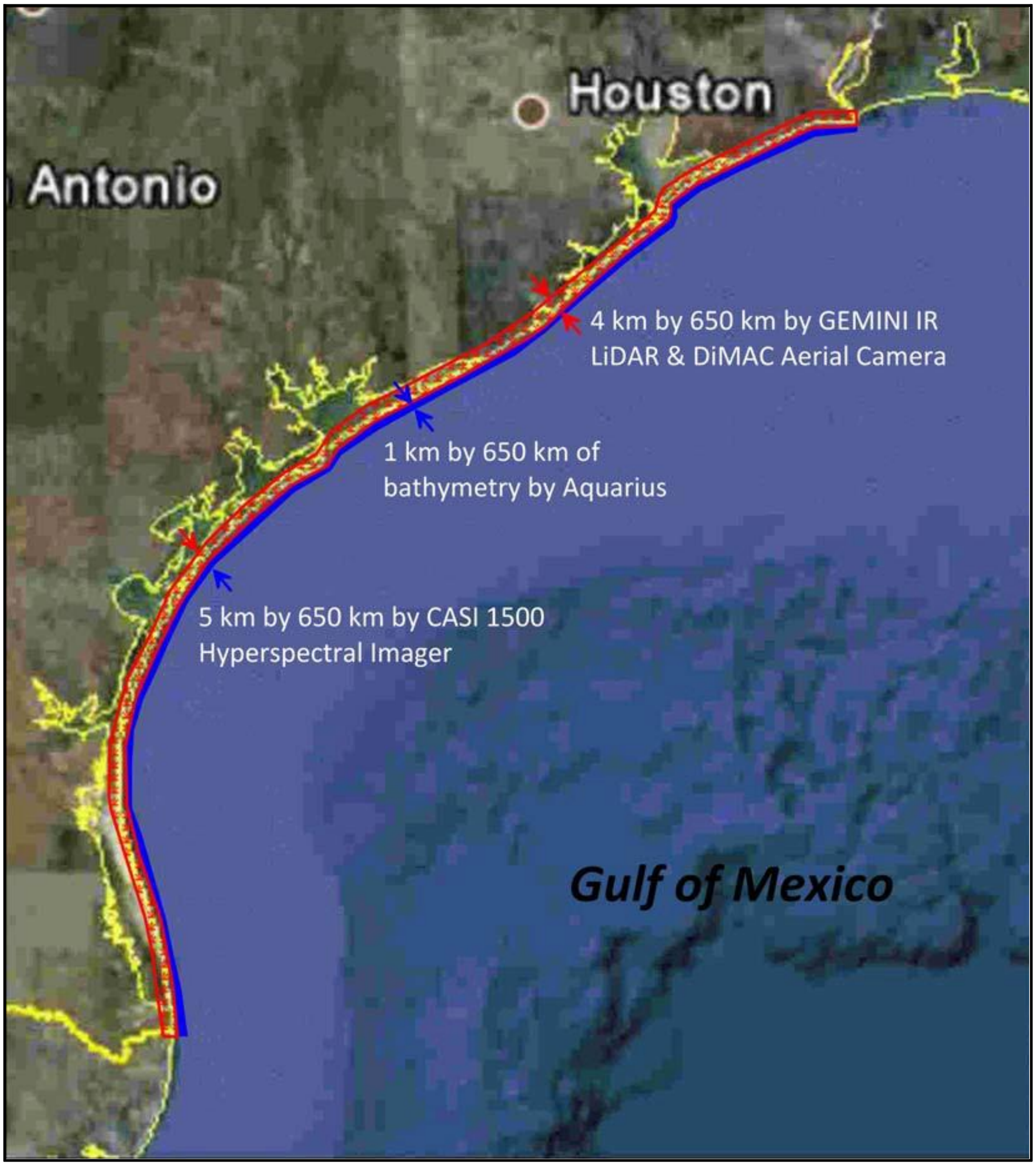

Figure 2. Approximate Data Collection Boundaries

Aquarius Bathymetric LiDAR — While the Gemini Laser will provide a detailed topographic survey of the near shore environments, the near IR laser does not penetrate water. As a result, an additional survey technology will be required for proper mapping and modeling of the littoral zones. The Aquarius Bathymetric LiDAR is a green (532 nm wave length) sensor which provides high rate laser measurements over water and mixed water/topographic surfaces with a measurement rate of 70 kHz. The green laser allows the sensor to penetrate water up to 10 meters in depth, depending upon the turbidity of the water surveyed. Thus, the use of the Gemini and Aquarius sensors in parallel will provide seamless coverage of the onshore and littoral zones for bare earth and benthic layer determination as illustrated in Figure 4. The return energy from the Green LiDAR system is digitized using a 1 GHz waveform digitizing sampler, also manufactured by Optech. The digitized waveform will give the researchers access to a full sampled profile of the return energy spectrum from the surface, water column and benthic zone. A typical return waveform from a bathymetric system is given in Figure 5.

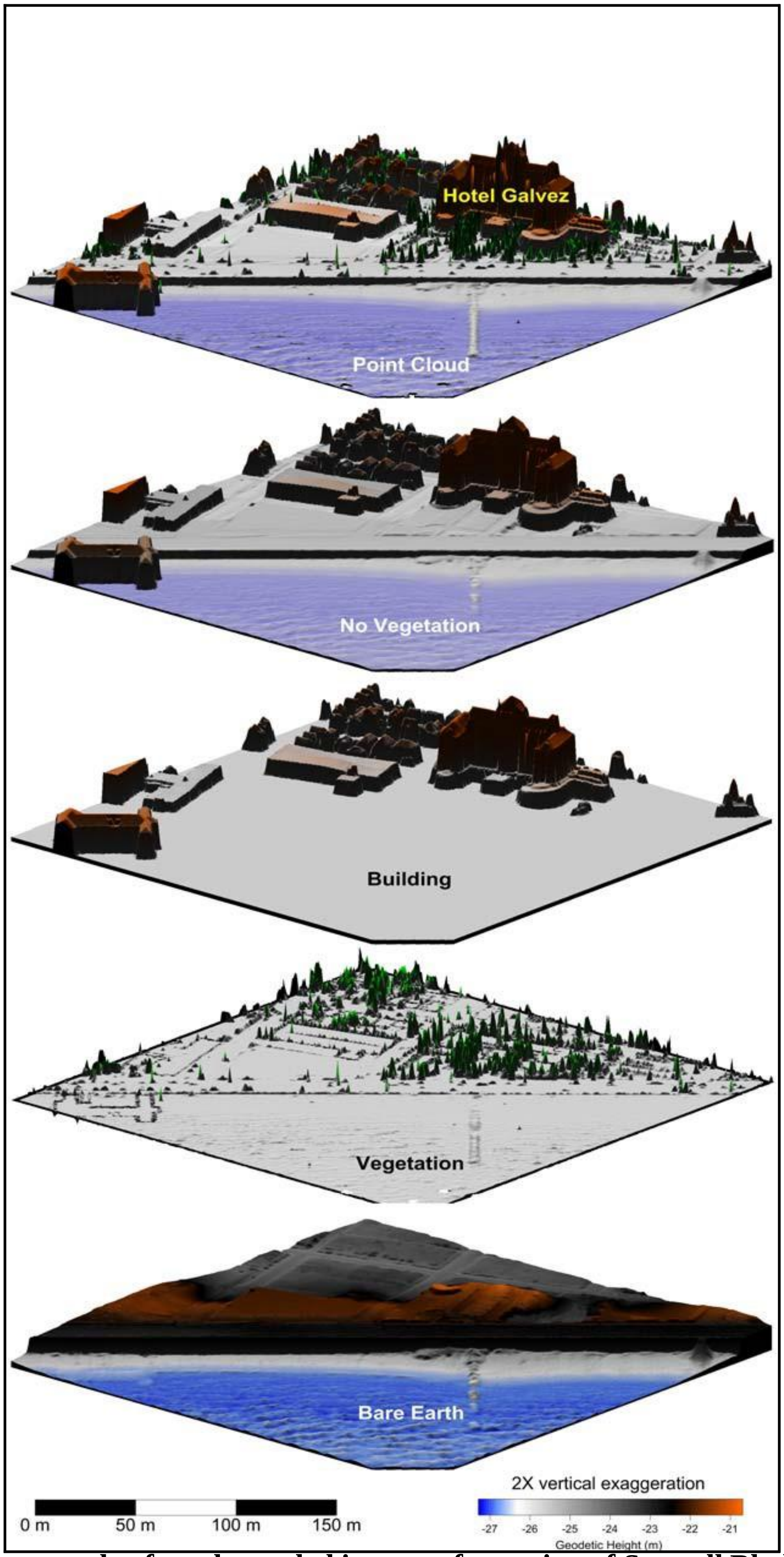

Figure 3. An example of a color coded images of a section of Seawall Blvd. in Galveston, TX mapped by GEMINI LiDAR on March 5, 2010 showing a variety of geo-spatial 3D data products.

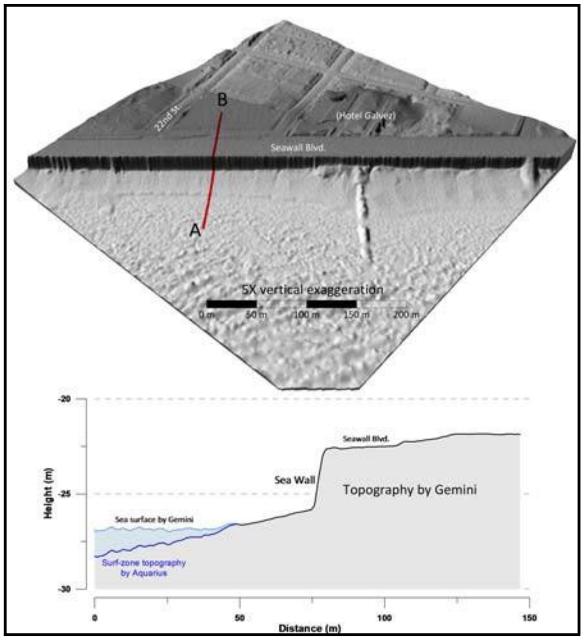

Figure 4. A gray scale image of 1m x 1m Digital Elevation Model (DEM) from bare earth irregular XYZ points (Digital Terrain Model - DTM) produced by LiDAR data (top) and characterization of topography and sea surface structures by a profile (bottom).

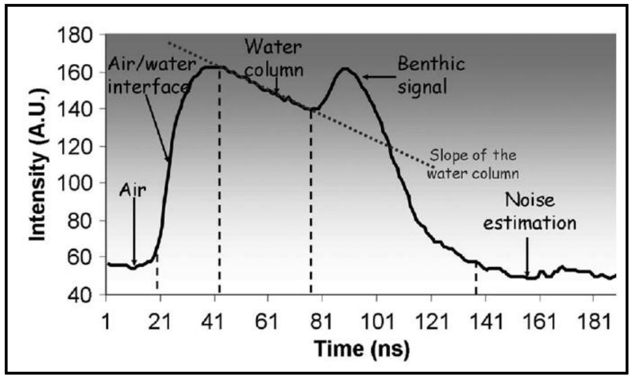

Figure 5. Sample of a Typical Raw Bathymetric LiDAR Return Waveform (Collin et. al., 2008)

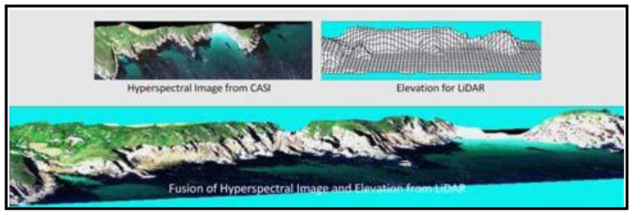

Figure 6. Elevation information from LiDAR fused with hyperspectral images from CASI (*Source:* ITRES).

CASI-1500 Hyperspectral Imager — Hyperspectral imaging collects and processes information from across the electromagnetic spectrum unlike three bands (RGB) by a digital aerial camera. Unlike the human eye, which only sees visible light, hyperspectral imaging can see visible light as well as the ultraviolet to infrared. Therefore this technology is capable of detecting vegetation species, monitoring the health of crops, mineral and oil exploration to surveillance. The ability of hyperspectral imaging to identify various minerals makes it ideal for the mining and oil industries, where it can be used to look for ore and oil it has now spread into fields as widespread as ecology and environmental mapping. Hyperspectral sensing of the coastal zone is commonly used to estimate estuarine and coastal water quality and map sediment and seabed type (Bachmann et al, 2008). Optical properties, substrate reflectance spectra, and water quality parameters, including suspended solids, chlorophyll concentration, and colored dissolved organic matter can be obtained via numerical radiative transfer modeling (Mobley et al., 2004).

UH NCALM owns and operates a CASI-1500 hyperspectral sensor which is manufactured by Itres. The CASI-1500 has a spectral resolution of 2.4nm in up to 288 channels with light wavelength coverage from 375nm to 1050nm. The system can provide ground pixel resolutions from 30 cm to 1 m based on the number of bands acquired and flying height of the instrument. Figure 6 gives an example hyperspectral image, and its fusion with a LiDAR elevation model for precise coast characterization. Figure 7 sows the fusion of hyperspectral images with NCALM LiDAR data over Wax Lake Delta, Louisiana. Lidar data was collected in 2008.

DiMAC Aerial Camera — UH NCALM DiMAC is a medium format digital aerial camera for vertical aerial image acquisition. The DiMAC combines best-in-class Bayer-filter CCD (8984 x 6732 effective pixels), with a forward motion compensation actuator, and a nominal 70 mm lens. The camera acquires 48 bit raw frames (16 bits per channel), for a large radiometric range. At a flight height of 1000 m above ground level (AGL), the DiMAC camera is capable of collecting imagery with a ground sample distance (GSD) per pixel of less than 10 cm (Figure 8).

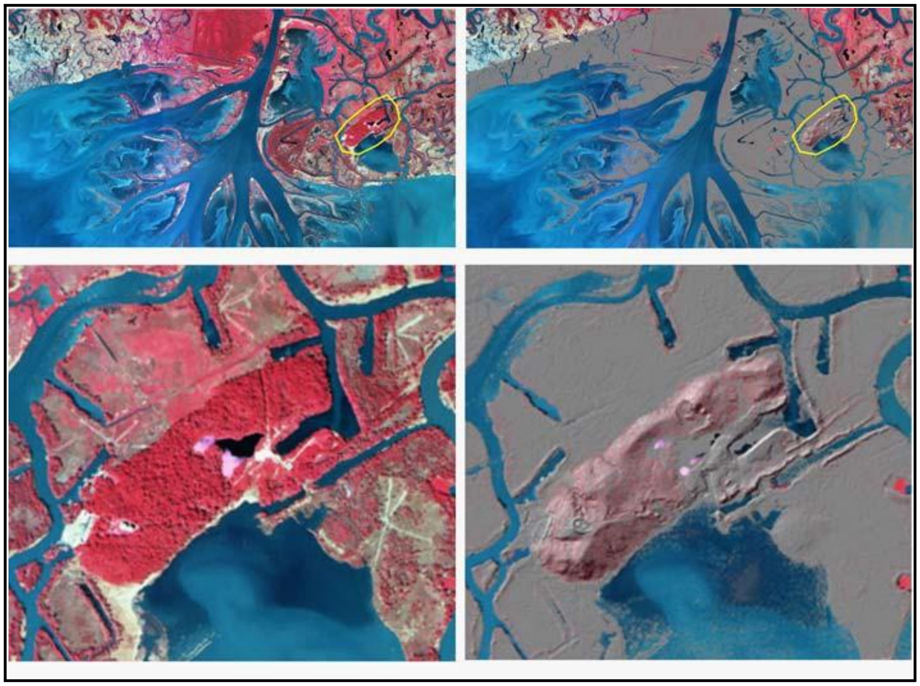

Figure 7. NCALM LiDAR in Wax Lake delta, Louisiana. (top left) 1-meter aerial imagery collected by US Department of Agriculture (USDA), (top right) overlay of NCALM LiDAR on the imagery. LiDAR was collected in January 14-15, 2008 showing detail topography and elevation (in grey), (lower-left) a small portion of delta in aerial image, and (lower -right) bare earth clearly visible in LiDAR. LSU ecology researchers have used the LiDAR data to generate a synoptic relationship between plant type and density and island elevation from NCALM LiDAR - work that before the LiDAR was carried out along a limited number of transects rather than across the entire delta surface. The groups at UT, UIUC (U of Illinois, Urbana-Champaign) and UM are using the topography to guide the development of sedimentation models for the delta (D. Mohrig, UT Austin, *"personal communication"*).

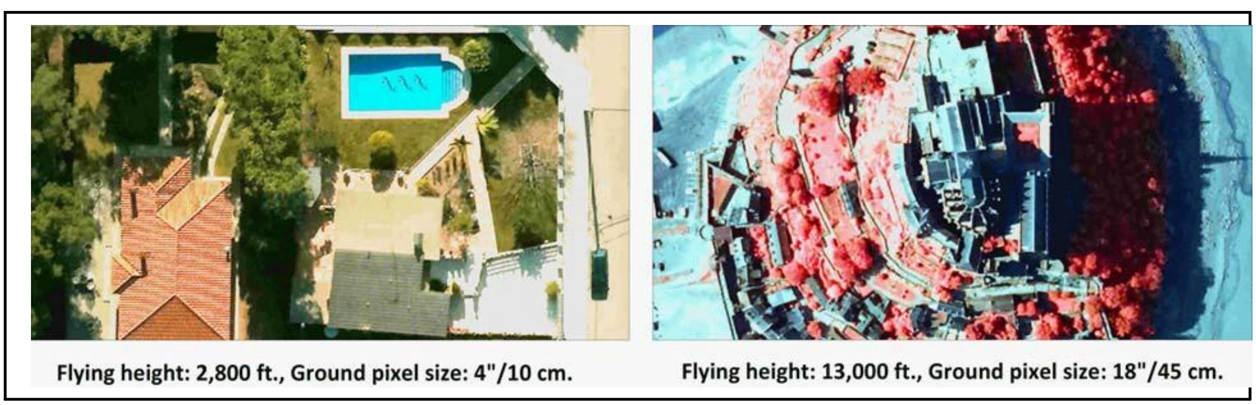

Figure 8. High-resolution digital image from DiMAC digital aerial camera using 80 mm lens. Simultaneous data collection by LiDAR and DiMAC produces ortho-rectified digital images such as sown in the figure for the entire Texas coast instead of snap shot of pictures at random spots. Ortho-rectified images can easily be imported into a GIS (*Source:* Optech)

POST DISASTER DATA ACQUISITION RESPONSE

In the unlikely event of a significant disaster occurring in the Gulf of Mexico, UH/NCALM will also be in "stand-by" mode during a disaster event and will deploy its airborne GeMS and any other necessary resources to map the disaster affected area in Texas during and after an event. Again, in the event of a disaster, the GeMS geo-spatial will be made available in near-real time to the public and scientific community.

INTEGRATED OCEAN AND COASTAL MAPPING CENTER

We will coordinate with State, local municipalities and industry to submit a proposal to NOAA for additional support under the H.R. 146, "*Omnibus Public Land Management Act of 2009''* which has appropriated approximately $15 million dollars per year until 2015. The H.R. 146 mandates to create three centers— Integrated Ocean and Coastal Mapping (IOCM) Centers which will serve as hydrographic centers of excellence to conduct:

(1) research and development of innovative ocean and coastal mapping technologies, equipment, and data products;
(2) mapping of the United States Outer Continental Shelf and other regions; (3) data processing for nontraditional data and uses;
(4) advancing the use of remote sensing technologies, for related issues, including mapping and assessment of essential fish habitat and of coral resources, ocean observations, and ocean exploration.

First center has already been created at University of New Hampshire. University of Houston is ideally suited and located for one of the two remaining centers. In addition to the above mandated scopes, this will have following additional scopes:

(1) Real-time Wind and Meteorological Sensors Instrumentation,
(2) Data Archive and Distribution System,
(3) Computational Cluster,
(4) Graduate Education Training, and
(5) Hurricane Research Lab.

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