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# Research-quality LiDAR and High-resolution Topographic and Bathymetric Observations in Support of COCONet

## A WHITE PAPER

Submitted to:
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## 1. SUMMARY

The serious threats posed to the large population of the Caribbean nations by seismic events, hurricanes, volcanic eruptions, and sea-level change require development of predictive models which mandates the collection of high-resolution topographic mapping of the landscape. The capacity to understand, prepare for, adapt to, and in some cases predict these natural hazards requires not only Earth observations but also high-resolution representation of the earth surface on both large and small scales. Development of a large scale geodetic infrastructure in the Caribbean by COCOnet is expected to form the backbone for a broad range of geoscience investigations similar to those in the western United States associated with EarthScope and Plate Boundary Observatory(PBO).

In order to fully understand the science and hazards associated with the regional crustal dynamics, hurricanes, volcanos, and sea-level change due to climate change, acquisition of high-resolution topographic data is central. High-resolution topographic measurements derived from airborne sensors such as LiDAR (topographic and bathymetric), digital cameras, hyperspectral spectrometers, and Interferrometric synthetic aperture radar (IFSAR) permit large scale documentation of the earth's surface at centimeter levels (Merritts, et al., 2009; Prentice, et al., 2009; Carter, et al., 2007). Therefore COCONet's research and operation plans should include the collection of high-resolution data over the Caribbean, and open consultation with the scientific and other stakeholders to: define optimal target areas; do careful mission planning accounting for logistical and data requirements; collect GPS observations efficiently and with immediate access; assess data quality; and deliver the data and derived products to scientists, engineers, and educators. In collaboration with COCONet and UNAVCO, the NSF National Center for Airborne Laser mapping (NCALM) is uniquely qualified and ideally located to collect, process, and deliver research quality high-resolution topographic and bathymetric data for an end-to-end solution (Slatton, et al., 2007; Mader, 1992)

The data will have a range of applications. They will provide a broad, high-resolution and high-accuracy baseline data set for monitoring future geomorphic and hazard related changes. The data will also be widely useable by emergency managers and land use planners. The data will show the critical zone from the ground to the top of the built environment and vegetative canopy, providing a synoptic and highly detailed depiction of the association of infrastructure with the geometry of the earth's surface and vegetation.

2. NSF NATIONAL CENTER FOR AIRBORNE LASER MAPPING

**2.1 Resources and Expertise:** The NSF National Center for Airborne Laser Mapping (NCALM), 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. In January 2010, NCALM relocated to University of Houston (UH) with significant support to purchase additional airborne 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 graduate research program in Geosensing Systems Engineering (GSE). A 60 MP aerial camera, and a 288 band airborne hyperspectral spectrometer have been ordered. Three of the new faculty have already been hired and the remaining 4, are expected to be in place by Fall 2011. Work has begun to create a multi-disciplinary graduate research program at UH that is expected to provide new research opportunities to scientists and engineers. UH is investing millions of dollars to secure the next generation hardware and software required to advance the frontiers of geosensing for geoscience.

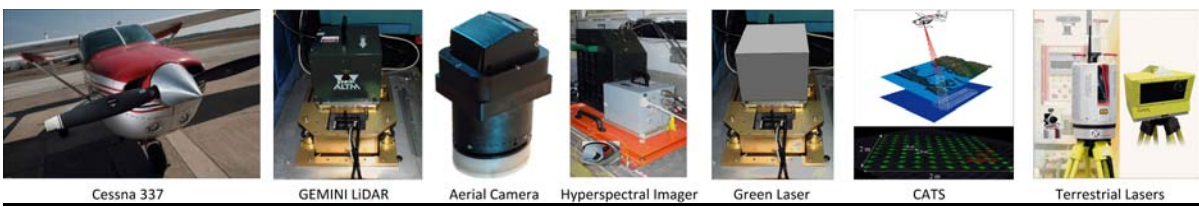


**Figure 1. Geodetic Mapping Systems (GeMS)**, NSF National Center for Airborne Laser Mapping (NCALM), University of Houston: (1) Cessna 337 Twin Engine Aircraft, (2) 167 kHz GEMINI LiDAR: ***4 stops and intensity, vertical accuracy 4 - 7 cm, point density 6 - 20 per sq. meter,*** (3) 60 mega-pixel Forward Motion Compensation (FMC) DiMAC Aerial Camera***: Pixel resolution 6 - 8 cm***, (4) 288 bands CASI 1500 Hyperspectral Spectrometer***: pixel resolution 30 cm to 1 m,*** (4) 70 kHz Green Laser sensor head for bathymetry: ***vertical accuracy 5 - 10 cm, point density 5 - 10 per sq. meter,*** (5) Coastal Area Tactical-mapping System for ***bathymetry and topography*** (800 kHz equivalent), and (6) Terrestrial Laser Scanners (TLS).

NCALM researchers at UH are uniquely qualified and ideally located in the Gulf Coast geographic region, and as the NSF's National Center for Airborne Laser Mapping operational center, have a unique and powerful suit of sensors (Figure 1) that could be deployed to fully document the natural and engineered features in the Caribbean region, before and immediately after a hurricane or any other significant natural hazard events. With time, a comprehensive data base would be accumulated for the region that would enable academic, state, federal agencies, and the scientific community to best prepare and respond to the inevitable occurrence of disasters in the Caribbean. Hurricanes and hazard are generally multi-state regional events that ultimately affect the welfare of the region as a whole, and therefore efforts to minimize their impacts should be initiated and appropriately supported.

The current UH-NCALM suite of airborne sensors (Gemini 167 kHz IR LiDAR, 60 mega pixel aerial camera, 288 bands hyperspectral spectrometer, green bathymetric LiDAR), augmented by the second generation CATS unit will provide the means to detect, classify, and identify surficial details as well as chemical and biological agents in all types of environments, while conducting vulnerability and threat prevention analysis missions at sea and on land.

The LiDAR system owned and operated by US academic universities was purchased by NCALM researchers in 1998 when they were at the University of Florida (UF). After two attempts, NCALM funded by NSF was established in 2003 to provide research quality LiDAR data for projects funded by NSF through peer review. During the past seven years NCALM upgraded the original LiDAR unit a number of times, before replacing it completely with a next generation system. In 2010 the next generation unit was upgraded to include full waveform recording, and a green sensor head was ordered, which will enable mapping topography (streams, lakes, coastal areas) covered by shallow (<10 meter deep) water beginning in 2011.

**2.2 NCALM Experience:** NCALM has collaborated with over 30 university PIs in over 100 projects to provide research quality LiDAR data. With the new additional sensors as mentioned in GeMS, we expect a significant growth in the use of NCALM resources by many scientific communities and organizations, including UNAVCO.

**2.2.1 Observations for Plate Boundary Observatory:** In 2008, NCALM collaborated with UNAVCO in the collection of 5,788km$^2$ of high-resolution airborne LiDAR data during four major campaigns (Figure 3 and Table 1) as a part of the EarthScope Facility construction project funded by the National Science Foundation, and executed as a part of Plate Boundary Observatory (PBO). A high-resolution LiDAR data set capable of supporting a wide range of interests and applications was collected by NCALM. Particular care was taken to ensure the highest data quality possible data within scope and budget, with special considerations given to effective ground point density and geodetic control (Phillips, et al., 2008).


**Figure 3.** GeoEarthScope data coverage. Research-quality data were collected along major active faults of the western US (including a portion of the Denali Fault in Alaska not shown here). Tens of thousands of 1 km$^2$ tiles of bare earth and unfiltered DEMs have been downloaded from OpenTopography by over 1,000 users with unique IP addresses.

**Table 1.** GeoEarthScope Lidar Data Collection by NCALM

| **Project Region** | **Major Targets** | **Coverage Area** | **Acquisition Dates** |
|---|---|---|---|
| Death Valley - Fish Lake Valley | Death Valley - Fish Lake Valley fault | 420 km$^2$ | Nov. 2006, Oct. 2007 |
| Northern California | San Andreas, Hayward, Calaveras, Maacama, Green Valley, Little Salmon faults, Shelter Cove Swath | 1,970 km$^2$ (Including targets funded by USGS and other partners) | Mar. - Apr. 2007 |
| Southern/Eastern California | Garlock, Elsinore, Panamint Valley, Ash Hill, Owens Valley, San Cayetano, Calico, Lenwood, Blackwater, Helendale, San Andreas faults | 1,995 km$^2$ | Apr. 2008 |
| Pacific Northwest | Yakima fold and thrust belt | 290 km$^2$ | Apr. 2008 |
| Yellowstone/Intermountain Seismic Belt | Yellowstone, Teton fault, Wasatch (Nephi) fault | 696 km$^2$ | Jul. 2008 |
| Alaska | Denali, Totchunda faults | 427 km$^2$ | Jul. - Aug. 2008 |
| | **Total** | **5,788 km$^2$** | |

**2.2.2 Observations for Archeology:** The scientific applications of LiDAR observations have now spread well beyond the earth sciences (Perron, et al., 2008; Dietrich and Perron, 2006) and include, for example, archaeology (Chase, et al., 2011). A paper entitled "Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize," *The Journal of Archaeological Science, (JAS), 38 (2011), pp. 387-398*, reports the remarkable results obtained from LiDAR mapping in an area covered with a rain forest. After 25 years of ground surveying and on-foot exploration of the area archaeologists were amazed by the detail of the bare-earth DEM derived from the LiDAR observations. The LiDAR observations, collected in just 5 days, revealed extensive areas of structures, causeways, and terraces with relief as low as 5 to 30 cm—many previously unknown. Based on the results of the Caracol mapping, the authors of the JAS paper conclude that LiDAR will ultimately replace traditional ground-surveying for archaeological mapping in areas covered with tropical rainforests, because of its ability to cover large areas in short periods of time and at relatively low cost (Figure 2).

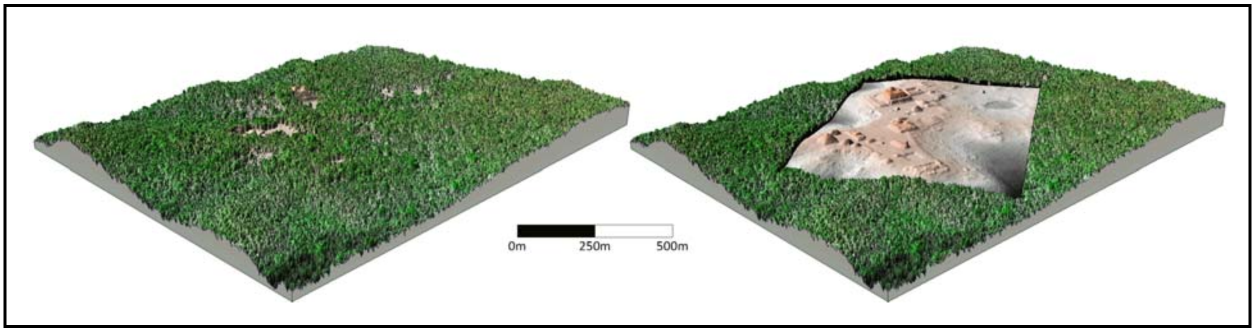


**Figure 2.** The left image is a false color image of the first laser returns, which are mostly from the upper surfaces of the tropical rain forest that covers the site and surrounding terrain of the ancient Maya settlement of Caracol, Belize. The right image is a composite false color image of the rain forest and a shaded relief image of the "bare earth" in the area of the settlement obtained by filtering the laser returns to remove those classified as returns from the vegetation. The remains of many buildings are obvious in the bare earth portion of the image, and careful inspection of the terrain in the central portion of the image reveals agricultural terracing, some of which are only 5 to 30 cm high.

The impact of the success of the Caracol, Belize, LiDAR project is yet to be fully known. A reporter for the *New York Times* newspaper was impressed enough to write an article reporting the success (http://www.fullissue.com/index.php/mapping-ancient-civilization-in-a-matter-of-days.html). And that Times article led one reader to seek out and read the JAS paper, then contact NCALM to discuss the possibility of a collaborative effort to locate a "lost city" in Honduras. Previous efforts to find the city using airborne radar and a ground-party resulted in a television documentary some fifteen years ago, but failed to locate the lost city. Discussions, planning, and a search for funding were initiated in December 2010. The Honduras project may or may not become reality, but the very fact that it is being seriously explored testifies to the remarkable success of NCALM.

**2.2.3 Observations for National Ecological Observatory Network:** NCALM has collaborated by collecting discrete and full waveform LiDAR data for the National Ecological Observatory Network (NEON) as part of NEON's pathfinder airborne flight campaign to begin the development of its prototype field and airborne measurement techniques and the associated data processing algorithms in preparation for the construction of the observatory. NEON, funded by NSF, is a continental-scale research platform for discovering, understanding and forecasting the impacts of climate change, land- use change, and invasive species on ecology. NEON is designed to produce continental-scale estimates of ecological states and processes by linking site-based to geospatial information via next-generation models and analyses. The program is designed around a scaling or extrapolation strategy designed to infer processes at organismal scales and analyze their consequences at regional and larger scales. Airborne remote sensing plays a critical role in the scaling strategy of the Observatory by making measurements at the scale (1-3 meters) of individual shrubs and larger plants over hundreds of square kilometers.

**2.2.4 Observations for Critical Zone Observatory:** NCALM's contributions to NSF science community continues to grow. NCALM has collected more than 90% of the LiDAR data for all six Critical Zone Observatories (CZO) containing high-resolution discrete and limited waveform LiDAR data (Table 2). An example of a small data sets in Jemez River Basin, NM is shown in Figure 3.

**Table 2.** CZO LiDAR Observations by NCALM.

| **Study Area** | **Collections** | **Total Area ($km^2$)** |
|---|---|---|
| Boulder Creek, CO | Snow on & off | 866.3 |
| Southern Sierra, CA | Snow on & off | 121.8 |
| Susquehanna Shale Hills, PA | Leaf on & off | 339.6 |
| Jemez River Basin, NM | Snow on & off | 492.7 |
| Cristina River Basin, PA | Leaf on & off | 242.8 |
| Luquillo, Puerto Rico | Leaf on | 217.1 |
| | Total | 2,280.3 |

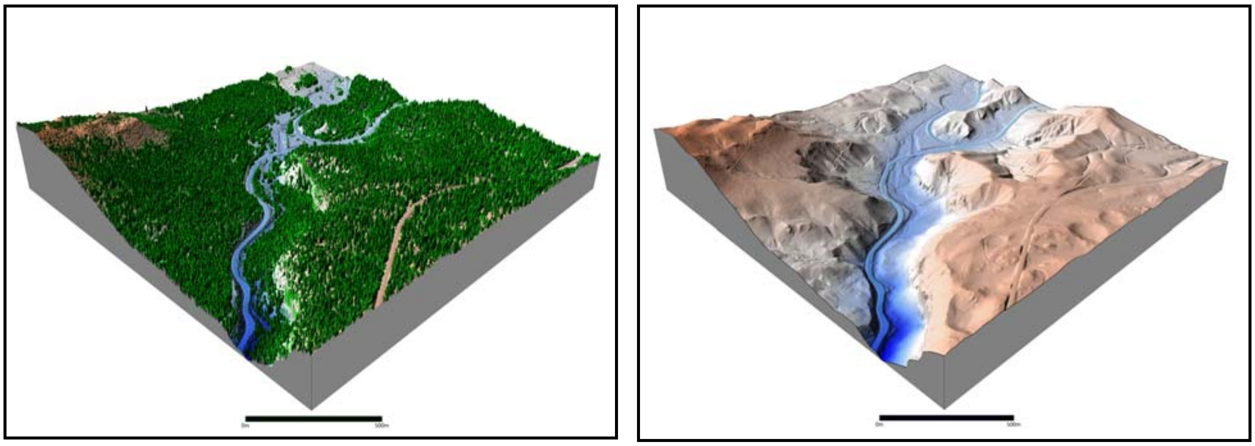

**Figure 3.** False color images of LiDAR observations for CZO of a small section of Jemez River Basin, New Mexico . Left image is the false color representation of the first discrete returns and right image is the representation of the “bare earth” after filtering the vegetation and man made structures.

## 3. BROADER IMPACT

The NCALM’s mission and the research program at UH outlined here is cross-disciplinary and addresses significant areas of national and international needs by providing technology and observations which provides rapid and effective methods of mitigating the effects of and responding to natural disasters and hazards. The technology development gives tools for communities at large to provide important scientific data for the analysis, and understanding of our natural environment on large and small scales, and at resolution previously unobtainable. The NCALM research team also has significant ties to the remote sensing industry, and will be able to realize the transfer of this technology to commercial companies to further support research and development within the scientific community.  NCALM and UH graduate research program in Geosensing Systems Engineering aims to recruit high quality students, postdocs and staff to work on the program, and graduate a high quality, technologically savvy employee pool with a unique set of skill sets that will be highly valued in the workforce.

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