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NCALM's Lessons Learned and Insights into the Future from Ten + Years of Providing Geodetic Images for the Monitoring of Hazards and the Response to Disasters

NCALM
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University of Houston • University of California, Berkeley

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2001: Terrorist Attacks of September 11—NYC

Two days after the tragic attacks on September 11, 2001, the Office of the Deputy Under-secretary of Defense approached the US Army's Joint Precision Strike Demonstration (JPSD) to inquire about specific technology capabilities to aid in surveying the New York Ground Zero. JPSD approached Optech and the University of Florida Geosensing Systems Engineering center for personnel and equipment support. A multi institutional group was established; Optech provided an Airborne LiDAR (ALTM), two ground-based LIDAR scanners (ILRIS) and personnel to operate and process the data; NOAA provided a Citation II jet and personnel for remote sensing and geodetic support; the University of Florida provided personnel to help monitor GPS stations and process the airborne LiDAR data. Airborne Laser surveying began on September 23, two airborne missions were flown at altitudes of 6,300 ft. and 3,800 ft; the first over ground zero and the second over the entire southern tip of Manhattan. 1-m Digital elevation models were produced from the airborne data and was used to measuring debris volumes and to monitor depressions and subsidence.

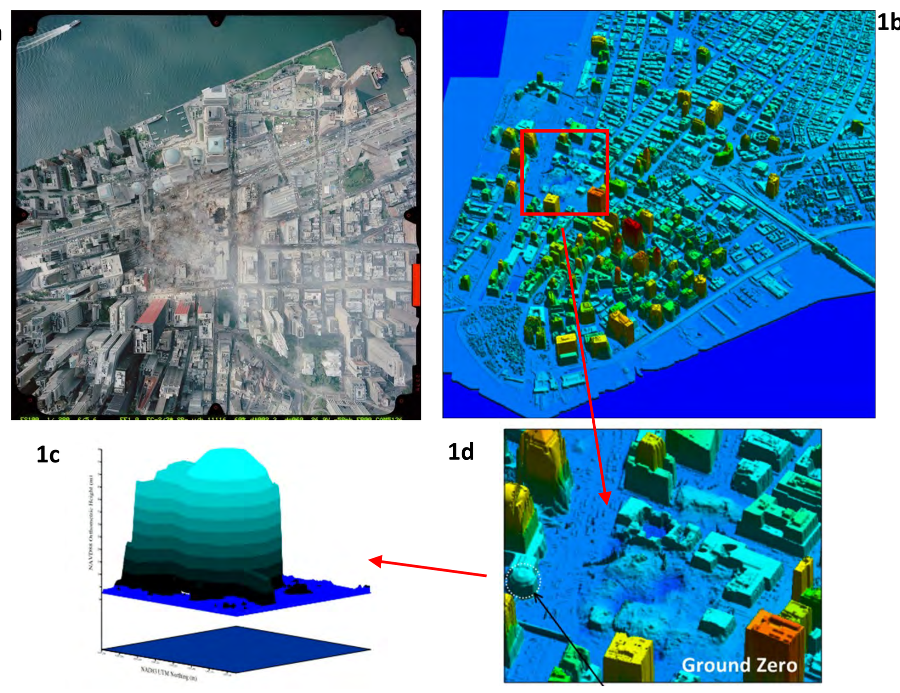

Figure 1a shows a High Altitude large format digital image of Ground Zero.
Figure 1b shows a high resolution digital surface model (DSM) of southern Manhattan.
Figures 1c and 1d show close ups of the DEM from Ground Zero.

Refs: J. Kern, "*Mapping Ground Zero*," Professional Surveyor Magazine - November 2001. & http://www.ngs.noaa.gov/RSD/special/sept11/pobarticle.shtml

2005, 2007-2008: OSU/USGS B4 and the UNAVCO GeoEarthScope Projects

In May 2005 NCALM collected high resolution airborne LiDAR data for ~1000 km along the San Andreas and San Jacinto fault systems in Southern California as part of the "B4" project. The B4 project was funded by the National Science Foundation (NSF) and led by The Ohio State University and the U.S. Geological Survey (USGS) with the collaboration of NCALM (at that time at the University of Florida) UNAVCO, Optech International, and NAVTEC. The main goal of the project was to create an unprecedented accurate digital elevation model (DEM) along the San Andreas and San Jacinto Faults in southern California before (B4) the occurrence of the widely anticipated major earthquake in the fault system. Differencing LiDAR data obtained after the big earthquake and the B4 dataset will yield a high resolution map of the three-dimensional displacement field along the entire rupture zone.

Following the B4 project, UNAVCO led a similar mapping effort as part of the GeoEarthScope project to map active fault zones. The GeoEarthScope mapped faults located in Northern, Southern and Eastern California, the Intermountain Seismic Belt in Wyoming and Utah, Yakima in Washington State and Denali Totschunda in Alaska. In three field campaigns spread over a two-year period between 2007 and 2008 NCALM mapped more than 5000 km² along these fault zones at point densities greater than 5 pts/m².

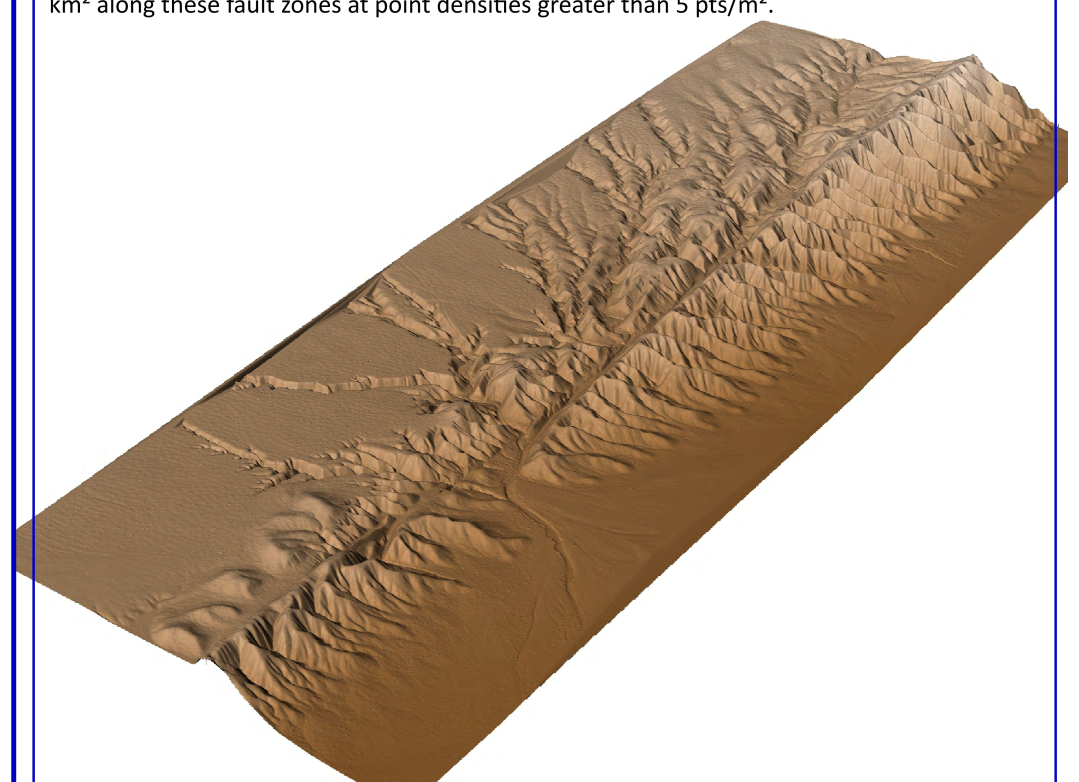

Figure 3. A 3D surface model obtained from a high resolution Digital Elevation Model (DEM) of the Dragon Back Ridge near Maricopa, CA collected during the B4 project.

Refs: M. Bevis et al., "The B4 Project: Scanning the San Andreas and San Jacinto Fault Zones," Abstract H34B-01 AGU Fall Meeting 2005.
C. Toth et al., "LiDAR Mapping Supporting Earthquake Research of the San Andreas Fault," ASPRS Annual Conference 2007.

2003-2005: Impact of Hurricane Landfall on Florida's Coasts

Even before the creation of NCALM in 2003, University of Florida researchers had been studying and applying LIDAR remote sensing to environmental issues in Florida. As early as October, 1996, a demonstration/test project was conducted for the Florida Department of Environmental Protection in collaboration with Optech, the Florida Department of Transportation (FDOT) and the US Geological Survey Center for Coastal Geology. During project LASER (Laser Swath-mapping Evaluation and Resurvey) more than three hundred kilometers of beaches (Mexico Beach, FL, to the western tip of Perdido Key, AL) and a portion of Interstate 10 were mapped using an Optech Inc. ALTM 1020 laser ranging system. (Carter & Shrestha, 1997). Shortly after, in 1998 UF in conjunction with the Florida International University (FIU) purchased its first LIDAR mapping unit, an Optech 1020 ALTM. Since then periodic surveys were conducted along the Gulf and Atlantic Florida coasts. During the 2004 – 2005 Hurricane seasons, Hurricanes Ivan and Dennis made landfall along the Florida Panhandle and Hurricanes Charley, Frances, and Jeanne made landfall on the Atlantic coast. NCALM researchers performed post-hurricane mapping of the beaches.

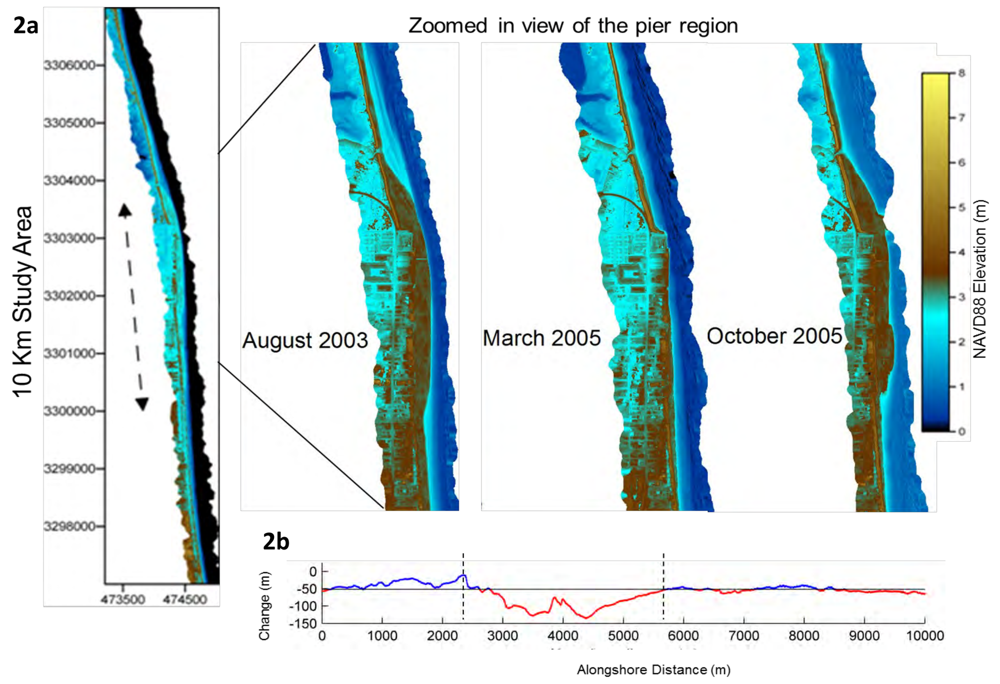

Figure 2a shows multiple elevation maps derived from multi-temporal LIDAR collections over St. Augustine Beach, FL. This area is an erosion "hot spot", during the 2004 Atlantic hurricane season four storms impacted the Florida coast exacerbating the shoreline retreat.

Figure 2b elevation profile showing shoreline change between August 2003 and March 2005 collections. The solid line is mean shoreline change over the entire study area.

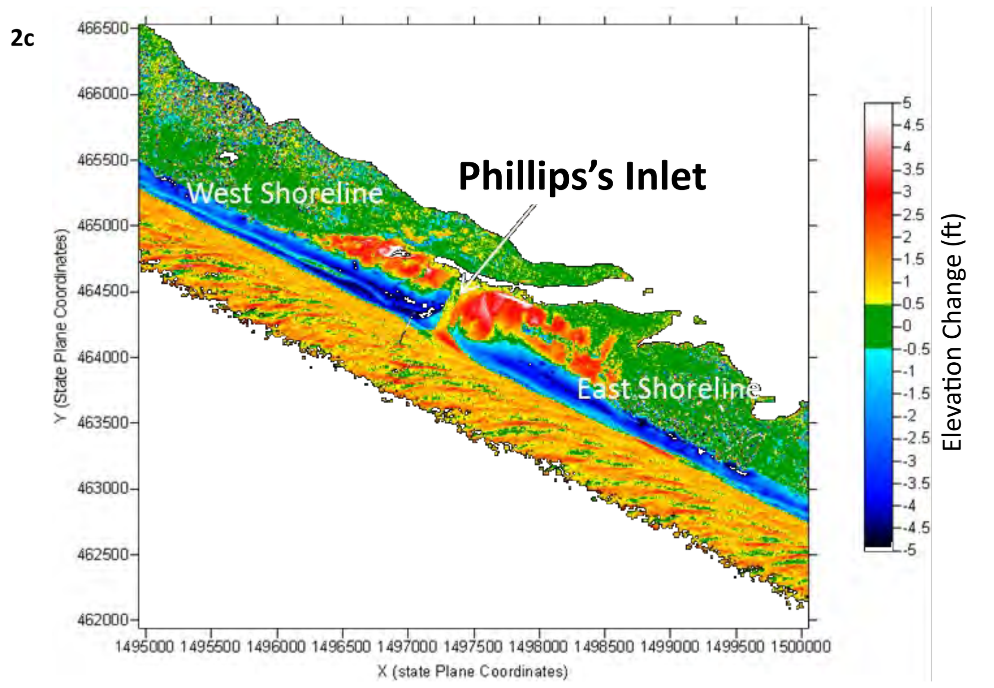

Figure 2c is an elevation change detection map centered around the Phillips Inlet barrier island region located in Bay County, FL. This airborne laser data was collected shortly before and after Hurricane Ivan in 2004. Massive shoreline retreat was observed on the west side of the inlet, the east side of the inlet experienced relatively minimal shoreline retreat, and there was significant deposition on the eastern backside of the inlet.

Figures courtesy of Dr. Michael J. Starek, Harte Research Institute for Gulf of Mexico Studies and a former graduate student at UF at the time this work was conducted.

Refs: R.L. Shrestha et al., "*Airborne Laser Swath Mapping: Quantifying changes in sandy beaches over time scales of weeks to years*," ISPRS Journal of Photogrammetry and Remote Sensing, Volume 59, Issue 4, June 2005.

INTRODUCTION

The National Center for Airborne Laser Mapping NCALM was created in 2003 through a grant from the National Science Foundation to support the use of airborne laser swath mapping technology (ALSM aka LiDAR) by the scientific community. NCALM is a joint collaboration between Department of Civil & Environmental Engineering, Cullen College of Engineering, University of Houston and the Department of Earth and Planetary Science, University of California-Berkeley. At the time of NCALM's creation, two of the original UH researchers were based at the Department of Civil and Coastal Engineering at the University of Florida. NCALM's main goals are to provide research quality airborne LiDAR observations to the scientific community, to advance the state of the art in airborne laser mapping, and to train and educate graduate students with knowledge of airborne mapping to meet the needs of private industry, government agencies and academic institutions. Even before its creation, NCALM researchers had been exploring the application of LiDAR technologies for the monitoring of Geohazards and the response and recovery from man-made and natural disasters. Some of these applications include: mapping devastation caused by the 11 September 2001 terrorist attacks in New York City; mapping thousands of km of faults along the Pacific coast of the US extending from Southern California to Alaska, through the OSU/USGS B4 and UNAVCO GeoEarthScope projects; mapping of lava fields in Hawaii; mapping post-forest-fire zones in the San Gabriel Mountains, CA and Valles Caldera, NM; mapping beach erosion/deposition induced by hurricanes along the Panhandle and Atlantic coasts of Florida; rapid-response mapping of the Iowa river floods in 2008 and the El Mayor - Cucapah Earthquake in 2010.

LESSONS LEARNED

The experience gained and lessons learned by NCALM regarding the long term data collection for monitoring hazards for the preparation, response and recovery of disasters range from navigating the regulatory and logistic challenges of being present in a disaster area, to the production of real-time geodetic imagery and data to support the appropriate authorities, to performing change detection (surface deformation, sediment transport, infrastructure damage) using LiDAR data products obtained by different vendors, with different equipment and operated under different specifications. In this work we will briefly expand two of these topics. The first relates to the complexities of change detection based on multi-temporal LiDAR datasets, and the second one is related with the challenges of quickly deploying equipment and personnel to a disaster area.

THE CHALLENGE OF LIDAR CHANGE DETECTION

The most common LIDAR data product used by researchers is the digital elevation model (DEM). A DEM being a regularly spaced data set allows for manipulation with relative ease and the application of traditional image processing techniques. In principle change detection of LIDAR derived elevation data should be as simple as a DEM differencing. However, the rapid rate of advance of LiDAR hardware, processing software and best practices makes DEMs change detection a non-trivial issue. Among the many complications are differences among the collections in terms of: equipment and flight parameters, fired point densities, point classification techniques, point to DEM interpolation methods, DEM resolution, DEM node definition, and vertical and horizontal datums. Many researchers have faced difficulties even when differencing DEMs that share the same resolution and datums; these issues arise from not calibrating and accounting for the instrument errors properly. The most challenging scenarios for change detection arise in two terrain extremes: very low relief areas and areas with high slopes. In areas with low relief errors improperly calibrated scale factors can create errors that are not evident in a single dataset but become obvious when compared to repeat mappings of the same area. In areas with high slopes dramatic changes in elevation due to the uncertainty of the horizontal positioning of laser shots caused by calibration issues are magnified. The best solution to deal with these issues and to move towards more accurate change detection products is to archive all the data products from the LIDAR work flow. Starting with the raw data (range data, GPS and navigation data), continuing to the preliminary processed data (point clouds strips), the intermediate products (classified tiles), and the final gridded products. Having all this information enables reprocessing of the older data using the procedures, software, and best practices available in the present. It is almost impossible to correct data artifacts if only the final products are available.

CHALLENGES AND SOLUTIONS RELATED TO QUICK RESPONSE

End-users of the information uniquely provided by airborne LiDAR have rapidly realized its value and are increasingly calling for the mapping of high-risk areas before emergencies, and as soon as possible after a major event. NCALM has been developing quick response capabilities in terms of rapid mobilization to the project site (within a week of receiving a call) and quick data production (within hours of the collection). Both of these are possible within the lower 48 US states.

Unfortunately, obtaining immediate approval of export licenses for components subject to the International Traffic in Arms Regulations (most particularly high accuracy Inertial Measurement Units) and obtaining aviation and mapping permits from foreign countries continues to be a major issue in rapidly responding to events in locations outside the United States. NCALM researchers have been working on alternatives to address several of the issues that limit quick response to events in the US and abroad. Even though currently there is a lot of uncertainty about the regulation of Unmanned Aircraft Systems (UAS aka UAVs) in the US and around the world, they promise to be a valuable tool for hazard monitoring and disaster response. On the high and big side of the UAS ecosystem, high altitude long endurance (HALE) platforms such as Boeing's Phantom Eye, Northrop Grumman's Global Hawk or Qinetiq's Zephyr have the capability of flying above 60, 000 ft MSL and staying in the air for several days. These capabilities open the possibility of having a surveying mission take off from the US or an US territory to fly to the area of interest, survey for a couple of days while it can transmit the remotely sensed data to the researchers base, and fly back to US territory. This mission scenario implies that the sensitive ITAR regulated equipment is not exported abroad and hence does not need to go through the export license process. A HALE platform also has the advantage over a traditional airborne survey system in that it does not put additional strain on the critical aviation infrastructure and resources from an endangered or disaster area. It does not add traffic to the critical airspace used for disaster relief. The development of a LIDAR system that is capable of providing sub-meter sampling from 65,000 ft is an area of interest for NCALM researchers. (see Shrestha et al., "*NH-30: Geodetic Imaging Using Unpiloted Aerial Vehicles: Reducing the Human Suffering and Economic Toll Caused by Natural Disasters*," Poster in 2012 AGU Science Policy Conference)

On the small and low extreme of the UAS ecosystem, NCALM researchers in conjunction with researchers of the University of Hawaii have significantly downsized the traditional LIDAR mapping platform into a low cost balloon LiDAR system that weighs about 25 pounds and can map from heights of up to 125 meters. The balloon can be towed by a vehicle or by a group of persons moving at a few meters per second. This system can map small areas at resolutions of thousands of pts/m². This system can significantly lower the costs of providing high resolution topographic mapping for the monitoring of hazards and responding to small scale disasters. (see Glennie et al., "*G23A-0886: Compact Adaptable Mobile LiDAR System Deployment*" Poster in 2012 AGU Fall Meeting)

2008: Iowa City Floods

Larger than normal snow pack from the winter of 2007, and prolonged and intense rainfall in late May and early June, 2008 produce record flooding in the Iowa River and Cedar River Basins in Iowa. The Iowa statewide rainfall average for the period between May 29 and June 12 was 9.03 inches, about 3.7 times the normal statewide average for the same period. On May 27, 2008 a Federal disaster declaration was issued, starting in Butler County but eventually include 85 counties, to help recover from the damage that occurred between May 25 and August 13, 2008. The greatest urban damage took place in Cedar Rapids and Iowa City. NCALM mapped two flooded areas around Iowa City, the first was along the Iowa River, south of Iowa City with an area of 285 km² and the second was the Clear Creek watershed just west of Iowa City and with a surface area of approximately 385 km². Data was collected between June 19th the 21st.

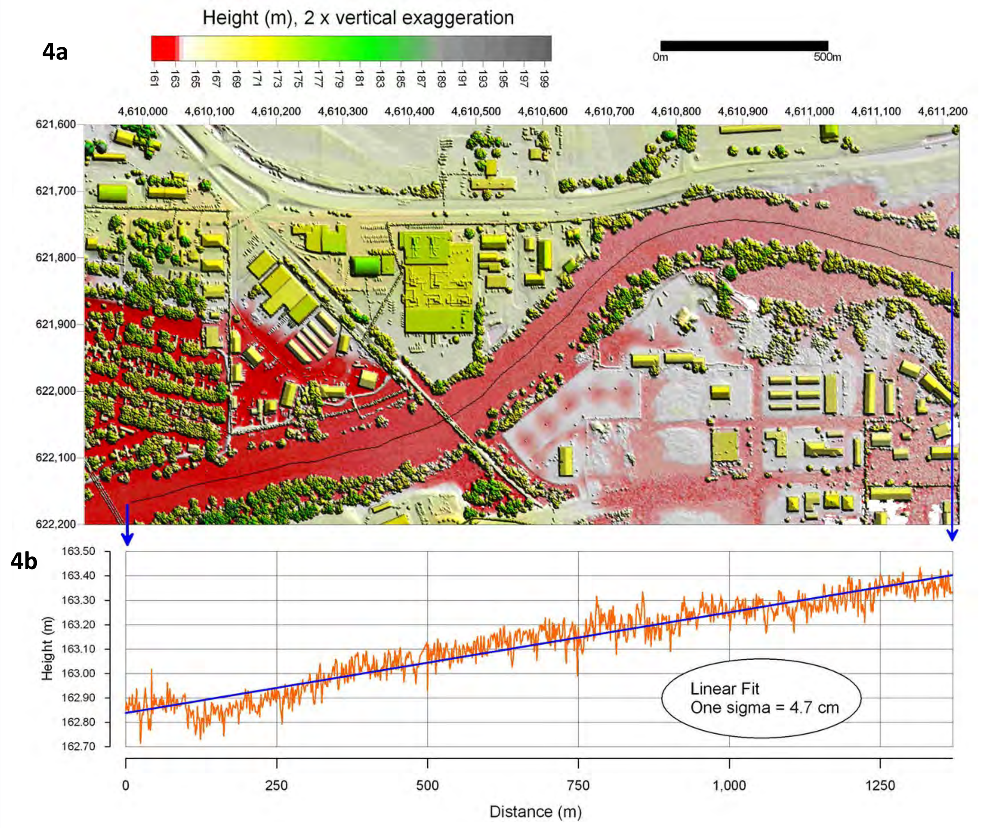

Figure 4a is a digital surface model (DSM) of a section of Iowa City showing red areas affected by the flood.

Figure 4b is a flood profile along the centerline of the Iowa River.

Refs: Linhart, S.M., and Eash, D.A., "*Floods of May 30 to June 15, 2008, in the Iowa and Cedar River basins*," eastern Iowa: U.S. Geological Survey Open-File Report, 2010.

2009: 1984 Lava Flow Mauna Loa, Hawaii

After a period of quiescence lasting nine year since the last eruption, Mauna Loa entered an eruptive phase on March 25th, 1984. The eruption continued until April 15th, 1984. During this time period several lava flows advanced downhill toward Hilo. Fortunately, gentle slopes, the break of the flow into different parallel flows, dense vegetation that provided resistance to the flow, relatively high viscosity of the lava due to low temperature, and the gradual decline of the eruptions spared Hilo from catastrophe. The lava flows stopped about 10 kilometers from the Hilo city limits. In 2009 NCALM conducted a LIDAR survey of an area greater than 130 km² covering the 1984 lava flows and more than 100 km² covering the Kilauea Caldera and its 1974 lava flow.

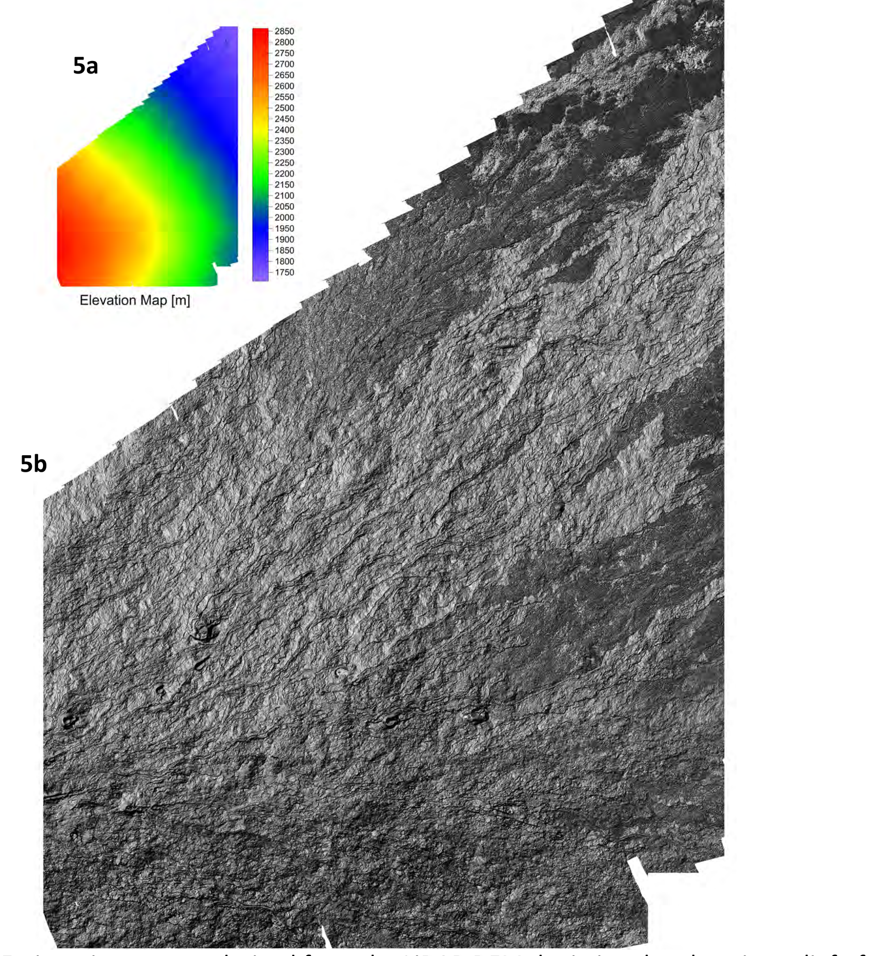

Figure 5a is an image map derived from the LiDAR DEM depicting the elevation relief of a section of the 1984 lava flow.

Figure 5b is a shaded relief map derived from the LiDAR DEM showing the morphology of the lava flow.

Refs: J.P. Lockwood et al., "*Mauna Loa 1974-1984: A decade of intrusive and extrusive activity*," in Volcanism in Hawai`i, U.S. Geological Survey Professional Paper 1350, 1987.

2010: El Mayor - Cucapah Earthquake

On 4 April 2010 the El Mayor–Cucapah earthquake (Mw 7.2) produced a multi-fault rupture 120-kilometer-long through northernmost Baja California, Mexico. This area had been previously mapped using LiDAR in 2006 by the Mexican Instituto Nacional de Estadística y Geografía (INEGI) at a ground sampling spacing of 5-meters. In mid-August 2010 NCALM mapped a corridor roughly 100 km of length in a NW-SE direction with an average width of 3 km. Overall, the survey spans, from just south of the border to the tidal flats of the Colorado River delta at the head of the Gulf of California. A total of 3.8 billion point measurements were obtained with an average density of 11 pts/m². Researchers led by Michael Oskin of UC Davis differenced the pre and post earthquake LiDAR DEMs to compute the near-field deformation from the earthquake.

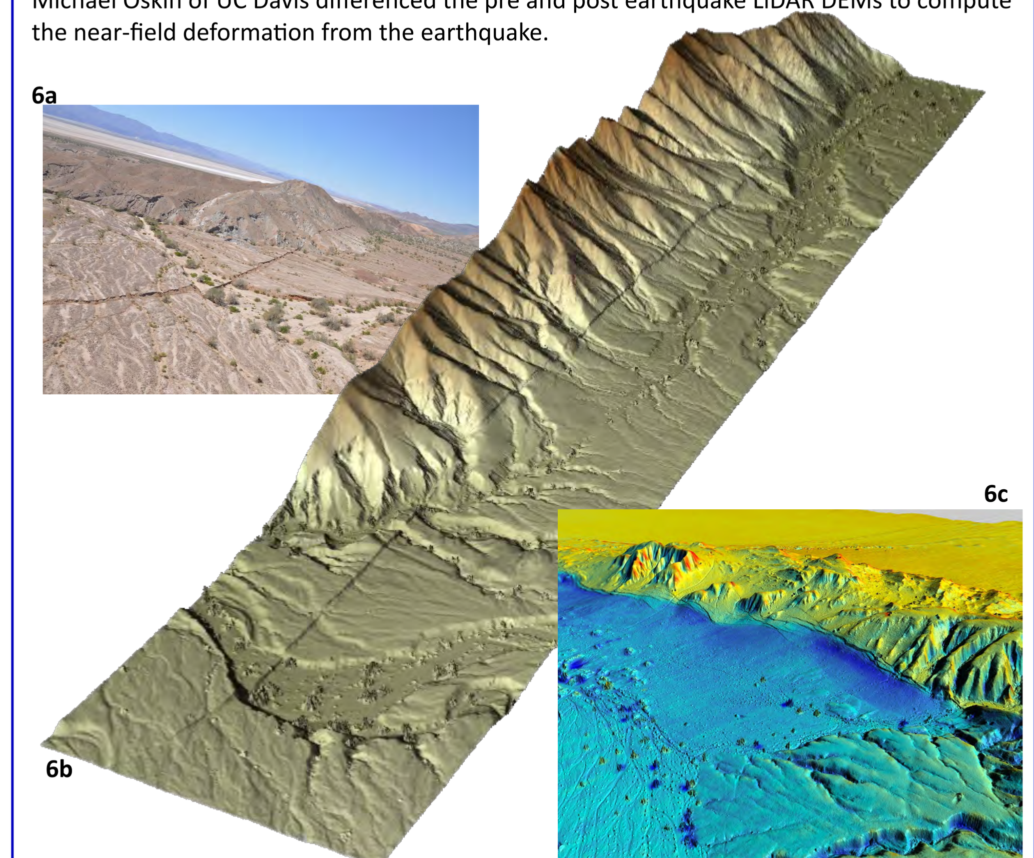

Figure 6a is a photo showing a section of the surface rupture due to the El Mayor earthquake. Photo courtesy of Alejandro Hinojosa (INEGI).

Figure 6b 3D surface map derived from the 2010 LIDAR DEM showing the surface rupture.

Figure 6c is 3D surface map derived from the 2010 LIDAR DEM overlaid with 1D elevation difference from the 2006 and 2010 LiDAR DEMs. Blue indicates lower elevation post-earthquake in a range starting at -3 meters, and red indicates a higher elevation with a max range value of +1 meter. Figure courtesy of Dr. Michael Oskin, University of California, Davis.

Refs: M. E. Oskin et al., "*Near-Field Deformation from the El Mayor-Cucapah Earthquake Revealed by Differential LIDAR*," Science, 2012

2012: Impact of the 2011 Las Conchas Fire, NM

Las Conchas Fire, the largest wildfire in New Mexico's history, began with a tree falling onto a power line on June 26, 2011. In its first 13 hours it burned over 44,000 acres and over the coming weeks it grew to over 156,000 acres before being contained on the evening of August 1, 2011. The fire affected among many other areas the Santa Fe National Forest, the Bandelier National Monument and the Valles Caldera National Preserve. NCALM had collected more than 630 km² of pre fire LIDAR for the burnt area in 2010 as part of the NSF funded CZO LIDAR collection and the Valles Caldera NP LiDAR. A post fire collection of over 160 km² was performed in May 25-28, 2012 for Jon D. Pelletier of the University of Arizona to conduct a post-fire landscape response study.

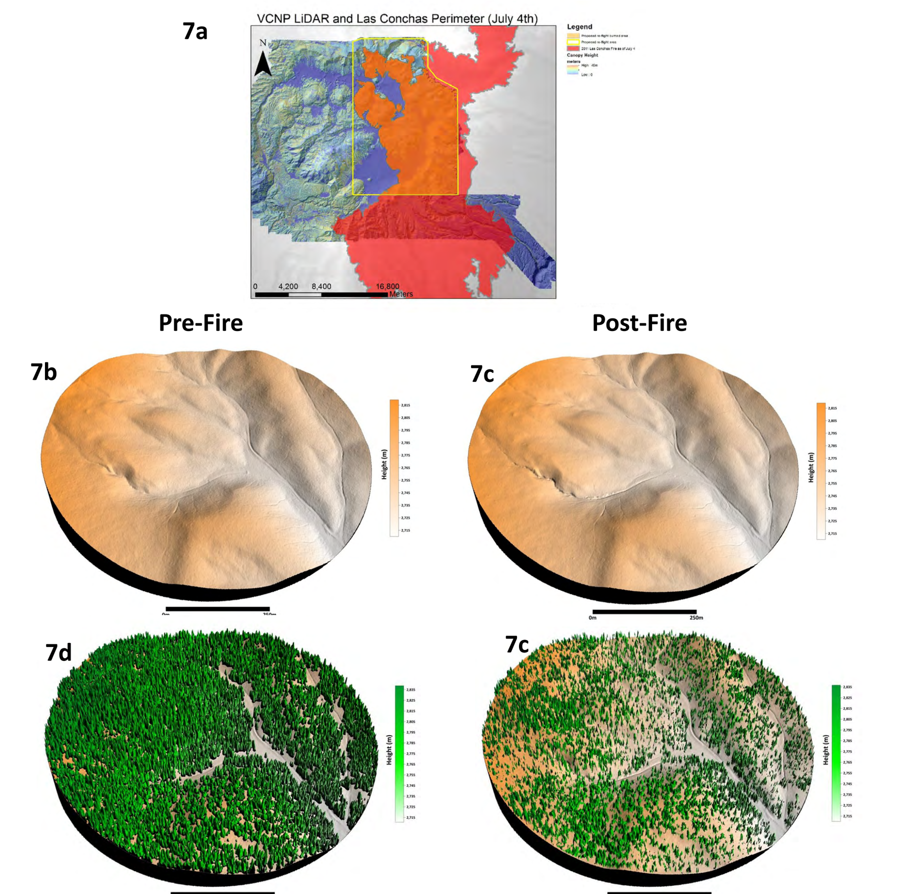

Figure 7a. shows the extent of the fire over a NCALM high resolution DEM and a 10-m USGS DEM, burn severity from MTBS. Figure is courtesy of Tyson Swetnam, Fire and Restoration Ecology Lab, The University of Arizona.

Figure 7b and **7c** are pre and post fire bare earth DEMs showing fire erosional effects evident in the incision of channels.

Figure 7d and **7e** are pre and post fire first surface models (DSM) showing the effects of the fire on the forest canopy.

Refs: http://www.inciweb.org/incident/2385/
http://www.nps.gov/band/naturescience/lasconchas.htm