Windstorm Simulation & Modeling Project

Palm Beach County Digital Elevation Models

Progress Report

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May 30, 2002

Executive Summary

The following is an interim report describing estimated accuracy, limitations, and conformance standards to published standards as part of the Windstorm Simulation & Modeling Project per the contract agreement established January 9, 2001 between, Florida International University International Hurricane Center (IHC) and Palm Beach County. The report will also discuss accuracy and compatibility of available U.S. Army Corps of Engineers (USACE) data in Northern Palm Beach County.

The IHC LIDAR data was compared with elevations from 11 surveyed ground profiles. Overall, the RMS error for all 368 ground points is 0.34 ft (10.4 cm). This corresponds to a vertical accuracy of ±0.67 ft (20 cm) at the 95% confidence level. The IHC and USACE LIDAR datasets were tested for compatibility. In regions where the 2 datasets overlap, the USACE elevations are offset below the FIU elevations by 1.7-2.2 ft. This offset is mainly due to errors in the USACE elevations.

Introduction

In 2000- 2001, The International Hurricane Center (IHC) was awarded grant funding by Federal Emergency Management Division (FEMA) and the Florida Department of Community Affairs (FLDCA), for a program entitled the Windstorm Simulation and Modeling project. Four tasks under this three year project included 1) the re-evaluation of existing storm surge models including SLOSH, CMEPS and TAOS, 2) data acquisition of high-resolution elevation data via LIDAR technology for participating South Florida counties 3) computer simulation of findings for researchers and the general public and 4) development of public awareness and education programs in regards to human vulnerabilities to hurricanes and the means to mitigate the risks. This project is also supported partially from matching funds provided from participating counties including Broward, Miami-Dade, Palm Beach, and Martin Counties.

On January 9, 2001, Palm Beach County and the IHC reached a final contract agreement about participating in this project and as part, use Airborne Laser Terrain Mapper (ALTM) technology for their evacuation zone revision project. Following this agreement initial field reconnaissance was conducted, base stations were established, and the ALTM system was used to collect detailed topographic data in Palm Beach County in July and August 2001. This report describes the estimated accuracy and limitations of the FIU/IHC LIDAR data set as well as a compatibility assessment of the U.S. Army Corps of Engineers LIDAR data in northern Palm Beach County.

Data Collection

On July 13-17 and August 6- 7, 2001, an Optech Airborne Laser Terrain Mapper (ALTM) 1210 LIght Detection And Ranging (LIDAR) mapping system mounted in a Cessna 337 aircraft was used to collect topographic data in Palm Beach County. Data was collected at a nominal altitude of 1100 m (3600 feet) with the survey consisting of 128 overlapping 600-m-wide swaths. Data gaps re-flown on May 1, 2002 were collected

at a nominal altitude of 915 m (3,000 feet) with a survey consisting of 3 overlapping 660-m-wide swaths. Ground control was provided by 3 Ashtech Z-12 GPS receivers equipped with choke ring antennas. The total coverage of low-lying areas exceeded 100,000 acres and included all areas depicted in Figure 1. Over 100 million irregularly spaced ground surface elevations were measured with a nominal point spacing of 2.5 m (8.2 feet

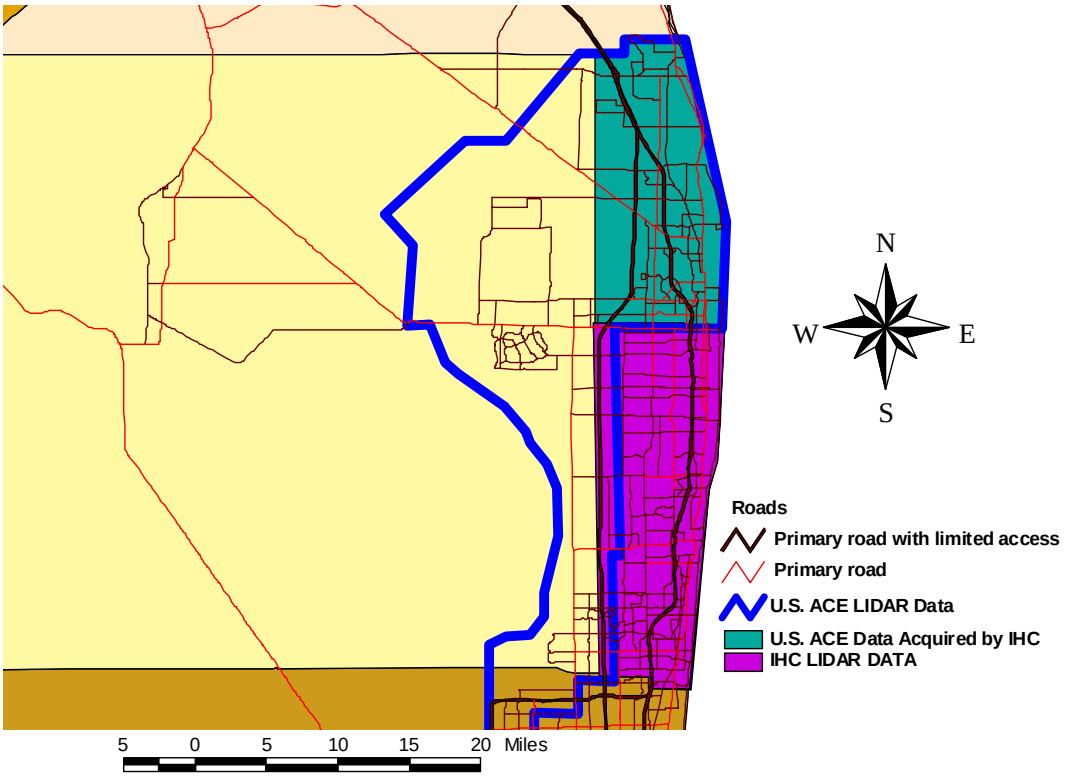

Figure 1. Index map showing location of LIDAR data in eastern Palm Beach County.

Processing

After each flight, aircraft and ground station GPS carrier phase data are differentially processed to produce a kinematic aircraft trajectory. The trajectory information is combined with the range, scan, and Inertial Navigation System (INS) data to produce laser return coordinates. Data for each swath are outputted as ASCII text. Horizontal coordinates are transformed to NAD83, State Plane, FL East zoon, feet. Elevations were converted from GPS ellipsoidal heights to NAVD88 orthometric heights with the NGS GEOID99 model.

The large volume of data presented considerable challenges. Accordingly, data from overlapping swaths were checked for internal consistency, combined and subdivided into smaller and more manageable sized portions. These consisted of 5000 by 5000 ft tiles, each containing from 1 – 2 million points. Each tile was gridded using kriging interpolation with a linear variogram model and a 50 ft search radius to produce a

set of 5 ft resolution, (1000x1000), DEMs. This DEM resolution was selected to be consistent with the 8 ft nominal point spacing.

The raw data consists of a 3-dimensional cloud of points corresponding to laser reflections off various objects. In order to model and visualize variations in the ground surface, reflections from non-ground features such as buildings, vegetation, and vehicles must be classified and removed. Since a given DEM pixel can often contain both ground and non-ground surface reflections, terrain classification is best performed on the raw, irregularly spaced laser points rather than on gridded data. After classification, the remaining ground surface points are then gridded to produce a "bare earth" DEM for each tile.

For modeling and display purposes, a lower resolution dataset was produced by subaveraging the 5 ft pixels to 100 ft resolution. First a 21x21 focalmean filter was applied to each of the bare earth 5 ft resolution DEM tiles. Then the tiles were resampled by a factor of 20. Finally the tiles were mosaiced to form the 100 ft DEM.

Error Analysis

Comparison of the LIDAR data with an independent dataset of higher accuracy is necessary in order to estimate absolute uncertainties in the elevations. Verification of LIDAR data is also necessary in order to ensure against systematic errors or offsets in the data caused by instrument malfunctions or processing errors. An error analysis was performed using surveyed surface profiles as ground control. Palm Beach County provided surveyed point profiles of street intersections as part of their cost matching for the IHC LIDAR data. IHC personnel collected ground profiles using rapid static GPS methods. These profile elevations were compared with elevations interpolated from the 5 ft resolution bare earth DEMs.

Bill Etheridge of the Palm Beach County Planning Department provided surveyed profiles at four street intersections within Palm Beach County: Forrest Hill Boulevard and Jog Road (FHJOG), Lantana Road and Congress Avenue (LANCON), Linton Boulevard and Congress Avenue (LINCON), and Palmetto Park Road and Military Trail (PPMIL). At each site, profiles were collected in both the N-S and E-W directions.

The IHC surveyed three additional locations for the Palm Beach County data set: Lantana, Pioneer, and 2815. The GPS data were collected using Ashtech equipment. At each study location, a base station was set up at a known point of verified positional accuracy. Ashtech Z-12 receivers were used with Ashtech Choke Ring antennas mounted on 2 m fixed height tripods. The rapid static GPS survey used an Ashtech Z-Extreme receiver with a Geodetic-IV antenna fixed onto a 2.056 m fixed height bipod. Points were collected at 12-second intervals. GPS data were differentially post-processed using Ashtech Solutions software.

The results of the error analysis are shown in Table 1. Three separate statistics were used to describe the goodness of fit at each profile: mean, standard deviation, and root mean squared error (RMSE). The mean offset is a measure of the static offset

between the LIDAR surface and the ground profile. Positive offsets indicate that the LIDAR surface is below the true ground surface. Static offsets usually result from errors in the aircraft trajectory.

Table 1: Statistical comparison between ground profiles and the LIDAR surface. N Points: number of points on profile. The weighted mean reflects the statistics for the whole dataset.

Site	Source	N Points	Mean Offset	STD	RMSE
FHJOG N-S	PBC	26	-0.32	0.12	0.35
FHJOG E-W	PBC	18	-0.36	0.16	0.39
LANCON N-S	PBC	22	0.55	0.16	0.57
LANCON E-W	PBC	23	0.50	0.22	0.55
Lantana E-W	IHC	68	0.27	0.20	0.34
LINCON N-S	PBC	22	-0.18	0.19	0.26
LINCON E-W	PBC	17	-0.07	0.20	0.21
PPMIL N-S	PBC	24	-0.27	0.17	0.32
PPMIL E-W	PBC	22	-0.28	0.20	0.34
Pioneer E-W	IHC	67	-0.18	0.16	0.24
AD2815	IHC	59	-0.32	0.17	0.36
Weighted Mean		368	-0.06	0.18	0.34

Static offsets were better than 0.36 ft (11 cm) at all locations with exception of the LANCON location. The LANCON site had a positive offset of greater than 0.5 ft. (15 cm). This offset may partially be due to poor survey control on the ground profile. The LANCON profile was referenced to the NGS site AD7891. Prior to the data collection, IHC personnel conducted a 5 hour CORS GPS occupation of this bench mark which indicated that the reported NGS ellipsoidal height was in error by 0.28 feet. As a result, IHC conducted a rapid static GPS survey at the LANCON area, and reveled that the offset between the IHC DEM and GPS surveyed points was only 0.27 ft (8.2 cm).

The root mean square error (RMSE) provides a convenient means to quantitatively estimate the error in a set of measurements. The National Standard for Spatial Data Accuracy (NSSDA) defines the RMSE to be the square root of the average of the squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy (Federal Geographic Data Committee, 1998). For a DEM, the vertical error, $RMSE_z$ is defined as

$$RMSE_z = \sqrt{\frac{\left(z_{t,i} - z_{m,i}\right)^2}{n}}$$

where $z_{t,I}$ is the elevation of the ith test point, $z_{m,I}$ is the interpolated DEM elevation at the test point, and n is the number of test points. NSSDA recommends using a minimum of 20 test points distributed over the geographic area of interest.

Accuracy is reported in measurement units at the 95% confidence level. A 95% confidence level means that 95% of the measurements will have an error of less than or equal to the reported accuracy. If the error is normally distributed with zero mean, the 95% vertical accuracy is equal to 1.96 times the $RMSE_z$.

Comparison of the LIDAR DEMs with the surveyed profiles showed a fit of better than 0.39 ft (12 cm) RMS at all locations with exception of the previously mentioned LANCON location. Overall, the RMS error for all 368 ground points is 0.34 ft (10.4 cm). This corresponds to a vertical accuracy of +/- 0.67 ft (20 cm) at the 95% confidence level.

IHC & USACE Compatibility

The U.S. Army Corps of Engineers contracted the collection of airborne LIDAR data in 2000 over coastal regions of northern Palm Beach County as part of their Everglades Water Preserve Area study. Ungridded bare earth points and metadata are available on the Internet at http://mapsrv.evergladesplan.org/lidar/a362.html. This data when combined with the FIU LIDAR data provides almost complete coverage for most of populated eastern Palm Beach County (Figure 1).

In order to provide complete LIDAR coverage eastern Palm Beach County for storm surge analysis, USACE data east of the Florida Turnpike were downloaded from the web site (Figure 1). Following the procedure used with the FIU LIDAR data, the data were sorted into 5000x5000 ft tiles and gridded into 5 ft resolution DEMs. These datasets were then analyzed for compatibility with the FIU data. In addition, a lower resolution dataset was produced by subaveraging the 5 ft DEMs to 100 ft.

The coverage of the USACE data is shown in Figure 2. In general the quality of this data was significantly lower that the FIU data. First, the point density of the USACE data is much lower that that of the FIU data by over a factor of 4. The on-line dataset also contains 3 large data gaps in the northern part of the County. The northernmost of these data gaps is situated in a storm surge zone and will limit analysis in that area. The source of these data gaps is unknown, but is probably due to a processing error. In addition, a portion of the USACE data contains data subsampled to 50 ft postings rather than the more closely spaced LIDAR postings. Fortunately, this lower posting spacing will not effect the lower resolution 100 ft DEMs that are being used for storm surge analysis.

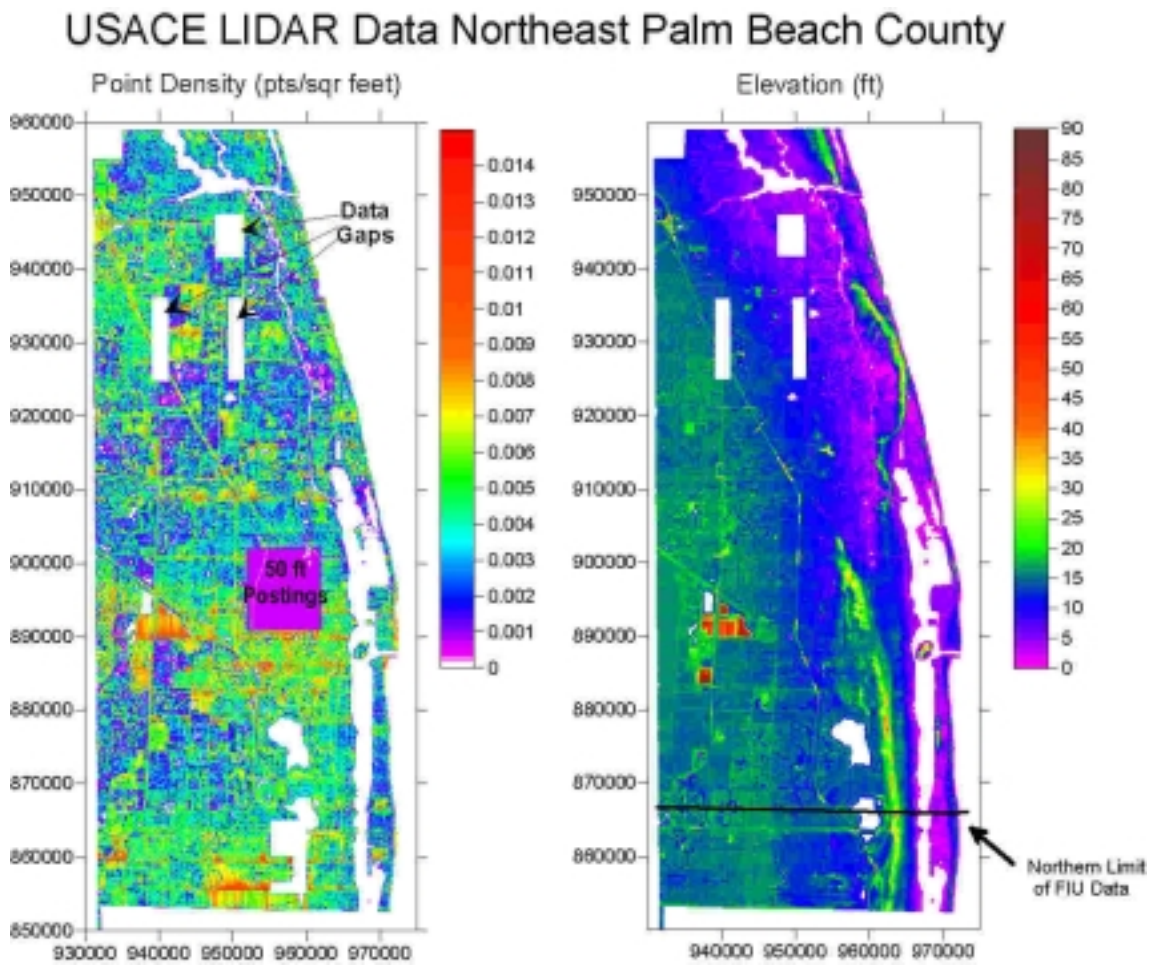

Figure 2. US Army Corps of Engineers data acquired by FIU. Left: Point density map of the USACE dataset showing coverage and data gaps. Right: Elevation map (ft, NAVD88) of the USACE data.

The IHC tested the compatibility between the IHC data and the USACE data. Two transects were extracted from the IHC and USACE LIDAR DEMs on the runways at Palm Beach International Airport. One transect was extracted from northwest to southeast, and one transect was extracted from west to east. On both transects, the USACE elevations are offset below the IHC data. The offsets range between 1.6 ft (48 cm) on the northwest to southeast transect, and 2.1 ft (64 cm) on the west to east transect (Figure 3). These offsets are large when considering the use of these datasets for flood modeling.

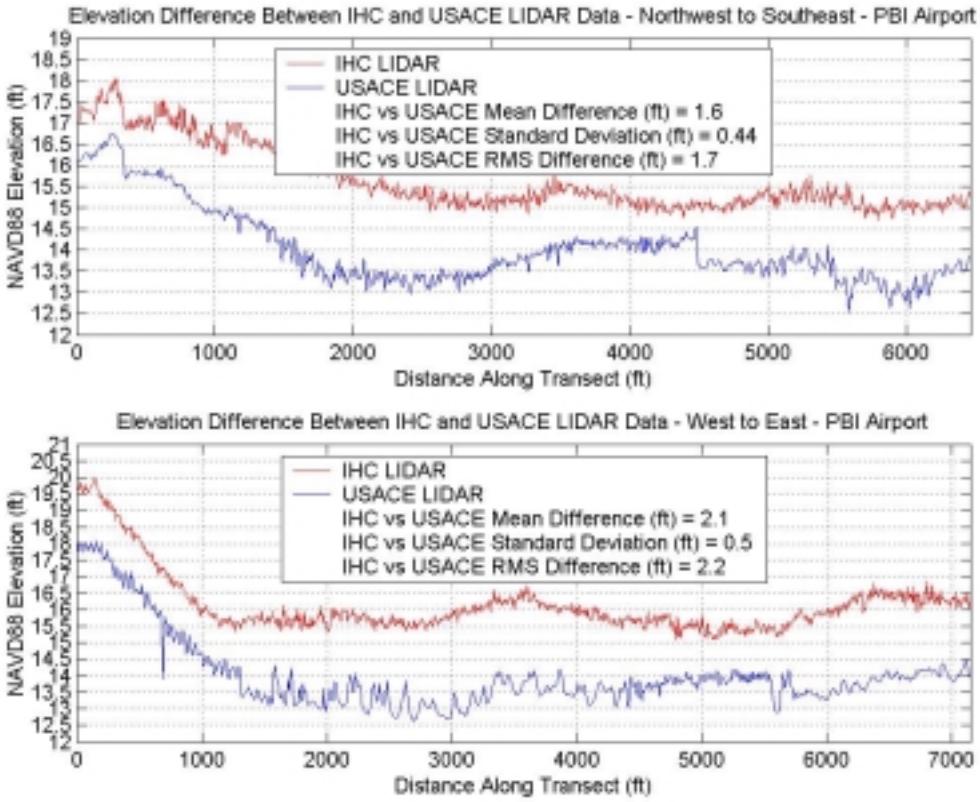

Figure 3. Two transects extracted from the IHC data (red) and the USACE data (blue) located on the runways at Palm Beach International Airport.

In order to assess the source of the offset between the IHC and USACE LIDAR data, the IHC collected a rapid static GPS survey just north of Belvedere Road on Mercer Avenue (transect AD2815, Table 1). The GPS surveyed points and the IHC/USACE LIDAR DEM extracted profiles were compared by calculating the mean difference, standard deviation, and RMS difference of the points located on the DEMs. The land survey profile showed a fit of better than 0.36 ft (11.0 cm) RMS when compared to the IHC LIDAR DEM (Figure 4). In contrast, the USACE LIDAR data appears to be offset below the land survey profile by 1 ft (30.5 cm). We therefore conclude that the offset between the 2 datasets is largely due to errors in the USACE elevations.

It is unknown at this time whether this offset seen in the USACE data is representative of the dataset as a whole or is instead only a local variation. In light of this offset, the IHC recommends that the FIU and USACE LIDAR datasets not be merged and instead be treated as separate datasets for the purpose of modeling storm surge.

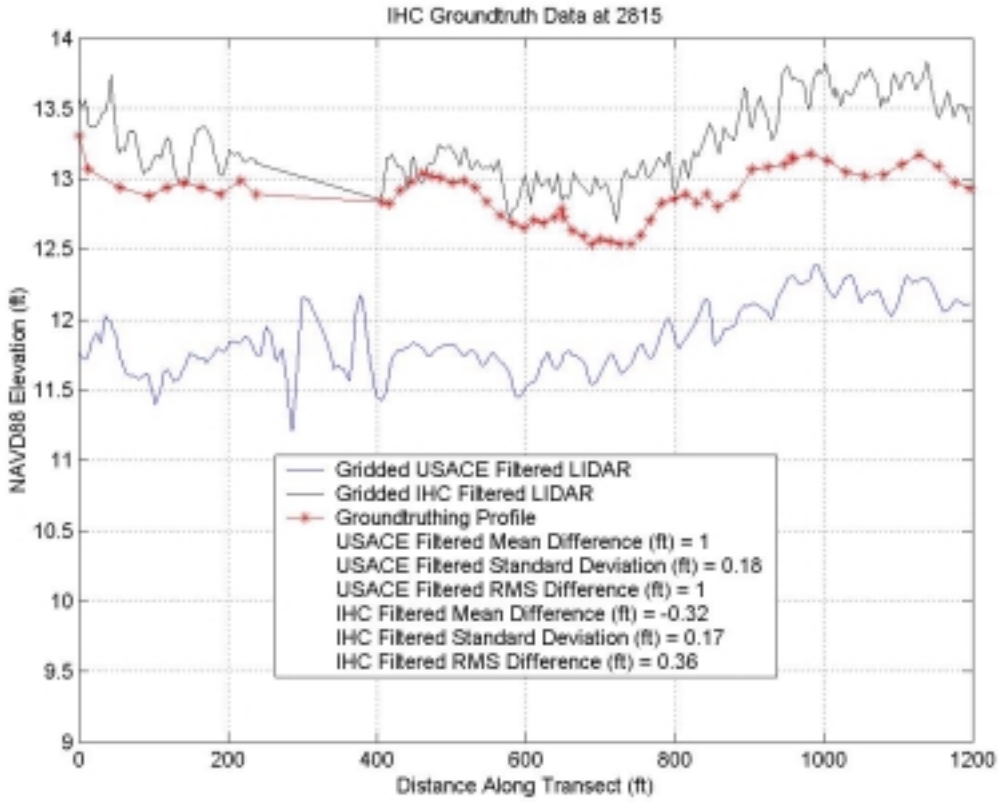

Figure 4. Ground survey AD2815 (red) compared to IHC (black) and USACE (blue) LIDAR data.

Deliverables and Formats

The enclosed CDROMs contain DEMs of the Palm Beach County LIDAR data produced at 5 ft and 100 ft resolution. Horizontal coordinates of all files are in U.S. Survey Feet, State Plane, Florida East zone, NAD83 datum. Elevations are given in NAVD88 feet. The data is supplied in ESRI Binary raster import format and as space delimited ASCII x,y,z files.

There are 10 CDROMs that are delivered with this report. The following are their contents:

Disk 1: 100 ft DEMs, Surge Flooding Layers, and ancillary data

- Interim report in PDF format
- Shapefiles containing SLOSH MOM maps for category 1-5 hurricanes for the Palm Beach Basin, and a tile index
- 100 ft resolution DEMs for Eastern Palm Beach County in ASCII and Binary format
- Preliminary 100 ft resolution raster storm surge flooding layers in ASCII and Binary format
    - Category 1-5 SLOSH MOM heights resampled to 100 ft

    - Category 1-5 SLOSH MOM flooding depth layers
    - Category 1-5 flood zone layers
- Readme.txt file describing contents

Disk 2: Bare Earth DEM Grids (part 1)

- Tiles containing 5 ft resolution bare earth DEMs
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Disk 3: Bare Earth DEM Grids (part 2)

- Tiles containing 5 ft resolution bare earth DEMs
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Disk 4: Bare Earth x,y,z points (part 1)

- GZIP folder containing program to unzip data
- Compressed point files in space delimited ASCII x,y,z format
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Disk 5: Bare Earth x,y,z points (part 2)

- GZIP folder containing program to unzip data
- Compressed point files in space delimited ASCII x,y,z format
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Disk 6: Unfiltered DEM Grids (part 1)

- 5 ft resolution DEMs
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Disk 7: Unfiltered DEM Grids (part 2)

- 5 ft resolution DEMs
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Disk 8: Raw, unfiltered x,y,z points (part 1)

- GZIP folder containing program to unzip data
- Compressed point files in space delimited ASCII x,y,z format
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Disk 9: Raw, unfiltered x,y,z points (part 2)

- GZIP folder containing program to unzip data
- Compressed point files in space delimited ASCII x,y,z format
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Disk 10: Raw, unfiltered x,y,z points (part 3)

- GZIP folder containing program to unzip data
- Compressed point files in space delimited ASCII x,y,z format
- Preliminary metadata in ESRI FGDC format (.xml)
- Readme.txt file describing contents

Summary and Conclusions

This report presents the findings of the LIDAR study for Palm Beach County initiated in Summer 2001. The summary of these finding is as follows:

- Data acquisition for the subject areas outlined in the contract agreement were completed successfully
- The IHC recommends that the FIU/IHC and USACE LIDAR datasets not be merged and instead be treated as separate datasets for the purpose of modeling storm surge
- At this time the project is still on schedule

Future Activities

Future activities for this project include the following:

30- June 2002

- Delivery of Quarterly Progress Report to FLDCA and Palm Beach County

30- September 2002

- Delivery of Quarterly Progress Report to FLDCA and Palm Beach County

31- December 2002

- Delivery of reprocessed data sets to the County in GIS compatible format
- Delivery of Quarterly Progress Report to FLDCA and Palm Beach County

1- April 2003

- Delivery of Quarterly Progress Report to FLDCA and Palm Beach County

30 - September 2003

- Delivery of Quarterly Progress Report to FLDCA and Palm Beach County

31- December 2003

- Delivery of final report with complete analysis
- Review of DEM and recommendations for refinement
- Preliminary report indicating the findings of re-evaluation of storm surge models including recommendations on use of new data to model storm surge event flooding
- Education and training support in use and application of new data set
- Delivery of Quarterly Progress Report to FLDCA and Palm Beach County