Evaluation of ADS40 and IfSAR Derived High-Spatial Resolution Topographic Data Products for Coastal Resource Management Applications

Executive Summary

High resolution elevation data is an important piece of information for the coastal management community; in coastal areas a change in elevation of one foot can make large differences in habitat composition and human safety. In recent years several elevation data sources have become widely available to meet these management needs; each with their own set of cost, accuracy, and availability considerations. This report provides a comparison of 'bare earth' elevation data from three typical aerial data sources – Light Detection and Ranging (LiDAR), Interferometric Synthetic Aperture Radar (IfSAR), and photogrammetrically derived elevation data from the Leica Geosystems ADS40 airborne digital sensor (ADS40). These sources cover the range – laser, radar, and photogrammetry – of typical aerial elevation collection techniques and are available from the Coastal Services Center (CSC). Processing of the data remains a variable; each has a different degree of processing to remove vegetation and it can differ between projects. In this case, the data were taken as provided to the CSC for the eastern portion of Walton County, Florida.

In this study LiDAR data was used primarily as a 'ground truth' source as it had already undergone a rigorous QA/QC process. This paper aims to provide a relatively wide range of analysis, but does not cover all aspects of the surface characteristics. That being said, the differences between the two primary surfaces being investigated and compared (IfSAR and ADS40) are fairly consistent across the different analyses.

The trends are highlighted by the magnitude of error (root mean square error) in the point to point analysis (Table A). This provides a basic view of the accuracy of the data in different land covers and uses. The IfSAR are accurate in the non-vegetated areas and where small features (e.g. single family homes) have been removed. The ADS40 data are less accurate, but maintain consistency across the different land cover categories. In most cases the ADS40 overestimates the elevation and may be corrected with a global negative shift in elevation.

Table A. Root mean square error (RMSE) values for the different elevation products.

RMSE (meters) as compared to LiDAR data			
Land Cover	**(# Pts)**	**IfSAR**	**ADS40**
Bare Earth	242	0.38	1.68
Grass-Crops	250	0.33	1.50
Evergreen Forest	246	8.16	1.71
Palustrine Wetland Forest	242	8.89	1.93

Analysis using profiles across the surfaces showed a comparable trend (Figure A) with similar RMSE values. The ADS40 provides a fairly consistent profile across the various land covers, while the IfSAR is accurate only in the cleared areas (right side of Figure A), where it does provide elevation values similar to LiDAR.

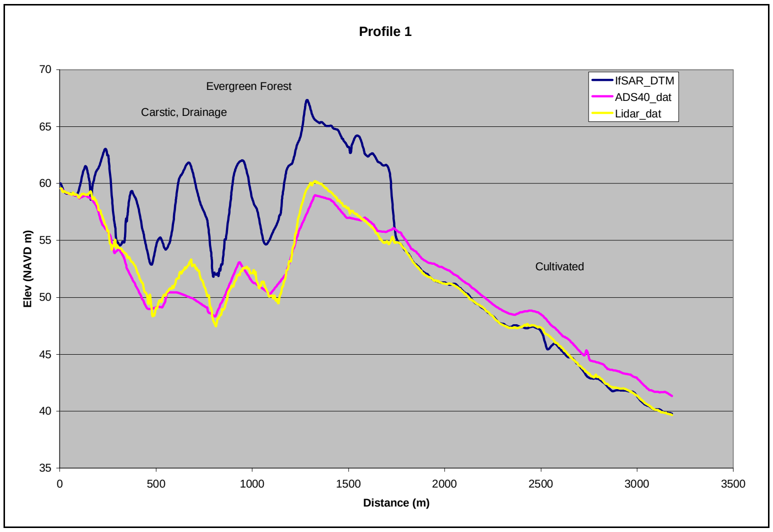


Figure A. Profile through a typical section of the study area.

When using the data in conjunction with the inundation output from a commonly used hurricane flooding model (Sea, Lake, and Overland Surges from Hurricanes – SLOSH; Figure B), the ADS40 and LiDAR depicted flood extents were comparable. As such, ADS40 DTM's may prove to be a lower cost alternative to LiDAR in some locations or modeling applications. When using the IfSAR in conjunction with SLOSH the results varied from the LiDAR generated boundaries; however, in areas with sparse vegetation the IfSAR more closely approximated the LiDAR/ADS40 boundaries.

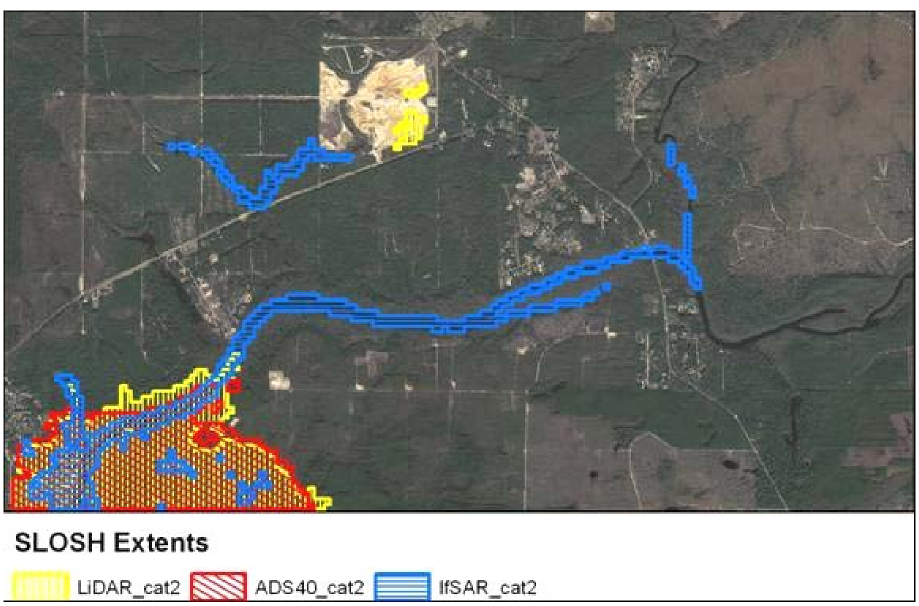


Figure B. SLOSH model output using the different elevation data sources.

For data visualization, the IfSAR is more intuitive in 3D than the ADS40 since it does contain vegetation and has a higher native resolution. The data processing and/or higher native resolution of the IfSAR facilitate more visually intuitive contours; however, the ADS40 contours are generally more accurate. Finally, in coastal areas the IfSAR appears to be a better elevation data source for constructing shorelines, likely a result of the higher accuracy in open areas (Figure C), but there has been some processing that may hinder the correct inland extent of the shoreline where features (e.g. bridges) exist.

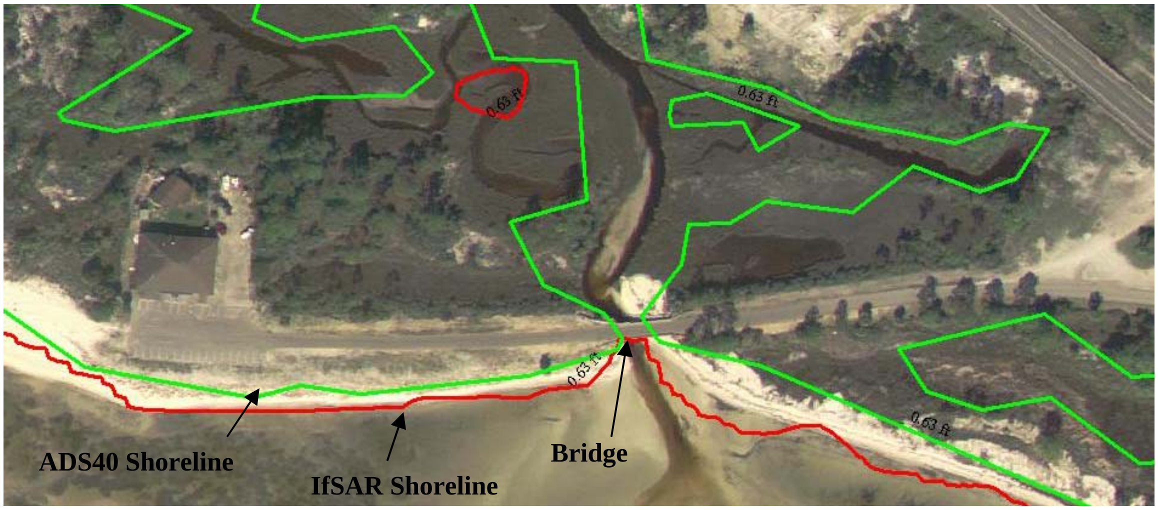


Figure C. Mean high water (MHW) shorelines derive from IfSAR (red) and ADS40 (green) topographic data

In summary, the ADS40 DTM is a more correct overall surface than the IfSAR DTM, but suffers from some over-smoothing and a lower native spatial resolution. The IfSAR DTM is accurate in open areas, but in locations where significant vegetation is present the values are highly suspect. The precision and accuracy values of both products do not duplicate LiDAR technology, but under the appropriate circumstances may offer a sufficient, if not equitable alternative. However, with the tested degree of processing, neither can provide the same level of applicability as LiDAR in coastal areas where slight elevation variations can be extremely important to human safety or ecologic habitats.

Evaluation of ADS40 and IfSAR Derived High-Spatial Resolution Topographic Data Products for Coastal Resource Management Applications

Introduction

High resolution elevation data is an important piece of information for the coastal management community; in coastal areas a change in elevation of a foot can make huge differences in habitats and human safety. For example, a difference in elevation of a couple centimeters in a low lying area (i.e. marshes) can control the limits of entire habitats. Similarly, dune elevations are a primary factor in coastal storm protection and areas with slightly (i.e. 2 feet) lower dune elevations can be at significantly higher risk of damage (Mihalasky et al., 2007).

New data sources and techniques have been developed in the past ten years and are now becoming available to meet these management needs. Each has their own set of cost, accuracy, and availability issues. This report is meant to compare and contrast several of these 'high spatial resolution' topographic data sets; each was collected using a different technology and utilized varying levels of post-processing. The high resolution designation is somewhat arbitrary but is based on the present level of readily available data, the National Elevation Dataset (NED). We are tentatively designating data collected/processed with a 5 meter grid resolution or better as a 'high resolution' data set. Each of the data sets being compared has been provided at a 5 meter resolution (grid size) or better.

Because small relative differences in topography can have large outcomes in the coastal zone, there has been an increased level of importance placed on collecting high resolution data. The advantages to high resolution data in the coastal zone have been well documented (NRC, 2004) and use of high resolution data is becoming a national trend. Some of the more prominent uses include water flow for drainage and wetlands, subsidence, emergency response, flood mapping, storm surge inundation, beach volume changes, and shoreline changes. Flood mapping is among the largest drivers of high-resolution data and for the flood studies to become more detailed and precise there needs to be an improvement in the topographic data (NRC, 2007), which is predominantly the 1/3 arc second (about 10 meter grid size) NED data sets.

There are numerous remote sensing technologies/sensors that exist for collecting high-spatial resolution topographic data. They include among others:

- Stereo Aerial Photography or Satellite Imagery
- Light Detection and Ranging (LiDAR)
- Interferometric Synthetic Aperture Radar (IfSAR)
- Airborne Digital Scanning Systems (pushbroom or whiskbroom)

Each technology has advantages and drawbacks that should be considered before utilizing the derived topographic data products for a specific application or model. This research evaluates the relative vertical accuracy and qualitative properties (e.g. vegetation removal, smoothing, and ease of visualization) of topographic data products acquired with Leica Geosystems Airborne Digital Scanner 40 (ADS40) and Intermap Technologies STAR-3i IfSAR sensor. The accuracy is measured in regards to a recently collected LiDAR data set that has passed several QA/QC processes for vertical accuracy and qualitative use.

The primary objective of this report is to better understand the strengths/limitations of the IfSAR and ADS40 topographic data in terms of information utilized by the coastal resource management community. Some of the more common uses of data sets for coastal management are flood mapping, development planning, wetland and littoral zone mapping, hazard and emergency planning, orthorectification of aerial images, and legal or jurisdictional mapping (NRC, 2004). Aspects common to each of these applications will be assessed along with the overall accuracies of the data. Relative cost information is provided, however, each mission or data set can have significantly different costs depending on a number of logistical factors.

Background

There are several types of data monikers or descriptions used to explain elevation products or surfaces; a quick review of the terminology is presented. The three terms often referred to when describing an elevation product are;

- a Digital Elevation Model (DEM),
- a Digital Terrain Model (DTM), and
- a Digital Surface Model (DSM).

The DEM term is typically used as an over-riding description of an elevation surface. It's often used in conjunction with a specific or additional description, such as a Bare Earth DEM or Topo-Bathy DEM, which provides further information. A DTM is commonly a bare-earth product, or one that is intended to provide a best representation of the terrain, and may incorporate ancillary information (i.e. breaklines) to better represent the surface. A DSM is a more loosely defined term and can include any type of product that represents a surface, whether bare-earth or the surface along the tops of trees. The products used in this analysis are all either bare-earth DEM's or DTM's.

Data Standards/Guidelines for Use in Coastal Management

Data standards for topographic data have been modified and improved as a result of the increased resolution datasets and their widespread application and use. There are four primary documents that have helped define the process of measuring, reporting, and defining the accuracy of elevation data. *Guidelines for Digital Elevation Data* (NDEP, 2004), *ASPRS Guidelines, Vertical Accuracy Reporting of Lidar Data* (ASPRS, 2004), and *National Standards for Spatial Data Accuracy* (FGDC, 1998) provide guidance and formulas for determining elevation data accuracy. *Guidance and Specifications for Flood Hazard Mapping Partners* by the Federal Emergency Management Agency (FEMA, 2003) draws on these other data standards documents and includes a definition of what types of data are needed for some specific flood mapping applications. That being said, there is still significant variation in the types of data that can and are being used; the notion of best-available data is still acceptable for many studies.

More important for the coastal management community is how the data can be used for multiple projects (NRC, 2004). For instance can a given data set be used to support flood mapping, shoreline definition, and mapping ecological habitats? This report begins to address this issue as a matter of data set comparison; however, guidance on use of high-resolution elevation data for specific uses is beyond the scope of this report. A full report on the important aspects of elevation data for more specific coastal management and research is planned. As such, this document is not intended to highlight all the pertinent aspects of the data, but rather to compare aspects of the overall datasets as they relate to issues that would be considered in the daily implementation of the data sets.

Applications of elevation data for coastal resource management range from coastal engineering and infrastructure to habitat mapping and biologic diversity (NRC, 2004). The level of accuracy and consistency is tied both to the use and scale at which it is used. Elevation data used in conjunction with models or engineering outputs have varying accuracy and 'operational' requirements. The following provides a general overview or 'order of magnitude' assessment of coastal topography data use, but it is understood that the specifics of a single project can be quite different than what is presented here.

Floodplain mapping in support of FEMA Digital Flood Insurance Rate Maps (DFIRMs) has a fairly tight requirement that the data meet a 'bare-earth accuracy' specification and an 'overall accuracy' specification that includes forested areas. In the terrain that is being examined (i.e. generally flat), the data should support creation of 2-foot contours to meet FEMA standards (FEMA, 2003). To create 2 foot contours the data should be accurate to about 1.2 feet at a 95% confidence (i.e. 95% of the data will be within 1.2 ft of actual elevation). Flood inundation studies for emergency management are also affected by the accuracies of the model runs as well as the elevation data that is used in conjunction with the outputs. To date, however, no specific accuracy values have been established. Future work is expected to provide general guidance on acceptable elevation accuracies.

Mapping applications have traditionally relied on contour information that was largely based on map scales (i.e. non-varying). As use of geographic information systems (GIS) and data availability has increased the intended application can now be used to define the properties of elevation data needed. There is now flexibility to incorporate varying data sources and define how they are manipulated to produce the desired information. Shoreline definition, for example, can require a high level of accuracy (i.e. order of centimeters) if the products are used in applications such as jurisdictional cases or permitting decisions (e.g. set-backs) but lower levels (i.e. 10's to 100's of centimeters) if used for habitat mapping.

Use of topography to improve ecological habitat mapping or for coastal planning requires a level of clean or consistent data with regards to the removal of vegetation as well as fairly tight horizontal resolution (i.e. grid size) for consistent definition of slope breaks (e.g. beginning of dune, edge of marsh, roadways, etc.). Absolute accuracy is somewhat less important since the feature attributes (i.e. size, shape) are the primary products; one to three meter accuracy is likely an acceptable accuracy. Visualization is also an important aspect, but requires no specific level of accuracy.

Orthorectification of aerial imagery is an ancillary operation often undertaken by a private firm, but the ability of a local or state coastal resource agency to supply a standard DEM provides a level of consistency among the varying base layers. Orthorectification does not typically require as high accuracies as engineering or mapping operations (i.e. order of meters) and vegetation removal is not as critical.

Permitting is an overarching activity that draws on all of the above. It is necessary to have accurate data as well as the ability to examine the information in a regional perspective. This requires a balance between dense data (LiDAR) and typical desktop computing limits. The ability to have a single surface portray both regional and local scale features accurately is an important consideration.

Technologies and Data

The three technologies examined were all collected from aircraft platforms. The collection dates varied over 2 years, from the middle of 2004 for IfSAR, late 2004 for the ADS40, to middle 2006 for the LiDAR data. The levels of processing on the 'raw' elevation data can vary depending on needs and costs and are quite commonly trade secrets; the specifics have not been provided to the CSC and will not be covered. An overview of the technologies, however, is presented; for more information on the techniques see:

- Intermap (http://www.intermap.com),
- LiDAR (http://www.csc.noaa.gov/crs/rs_apps/sensors/lidar.htm), and
- ADS40 (http://gis.leica-geosystems.com).

LiDAR

LiDAR is an active remote sensing technology that measures the time it takes for an emitted laser pulse of near infrared light to strike an object and return to the receiver. The location and elevation of the reflecting surface (e.g. Earth or trees) is derived using the measured pulse time and location of the LiDAR receiver, which is calculated using GPS and inertial measurement unit (IMU) technology (NRC, 2007). Mounted to an aircraft, LiDAR instruments can rapidly measure the Earth's surface and record up to five returns per pulse, at sampling rates greater than 100 kHz (i.e. 100,000 pulses per second). The resulting product is a densely spaced network of highly accurate geo-referenced elevation points – a point cloud – that can be used to generate 3-dimensional representations of the Earth's surface and its features. Typically LiDAR elevations are accurate to about 10 – 15 cm (RMSE) (about 6 inches) with horizontal accuracies better than 1 meter.

IfSAR - Intermap Technologies STAR IfSAR Sensor

Intermap's STAR Interferometric Synthetic Aperture Radar (IfSAR) technology is an aircraft-mounted sensor designed to measure surface elevation; however, instead of infrared wavelength energy the system emits and receives energy in the microwave (radio frequency) wavelength (NRC, 2007). Radar pulses are emitted towards the Earth's surface, and the return signals are received by two antennas that record the elevation (z) at specific coordinates (x, y). These data can be processed to produce topographic information in the form of orthorectified radar imagery (ORRI) that can be analyzed to produce DEMs (Intermap, 2004). IfSAR data has a resolution of about 4.5 meters and varying vertical accuracies based on surrounding features, but in open areas is on the order of 1 meter (RMSE) (about 3 feet) (NRC, 2007). Horizontal accuracies are on the order of 2 meters.

The data being examined is part of the Intermap NextMap® product line and is a standardized product with a moderate level of processing. Certain features such as major roads and streams are 'burned' or artificially added into the DEM from other outside sources to provide consistency but not necessarily accurate elevations. The Intermap handbook (Intermap, 2004) provides guidance on its use and areas (such as highly vegetated areas) that are not processed to provide terrain information. Higher levels of processing are available on the upper end products. A Coastal Services Center white-paper (CSC, 2006) is also available to highlight the uses and limitations of the data set.

The data set being used in this research is part of a CSC purchase that includes the Northeast Gulf of Mexico. This data set is not feely distributable; it is a licensed product that can be used by NOAA and State and local governments for coastal management issues. NextMap® data, which covers large areas of the US, can be purchased, however, from Intermap or their re-sellers.

Leica Geosystems ADS40 Sensor

Traditional photogrammetric methods can be used to create a DEM from two or more vertical aerial photographs of the same location captured from different viewing angles (i.e. stereo photography). Photogrammetric measurements are based upon the principle of triangulation, whereby intersecting lines in space are used to compute the 3-dimensional location of a point. The ADS40 is somewhat different in that it is a push-broom sensor that captures a continuous one pixel wide forward, downward, and backward looking scene from multiple angles. Each pixel line is georeferenced, which, taken together, provides the information needed to derive photogrammetric elevations (NRC, 2007). Photogrammetric elevations can be as accurate as LiDAR elevations; however, they are limited in areas of dense tree canopy and the point coverage is less dense.

The data for this comparison was collected in 2004; consequently, they are early examples of the process to derive elevation data from the ADS40 scanner. Future development of the technology is expected. The specific accuracies of the data vary between projects in response to the degree of processing. The data being used here has a stated vertical accuracy of 0.5 meters (RMSE) and a horizontal accuracy of 2 meters and were purchased (and freely available to the public) in conjunction with the Nature Conservancy to map a region of Northwest Florida.

Data

The data from each of the data sources is summarized below. This information comes from the associated metadata; order of magnitude costs are from the CSC at the time (year) of acquisition.

Topography Data Source	Date	Resolution Provided	Stated Accuracy (cm, RMSE)	Approximate Costs (sq mile)	Cost Notes
LiDAR	7/2006	0.75 m	13	$325	County size collection
IfSAR DTM	7/2004	4.5 m	100	$10	Licensed Data – limits to use
ADS40 DTM	12/2004	2 m	50	$75	Imagery is prime product; approx DTM portion only

Methods

The study site (Figure 1) is located in Walton County, Florida in an area known as the Northwest Florida Greenway. This area was flown with the ADS40 sensor in conjunction with the Nature Conservancy, LiDAR in conjunction with the Northwest Florida Water Management District, and IfSAR data was purchased for the coastal management community in the greater Northeast Gulf of Mexico. Two 10 km x 10 km areas (Figure 1, solid red boxes) have been chosen for the in-depth review of the data sources. These study tiles are located in a fairly small area where the three data sources overlap in coverage.

Figure 1. Study location in the Northwest Florida Greenway

The two primary areas of interest or sampling zones fall largely in a presently undeveloped area (The Greenway) on the northeast end of the Choctawhatchee Bay near the mouth/delta of the Choctawhatchee River (Figure 2). The study area is also close to the barrier island connector and thus has a potential for future development. It is dominated by cultivated cropland and evergreen forests with some scrub-shrub wetlands.

The terrain is gently rolling and modestly hilly for the coastal zone with elevations up to 60 meters above sea-level (northern study area). There are numerous incised streams with classic dendritic drainage patterns. The area is representative of the Southeastern United States coastal plain, and therefore the results are indicative only of this type terrain; for example, the results may be dramatically different in other coastal terrain (e.g. Coastal Maine or California).

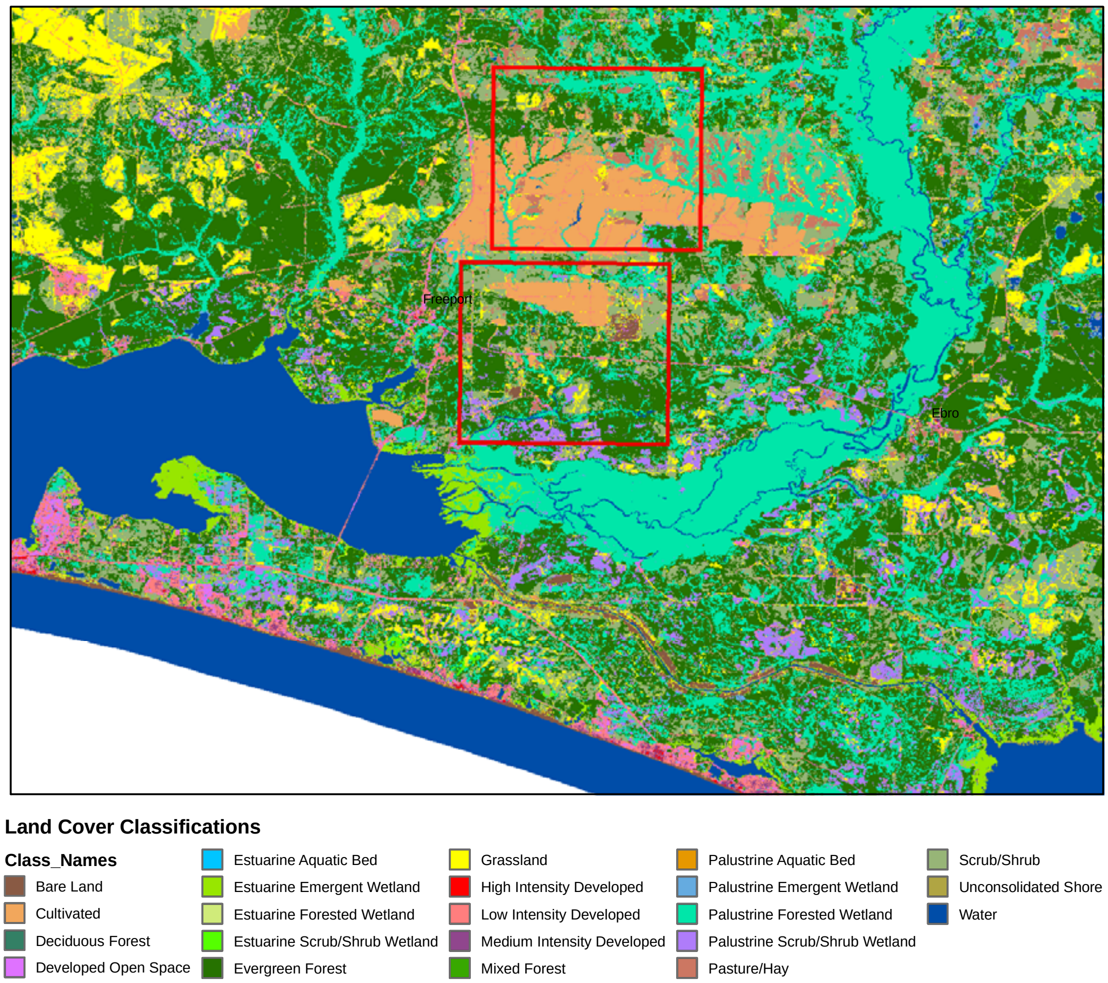


Figure 2. Land Cover classifications in the areas of interest from Coastal Change Analysis Program (CCAP) data

Elevation Surfaces

IfSAR and ADS40 elevation data were received from the vendors as gridded products; the LiDAR data were received as points. A gridded LiDAR elevation surface was created for consistent analysis. It should be noted that the LiDAR surface will likely be less accurate then points themselves; but as a matter of use, most operations require a gridded product.

IfSAR and ADS40

The IfSAR and ADS40 data were received as floating point binary rasters (.bil format for IfSAR and .flt format for ADS40) and were converted to ESRI ArcGrids. The delivered grid sizes were maintained at 4.6 meters for IfSAR and 2 meters for the ADS40. There was very little difference between the original floating point files and the grid format product. A profile between the two formats yielded a max difference of 3 cm with an average of 0.0 for the IfSAR grids. It is not entirely clear why there was any difference; there may have been some slight change in cell size when going from a decimal degree defined size to a linear unit.

LiDAR

The LiDAR data was received at a point spacing of about 0.7 meters; however, only the bare earth points were selected and in some areas this dramatically increased the point spacing (forests). Using only the bare earth points, a 2 meter grid was created with an Inverse Distance Weighted (IDW) routine. A point distance search radius of 5 meters was selected so that only areas with at least one point within a 5 meter radius were gridded. As a result, some of the water areas and forested locations were not surfaced and, subsequently, not used in the following analyses.

Point to Point Comparison (1D)

Check points or ground-truth points were surveyed for the LiDAR data validation. These highly accurate points were used to assign the accuracies of the LiDAR data set as a whole and include bare earth, urban, and obstructed (trees and shrubs) locations. Points provide a simple and intuitive way to assign an overall accuracy to the data sets.

The rigorous quality assessment of the LiDAR data provides a base elevation or ground truth data set with a known error from which the other data sets can be compared. Defined sample points based on land cover and imagery information within the area of investigation were used to calculate the relative accuracies of the IfSAR and ADS40 data sets in comparison to the LiDAR data.

Point locations were selected using high resolution aerial images (ADS40 RGB Images) and land cover classifications. Polygons of different land cover categories were created to extract a specific number of random points from each land cover using a point generator. Four land cover categories were chosen; bare earth (manicured lawns), cultivated fields and crops, evergreen forested, and palustrine forested wetlands. Palustrine forested wetlands were chosen since there is a significant portion of the area that is comprised of this class. Elevations were derived from the points in the different land cover classifications to define relative accuracies.

Statistics

The Root Mean Squared Error (RMSE) is a common way to report the error of elevation data as it measures the magnitude of the error, which includes the positive and negative values. The mean error value gives an overall shift, both magnitude and direction, of the data from the reference surface. The skewness is a measure of the asymmetry of the distribution of points. The Vertical Accuracy is a defined term; it is a measure of the data at the 95% confidence level, such that 95% of the elevation errors are less than the value. It can be computed from RMSE when the population is normally distributed and graphically derived when it is not. The RMSE is known for the LiDAR points in the various land cover classifications and is provided along with the results of the IfSAR and ADS40 elevation products.

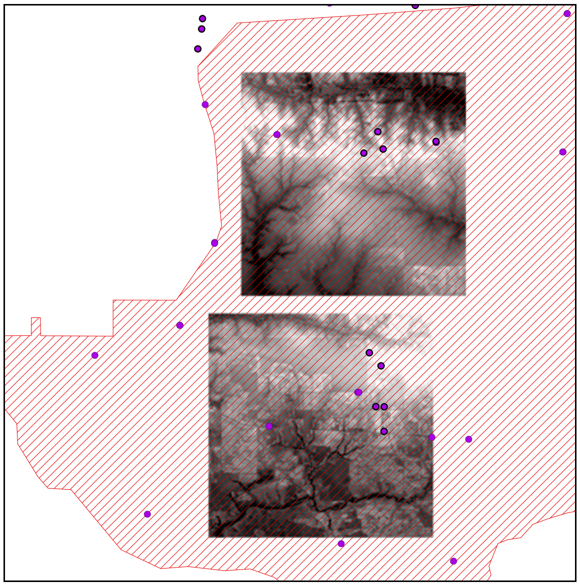


Figure 3. Location of surveyed ground truth points within the area of interest

Profile Comparisons (2D)

Profiles take points a step further and provide a denser means of looking at differences. Profiles are used in flood mapping, habitat delineation (e.g. wetlands, dunes) and also provide an easily portrayed way to highlight differences across specific features (e.g. cultivated field), between specific features (e.g. wetland to upland) or at the land-water interface. Profiles across the surfaces can provide quantitative information as well as a visual comparison (qualitative) and are used extensively to analyze surface data. They do not, however, provide the same level of information for statistical comparisons that can be achieved with point data because they do not sample the population (random, ordered), but rather a specific inter-related set in the population.

Surface to Surface Comparisons (3D)

Two surface comparison techniques were used to examine the surface variability. The first is semi-quantitative and highlights any patterns in surface departures; the second is qualitative and examines the different outputs when using a single modeled input. The first can be compared with ground-truth information or data sets (LiDAR) while the second can only provide a range of results as there is no accepted or measured value from which to define correctness.

Locations of Major Variability

When mapping on a large scale it is important to note where the variability is most prevalent; so, for example, are elevations in wetland areas with scrub/shrub consistently higher (vegetation not completely removed) in one product as compared to another. To show these variations, one data set (ADS40) was subtracted from the other (IfSAR) to highlight areas where the values are not close to zero. Use of previously defined point data helped to determine the quantitative difference, which is less important than the spatial patterns and how they relate to the land cover or ground features.

Modeled Output

Model outputs do not have 'correct' values so they can not be assigned errors, but they do have levels of agreement. So for example, if Surface B and the LiDAR surface have similar outputs, but Surface A has a dramatically different output, it is important to note the variation, whether correct or not. The use of surfaces in models is an important aspect and one that will only continue to grow. Surface 'agreements' were examined by comparing differences in inundation outputs by varying only the elevation surface coupled with otherwise identical SLOSH model outputs. The SLOSH outputs were chosen to examine the extent of inland flooding from Category 2 and Category 5 hurricanes.

Visualization and Product Generation (2D and 3D)

Visualization and product generation is an important but typically un-quantifiable aspect of surfaces. It is helpful if the user can discern what it is they are looking at, whether entirely correct or not. In the same vein, automated creation of mapping products, such as a shoreline or contour lines, is an important user aspect of the data. Contour lines, for example, should both accurately portray the elevation and provide an intuitive, clean representation of the data. This can be a compromise between accuracy and presentation.

Results

The results of specific analysis routines have been grouped by analysis type. Each provides a metric for the describing overall data set content and properties, as well as a specific analysis for uses requiring a single aspect of the data (i.e. modeling output). It is important to note that the collection dates varied. Every attempt was made to avoid analysis in locations with the appearance of active processes; however, there may be some time dependent variation that was not recognized.

Points

The points in differing land cover types (Figure 4) were defined using the land cover data from the Coastal Change Analysis Program (CCAP) and cross checking with the high resolution images. Strict guidelines were used to define the bare earth points (low grass surfaces) and there were few areas in the study that fell into this category; a total of 242 bare earth points were used. Much of the area consisted of crops and cultivated fields; 250 points in the cultivated fields/crop land cover classification were used. Two forested land cover categories were sampled – evergreen forests and palustrine forested wetlands. The evergreen category had 246 points and the palustrine forested wetland had 242 points. A total of 980 points were used in the analysis.

Error values for IfSAR and ADS40 at each point are based on the LiDAR derived elevation at the points. LiDAR data are generally a very good approximation of the ground surface; however, the error values do not necessarily indicate the real error between the earth surface and the measured surface. The LiDAR data does, however, have a known error to the earth surface (Table 1).

Table 1. LiDAR specifications for Walton County, Florida

Land Cover	(N)	RMSE (m)	Mean (m)	Median (m)	Std Dev (m)
All	99	0.15	0.01	-0.01	0.16
Open Terrain	20	0.13	-0.04	-0.05	0.12
Weeds/Crops	20	0.14	-0.06	-0.09	0.13
Scrub	20	0.16	0.07	0.08	0.14
Forest	19	0.21	0.06	0.02	0.21
Urban	20	0.13	0.01	0.03	0.13
Negative values denote values below earth surface					

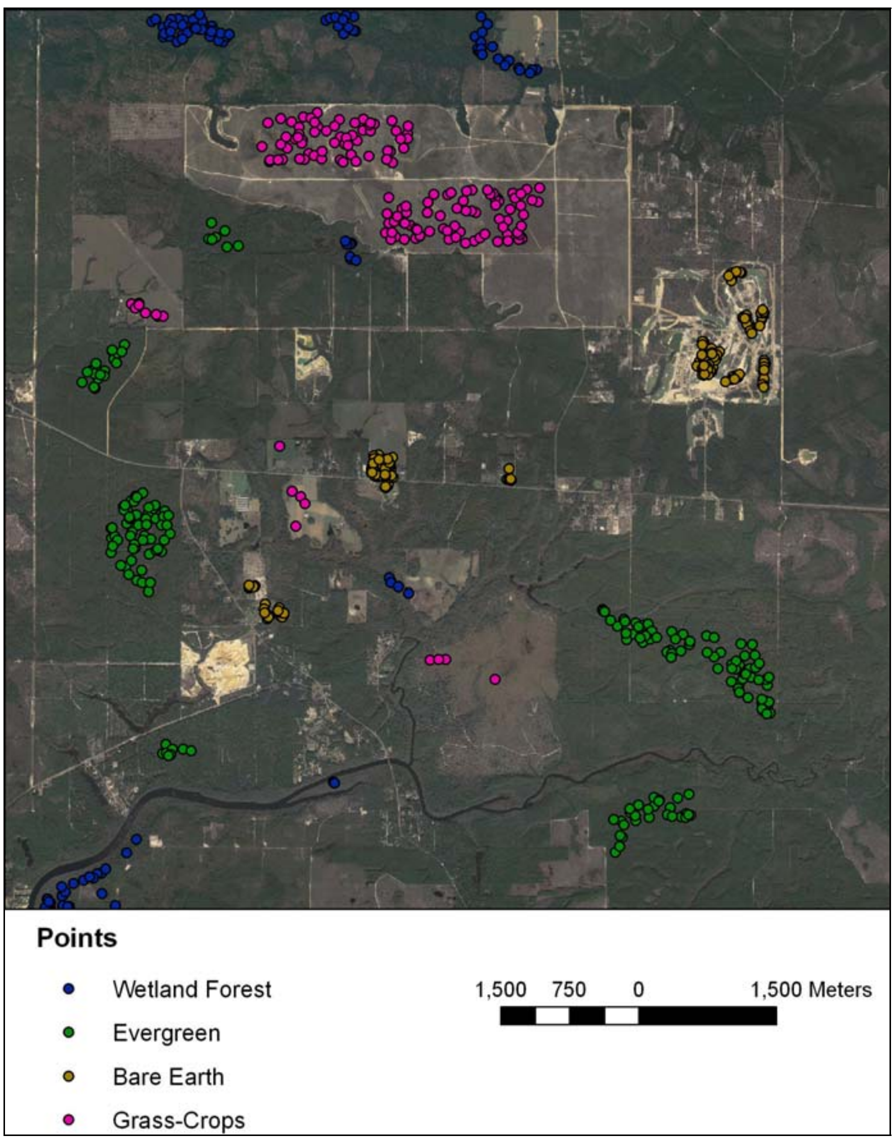


Figure 4. Point locations on southern tile

RMSE

The RMSE of the points is often used to describe the general state of the data set (Table 2). There is a clear difference between the IfSAR and ADS40 products; the IfSAR data have not been cleaned of vegetation in large stands of trees. Intermap's product literature and guidance clearly state these areas are not processed to remove vegetation. The ADS40 elevation grid, although less accurate in the non-vegetated land cover types, is consistent between the land cover groups. For comparison, the maximum errors for IfSAR and ADS40 in the Bare-earth category were 2.06 meters and 2.94 meters respectively.

Table 2. RMSE values

		RMSE (meters)	
Land Cover	**(N)**	**IfSAR**	**ADS40**
Bare Earth	242	0.38	1.68
Grass-Crops	250	0.33	1.50
Evergreen Forest	246	8.16	1.71
Palustrine Wetland Forest	242	8.89	1.93

Mean

The mean of the errors is a good measure of the data's overall biases (Table 3). The IfSAR has very little mean error in the non-vegetated classes but has a large mean error in the tree classes (probably the average height of the trees in meters). The ADS40 is much different, it has a nearly consistent error between classes and they are all above the LiDAR surface. It may be that a uniform elevation shift could be performed on the ADS40 data to create a better surface.

Table 3. Mean values

		Mean Error* (meters)	
Land Cover	**(N)**	**IfSAR**	**ADS40**
Bare Earth	242	-0.01	-1.47
Grass-Crops	250	0.08	-1.37
Evergreen Forest	246	-7.72	-0.94
Palustrine Wetland Forest	242	-8.41	-0.83

*negative values indicate mean above LiDAR

Accuracy

Accuracy is a subjective term for the 95% confidence level. It can be calculated from RMSE (RMSE x 1.96) when the data is normally distributed and graphically when not. The IfSAR was, generally, not normally distributed in the forested categories and the ADS40 was. As with RMSE, IfSAR meets the stated accuracy specifications (Intermap, 2004) in the low-vegetated classes, but captures trees in the other classes (Table 4). The ADS40 data can more easily be summed up as having a global vertical accuracy of about 3 meters. Consistency of data error can be a distinct advantage when using the data across multiple land cover types.

Table 4. Accuracy of tested data sources by land cover

		Accuracy* (meters)	
Land Cover	**(N)**	**IfSAR**	**ADS40**
Bare Earth	242	0.80	2.40
Grass-Crops	250	0.60	2.94
Evergreen Forest	246	15.99	3.35
Palustrine Wetland Forest	242	14.35	3.86

*computed using RMSE when skew less than 0.5

Point Data Summary

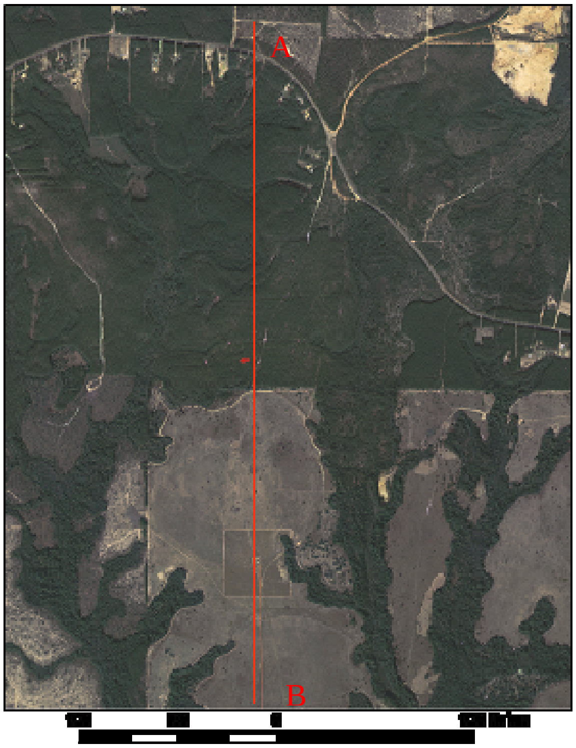
The results are fairly consistent across land cover categories with the low vegetation land cover showing better results. The IfSAR DTM includes, for the most part, the elevations at the tops of trees. The uniformity of the ADS40 across land covers is an important finding; the product and processing provides a reasonable amount of accuracy regardless of land cover.

It is important to note that all of the values are derived from a LiDAR surface, which itself has error and was flown about 2 years later than the IfSAR and ADS40. The temporal difference is an unquantifiable variable; the measured error (LiDAR RMSE; Table 1) is, however, roughly an order of magnitude lower than the two surfaces being compared and should have little effect on the overall accuracy statements.

Profiles

Profile locations were chosen to represent both single and multiple land covers. Eight topographic profiles (four per tile) of varying lengths were chosen to compare the elevation models and several profile examples are shown in Figure 5. A single water surface profile was also created to gauge the way it is represented in the ADS40 and IfSAR elevation models; no quantitative comparison with LiDAR surface was performed on this water surface profile. Three of the topographic profiles were created in single land cover categories (bare earth, cultivated, and roads/urban). The other topographic profiles were created to measure how small features and land cover classes appear.

The statistics of the analysis are less robust than the point data; however, the profile data is a point sub-type. Profile points are spaced at 4 meters and each has an elevation for the three data sources. The mean, standard deviation and RMSE was computed for each topographic profile.

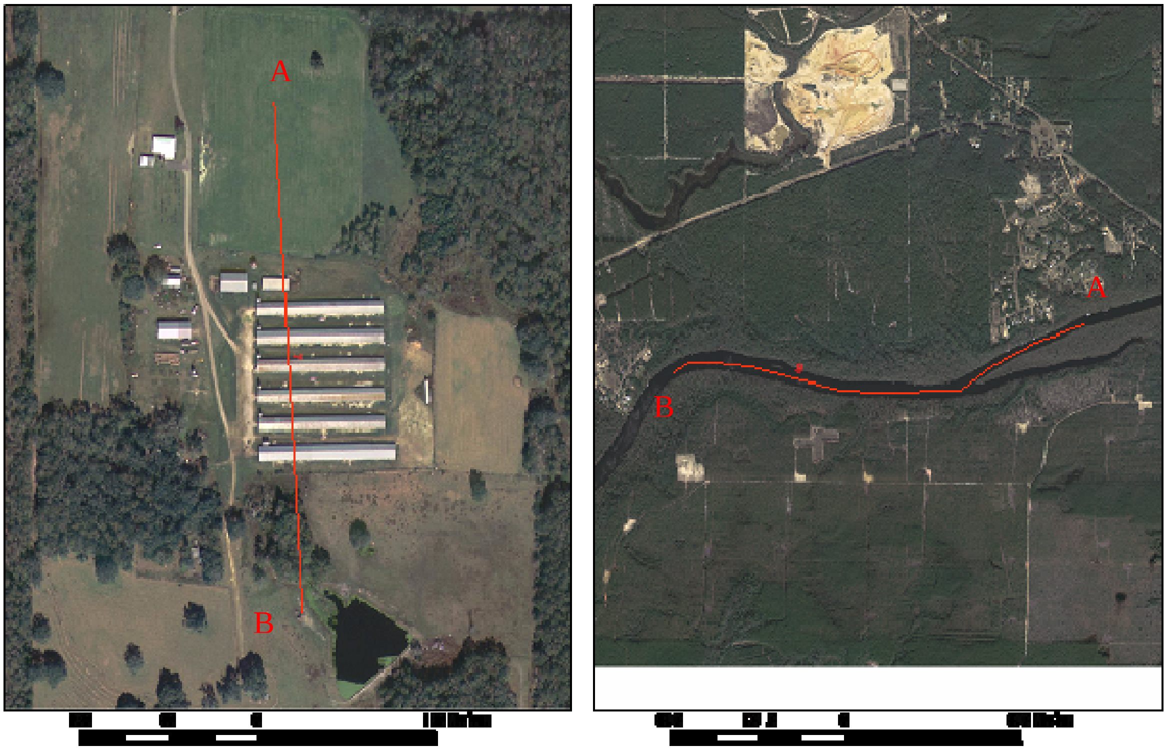


Profile 1

Profile 2

Profile 5

Profile 6

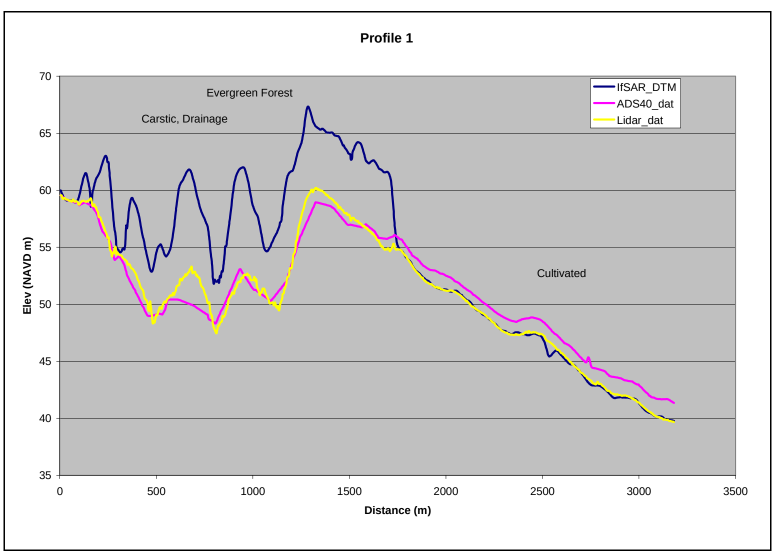


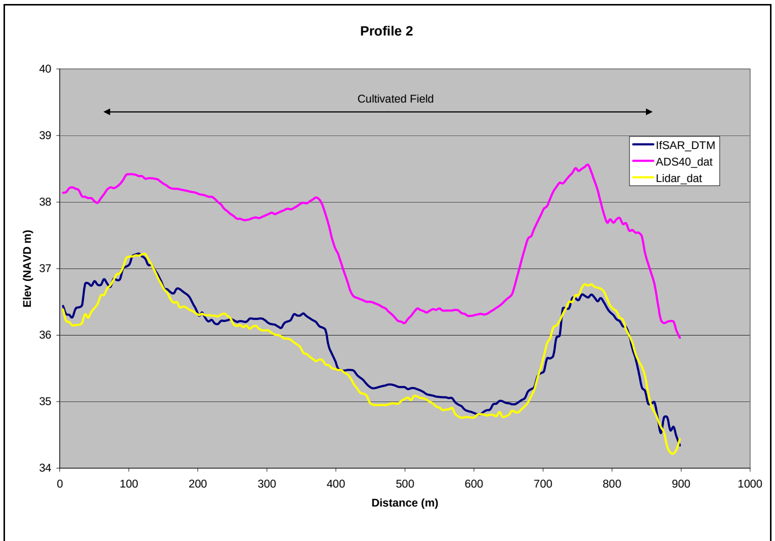
Profile 7 Stream profile

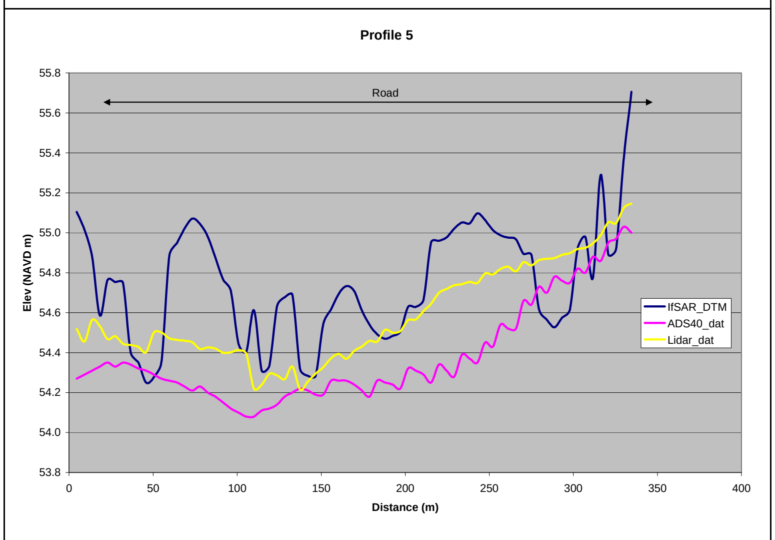
Figure 5. Example profile locations and measurement features

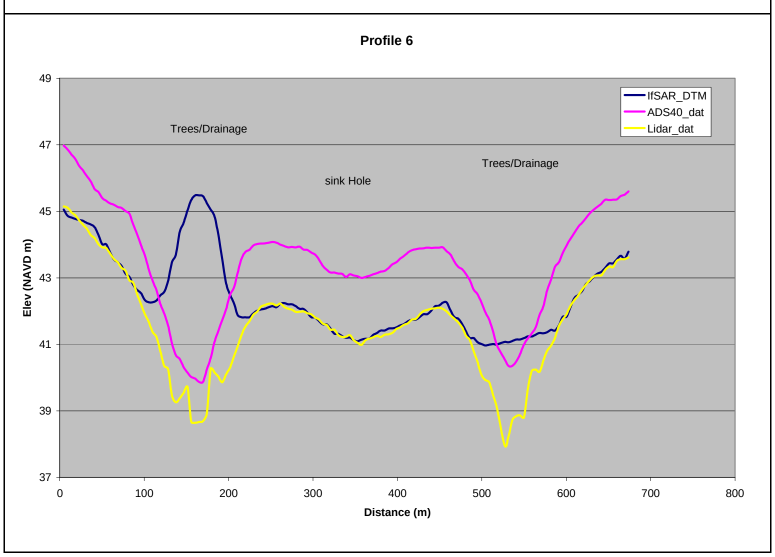
Profiles – Qualitative

Several representative profiles were chosen to show the general attributes of the elevation surfaces. The profiles provide a telling look at the surfaces, their strengths, and weaknesses. Profile numbers in the graphs (Figure 6) correspond to profiles in Figure 5.




Profile 2
Cultivated Field
IfSAR_DTM
ADS40_dat
Lidar_dat
Elev (NAVD m)
Distance (m)
40
39
38
37
36
35
34
0
100
200
300
400
500
600
700
800
900
1000


Profile 5
Road
IfSAR_DTM
ADS40_dat
Lidar_dat
Elev (NAVD m)
Distance (m)
55.8
55.6
55.4
55.2
55.0
54.8
54.6
54.4
54.2
54.0
53.8
0
50
100
150
200
250
300
350
400


Profile 6
Trees/Drainage
sink Hole
Trees/Drainage
IfSAR_DTM
ADS40_dat
Lidar_dat
Elev (NAVD m)
Distance (m)
49
47
45
43
41
39
37
0
100
200
300
400
500
600
700
800

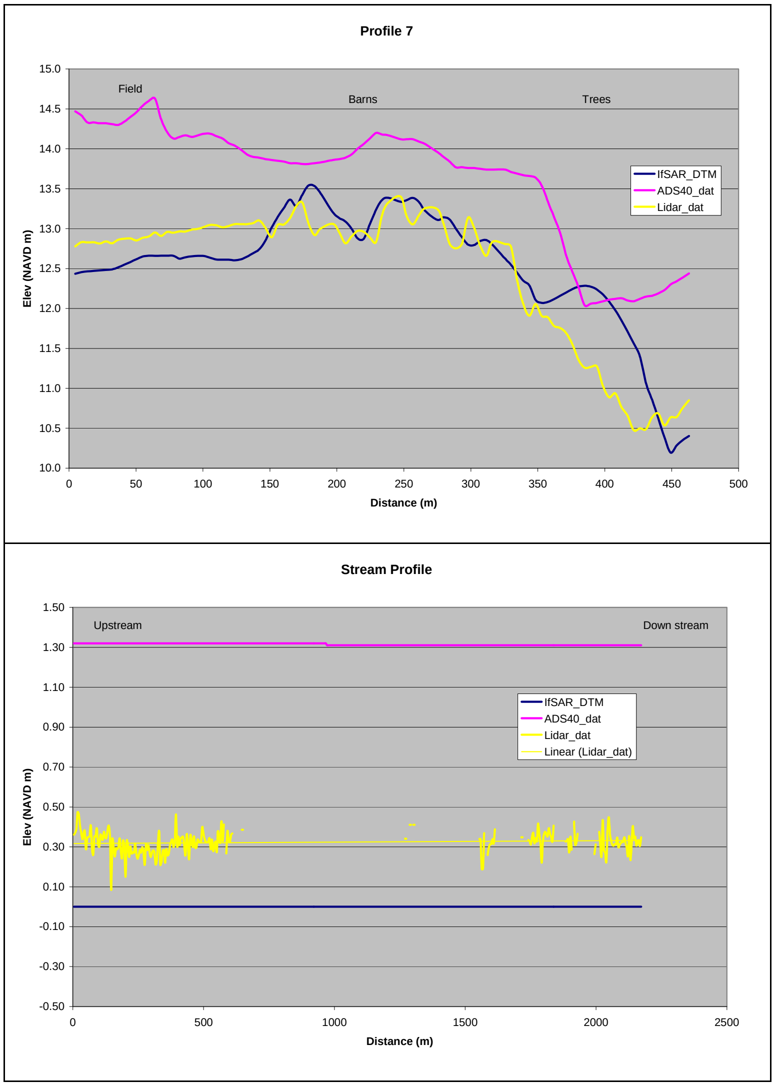


Figure 6. Cross-section views of example profiles from A to B (left to right)

The IfSAR surface is similar to the LiDAR reference surface in open areas (Profile 2) and areas with small patches of trees (Profile 7) and structures. In these areas it provides a realistic conveyance of the surface elevation. It also has a hard-coded (defaulted) flat water surface with an elevation similar to LiDAR (Stream Profile), which is, of course, dependent on water level during LiDAR collection. Areas with significant tree cover are obvious locations where the surfaces diverge; it is safe to say that the IfSAR is in error and is consistent with product specifications (Profile 1). The most problematic issue is in areas where there is drainage below trees (Profile 6). In these cases the IfSAR surface can convey an entirely different pattern; in the left side of Profile 6 there appears to be a mound when there is actually a ditch. Even when the trees are removed the underlying topography may not be captured as in the right side of Profile 6.

The general character of ADS40 elevation is similar to the findings in the point to point comparisons. It provides a consistent surface in all land covers but is not as accurate as IfSAR in the open terrains. Overall, the surface is typically a meter or two above the LiDAR surface (Profiles 2, 6, and 7) and may have a global bias as was shown in the point comparison results.   Road surfaces (Profile 5) are captured quite well, possibly as a result of the consistent spectral signature. The water surface is also hard coded but does show a slight gradient towards the down stream, which would help model water flow (hydrology).

Profiles - Quantitative

The profiles varied in regards to land cover classes and between ADS40 and IfSAR products. The profiles cross several land forms, land uses, and land covers so there are multiple variables. To help gauge the level of variability one may encounter using the different elevation products the profiles are being broken down into four categories:

- Low to non-vegetated areas such as roads, fields, or bare earth
- Small footprint vegetation/structures that would include a small stand of trees or houses
- Large footprint vegetation with simple morphology such as a tree-farm
- Large footprint vegetation with complex morphology such as a hilly or drainage riddled area

The profile values for IfSAR and ADS40 products are compared to the LiDAR profile data at the same points. Statistics for the 4 composite categories are provided (Table 5) to reduce the variability, cross check with the point data, and provide ancillary information to the point comparison. For example, Profile 7 is separated into three separate categories, each with a unique set of metrics.

Table 5. Quantitative results from profiles

Type of cover/terrain	N	RMSE (m)		Mean* (m)		Std Deviation (m)	
		IfSAR	ADS40	IfSAR	ADS40	IfSAR	ADS40
Low to Non Vegetated	878	0.36	1.60	-0.60	-1.47	0.36	0.64
Small Footprint Features	99	1.32	1.36	-0.82	-1.28	1.05	0.45
Large Footprint – Simple	95	7.05	2.06	-6.72	-2.02	2.12	0.38
Large Footprint - Complex	429	12.02	2.45	-5.02	0.19	2.60	1.14

* Negative values indicate that the elevations were above the LiDAR reference

The quantitative profile data is rather similar to the point data in terms of the vegetation vs. bare or low vegetation errors. IfSAR is about one meter more accurate in the areas with little vegetation but is virtually unusable in areas with trees. The ADS40, on the other hand, is consistent across the profiles with fairly low standard deviations. The two elevation data sets are similar in the measurement of small footprint features such as houses or small stands of trees and patchy shrub.

Surface Variations

Major Variability

The areas of major difference between the IfSAR and ADS40 digital elevation products are easily visualized (Figure 7). Clearly, the dominant difference lies in areas with significant vegetation. The surface itself is a good indication of vegetation heights as well as the difference in surface elevations.

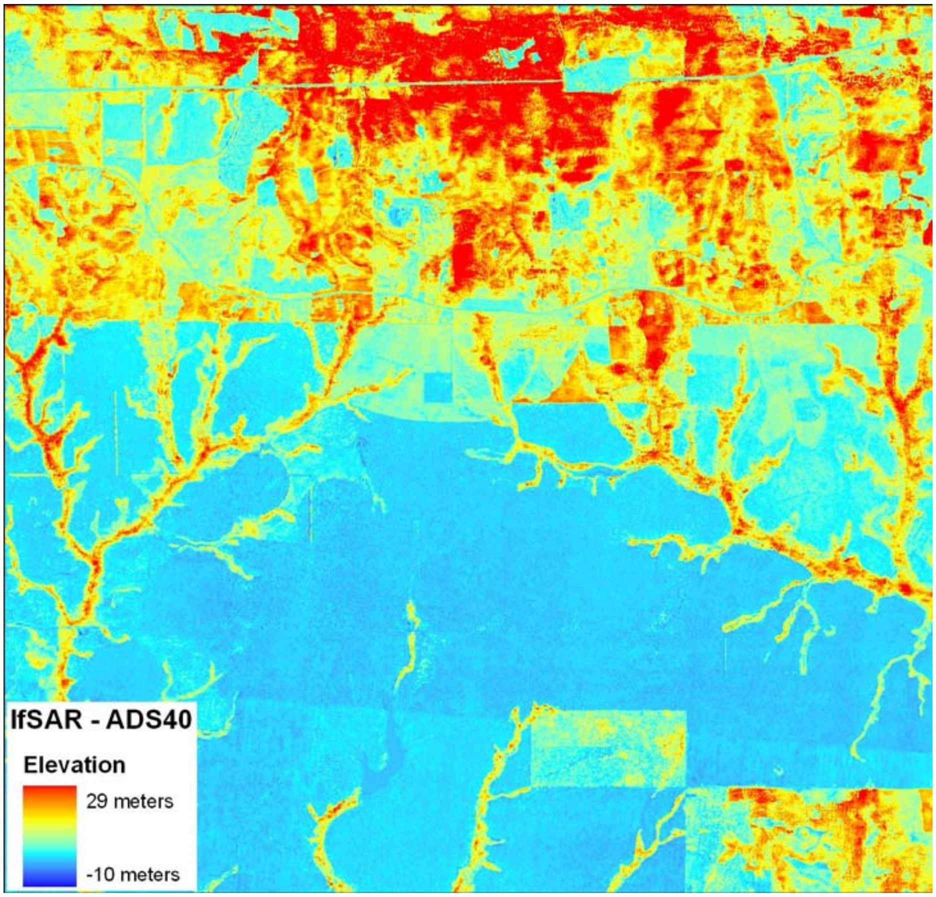


Figure 7. 3D visualization of the surface height variations (IfSAR minus ADS40 elevations) between the IfSAR and ADS40 elevation products

Upon closer inspection, there are areas or features that have been corrected in the IfSAR that are below trees (Figure 8). For example, note in Figure 8 some drainage areas (labeled with 'A') were 'processed' to remove trees even thought the adjacent areas were not. Elevation data in shrub land cover has also been processed in the IfSAR (B in middle of image) and it highlights the previously establish trend of the ADS40 data having higher elevations in areas of bare earth and where the IfSAR was processed to remove features. These findings suggest that IfSAR data is only applicable to land cover areas (Figure 2) with limited high vegetation and, thus, land cover data may provide a rapid method to detail the extent of its primary use. For example, polygons of the areas (within some project) that consist only of open or low vegetation land cover types may be used to define the 'appropriate use boundaries' of IfSAR data.

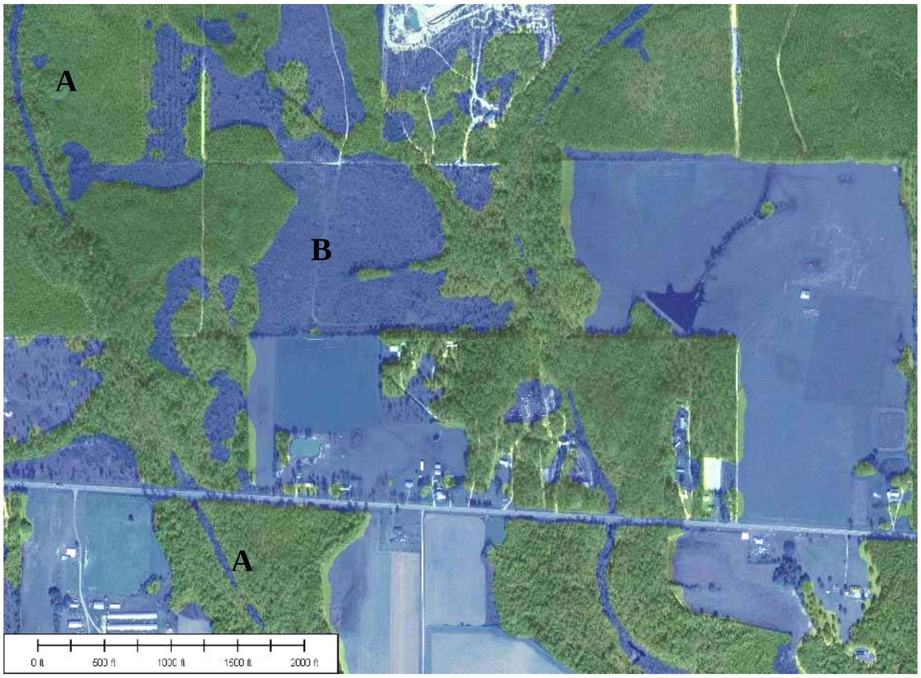


Figure 8. 3D variations between IfSAR and ADS40 - large scale; aerial image overlain on elevation difference; blue areas are where the IfSAR elevation is below the ADS40; green areas (vegetation) are where the IfSAR is higher.

Modeled Output

Elevation surfaces are increasingly used as model inputs. The specific aspects of the surface can have significant impacts on the model output. In low lying coastal areas elevation data are often used in inundation models. The test site is a good example of this. Each elevation data set was used with a modeled SLOSH (Sea Lake and Overland Surges from Hurricanes) output from a Category 2 and a Category 5 storm. The data sources were not used in the SLOSH model run; they were used to define the extent of inundation from the output surge information.

The Category 2 Hurricane (Figure 9) inundation extents are quite similar when using the ADS40 and LiDAR elevation data. The IfSAR data is much more constrained and reflects the presence of trees. The IfSAR does, however, predict up-stream extent of the surge, which is probably realistic and not portrayed by either the ADS40 or LiDAR data.

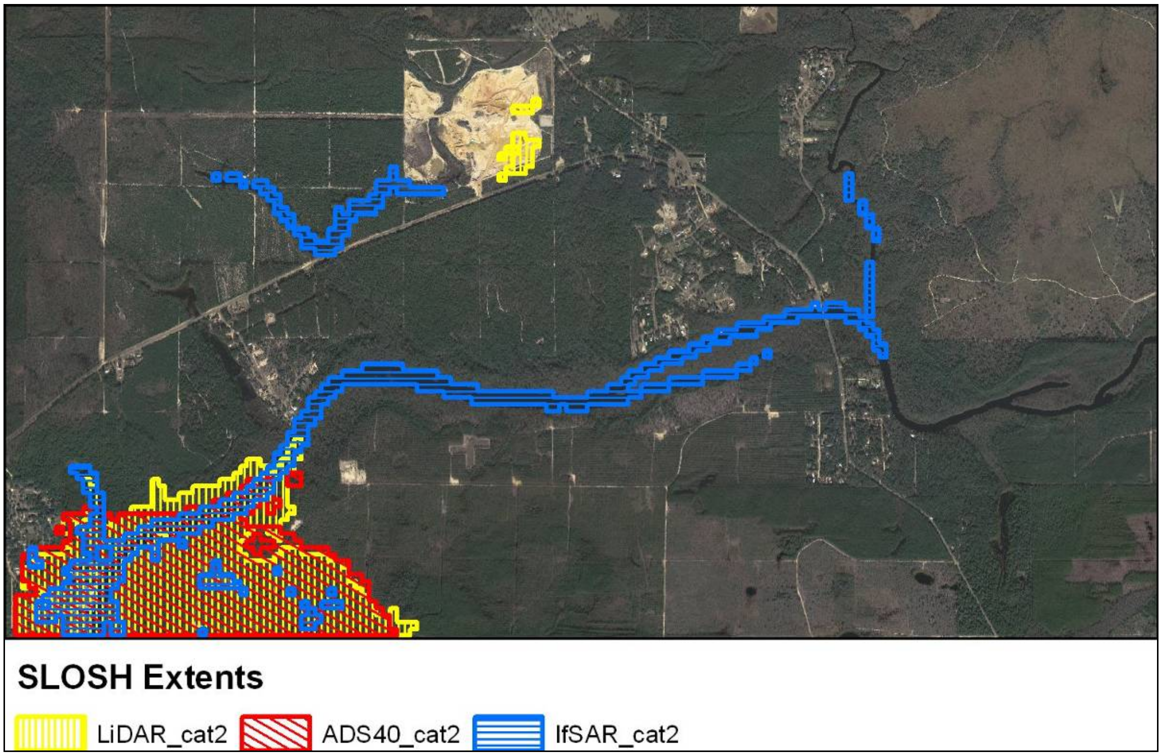


Figure 9. Category 2 inundation extents

The difference in the ‘developed’ or ‘open’ areas is less than the overall difference between the three model outputs (Figure 10). In these areas trees are either not present or have been removed from the IfSAR surface; the net effect is that the IfSAR does provide a similar output in terms of the structures or people that would potentially be impacted. The ADS40 and LiDAR are in very close agreement.

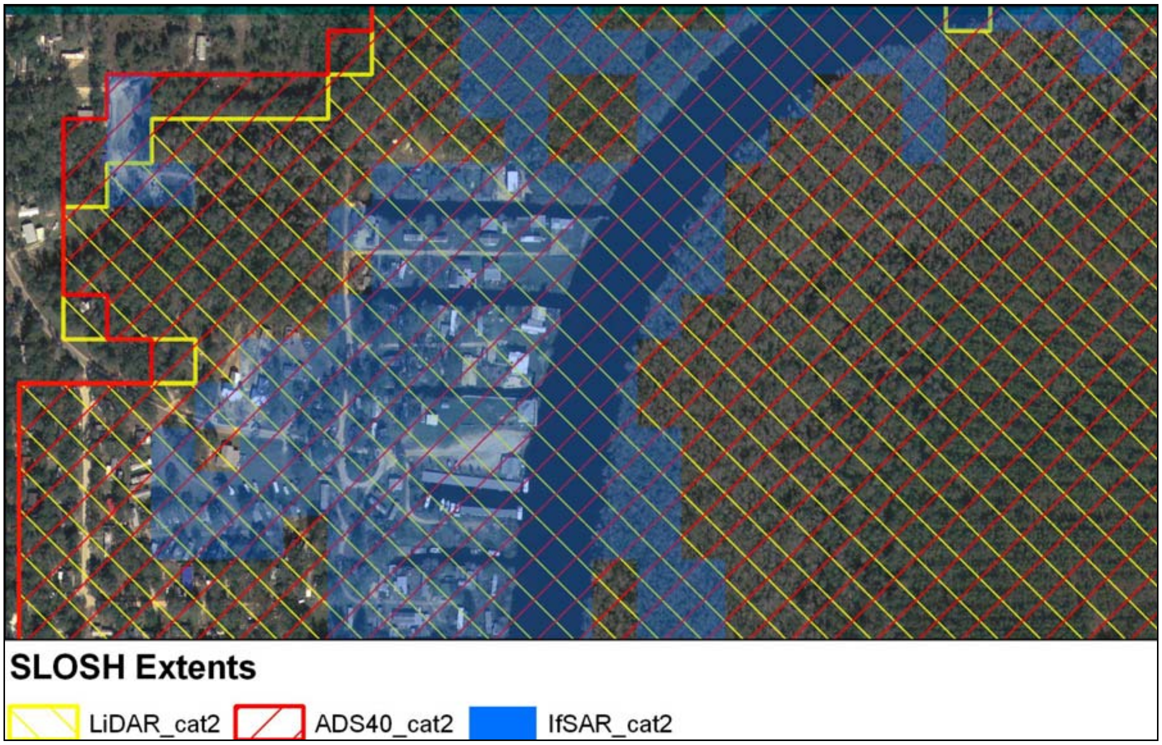


Figure 10. Close-up of inundation extents for category 2 hurricane

At the category 5 level (Figure 11), all of the elevation surfaces provide a similar extent of inundation. Again, the IfSAR data tend to under predict the extents in treed areas. The overall sensitivity, however, seems to suggest that the larger the flood simulation, the less sensitive the underlying elevation data are to the final result.

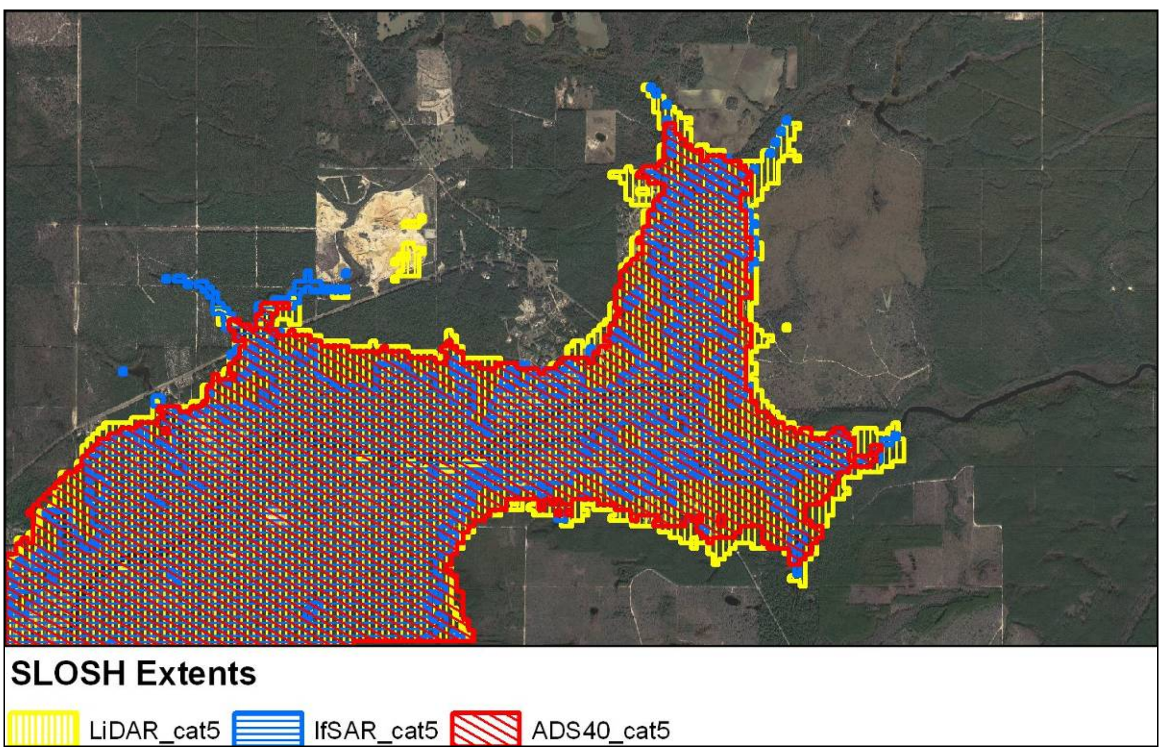


Figure 11. Category 5 inundation extents

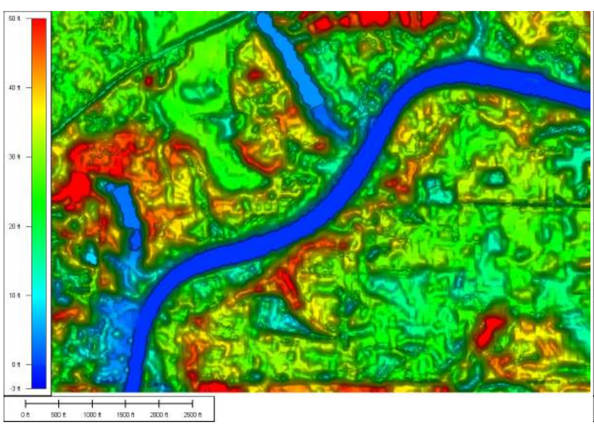
Visualization and Product Generation

Use of surface data for visualization is common and highlights a different aspect of the data. For 3D visualization the absolute accuracy is not as important as the level of detail or the perceived resolution (i.e. ability to discern separate features). For contours, a degree of smoothness is needed, which is also relevant to the 3D visualization requirements.

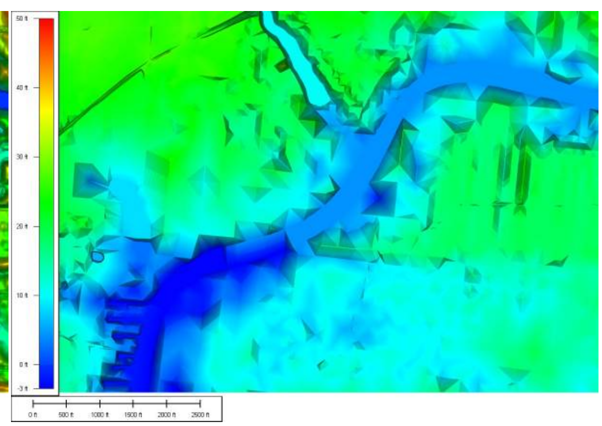
3D Views

There are several ways to visualize elevation (Figure 12) data in commonly used GIS software packages. Hill shading (simulating shadows) helps provide a 3D perspective in 2D space; a true 3D perspective can be created from the data by many GIS programs; and using a texture draped over the surface, such as an image, while in either a 2D (hill shade) or 3D environment is also a common feature of most higher-end GIS programs. Each helps the user visualize the terrain and extract information in a different way. Since this is a subjective test only the IfSAR and ADS40 elevation grids are compared.

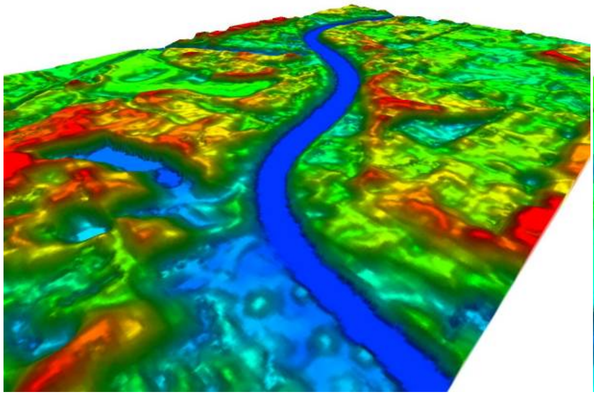
The clear difference in the hill shade and perspective views is, again, the inclusion of ‘tree elevations’ in the IfSAR product. While it is detrimental to the overall accuracy of the product, it is visually intuitive. The ADS40 suffers from a fundamentally lower resolution, even though provided at denser grid spacing. The addition of texture (aerial photo) to the ADS40 elevation grid helps remove some of the low resolution attributes and improves the usability. The texturized IfSAR surface is created from draping the aerial image over the elevation and is visually pleasing but does portray ‘incorrect’ information. For example, the river looks like it is incised into the terrain when in fact the banks are rather subtle.



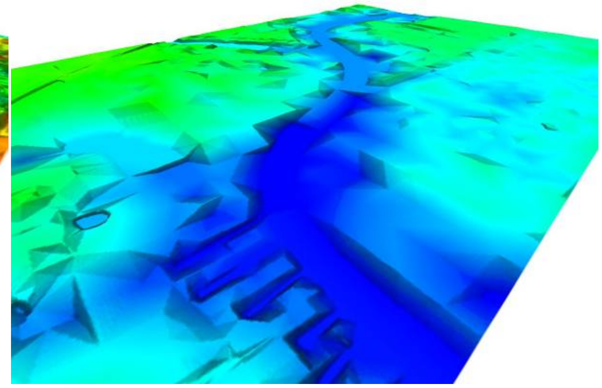
IfSAR 2D with hill shade



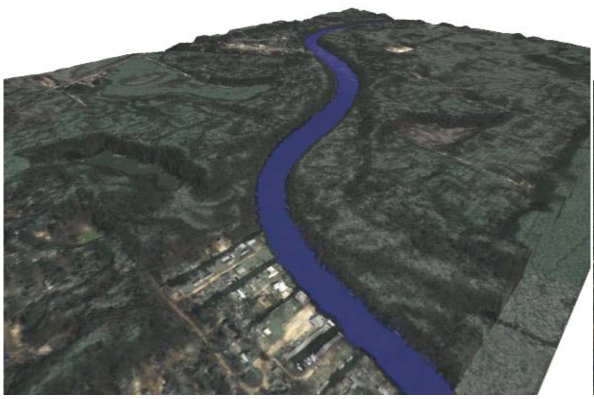
ADS40 2D with hill shade



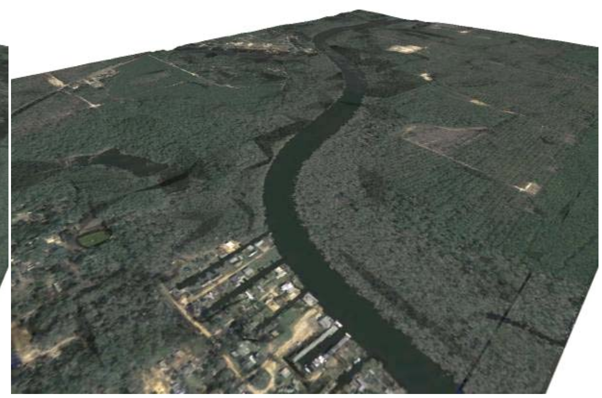
IfSAR in 3D perspective



ADS40 in 3D perspective



IfSAR in 3D texture

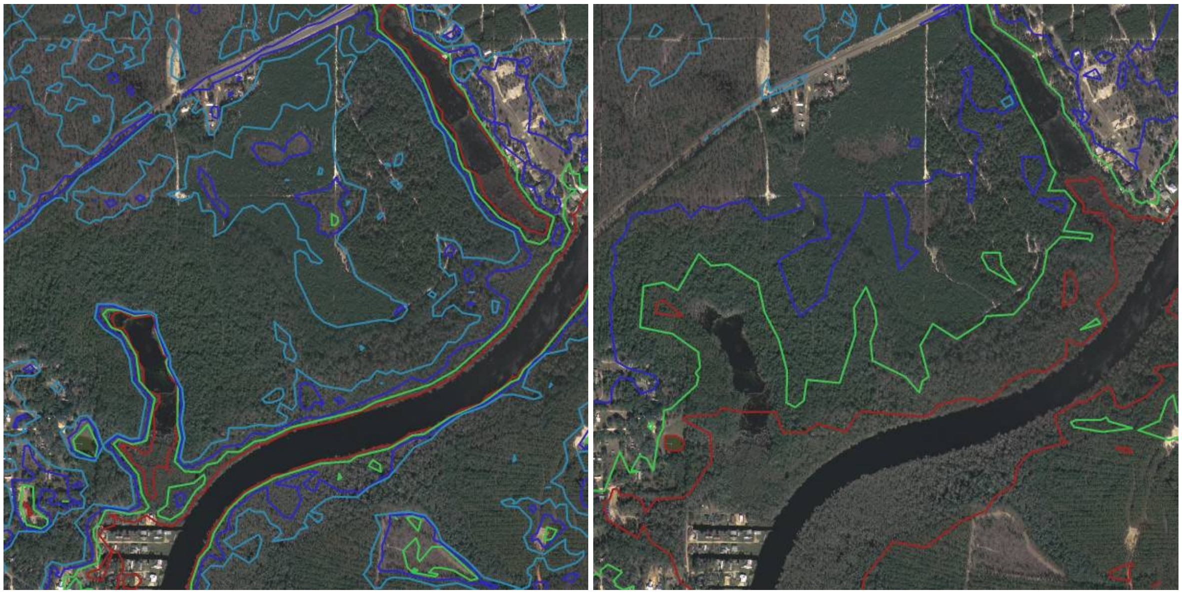


ADS40 in 3D texture

Figure 12. Visualization examples; color ramps (elevation colors) are the same for both IfSAR and ADS40 views

Contour Lines

Contours are used extensively to ‘visualize’ surfaces in 2D maps (Figure 13). They are cartographic features and often adjusted to provide a ‘realistic’ perspective. The generated contours from the IfSAR and ADS40 products have not been edited but represent a product that may be generated on the fly by a resource agency for field work or display to the public.



IfSAR generated contours ADS40 generated contours

Figure 13. Generated contours for southern area of study area

Obviously, there is a difference between values, and the ADS40 values are considered to be a more 'correct' portrayal of the terrain; any assumptions on water flow or terrain from the contours can not overlook this basic fact. As for the 3D visualization, however, the IfSAR surface provides a more intuitive (pleasing) portrayal of contours. Contours highlight the 'real' sampling intervals of the products and not simply the grid sizes that they were delivered in. Smooth contours typically represent tighter sample (grid size) spacing and a higher level of processing to generate a smooth (realistic) terrain.

Mean high water (MHW) is a specific contour that has many uses in the coastal community. An area in Bay County, Florida that contained coverage of both the ADS40 and IfSAR was selected to compare generated shorelines (Figure 14). There was no LiDAR data available in the area so the comparison is primarily qualitative. The MHW elevation (0.63 ft NAVD88) for the shoreline was taken from the Florida Land Boundary Information System (LABINS).

Figure 14. MHW contours; the green 'shoreline' is from the ADS40 DTM, the red is from the IfSAR DTM

There are three basic issues, one is similar to the contour examples above and includes the 'view-ability' of the shoreline, the second is the extent of the shoreline, and the last, but not least, is the exactness of the shoreline. Neither data set was clearly better in all three categories. The IfSAR shoreline is smoother and probably more accurately portrays the actual shoreline trend since the area has fairly simple morphology. In some locations the shorelines are almost co-located; in other areas there is over 100 ft of difference. In the areas with significant difference the ADS40 shoreline is erroneously landward and encroaches on the vegetation line (the aerial image is from the same date as the ADS40). The ADS40 derived shoreline does extend further upstream in the small bayou and, in that regard, is more reasonable since it appears that there is a significant tidal exchange (i.e. small ebb delta present). As a whole, based on the information from this one area, it appears the IfSAR data is more appropriate for generating shoreline information.

Conclusions

This paper provides a fairly wide range of analysis but does not cover all aspects of the surface characteristics. That said, the differences between the two primary surfaces being investigated are fairly consistent across the different comparisons. The general trend was brought out in the point to point analysis. The IfSAR surface is quite accurate in the non-vegetated areas and those with small features removed. The ADS40 data are less accurate in the non-vegetated areas but maintain consistency across land covers. In most cases the ADS40 overestimates the elevation and may be corrected with a global negative shift in elevation. For modeling the SLOSH output the ADS40 is very similar to LiDAR and may prove to be a cost effective alternative to LiDAR in some locations and in some coastal models. The IfSAR did not portray the same boundaries as the LiDAR but in areas without vegetation the IfSAR did more closely approximate the LiDAR/ADS40 boundaries. For visualization, the IfSAR is more intuitive than the ADS40 since it has a higher native resolution and, while lowering accuracy, does contain vegetation, which adds perspective. The actual sampling distance (native resolution) of the IfSAR data also facilitates better contour creation. Finally, the IfSAR appears to be a better elevation data source for constructing shorelines on open (i.e. no trees) shorelines, but there has been some processing that may hinder the correct inland extent of the shoreline where features (bridges) exist.

In summary, the ADS40 DTM is a more correct overall surface but suffers from some over-smoothing and a lower native resolution. The data was supplied in 2 m grids but is probably more consistent with 10 m grids. The IfSAR DTM is quite accurate in open areas but if significant vegetation is present the values are highly suspect and should not be used for any type of terrain determination. Despite these problems, both data sets can be effectively used if the inherent issues are understood; however, the as-tested ADS40 and IfSAR data sets, with the ‘base’ level of processing, can not alone provide the same level of overall applicability as LiDAR.

References

ASPRS, 2004. Guidelines for Vertical Accuracy Reporting for Lidar Data, American Society for Photogrammetry and Remote Sensing.

FEMA, 2003. Guidance for Aerial Mapping and Surveying, Appendix A in Guidelines and Specifications for Flood Mapping Partners, Federal Emergency Management Agency.

FGDC, 1998. National Standard for Spatial Data Accuracy in Geospatial Positioning Accuracy Standards, Federal Geographic Data Committee.

Intermap Technologies, Inc, 2004. Intermap Technologies Product Handbook and Quick Start Guide.

Mihalasky, M.J., Farrell, S.C., Barone, D.A., and Kock, R.V., 2007, Beach-Dune System Susceptibility Assessment, Northern Ocean County, New Jersey, Version 1.0: New Jersey Department of Environmental Protection, Office of Engineering and Construction, Bureau of Coastal Engineering, Toms River, New Jersey, one CD-ROM disk.

National Resource Council, 2007. Base Map Inputs for Floodplain Mapping, The National Academies Press, Washington, DC.

National Resource Council, 2004. A Geospatial Framework for the Coastal Zone, The National Academies Press, Washington, DC.

NDEP, 2004. Guidelines for Digital Elevation Data – Version 1, National Digital Elevation Program.