Change Detection Using Geospatial Analysis

By

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ABSTRACT

The ability to use remotely-sensed information that accurately characterizes the earth's surface can be a powerful capability during immediate response and longer term recovery from natural disasters. Four sensor systems are described and their ability to characterize terrain or bathymetry illustrates. Multi-Scan Sonar is a rapid, high-resolution sensor technology for underwater surveying. Through data processing developments, changes in bathymetry over time can be translated to volumetric changes at specific locations. Examples of LIDAR systems to measure ground surface conditions are presented. Results at a calibration test site in California are shown. The third sensor described is Interferometric Synthetic Aperture Radar (IFSAR). IFSAR has special characteristics applicable to rapid mapping of terrain features. Examples of data collection projects with IFSAR in the Sacramento Valley of California are presented. The fourth system described is SHOALS. SHOALS is a LIDAR-based, helicopter-mounted bathymetry and near-shore terrain measurement system. The application of this system to recovery efforts following Hurricane Opal in the western Florida panhandle are presented.

KEYWORDS: change detection; remote sensing; LIDAR; terrain characterization; IFSAR; multi-scan sensor; SHOALS; natural disaster recovery; bathymetry; rapid mapping.

1.0 INTRODUCTION

Over the last few years, a number of remote sensing systems have been developed and refined for specific applications ranging from environmental management to accurate mapping of floodplains. These evolving sensors and related data processing technology can have direct benefit to natural disaster response. Particularly if accurate rapid characterization of the terrain conditions is important as in an earthquake or landslide event. This paper describes four different systems that could be considered part of the remote sensing tool kit available to improve disaster response.

2.0 MULTIBEAM SONAR INTEGRATION METHODOLOGY

Multibeam sounding technology is a significant enhancement over single beam sounding in areas where 100% bottom coverage is necessary to determine detailed changes that may have occurred. In single beam sounding, a single sonar beam with a width from 3° to 8° is used to measure the depth. The area of bottom which is actually examined is very small and is dependent on the depth and the beam angle. Multibeam sounding allows the user to measure up to sixty depths along a narrow swath. The swath can cover from 90° to 120° beneath the hull of the survey vessel. These measurements are made up of 14 times per second, providing users with millions of soundings per day of survey. To provide 100% coverage, the spacing between survey lines is dependent upon the depth below the vessel and the width of the multibeam scan (Roper, 1999). Multibeam technology also provides an extremely valuable reconnaissance

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tool for performing real-time examinations of break walls, dikes, levees, bridges and other surfaces (Niles, A., 1997).

2.1 Enhancements in Multibeam Systems

The Topographic Engineering Center (TEC) began analyses of multibeam systems in 1989 with a test and evaluation of the Bathyscan system produced by Marconi, Ltd, of England. The Bathyscan was the first multibeam system developed for shallow water (under 100 feet) and featured some innovative beam forming and backscatter detection techniques (TEC Report 0008, 1992). However, the on-board data processor used late 1970's technology, which produced slow data logging and limited processing capabilities. Data editing was tedious. TEC recognized the need for more robust data processing and system calibration procedures, and 3-D graphic editing to enable effective analysis of tens or hundreds of thousands of data points (TEC Report 0012, 1992).

TEC performed a second test and analysis in 1992 of the German Atlas Fansweep system, installed and used by John E. Change and Associates (JECA), Inc., of Louisiana. The system performed well and demonstrated the ability to perform multibeam surveys to Corps Class I hydrographic survey accuracy standards. However, the JECA system used customized data collection and processing algorithms on a Unix data processor. During the tests, acoustics experts and system programmers were present to operate the system and make software modifications as needed. Although the system gave JECA impressive capability as a survey contractor, such expertise is not available on Corps vessels. Until the software was available on common processors, i.e., PC-based computers, multibeam technology did not appear to be feasible for Corps vessels nor a majority of contractor boats.

With such multibeam analyses experience, TEC participated with Coastal Oceanographics to develop standard procedures for multibeam operation, such as the patch test described in the following section. The timing of these developments was favorable, since PCs were becoming powerful enough to perform sophisticated processing yet retain an effective user interface (Training Course, 1996).

A multibeam file is loaded into the Coastal Oceanographics HYSWEEP program and then examined for trackline, heave-pitch-roll, gyro, tide and draft corrections included with the data. Sound velocity correction data can also be incorporated at this point to correct for "ray-bending" caused by variations in the speed of sound through the water column on sound waves which are not parallel to the bottom. Once these inputs are examined and verified, the user calculates a discrete X, Y, Z for each measurement (Training Notebook, 1995). The number of coordinates can be enormous, since nearly 1,000 depths per second are collected in the multbeam systems.

A three-dimensional editor is then used to examine the data and to eliminate questionable points. Users can manually edit the data, or use one of several automated filters available in the package. Figures 1 and 2 show examples of products using these systems at two Corps of Engineers projects. Once the data has been edited, users can save to either a binary X, Y, Z Beam Angle file or an ACSII XYZ file. These files can be reduced in the MAPPER program, which has gridding routines, or they can be read directly into he TIN MODEL program for surface generation and volume computations.

2.2 Channel Volume Determination from Multibeam Output

Triangulated Irregular Networks (TINs) are a relatively new method which can be used to calculate dredge volumes. In the TIN method, a terrain model is created through the triangulation of the three-dimensional spatial coordinates. The triangles in this model have no gap and do not overlap. TINs commonly use the Delaunay Principle, in which TIN is easily determined, is essentially unique, and avoids long, narrow triangles as much as possible. The Delaunay Principle requires that the circle circumscribed around any triangle in the TIN contains no data points in its interior (TEC Report, 1993), as illustrated in Figure 3.

Through comparison of TIN models, volumes of material can be determined. In the case of scour or shoaling applications, a design model of a channel, consisting of planar surfaces for the floor and slide slopes, can be compared with the TIN representing the actual terrain. The TIN triangles are projected onto the design surface, resulting in volume elements for the area covered by the TIN. Volumes above the design surface would represent material to be dredged, while volumes below the surface represent areas where no dredging is needed or areas for dredge disposal. Similarly, two TIN surfaces, perhaps representing before- and after-dredge terrain, could show actual material that has been dredged or provide accurate information about dynamic surface changes (Training Notebook, 1995).

The TIN method, which can be computationally intensive, has become feasible with the availability of modern processors. TIN volume routines are now found in many site design and sophisticated survey software packages. TINs offer the user flexibility in the collection of survey data, since the data need not be aligned along pre-determined cross-section or profile patterns. A detailed analysis of the use of TINs in dredge volume applications was performed by TEC, and is presented in the following section.

TINs were being used at TEC in the 1980s for military applications involving terrain analyses. Much of the original software was for the terrain specific uses. TEC scientists, in coordination with mathematics experts from the National Institute of Standards and Technology (NIST), pioneered applications such as terrain visualization, line-of-sight determination, and flow analyses using TIN methods. From these applications, there was also potential to compute volume changes in civil applications.

2.3 Advances in TIN Volume Determination

The Surveying Division at TEC, therefore, began a detailed analysis in 1991 of the TIN volume technique which is documented in (U.S. Army, 1993) ETL 1110-2-348, The Use of TINs for Dredged Material Volumes. The analysis, in which NIST participated, included a mathematical examination of the method, comparison with the conventional average-end-area (AEA) technique, and the use of several test data sets. The test sets consisted of real and fabricated data representing navigation channel surveys. Among the more significant results, TEC and NIST concluded the follow:

1) TIN methods are at least as accurate as, and usually more accurate than the AEA technique. In straight, uniform channels with terrain above the design surface, results are essentially identical. In cases where the terrain extends above and below the design surface, the AEA technique overestimates the volume by as much as 50% or more, whereas the TIN accuracy is not affected.

2) The TIN method uses the survey data more effectively and efficiently. Unlike the AEA method, the data points need not be aligned in parallel cross-sections and can be utilized in any pattern. Multibeam or multi-transducer survey data, which produces virtually total bottom coverage, can be effectively used only with the TIN method. The technique can also utilize combined cross-sectional and longitudinal data, which are recommended for single-transducer systems to perform consistency checks (see ETL 1110-2-348). Complete utilization of the survey data without realignment or shifting to a required pattern results in more accurate volume results.

3) For the TIN method, verification of results by a manual method is not feasible. In cases of disputes with dredging contractors, Corps of Engineers districts have cited the need to reproduce computed volumes using hand computation or manual drafting methods. Such capability has always been an advantage of the AEA method. However, summing thousands, or even millions of TIN prismoidal volume elements is essentially impossible. Verification

of TIN volumes will only be possible when the technique has gained general acceptance by Corps offices and dredging contractors, and analysis of the utilized TIN algorithm and the user procedures will provide sufficient verification of results. TEC's demonstration and publication of TIN analysis results has helped achieve that acceptance.

4) At the time of TEC's analyses, there were no commercially available TIN software packages specifically designed for dredge volume applications. For example, none of the routines enabled computation of volumes on a station-by-station basis. More significantly, channel designs that did not consist of a simple, straight configuration could be tedious and difficult to create, and different users might obtain different results. As a result of the TEC/ Coastal Oceanographics Construction Productivity Advancement Research (CPAR) program, a software package that solves these problems is now available.

Prior to the detailed analyses, TEC and NIST began to develop a TIN software package specifically for dredge volumes. At the time, no commercial TIN routines for general civil use existed and the software, developed with Civil Works Research and Development funds, when completed, was planned for distribution to all Corps offices. However, TIN volume routines began to appear in site design software, such as Intergraph's InRoads application. Therefore, TEC abandoned plans to distribute the TEC/NIST program, and instead used the software for benchmark testing and the analyses described above.

The TEC/NIST routine, in FORTRAN language, was written primarily by the NIST mathematicians who are regarded as authorities in TIN and grid terrain modeling. The software uses a Delaunay triangulation scheme and computes volumes relative to design surface. The software also permits the use of break lines, which can be used to control triangulation so that prominent features, such as peaks or ridges, are not blunted in the model. The software has no graphical user interface, and uses six to eight input files to define the terrain, design surface and certain tolerances (Niles, 1997).

2.4 Product Development for Dredging Applications

Through a partnership with Coastal Oceanographics, the TIN modeling capability was enhanced. Coastal Oceanographics used algorithms in the TEC TIN software to create an improved routine in HYPACK. The TEC algorithms offered a robust TIN generation module, but had a weak interface. Coastal Oceanographic developed new graphical interfaces and adapted the TIN routines to read coordinate files from HYPACK. Coastal Oceanographics also re-coded much of the computation sections and modified the data structures for faster and more efficient run time.

Once development of the TIN routine was complete, Coastal Oceanographics developed terrain visualization pack algorithms and dredge volume capabilities (Coastal Oceanographics, May 1995). A contour algorithm using B-spline smoothing was integrated, along with the flexibility of user-defined color designations. The result is compatibility to generate plan-view plots showing user-defined contour intervals or 3-D perspective plots showing realistic terrain undulations, as in Figure 5. For volume calculations, Coastal Oceanographics developed a channel template routine that enables the user to specify angular vertices and/or side slopes. Using this procedures, channel designs, which can include any combination of turns, wideners, depths and side-slopes; can be easily entered with the completed layout displayed for review. An application in North Carolina is shown in Figure 6.

3.0 GROUND SURFACE CHARACTERIZATION WITH LIDAR

LIDAR-topographic-mapping systems have considerable promise for producing high-resolution digital elevation models (DEMs). Satellite communications and GPS navigation systems are critical parts of LIDAR mapping systems. TEC has acquired multiple LIDAR-topographic-mapping data for the purpose of producing high-resolution DEMs. These will be evaluated and the results used to help develop criteria for future applications for floodplain mapping (Roper, June 1999).

However, processing of raw LIDAR data into useful and reliable DEMs is not yet mature. For example, unless exceptional effort is made to produce accurate LIDAR calibration, significant merging artifacts, and their associated errors, can occur. Another example is with merging artifacts that can presently be found in Houston Advanced Research Center (HARC) data.

Merging artifacts in LIDAR data are generally due to mis-calibration of the LIDAR sensor or residual GPS errors. Both kinds of errors can be described by mathematical models and corrected. Because data within overlap regions should match, the parameters of the mathematical models can be calculated. Subsequently, the data can be adjusted so that the errors are minimized. Least-squares estimation techniques have proven to be efficient, accurate, and reliable for this purpose,. The overall process is a least-squares model-based merging.

3.1 LIDAR Test Program in Lakewood, California

TEC is currently analyzing the LIDAR data sets from the FEMA-sponsored LIDAR collection in he Lakewood community, Los Angeles, California. This effort will undertake to develop appropriate mathematical models of merging errors. This LIDAR data set will be further developed to establish an automatic processing methodology, based on least-squares model-based merging, for adjusting the data to minimize merging errors. Sample collection images from Lakewood, California, are shown in Figures 7 and 8. There are clear differences in the sample images. Also, because of the high resolution, the data bases are time dependent,.

The LIDAR collection plan for the Lakewood, California, area includes a number of collection actions and products (Jorgensen, 1998). These include:

- Multiple LIDAR collections
- Long cross-flights over the AR zone
- Small mosaic area
- LIDAR-derived DEM at 3-meter postings
- X, Y, Z data from each LIDAR return
- LIDAR used to improve vertical accuracy of products

3.2 LIDAR Application for Levee Survey and Floodplain Mapping

Airborne LIDAR systems are capable of precise platform-to-ground ranging that produce decimeter-level height accuracy and meter-level post spacing topographic information of the surface. Some systems are capable of return pulse waveform digitization which provide precise ground surface AND vegetation height and volume measurements. Laser altimeter measurements are acquired along profiles or swaths up to a few hundred meters wide using small aircraft. These swaths could replace channel cross-sections (currently obtained via costly ground-based surveys) required by flood backwater models, which are used to predict floodplain extent.

A portion of the Jet Propulsion Laboratory (JPL) LIDAR data collection effort was over the levee system of the Sacramento River near Sacramento, California. This levee survey route is shown in Figure 9. A segment of this data set in the Meling Orange Grove area of California is shown in Figure 10. In the oral presentation of this paper, a 3-D dynamic fly-thru of this LIDAR data is shown. The fly-thru illustrates the ability to virtually enter the representation of the terrain and better understand the ground attributes.

4.0 INTERFEROMETRIC SYNTHETIC APERTURE RADAR (IFSAR) BASED FEATURE CLASSIFICATION MAPPING

The state of the art in exploiting interferometric synthetic aperture radar (IFSAR) for terrain information is advancing, and provides significant potential for use in floodplain mapping, and flood crisis support operations, as well as other situations. Unlike conventional SAR imagery, IFSAR data permits the generation of rectified synthetic aperture (SAR) images co-registered with an accurate terrain elevation file. This imagery can have an absolute geographic accuracy of 3 meters RMS or less. The rapidity with which IFSAR data can be collected and processed over wide areas, and the all-weather, day-night capability offers significant potential for providing direct support to crisis situations as well as enhancing the performance of spectrally based assistance (Roper, 1998). In addition, IFSAR terrain elevations can be employed to rectify hyperspectral and other imagery, allowing for the registration of radar and hyperspectral imagery in the ground plane thus providing an improved, rapid digital elevation model (DEM) product (Figure 11).

The Interferometric Synthetic Aperture Radar for Elevations (IFSARE) was a joint industry-government program between TEC, the National Aeronautics and Space Adminstration, JPL and the Environmental Research Institute of Michigan (ERIM). This research effort resulted in the fabrication of an interferometric radar system integrated with a GPS internal navigation system which was mounted on a Learjet 36A. The National Aeronautics and Space Administration joined with the Jet Propulsion Laboratory in California to develop the processing software and the ground-processing environment. This software and ground processing capability has now been transitioned to Intermap Technologies Company and is available for commercial applications (Roper, 1998).

This effort represents a convergence of technology development by a large number of investigators and a pressing need for low cost, fine resolution, highly accurate terrain elevations for a wide variety of applications. It is critically dependent on recently devised Global Positioning System (GPS) capabilities and the advent of high-speed data processing capabilities.

It is anticipated that significant IDSAR data collections will occur in the next few years. Ongoing activities within the Topographic Engineering Center are focused on quantifying the performance of IFSAR techniques. Additional work will also be underway for demonstrating the capability to merge radar and LIDAR data.

TEC has been actively involved with the development of a capability to create maps from IFSAR with a minimum of human intervention. Automated algorithms operate on the IFSAR data files to extract land use classification, DEM generation, and bald earth estimations. Hydrology, elevated structures, power lines, and road network data layers can also be automatically extracted. TEC continues to enhance these automated algorithms to assess floodplain soil roughness and extend structure identification capabilities. A series of map products will be produced with IFSAR-based technology for selected test areas.

4.1 Floodplain Mapping With IFSAR and LIDAR

The California Department of Conservation (CalDoC), Federal Emergency Management Agency (FEMA), and the Topographic Engineering Center (TEC) initiated a joint project to assess IFSAR and LIDAR for floodplain mapping for California in 1998. The project was funded by FEMA with TEC as the project manager and CalDoC providing user input. The planned project area is shown in Figure 12. The Star-3I X-band radar terrain mapping system, operated by Intermap, was used to acquire the IFSAR DEM data. The NASA Jet Propulsion Lab's multibeam laser altimetry system was used to collect the LIDAR data.

Coverage of the flood data set extends from north of Sacramento south to Fresno, following the Sacramento and San Joaquin Rivers. The project area covers about 17,000 square kilometers (or 6,564 square miles). Data was initially collected during September 1997 in two flights, one each for a northern and southern area. Strong turbulence caused the southern mission to be aborted; it was reflown in July 1998. Intermap began processing data in early 1998 and was completed by February 1999. JPL LIDAR data processing was completed in late 1998.

4.2 The Star-3I System

Traditional SAR systems in the past only gave two-dimensional views of the Earth and included geometric distortions inherent in slant range SAR data. IFSAR was developed to provide an elevation component to SAR imagery. The additional information from interferometric techniques provides a three-dimensional view of the Earth and removes some of the geometric distortions.

Three files are generated from the IFSAR instrument; a magnitude file, correlation file, and an elevation file. The magnitude file is a backscatter image that provides information on the shape of features, as well as terrain texture. The correlation image provides information on surface or volume backscatter. The elevation data, or DEM, provide information on terrain elevation and height of features. A sample DEM of the San Joaquin Valley is at Figure 11.

The STAR-3I system consists of two X-band radar antennas mounted in a model 36A Learjet. Data collection from the twin antennas occurs simultaneously. The set of acquired data are "interfered" by a digital correlation process to extract terrain height data that are used to geometrically correct the radar image. STAR-3I uses post-processed Differential GPS (DGPS) data, together with on-board, laser-based inertial measurement data, to obtain highly accurate positioning control. Terrain height and positioning data are enhanced by calibration of the baseline (the distance between the two antennas). The accuracy of the positioning information and calibration is such that no in-scene control points are required. The only requirement is that a ground-based GPS receiver must be located within 200 kilometers of the data collection site so that DGPS processing can take place (Jordan, 1998).

The STAR-3I is typically flown at 12,000 meters and requires a 10-kilometer wide swath of 2.5-meters resolution on the ground. The system has been designed to collect DEMs at a rate of 100 square kilometers per minute with 3-meter accuracy. Improved DEM accuracy is achieved by reducing the aircraft altitude to 6,000 meters, which reduced the swath width to six kilometers. At this low aircraft height, ground resolution stays the same; however, the signal-to-noise ration is one-half that of the higher altitude, thereby improving precision in the vertical direction.

5.0 RAPID BATHYMETRY MEASUREMENTS USING SHOALS

The Scanning Hydrographic Operational Airborne LIDAR System (SHOALS) system provides the capability for high spatial density utilizing state-of-the-art LIDAR technology consisting of a scanning laser transmitter/receiver that produces 200 soundings per second. SHOALS operates from a helicopter and includes a separate ground based data processing system. It is a highly mobile system capable of rapidly covering large areas. This unique capability produces a more comprehensive measurement of inlets and the adjacent near short bathymetry. Output from SHOALS is an accurate X, Y, and Z (position/depth) from each laser (Lillycrop, Parson, etal, 1994) sounding that is easily formatted for most data analysis software tools such as Geographic Information Systems (GIS), volumetric computations, or other contouring and mapping systems.

The SHOALS hydrographic survey system was developed for the U.S. Army Corps of Engineers (USACE) through a cost-shared project with the Canadian Department of Science, Industry, and Technology. Built by Optech, Inc., of Toronto, SHOALS consists of an airborne laser transmitter/receiver capable of measuring 200 soundings per second. The system operates from a Bell 212 helicopter, flying at an altitude of 200 – 1,000 m with a ground speed of 0 to 100 knots. The Bell 212 is provided by the National Oceanic and Atmospheric Administration (NOAA), Aircraft Operations Center, through a Memorandum of Agreement. The SHOALS systems also includes a ground-based data processing system for calculating accurate horizontal position and water depth. Data processing utilizes a state-of-the-art depth extraction algorithm developed by the NOAA National Ocean Service. The SHOALS system completed field tests in February 1994. John E. Chance and Associates operate and maintain the SHOALS system, providing survey services nationwide (Roper, 1996).

5.1 Operating Principle

SHOALS uses LIDAR technology with the reflective and transmissive properties of water and the sea floor to gather high-density survey data. When a light beam hits a column of water, part of the energy is reflected off the surface and the rest, unless absorbed by particles in he water, is transmitted through the column.

Using this principle, SHOALS fires a laser into the water, where a significant amount of energy from the infrared beam is reflected off the surface and detected by receivers in the helicopter. The blue-green laser penetrates the surface and reflects off the sea floor. A computer calculates the depth from the time interval between the two reflected energy readings (Figure 13).

As the beam travels through the water column and reflects off the ocean floor, scattering, absorption, and refraction all combine to limit the strength of the bottom, return as shown in Figure 14; and, therefore, the system's maximum detectable depth. This depth is a function of water clarity, generally about three times the Secchi depth.

A typical plot of these energy readings, or waveform as illustrated in Figure 15. This graph shows the reflection off the water surface—the left most peak—to be a very strong return, while the bottom return, or right most peak appears much weaker.

The performance specifications for the SHOALS system are shown in Table 1.

5.2 Application to Hurricane Opal Recovery

As an example of rapid bathymetry analysis during recovery from a natural disaster, SHOALS was mobilized to assess shoaling problems at East Pass following landfall of Hurricane Opal.

In mid-October 1995, Hurricane Opal made landfall along the western Florida panhandle. Cited as one of the worst storms to hit that part of Florida in the past decade, the area has suffered billions of dollars in damage. Opal resulted in significant bathymetric change along Florida's coastline causing hazardous shoal formations in federally maintained navigation channels as well as severe beach erosion. The U.S. Army Corps of Engineers was tasked with quickly and accurately assessing conditions after Hurricane Opal and opted to use the SHOALS system to map two critical areas, Panama City Beach and East Pass. The SHOALS system collects water depths remotely from an airborne platform using state-of-the-art LIDAR technology. Under typical operating conditions, the SHOALS system is capable of surveying at a rate of three square miles per hour (eight square kilometers per hour) with a spatial resolution of 13 feet square (four meters), therefore providing complete coverage in a short time.

5.2.1 Opal's Impact in East Pass Area

During the storm, a 14-ft surge pushed a tremendous amount of water through the inlet and across Santa Rosa Island into Choctawhatchee Bay. The elevated bay, augmented by fresh water runoff from the Choctawhatchee River basin, drained out to sea through East Pass. Considering the height of the surge, it is likely that there were tremendous currents in the inlet and between the jetties as the ebb jet escape out to the Gulf.

Most of the coastal damage from Opal was caused by storm surge rather than from wind. Three surge effects can be seen in an aerial photograph of East Pass taken just after landfall (Figure 16). First, a narrow over wash fan projects into East Pass near the west end of the highway bridge. This part of Santa Rosa Island was low and provided little resistance to over wash. Second, almost half of the west jetty was over washed, with sand being carried from Santa Rosa Island into the channel. Third, Norriego Point was breached just to the northwest of the condominiums. Mobile District engineers, who conducted a post-Opal reconnaissance, estimated that about 80 percent of the above-water portion of the point was removed (Robinson, L., November 1995).

5.2.2 SHOALS Survey at East Pass

On October 10, 1995, just one week after Opal, the SHOALS system was used to survey East Pass. The survey was completed in just over one hour covering about one square mile and recording nearly 200,000 individual depth readings (Morang, Irish, and Pope, 1996). The results of this survey are shown in Figure 17.

The SHOALS generated results were compared with project channel requirements to determine changed dredging requirements. There was also an evaluation of risk to project structure, particularly the jetties, as a result storm induced changes within the inlet system. This analysis included a comparison of the SHOALS data with a 1990 survey (Morang, Irish, and Pope, 1996). A graphic display of the differences is shown in Figure 18. This clearly shows a significant growth in the scour hole at the tip of the west jetty. If it continues to deepen, the stability of the jetty tip may be at risk. There was also an accumulation of sediment north of the spur jetty.

For this disaster response application, SHOALS proved to be a rapid, accurate survey tool for accessing post storm changes in bathymetry. This can assist in post storm recovery planning and better allocation of recovery assets, and lead to an improved understanding of sediment dynamics of inlet and coastal systems. The SHOALS system is moving toward full deployment for Corps of Engineers projects. For the last nine coastal inlet surveys conducted there was a savings of $300,000 over traditional methods and a better product produced. When fully deployed, savings in the range of over $3 million is expected annually at Corps of Engineers projects. Through cooperative project applications for NOAA, Navy, Coast Guard and others, the savings to Federal government could be significantly greater. Planned improvement will further expand SHOALS capability, accuracy, and timeliness.

5.0 CONCLUSIONS

The remote sensing systems presented have unique capabilities for the applications they were initially designed for,. As a result, each system may fill a different need for the emergency response manager. For underwater detection, and characterization of changes in low visibility water, the multibeam sonar system has application. In clear water for wide area, rapid assessment, the SHOALS system is a good choice. For small area, high-resolution terrain features and changes, the LIDAR system works well. Lastly, for rapid, wide area, elevation terrain characterization, IFSAR is a good choice. In each case, the capabilities represented provide new tools to the emergency manager for better disaster response, recovery, and preventative planning.

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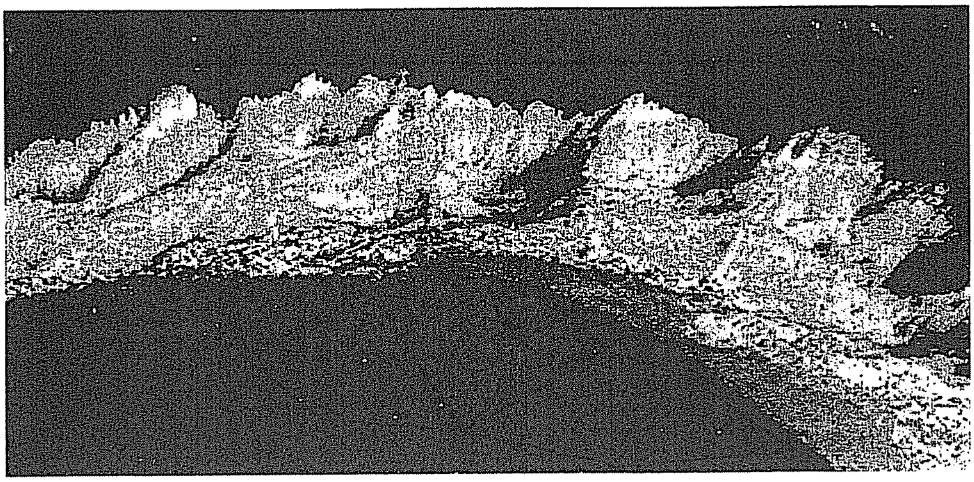

Figure 1: Bendway Weirs at Dogtooth Bend, Missouri

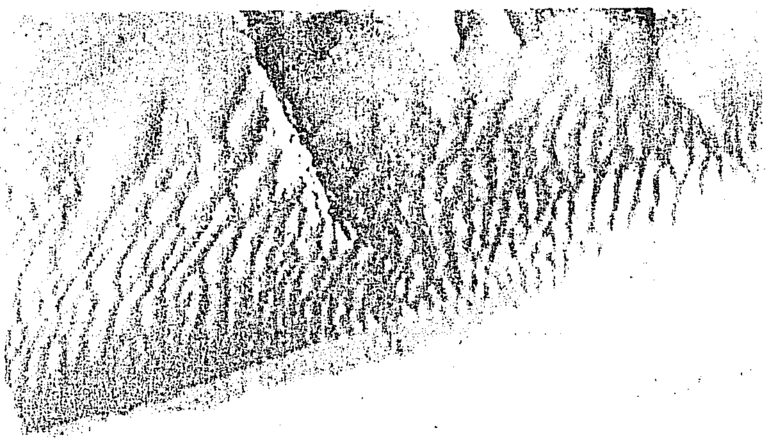

Figure 2: Sand Waves and Pipeline Crossings, Mississippi River

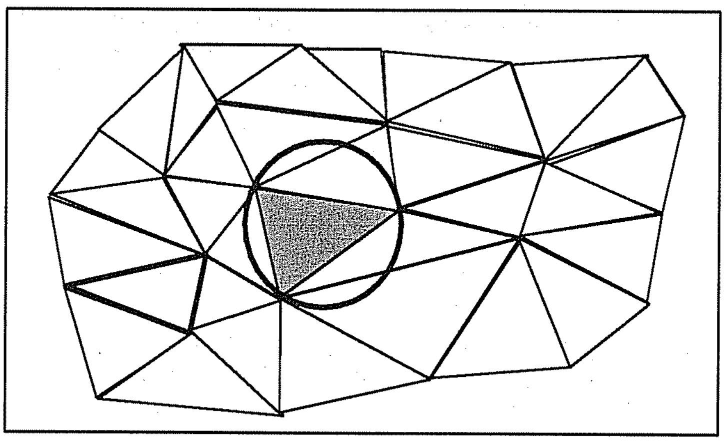

Figure 3: Delaunay TIN

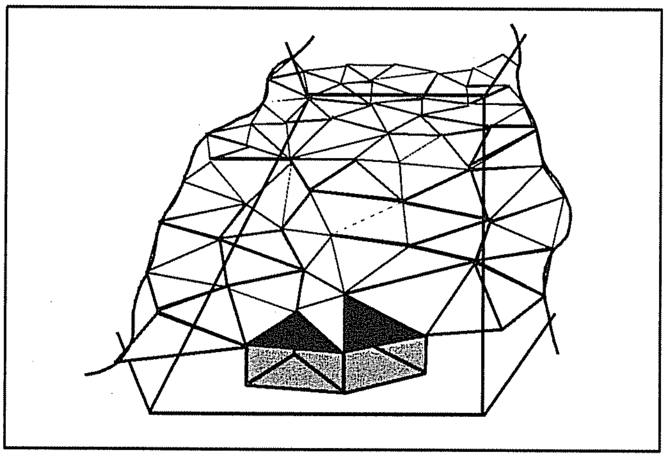

Figure 4: TIN Volume Determination

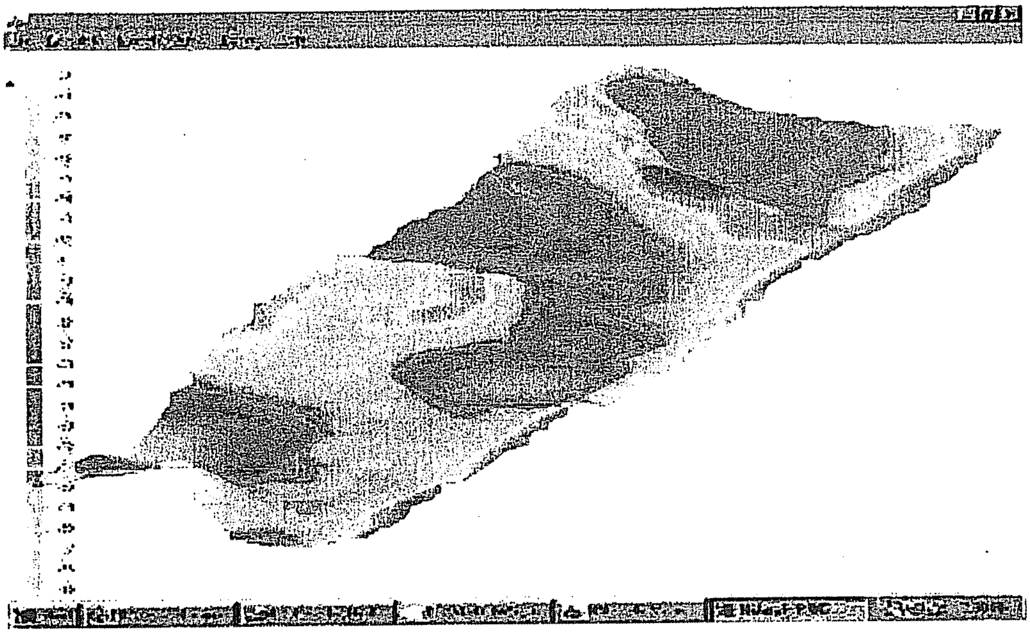

Figure 5: TIN Menu in HYPACK

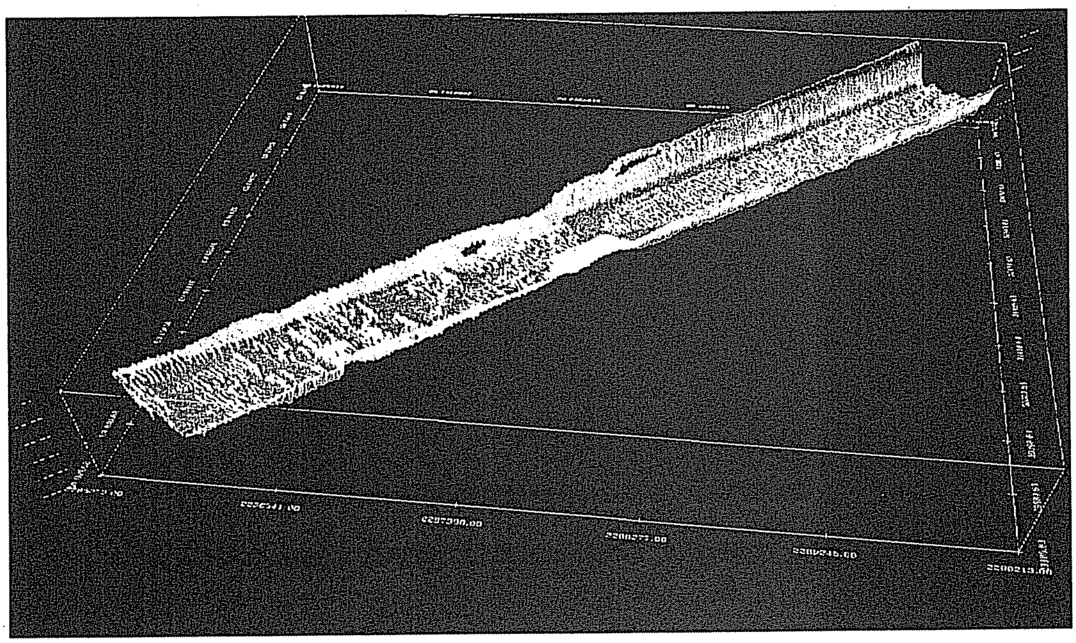

Figure 6: Wilmington Channel, Cape Fear River, NC

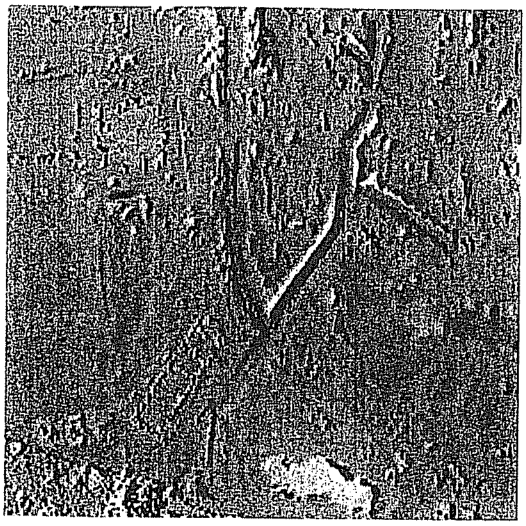

Figure 7: Lakewood, CA, Beginning of Circus Set Up

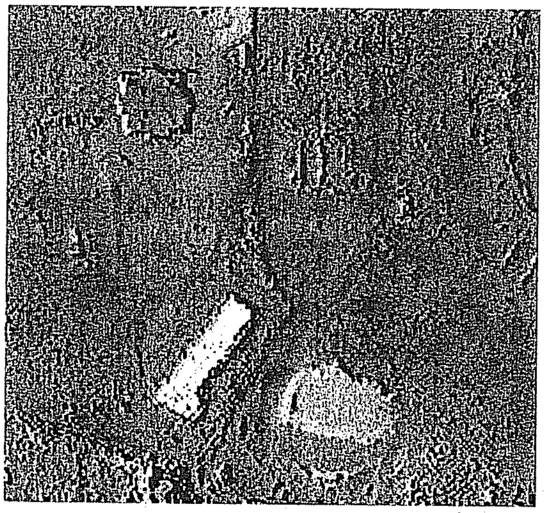

Figure 8: Lakewood, CA, with Tent & Other Attraction in Operation

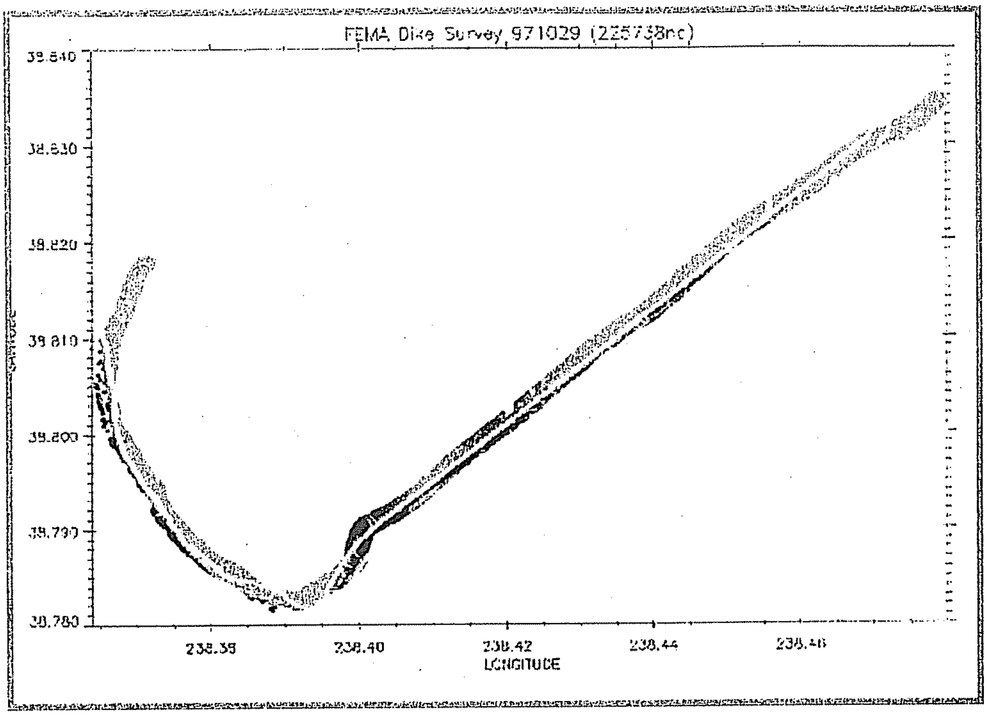

Figure 9: Portion of JPL LIDAR Collection Over Levees in the Sacramento Valley

Figure 10: DEM (Meling Orange Grove, CA)

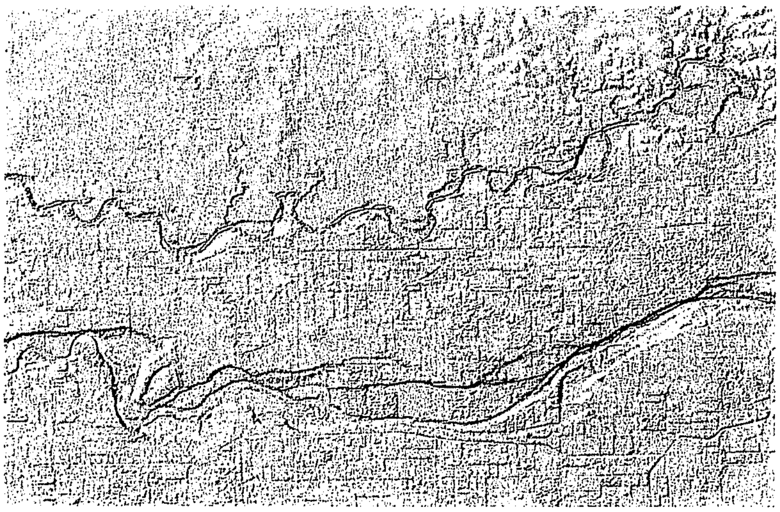

Figure 11: San Joaquin Valley IFSAR DEM

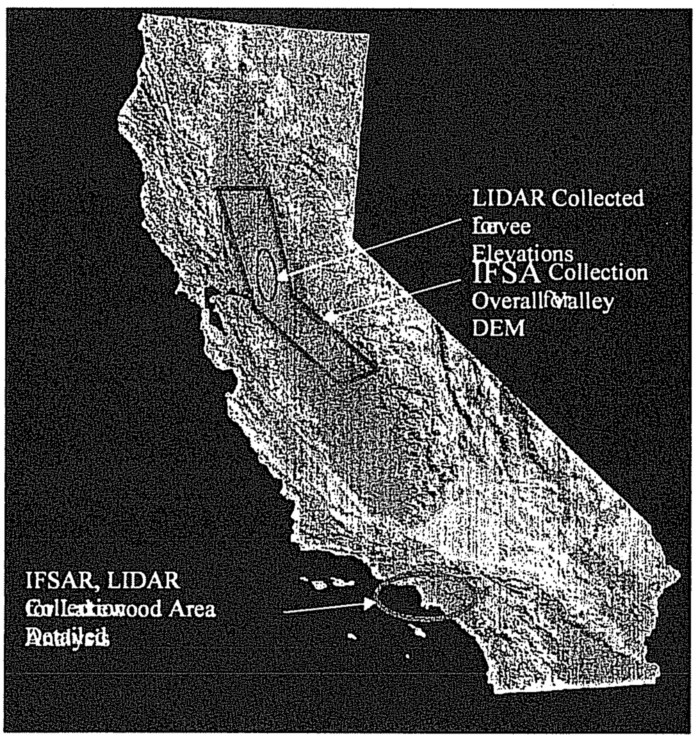

Figure 12: The California Test Areas

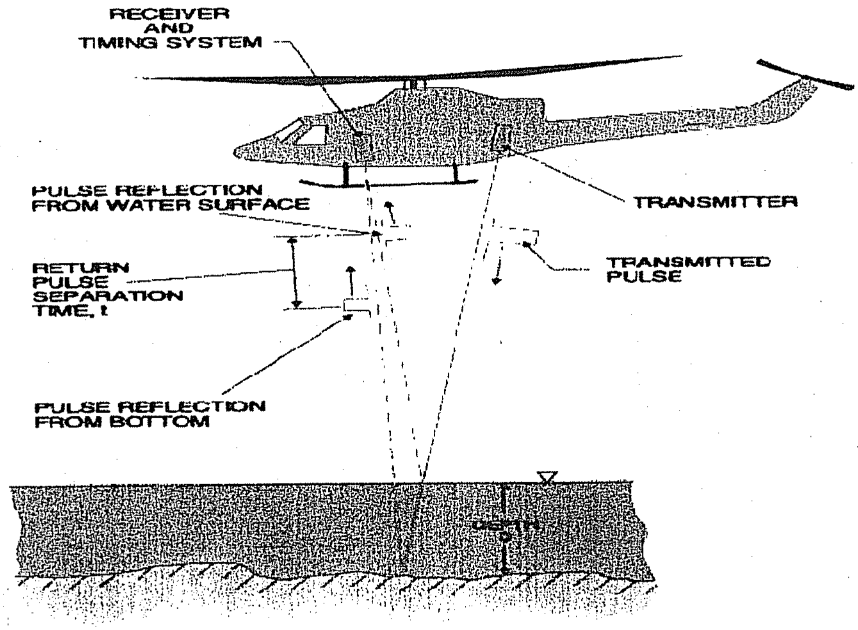

Figure 13: Overview of Operating Principles for SHOALS

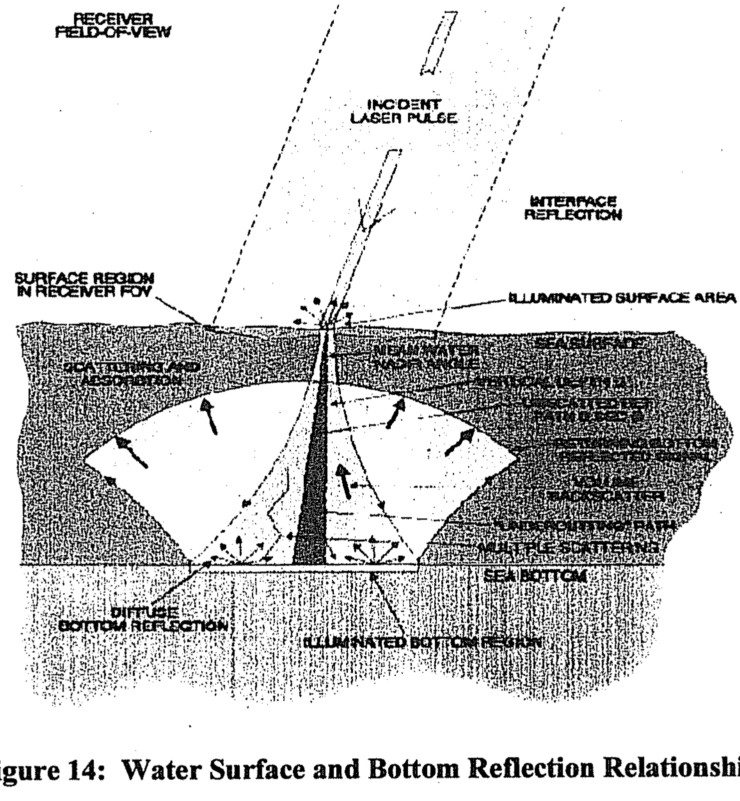

Figure 14: Water Surface and Bottom Reflection Relationships

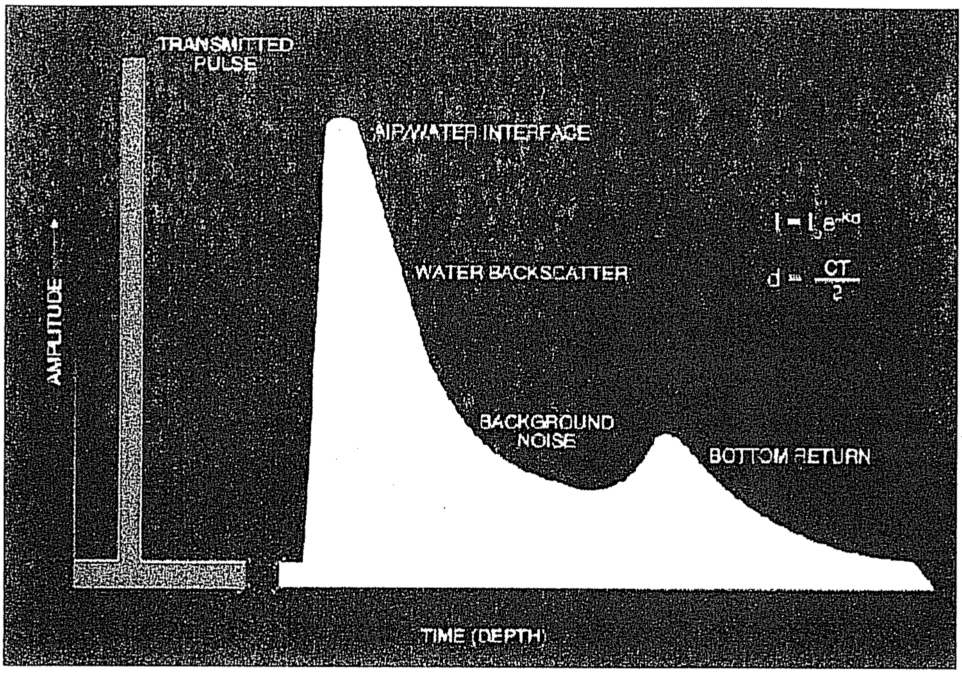

Figure 15: Typical Data Output Characteristics of SHOALS

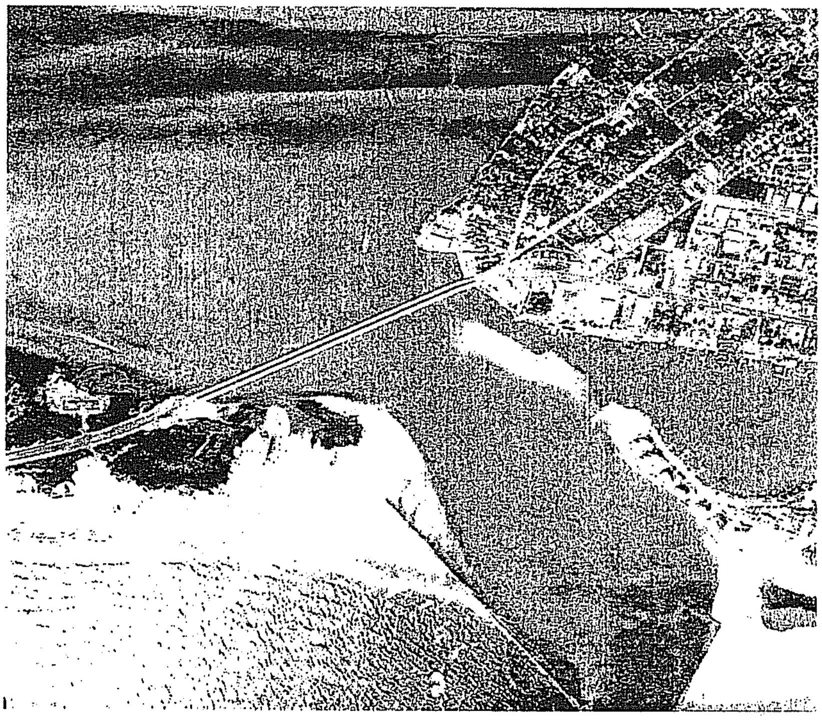

Figure 16: Aerial Photograph of East Pass After Hurricane Opal (north is to the top)

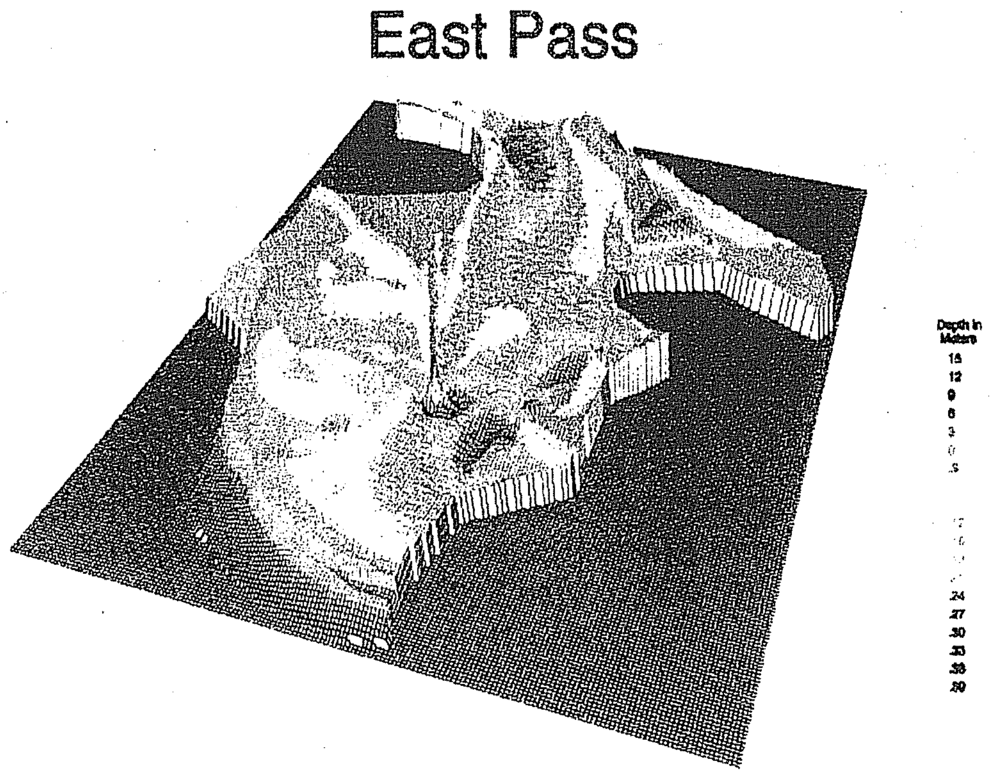

Figure 17: Elevation Plot of SHOALS Data at East Pass, Florida

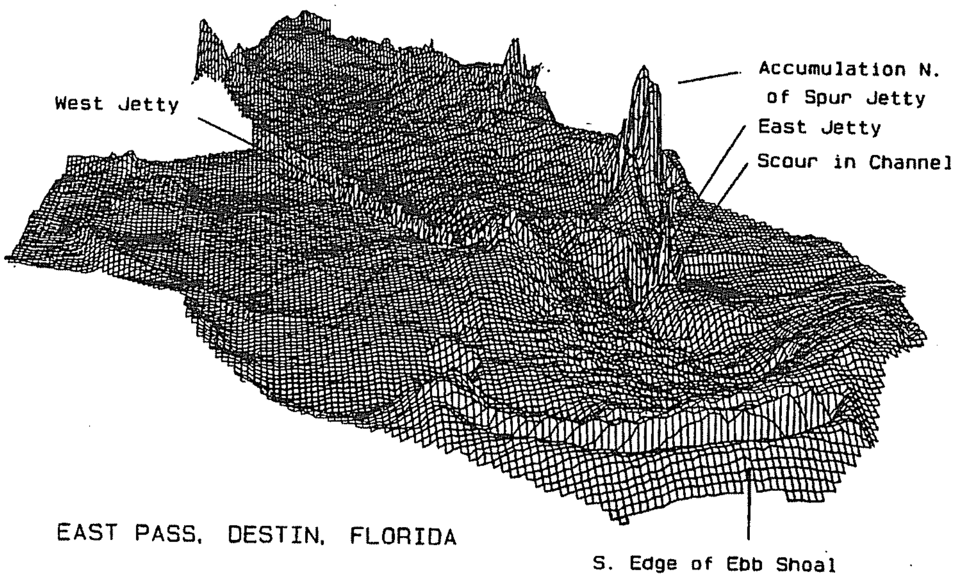

Figure 18: Sea Floor Elevation Changes Between 1990 and 1995 at East Pass

Vertical Accuracy	• +/- 15 cm
Horizontal Accuracy	• +/- 3 m
Depth Range	• maximum 60 m
Sounding Density	• 4 m x 4 m (variable)
Aircraft	• Bell 212 helicopter, Twin Otter fixed wing
Speed	• 20<v<120 knots
Altitude	• 200m<alt<800m
Data Processing	• 1:1

Table 1: Performance Specifications for the SHOALS System