

Use of Lidar Technology for Collecting Shallow Water Bathymetry of Florida Bay

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ABSTRACT

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Due to an accelerated decline in water quality, Florida Bay is the focus of an inter-agency restoration program involving a modeling effort to define water circulation patterns both internally and between its surrounding waters. Models such as these require adequate resolution of the Bay's morphologic features which are characterized by extensive shallow water networks of mud banks, cuts, and basins. However, the information necessary to resolve the complex bathymetry does not exist on current NOAA navigation charts. The Bay's expansive shallow water characteristics renders much of it inaccessible by conventional waterborne survey methods. Obtaining this information requires an alternative survey technology capable of covering large shallow water areas and producing high resolution bathymetric data. During the spring of 1994 the SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system was employed by NOAA to test its ability to resolve the complex shallow water bathymetry for a test area in central Florida Bay. Approximately 13 km² of area was surveyed with a total surveying time of 12 hours. The data set presented here demonstrates that airborne lidar bathymetric technology such as SHOALS can be a valuable and cost effective tool for surveying large shallow water areas, without damage to the environment, that are otherwise inaccessible by conventional methods.

ADDITIONAL INDEX WORDS: *Lidar survey, bathymetry, hydrographic survey, shallow water estuary.*

INTRODUCTION

Florida Bay is a large shallow water estuary situated between the south Florida mainland and the Florida Keys (Figure 1). Recently experiencing an accelerated decline in water quality, the Bay has been the focus of an inter-agency restoration program. A major component of the program involves a modeling effort to understand water circulation patterns within Florida Bay and between its surrounding waters. Such an effort requires adequate resolution of the Bay's bathymetric features. However, insufficient information exists on NOAA navigation charts to define the extensive shallow water network of mud banks, cuts, and semi-enclosed basins that are characteristic of the Florida Bay environment. Typical water depths of critical areas to be modeled range from only a few meters to less than a meter, which are not conducive to conventional acoustic-based waterborne survey methods. Besides the shallow water limitations, conventional survey methods consist of acoustical techniques operated from launch type vessels which are slow and resource demanding. The use of such vessels can cause damage to the shallow sea grass beds that are prominent in these areas. Other inherent limitations with these methods is that they produce sparse data sets that potentially miss information

which may lead to misinterpretation of bathymetric conditions.

Alternative hydrographic survey technologies are required to provide a fast and rapidly deployable system capable of high spacial sounding densities for comprehensive data acquisition over shallow water areas, such as Florida Bay, not accessible by conventional hydrographic survey methods. In the early 1980's the U.S. Army Corps of Engineers began investigating technologies that could augment existing survey capabilities at comparable cost and provide fast accurate surveys. In March 1988, the Corps began a cost-shared program with the Canadian government to design, construct and field verify an airborne lidar hydrographic surveying system. The term lidar is an acronym for Light Detection And Ranging. The Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system was developed through a joint Memorandum of Understanding under the U.S./Canadian Defense Development Sharing Program. The SHOALS system, pictured in Figure 2, provides the capability to acquire high spacial density bathymetric data utilizing state-of-the-art lidar technology consisting of a scanning laser transmitter and receiver that produces 200 soundings per second, operates from an airborne platform, and includes a mobile ground-based data processing system. This design permits SHOALS to be a highly mo-

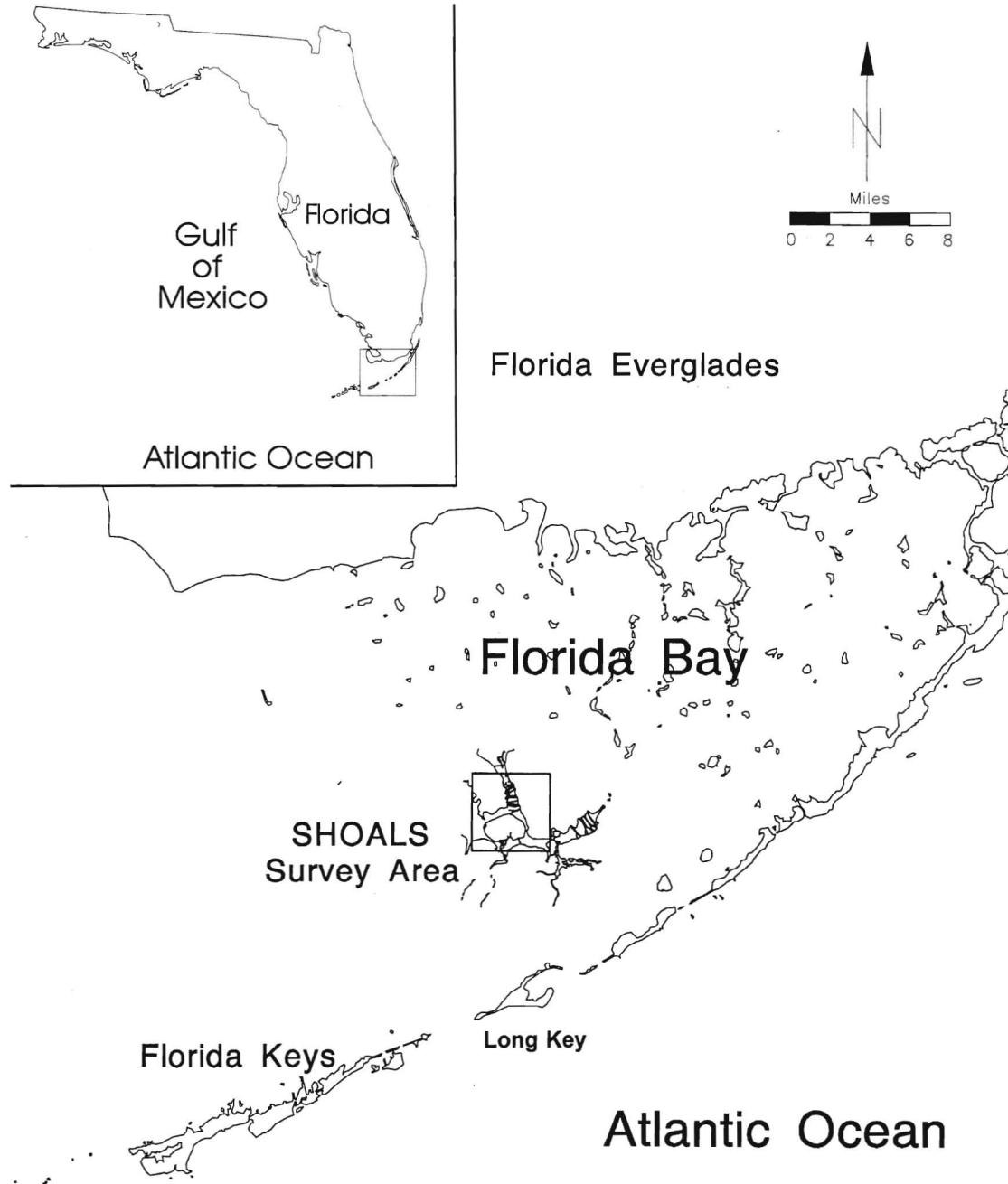


Figure 1. Location of Florida Bay. Situated between the Florida mainland and Florida Keys, the Bay is experiencing a decline in water quality.

bile system capable of rapidly covering large areas producing greater bathymetric resolution for modeling applications such as that required by the Florida Bay restoration program.

The SHOALS system was field tested over a two month period in January and February of 1994 (LILLYCROP *et al.*, 1994). The purpose of the tests were to determine the operational limits of the system under various environmental conditions. Field test evaluations showed that SHOALS met or

exceeded all performance specifications under defined environmental conditions (LILLYCROP *et al.*, 1994). SHOALS began its transition from a prototype toward a fully operational hydrographic survey system in April of 1994, when the system was employed by the National Oceanic and Atmospheric Administration (NOAA) to test its ability to resolve the complex shallow water bathymetry for critical areas in Florida Bay. These areas were identified by NOAA as high priority areas for water circulation modeling. The information gained



Figure 2. SHOALS helicopter and mobile field unit. The mobile unit provides the capability to process and output the lidar survey data while on site.

provided the opportunity to further evaluate minimum depth detection capabilities.

LIDAR TECHNOLOGY

The SHOALS system utilizes state-of-the-art lidar technology. The system operates by emitting laser pulses that

travel from an airborne platform to the water surface where some of the laser energy for each pulse is reflected back to the airborne receiver, as illustrated in Figure 3. The remaining energy penetrates the water surface, propagates through the water column, reflects off the sea bottom, and returns to the airborne sensor. The time difference between the surface return and the bottom return corresponds to water depth. As the light travels through the water column and reflects off the sea bottom it undergoes scattering, absorption, and refraction, which attenuates the return energy and limits the maximum depth of lidar penetration or depth of bottom detection. The maximum depth the system is able to detect is related to an interaction of bottom radiance, incident sun angle and intensity, and water turbidity. However, ESTEP, LILLYCROP and PARSON (1994) has shown that maximum depth detection is limited predominately by water turbidity and relatively insensitive to shifting bottom types. As a rule-of-thumb, the SHOALS system is capable of sensing bottom depths equal to two or three times the Secchi depth. A Secchi depth is calculated using an oceanographers tool, a Secchi disk, that is circular, painted alternating black and white quarters, and is lowered by a line down into the water column. The point where the Secchi disk is no longer visible is the Secchi depth. Thus, if a Secchi depth was measured to be 5 m then the maximum depth of SHOALS system bottom detection would be approximately 10–15 m.

Minimum depth detection is also a limitation when per-

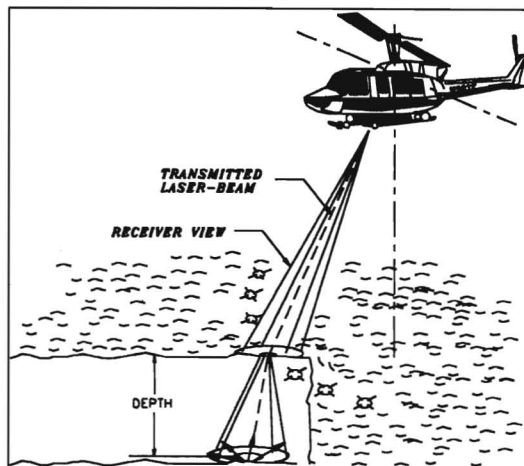


Figure 3. Lidar operating principle. Water depth is determined by measuring the time difference between reflected light from the water's surface and sea bottom. The light is supplied by the on board pulsating laser.

Table 1. SHOALS system performance specifications.

Maximum depth	40 meters
Minimum depth	0.9 meters
Vertical accuracy	±15 cm
Horizontal accuracy	±3 meters
Sounding density	3–15 meters
Operating altitude	200–800 m
Scan swath width	½ aircraft altitude
Operating speed	20–100 knots
Operating temperature	5°–40° C
Data processing	2 hrs processing for 1 hr of data
Aircraft	Bell 212
System Mob/Demob	8 hrs to install; 6 hrs to de-mob

forming lidar surveys. As depths become shallow, a condition is reached where the surface and bottom return signals overlap so that water depth cannot be determined. However, the use of a sophisticated depth extraction algorithm was designed to permit a minimum depth determination of 1.7 m. Surveys conducted in Florida Bay allowed for further testing of minimum depth capabilities and subsequently demonstrated the ability to measure depths of about a meter.

THE SHOALS SYSTEM

SHOALS is composed of two separate systems: the airborne system and ground-based data processing system. The airborne system operates from a Bell 212 helicopter and performs the task of data acquisition. The ground-based data processing system provides the data post-processing to calculate position and depth for each laser pulse. This design permits SHOALS to be a highly mobile system capable of producing a 4 meter sounding grid under normal operating conditions, however, the scan pattern and survey speed can be modified to obtain even higher or lower sounding densities. The SHOALS system performance specifications are presented in Table 1.

Airborne System

The airborne system is divided into three subsystems (LILY-CROP AND BANIC, 1993); Transceiver (TRS), Airborne Positioning and Auxiliary Sensors (APASS), and Acquisition, Control and Display (ACDS). These combined with the ground-based Data Processing System comprise the SHOALS system.

The Transceiver Subsystem consists of the laser, scanner, and receiver. The function of the TRS is to transmit laser pulses in a defined scan pattern (Figure 4) and receive back-scattered energy from these pulses to produce laser depth soundings and aircraft altitude information. The laser is a 200 Hz, Nd:YAG operating in the infrared and green frequencies. Returned laser energy is detected using several optic sensors providing the ability to discriminate between surface, bottom, and land returns.

The Aircraft Positioning and Auxiliary Sensors functions are to collect information from the Global Positioning System (GPS), inertial reference system (IRS), and video imagery system. Differential GPS is used for horizontal positioning and the IRS provides information about aircraft attitude, in-

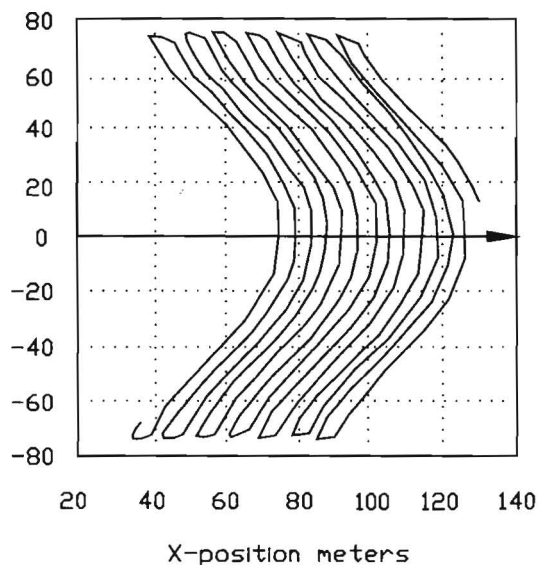


Figure 4. SHOALS scanner laser pattern. The laser is scanned in a 180° arc across the aircraft flight path producing a scan width about half the survey altitude.

cluding roll, pitch, heading, and vertical acceleration. Included as an auxiliary sensor is a video camera to record a video image of the areas being surveyed.

Central to the SHOALS system is the ACDS, which provides an operator interface and monitors and controls the airborne system. The ACDS provides five functions: data collection, operator interface, pilot guidance, airborne depth processing, and system integrity. The data collection function acquires and manages all data as it flows through the system and records it on high density magnetic tape at a rate of over 300 Kbytes per second. The operator interface allows human interaction between the operator and the system with access to all elements of the airborne system. The pilot guidance function provides aid to the pilot in navigating to the survey site and along each survey line. The airborne depth processing function calculates and displays preliminary water depth in real time, providing a means for data quality checking during the survey mission.

The last and perhaps most important function is system integrity. This function serves as the airborne system coordinator which continually monitors and interrogates communications between the various system components. Without precise (billionths of seconds) component communications timing the system could not function as a unit.

Data Processing System

The Airborne System acquires a tremendous volume of raw data during a single mission. The Data Processing System (DPS) is the hardware and software required to post-process the lidar data. Its main functions are to: 1) import airborne data stored on high density data tape; 2) perform quality control checks on initial depths and horizontal positions; 3) provide display and edit capabilities; 4) calculate depth and

position (XYZ) values for each sounding; and 5) output final positions and depths for each sounding.

The interface between the airborne system and DPS is via the high density tape containing the raw data acquired during the survey mission. All of the data types (GPS, IRS, lidar returns, etc.) are collected at varying rates and recorded in an asynchronous format. The primary task of DS is to transfer the raw data from the survey and store it in a database which requires some degree of pre-processing so that the information can be synchronized into a complete data set. DPS possesses a fully automated capability to post-process the data and update the database with corrected depth and horizontal positions within the accuracies presented in Table I. The software accomplishes this by identifying the surface and bottom returns from the airborne data. Depths are determined by computing the differences between the arrival times of the surface and bottom returns and applying corrections for depth biases associated with light propagation, water level fluctuations, and various inherent system characteristics (GUENTHER and THOMAS, 1984a and GUENTHER and THOMAS, 1984b). Sophisticated modelling algorithms are used to predict and apply corrections associated with these biases (GUENTHER, 1985).

Because depths are determined using the water's surface, errors are introduced by surface waves and aircraft fluctuations. During data acquisition a sophisticated algorithm models the waves and swells to determine a mean surface so that depths can be referenced to a common mean water level. Error introduced by wave heights up to 2 meters are removed using this method. An inertial reference system is utilized to compensate for the roll, pitch, and vertical fluctuations in the aircraft's movements. This information is supplied to the laser scanner for correction of these motions during surveying. Determining a mean water surface and isolating the aircraft's fluctuations allows for an accurate estimation of the mean water level. Applying tidal corrections then produces a depth reference to a known water level datum such as mean low water.

A manual processing capability allows hydrographers to evaluate anomalous data by providing display and edit functions of sounding data and system parameters. Video imagery of the survey area permits visual scrutiny of the area to aid the hydrographer in deciding whether to exclude suspect data from further processing. Output from the DPS is an accurate digital data set of XYZ (positions/depths) for each laser sounding that is compatible with most GIS and other contouring and mapping systems.

FLORIDA BAY APPLICATIONS

In April 1994, the SHOALS system was used to survey areas of Florida Bay that were identified by NOAA as critical to the circulation modeling effort as part of the Florida Bay restoration program. Bathymetric information of sufficient detail to resolve the complex bathymetry does not exist for most of these areas. The information contained on current NOAA navigational charts of central Florida Bay dates from surveys performed in the late 1880s and lacks any bathymetric information in some areas. The areal extent requiring

additional detail was too large for a trial application of SHOALS. The selection of a sub-area appropriate to a short term SHOALS field operation resulted in focusing on an area containing features of general interest to the application of the Florida Bay circulation model. The area selected satisfied other criteria necessary for the effort in that it was unmapped, close to deeper mapped water for calibration and verification purposes, and relatively close to available land based support.

The selected survey area encompassed two sites known as the "Mystery Basin" and of particular interest, an adjacent area called the "Little Rabbit Cuts", as shown in Figure 5. The area is located in the southwest corner of Florida Bay (Figure 1), approximately 15 miles northeast of Long Key, and just north of several islands known as the Arsnicker Keys. The Mystery Basin is an oval shaped basin measuring about 3 km east-west, 1.5 km north-south and averages 2 meters in depth. It is defined by very shallow mudbanks that are periodically exposed during extreme spring low tides, making access by conventional survey boats nearly impossible. Little Rabbit Cuts, situated adjacent to and north of the Mystery Basin, consists of an extensive mudbank transected by numerous channel cuts believed to provide a major influence on the water circulation patterns in the immediate vicinity. The channels are from 0.5 to 3 meters deep and 5-30 meters wide. This site offered a wide range of depths, water clarity conditions and bottom types providing a challenging situation for shallow water SHOALS operations.

The delineation of the survey areas were based on many factors. The most important was the total allotted survey time of 12 hours which had to be broken into segments due to the limited helicopter flight time. The sounding density and survey coverage during this time was based on altitude, swath width and air speed. Sounding densities of 3 meters were desired, however, the amount of available flight time would not permit total coverage at that density. The survey parameters were established based on a data sampling density of 5 meters allowing for much faster survey times. Each site was then surveyed twice to achieve the denser coverage. The final survey area was determined in the field based on site conditions. These included transit times to and from the air field, local environmental atmospheric and water conditions, and a sanctuary air space restriction requiring a 300 yd (275 m) no-fly area for bird rookery protection. Additional planning components included staging ground-truthing teams for depth and water parameter data control and a network of water level gages for vertical datum adjustment during the flights. The average tidal range observed in this area during the survey period was 21 cm with minimum and maximum ranges of 9 cm and 34 cm respectively. Corrections for tides at the time of surveying were applied during post-processing to reduce the data to a common vertical datum. Horizontal control was provided using differential GPS base stations. During the operation, wind conditions were unusually high creating potentially undesirable survey conditions, including water level set down and white caps on the water. Entrapment of air near the surface created by white caps causes a highly reflective condition which impedes propagation of the laser light through the water column. Such con-

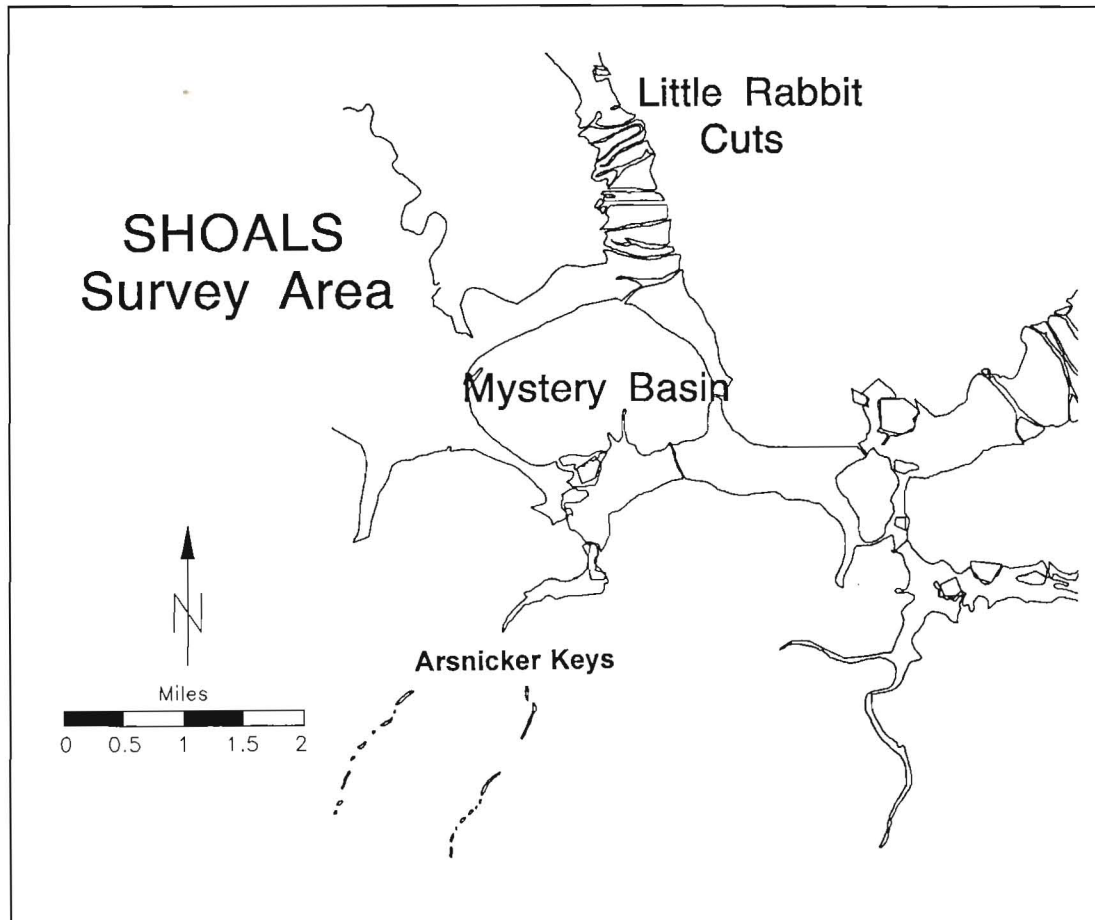


Figure 5. Location of SHOALS survey areas in the southwest of Florida Bay. The sites are approximately 15 miles northeast of Long Key. Surrounding areas are too shallow for access by conventional survey boats.

ditions can severely hamper SHOALS survey operations. Although the adverse wind conditions created unsuitable water clarity for most of the surrounding areas, the shallow mudbanks sheltered the project area from high wave energy, thus preserving water clarity and allowing for successful survey operations.

The entire operation took place over a period of one month. This included site reconnaissance, temporary tidal station installation and support logistics. The actual time in the field including staging, mobilization of crews and equipment, surveying and final demobilization was one week. The total time spent collecting data was 12 hours. For this effort a total of approximately 13 km² was surveyed (26 km² effective coverage considering that each site was surveyed twice). The amount of data collected approached 3,000,000 data points. Compared to the survey done in 1889 which collected 30,000 points in a 600 km² area, this represents nearly a 3000 fold increase in data density and collection rate.

A SHOALS survey data set of the Little Rabbit Cuts is presented in Figure 6. This particular survey covered roughly 6 km² with over a million soundings collected on a 3 meter

grid and took about 5 hours to complete. Depths are shown in feet to provide narrow zonations for enhancement of vertical relief in this shallow water area. The irregular vertical light colored area in the middle of the survey is an extensive shallow mudbank oriented north-south. Features such as these have been described in this area by GINSBURG (1984) as storm event depositional ridges and build up of carbonate mud stabilized by extensive stands of sea grasses. Most of the area over the ridge is less than a meter (about 3 feet) in depth, which was too shallow to be resolved by the SHOALS system. Tidal currents have created a series of channels or cuts through the mudbank which appear as the narrow horizontal features transecting the mudbank. The spacing between these bedforms average about 200–300 m and range in depth from about 1 to 3 m (3 to 10 feet). The maximum depth in the areas surrounding the mudbank and cuts were just over three meters (10 feet). Obtaining bathymetric data of these channels and cuts are of particular interest to the water circulation modeling effort. The data are necessary for determining the effects that these features have on the local water circulation patterns.

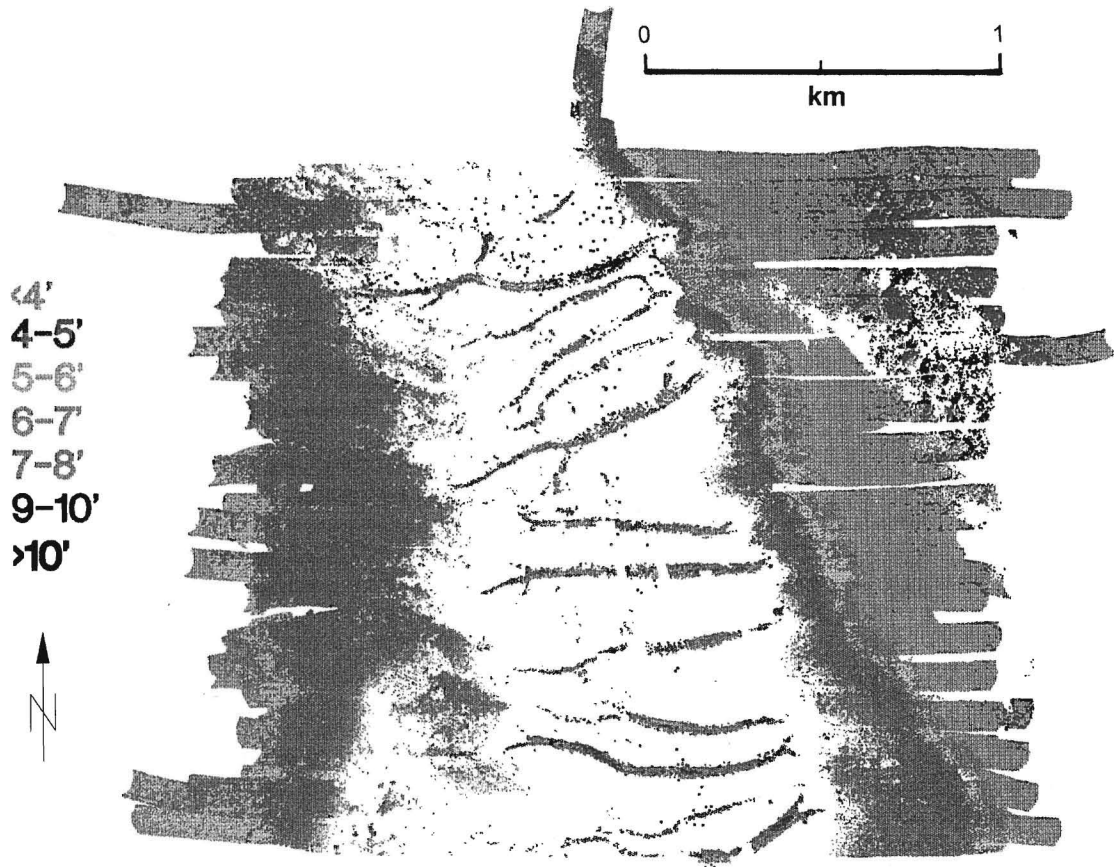


Figure 6. SHOALS survey of the Little Rabbit Cuts. Depths are shown in feet to enhance the vertical relief. The survey includes over a million soundings covering an area about 6km².

The “ribbon” stripes evident at the edge of the survey coverage are the individual swaths for each flightline. The survey parameters used during this survey required a swath width of about 100 meters. It is apparent that a comprehensive data set, such as this one, capable of defining the dimensions of the shallow network of mudbanks, channels, and cuts could not be possible using conventional survey techniques.

SUMMARY

The Florida Bay Restoration Program identified a need for an alternative hydrographic survey technology to provide the capability of collecting high spacial bathymetric data over shallow water areas that are otherwise not accessible using conventional waterborne survey methods. The SHOALS system was employed to perform trial surveys of two sites in central Florida Bay. Evaluation of the SHOALS data demonstrated that airborne lidar technology can meet performance specifications required to resolve the shallow network of complex bathymetry that is prominent in the unmapped areas of central Florida Bay. Accurate surveys of areas that are normally inaccessible by survey vessels were performed. Being an airborne system, the areas could be accessed and

surveyed despite the wind and wave conditions that were occurring at that time. Without the need to deploy a boat to the survey sites, the data was collected with absolutely no damage occurring to the fragile sea grass beds that exist throughout most of Florida Bay.

Airborne lidar technology exhibited outstanding potential for collection of high spacial resolution data over large shallow water areas in a fraction of the time required by conventional waterborne methods. With the ability to rapidly collect accurate, high density bathymetry in a cost effective manner, the SHOALS system proved to be an excellent tool for providing valuable information for the Florida Bay Restoration Program. These capabilities for greater speed and efficiency is a powerful step towards the rapid update of nautical charts for a variety of applications.

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