Airborne Lidar Bathymetry in the Management of Florida's Coastal Zone

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Abstract

Sand is a critical component of Florida's economy both in terms of the beaches that are the basis of its tourist industry and also the constant dredging required to maintain the state's ports and navigation channels. In the past, these components have often been managed separately, ignoring the dynamic littoral processes that inter-link all elements of a coastal system on both local and regional scales. Every navigation channel, structure, shoreline, tidal shoal, harbour area, and longshore feature contribute to the overall behaviour of the entire system. Assessing the performance of a coastal project requires determining how all these elements interact to define the behaviour of the system. Historically, costly management decisions for such projects have often been based upon sparse data collected for one, or possibly two, elements without knowledge of how those elements are affecting the overall system. As a consequence, the establishment of a sediment budget has been increasingly emphasised as one of the most important tools that coastal engineers use to understand and provide sediment management for coastal projects. It is because of this need that Federal and State agencies have turned to Lidar as a means of rapidly acquiring comprehensive datasets on a regular basis.

Figure 1
Sand is a critical component of Florida's economy

Figure 2
The USACE is typically concerned with channel shape, navigation structure condition and impacts to adjacent shorelines

Interested Agencies

The United States Army Corps of Engineers (USACE) is tasked with surveying and maintaining navigation projects throughout the U.S. and is typically concerned with channel shape, navigation structure condition, and impacts to adjacent shorelines. The Florida Department of Environmental Protection's (FLDEP) Bureau of Beaches and Coastal Systems is responsible for continuously monitoring and managing 680 miles Florida's coastline comprising the state's entire coastline except for Monroe County (Florida Keys) and Federal sites. This is an enormous and ongoing process since over 40% of this coast is suffering serious erosion, while, in addition, constant changes result from normal coastal processes and occasional storm events, as well as engineering activities associated with ports and harbours and shoreline stabilisation.

REGIONAL BEACH SURVEYS: THE CONCEPT

Understanding the need for a regionalised approach to sediment management, the USACE has begun demonstration of a systems approach to sediment management in the coastal regions of the northern Gulf of Mexico. The study region encompasses a complete section of 217 km of shoreline in Florida and 48 km in Alabama, including 8 State parks, the Gulf Islands National Seashore, Eglin Air Force Base and Tyndall Air Force Base. Also included are five Federal navigation projects (Panama City Entrance, East Pass and Pensacola in Florida, Perdido Pass on the Florida/Alabama border, and Mobile Bay Entrance in Alabama) and the 27 km long, 5.7 million cubic metre Federal beach erosion control and storm damage reduction project. The objective of the proposed demonstration is to assess the benefits of managing sediment, specifically sand, as a regional-scale resource and to identify the obstacles that may hinder or prevent the realisation of such benefits.

In parallel with this, Florida Department of Environmental Protection (FLDEP) has been a participant in the USACE sediment management initiative, which aims to foster cooperation working with local governments and the USACE in order to lower costs and establish long-term solutions to beach erosion. As a result, the FLDEP, Bureau of Beaches and Coastal Systems is revising the way it develops and implements erosion control projects, which historically have focused on local short-term needs and is instead working with local governments and the USACE to develop long-range beach management plans. These plans again emphasise a regional approach to sediment management as a key component of beach management strategy that will encourage coordination among local governments, lower costs and establish long-term solutions to beach erosion.

Figure 3 (below)
A regional approach to sediment management is a key component of beach management strategy

Figure 4 (bottom)
SHOALS is currently flown in a DHC-6/300 Twin Otter aircraft

THE TECHNOLOGY REVOLUTION

Traditional methodology for collecting survey data in and around coastal areas has typically been based on cross-sections surveyed using traditional hydrographic and levelling practices at 1000 ft intervals. These cross-sections include both the subaerial area (topographic), extending from the water line to an established baseline marked by survey monuments, and the nearshore area (hydrographic) extending from the waterline to either the 30 ft contour line or 2,400 ft from the shoreline, whichever is closer. Measurements are taken at fifty feet intervals and at points of slope change along these cross sections, which have also been supplemented by aerial photography to monitor structural changes in the coastal zone. Because of the time and cost of this methodology and the cost of maintaining control points (required so that subsequent surveys may be taken in the same locations), the FLDEP could only survey three to four counties' coastlines each year. Intrinsic to this approach was the consequence that the majority of the project areas were never surveyed so that detail information was typically unavailable at the regional level and features that have an effect on surrounding areas were overlooked. Meanwhile, ever increasing pressures on resources have led to a review of traditional methods of data collection and how these can be augmented by newer technologies to provide an accurate, quantified characterisation of a region over time, rather than the historical focus on local short-term needs.

In the past 10 years, however, the development of Airborne Laser Bathymetry (ALB), the ability to rapidly acquire comprehensive, high-density survey data over large areas has become a reality. The USA, Canada, Sweden, Australia and private industry have all fielded this technology and accepted its ability to meet International Hydrographic Organization (IHO) Order 1 standards. The system in use in the USA is the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS), which is the result of a development effort begun in 1988, and cost-shared with the Canadian government under the U.S./Canadian Defense Development Sharing Program. In developing SHOALS, the USACE looked to an established leader in the field of laser instrumentation, Optech Inc., to design and construct an airborne lidar (LIght Detection And Ranging) bathymetry survey system. Following extensive field testing which established that it met or exceeded all its design goals (including USACE Class 1 survey standard), SHOALS was accepted as an operational system in 1994. Since then, SHOALS has surveyed nearly 300 projects ranging in nature from small navigation, beach and structure projects to large (thousands of square kilometres) nautical charting projects. Today, this technology provides comprehensive high-density survey data, including both bathymetry and topography , required for accurate evaluations for an entire project area. The speed and coverage provided by an airborne system such as SHOALS results in survey capabilities never before available.

THE SHOALS SYSTEM

SHOALS is operated from the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), which is headquartered at the U.S. Army Engineer District (USAED), Mobile. The JALBTCX's mission is to operate the SHOALS system and to develop new products and applications. Additional goals for the JALBTCX include expansion of mapping and charting capabilities and the fusion of lidar bathymetry with auxiliary sensors such as muti-spectral imagery and Synthetic Aperture Radar (SAR). The system has been operated under contract by John E. Chance & Assoc. Inc. since its inception and is currently flown in a DHC-6/300 Twin Otter aircraft contracted from Ken Borek Air Ltd. of Calgary, Canada. This aircraft is a versatile short take-off and landing (STOL) aircraft, which is commonly operated from jungle, dirt and ice airstrips and is therefore extremely flexible for survey operations. With endurance in excess of 5 hours, the aircraft is commonly able to reach all survey locations from a centrally located base on the coastline to be surveyed.

SHOALS incorporates a 400Hz laser co-linearly scanning pulses of infrared ((= 1064 nm) and blue-green ((= 532 nm) light across a swath. Each laser pulse travels from the airborne transmitter to the water where some light energy is reflected and detected by onboard optical sensors. The remaining light passes through the water column, reflects from the sea bottom, and returns to the optical sensors. The time difference between the water-surface and sea-bottom returns indicates the water depth. Maximum penetration is heavily dependent on water turbidity, but in Florida, measured depths of up to 30 m are usual. Operating at an altitude of 300 to 500 m and at speeds up to 70 m/s provides measurements on a 4 to 8 m horizontal grid, covering up to 35 km2 per hour. Data density can be adjusted by flying higher or lower, at different speeds, or by selecting different scan widths. For the work in Florida, a grid of depths every 8 m is collected across a scanned swath of 220 m, while flying at a speed of 120 kts and an altitude of 400 m. A single operator can operate the airborne system, but due to the extended duration of flights it is usual to fly with 2 operators. Data collection and processing is all digital, enabling flexibility in product generation to meet the requirements of the end-user.

A down-looking video camera is used to provide a record of the scanned area and is stored on 8 mm video tape. The main function of the video is to provide a record of the area surveyed and to assist hydrographers while processing and mapping the data. When anomalous data are identified, the hydrographer can review video of the area to obtain information about the anomaly in question. The audio track may also contain verbal notations from the operator that may also be used to provide some indication of the data characteristics. Each video frame contains digital annotations providing a continual display of the time, latitude, longitude, altitude, and the pitch, roll, and heading of the aircraft. A set of cross-hairs also tracks the nadir alignment and provides the ability to obtain rough position and measurements of structures, navigation aids, and objects in the water.

The key to effective utilisation of ALB technology has been the development of Kinematic GPS, which has given SHOALS the ability to collect data independently of the

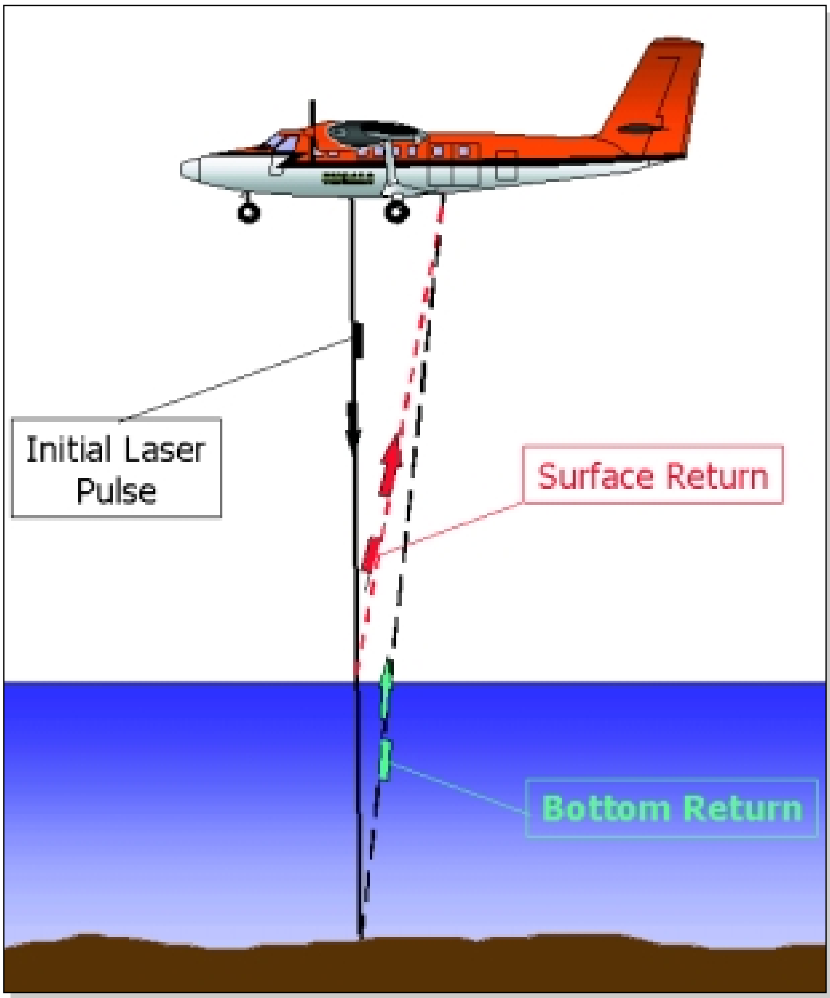

Figure 5
The time difference between the water-surface and sea-bottom returns indicates the water depth

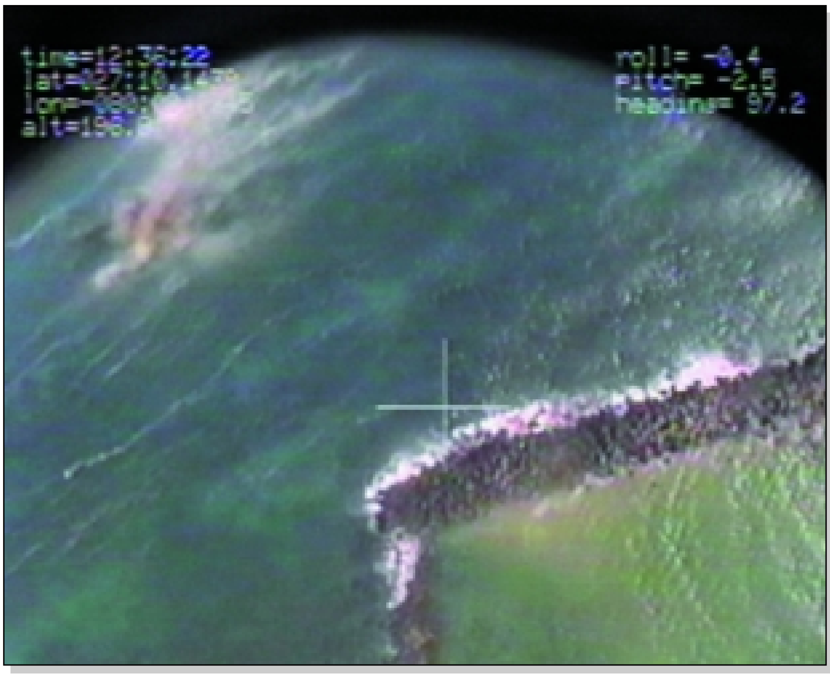

Figure 6
A set of cross-hairs tracks the nadir alignment and provides the ability to obtain rough position and measurements of structures, navigation aids and objects in the water

Figure 7
The ALB data is fused with other sources that include both airborne topographic Lidar data and digital aerial photography in a GIS for presentation and analysis

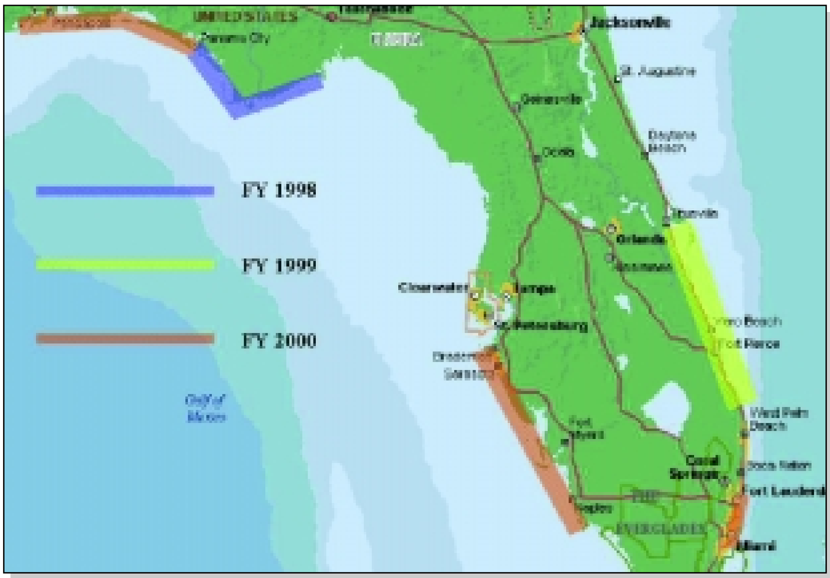

Figure 8
To date SHOALS has completed coverage of all the FLDEP coasts

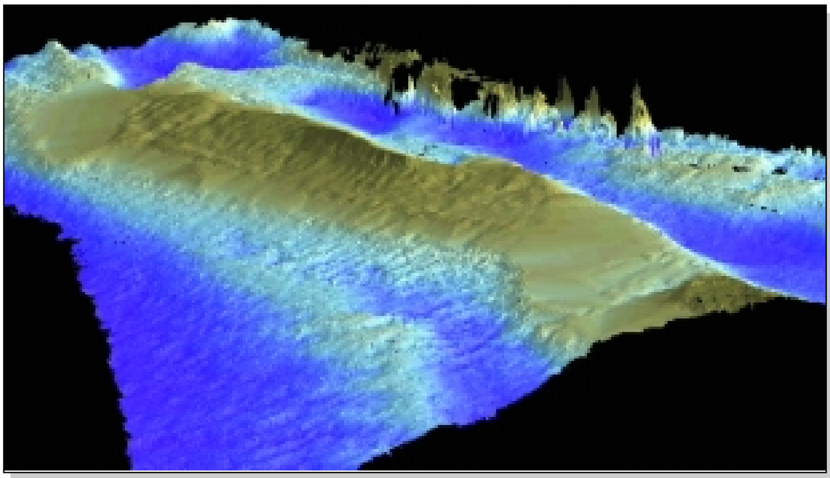

Figure 9
SHOALS data is used for creating plan view engineering drawings and 3-D digital elevation models

sea surface and therefore collect both bathymetric and topographic (above water) survey data, simultaneously. This enhancement to SHOALS operations was introduced as a direct result of the increase in USACE requirements to map beaches, dunes, and above-water structures. Since the need to use water surface as a vertical reference is eliminated, all vertical elevations are directly related to the ellipsoid and are not subject to errors introduced by tidal measurements and changing datum.

REGIONAL SEDIMENT MANAGEMENT: THE REALITY

The impact of ALB on regional beach surveying in Florida has been felt since 1998, when SHOALS commenced a programme that will result in the entire Florida coast being mapped every 2 years; 50% each year. By linking horizontal and vertical positioning to Florida's High Accuracy Resolution Network (HARN), historical and new data are compared quickly and easily without conversions. This also facilitates the fusion of the ALB data with other sources that include both airborne topographic Lidar data and digital aerial photography in a GIS for presentation and analysis.

To date SHOALS has completed coverage of all the FLDEP coasts and will now embark on re-surveys in future years. SHOALS data is used for creating plan view engineering drawings and 3-D digital elevation models. Such tools mean that sediment management performance and dredging needs can be comprehensively addressed in a more standardised and objective manner, while achieving reductions in manpower, time and resource requirements. The improved information and analysis support decision-making processes and assist managers in preparing maintenance plans, budgets and schedules. While such mapping at a regional scale on a repeat basis provides a valuable tool for long term coastal management, the data can also be used as a baseline for sporadic high intensity events including storms and ship grounding. Consequently, in recent years, SHOALS has also responded within days following both types of event in order to provide rapid damage assessment.

CONCLUSIONS

In summary, improved coastal zone mapping resulting from the combination of Lidar hydrographic and topographic data with digital orthometric photography represents a quantum leap in resource management from traditional methods. This is coupled with less effort spent maintaining survey control, more frequent monitoring and improved coastal zone management, meaning that the speed and cost effectiveness of SHOALS will enhance the USACE and FLDEP's ability to re-survey more beach areas on a more frequent basis.

ABOUT THE AUTHORS

Geraint R. West graduated with a BSc from the University of London before serving in the Royal Navy as a Seaman Officer for 15 years, 12 of these as a Hydrographic Surveyor. The majority of this time was spent in a variety of ships conducting surveys worldwide. Between 1995 and 1997 he served on exchange to the US Navy at the Naval Oceanographic Office as Hydrographic Technical Advisor to the Operations Director and his final appointment in the RN was as Officer in Charge of Surveys, onboard the Antarctic Ice Patrol Vessel, HMS Endurance. He joined John E. Chance & Assoc. Inc. in 1998 as Project Manager for the SHOALS system and since then has been involved in surveys in New Zealand, Hawaii, Europe, Bahamas and continental USA.

Charles E. (Eddie) Wiggins graduated in 1992 with a B.Sc. in Civil Engineering from Mississippi State University. Following graduation he became an intern with the U.S. Army Engineer District, Mobile, where he worked for 5 years on maintenance of navigation channels. This work involved hydrographic data collection, processing and analysis, contract development and inspection of dredging operations. In 1997 he began work as the Operations Manager for SHOALS, where he coordinates work with SHOALS' clients and oversees the implementation of the survey schedule.

IF YOU HAVE ANY ENQUIRIES REGARDING THE CONTENT OF THIS ARTICLE, PLEASE CONTACT:

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