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Shallow Surveying in Hazardous Waters

Thomas C. Lippmann
University of New Hampshire, Durham, t.lippmann@unh.edu

Gabriel M. Smith
Great Lakes Dredge and Dock Co.

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Thomas C. Lippmann
Center for Coastal and Ocean Mapping, University of New Hampshire, Durham, NH 03824
Tel. (603) 862-4450, Fax (603) 862-0839, Email lippmann@ccom.unh.edu

Gabriel M. Smith
Great Lakes Dredge and Dock Company
Tel. (614) 774-1610, Email gabe.g.smith@gmail.com

Abstract

Of order one importance to any study of nearshore processes is knowledge of the bathymetry in shallow water. This is true for studies on open coast sandy beaches where surf zone dynamics drive the system, inlet environments where bathymetric evolution can rapidly change navigation channels, and in more benign, lower-energy coastal environments that evolve slowly over 10's to 100's of years. Difficulties in obtaining shallow bathymetry where depth-limited wave breaking occurs, submerged hazards are present, or other harsh environments has led to the development of survey systems on highly maneuverable personal watercraft (Beach, *et al*., 1994; Cote, 1999; Dugan, *et al*., 1999; MacMahan, 2001). In this work we discuss shallow water surveying from the Coastal Bathymetry Survey System (CBASS), a Yamaha Waverunner equipped with differential GPS, single-beam 192 *KHz* acoustic echo-sounder, and onboard navigation system. Data obtained with the CBASS in three regions will be discussed, including an energetic surf zone located in southern California during the 2003 Nearshore Canyon Experiment (NCEX), on Lake Erie in 2002 (and compared with historical surveys dating back 150 years), and around Piscataqua River Inlet, NH, in 2007. Estimated accuracy (for sandy bottoms) in water depths ranging 1–10 *m* are 0.07-0.10 *m* in the vertical, and on the order of 0.1-1 *m* horizontally depending on water depth and bottom slope. The high maneuverability of the personal watercraft makes very shallow water bathymetric surveys possible with acoustic altimeters, particularly in regions where airborne remote sensing systems fail (owing to water clarity issues) or where repeated high resolution surveys are required (*e.g.*, where an erodible bottom is rapidly evolving).

Introduction

Bathymetric measurements are required for nearly all nearshore processes studies. The bathymetry defines the water depth as a function of spatial position, and in doing so defines the location, and often the nature, of the bottom boundary for nearshore models. Repeated surveys are usually required as the sediment transport in shallow waters is typically large particularly close to shore. These surveys must be done in two dimensions spanning the typical scales of bathymetric change on the order of 10^2-10^4 *m*. Surveys sampled with dense spatial resolution are used to calculate the result of net sediment transport, essentially observing the primary variable of interest, namely the evolution of shallow topography.

Tools and methods used to observe shallow water bathymetry have evolved significantly over the years, from spooled and lead-lines laboriously recorded manually to modern differential GPS-based systems coupled with digital fathometers onboard high performance personal watercraft. During this evolution of capabilities, the basis for the difficulties has remained the same: how to measure topographic elevation under water usually composed of surface (often breaking) waves, currents, and shallow hazards such as submerged rocks or shoals. For scientific studies on sandy, erodible bottoms, the problem is exacerbated by the need to observe bathymetric evolution during storms when the sediment transport is highest. For navigation, particularly around inlets, harbor mouths, and estuaries, the problems are often focused on hazards, made worse when conditions (such as water clarity, surface waves, or currents) are less than ideal. Even with the advent of sophisticated airborne LiDAR (Light Detection and Ranging) systems, adequately resolving shallow bathymetry on spatial and temporal scales of interest is non trivial and sometimes impossible if the water turbidity is too high.

In this work, we discuss surveying in three different shallow water environments using the Coastal Bathymetric Survey System (CBASS), a GPS-based survey system with single-beam echosounder onboard a highly maneuverable personal watercraft. The first environment is within the surf zone of a typical, energetic sandy beach. The second is on the more benign, but no less hazardous, Lake Erie shoreline. And the third is in and around the Piscataqua River Inlet located in near Portsmouth, NH.

The Coastal Bathymetric Survey System (CBASS)

The CBASS, constructed originally in 1999, is based on differential GPS positioning and accurate bottom finding using a single-beam echosounder. The vessel used in the CBASS is a 1998 Yamaha GP1200 Waverunner. The compact size of the two-seater vessel allows the system to be deployed and retrieved from open sandy beaches by two able-bodied persons, useful for application in marine regions with limited access (other than through the beach). Figure 1 shows a picture of the system with components. The GPS receiver is a Sokkia GSR2300 (consisting of Ashtech Z-surveyor hardware components) with marine antenna (changed periodically over the years) and Falcon Crest spread spectrum RTK radio with whip antenna. The GPS unit receives differential corrections from a nearby base station and outputs 1 *Hz* NMEA GGA messages that are used for onboard navigation and synchronization of other system components. The emphemeral GPS data is stored by both the receiver and base station for post-processing at 5 Hz. The real-time corrected signal is not relied upon for positioning accuracy (other than for navigation), but rather serves as a back-up for the post-processed data; thus, highly accurate surveying can continue even when radio signals are blocked by structural impediments or otherwise lost between the base and rover.

The sonar is a dual-transducer, 192 KHz single-beam echo-sounder custom built by EEConsulting, Inc. (Sonora, CA). The system samples at between 17 and 20 Hz, depending on the internal hardware, and maintains a self-adjusting auto-gain threshold for bottom finding in highly occluded, bubbly water typical of surf zone environments. The sonic beam width varies from 8 to 20 degrees depending on the transducers used. The transducers are mounted flush on the rear skid plate directly beneath the GPS receiver. A thermistor mounted near the transducers measures the surface water temperature. A ruggedized Husky computer records the temperature, sonar, and GPS data and powers an onboard navigation system that is displayed in a waterproof enclosure mounted on the handlebars. The battery systems is isolated from the waverunner to minimize noise. All components except the handlebar display unit and antennas are internal to the waverunner.

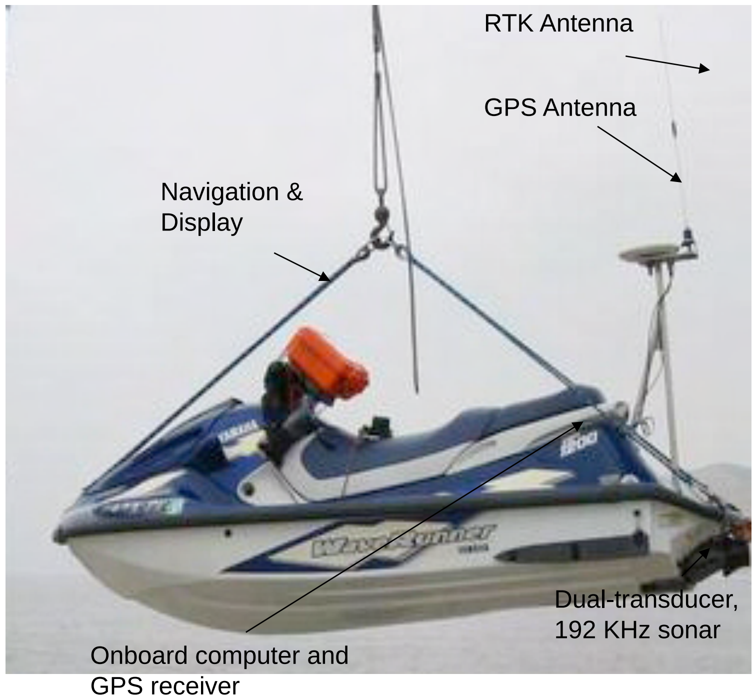

Fig. 1. CBASS with principal components labeled. The vessel is a 1998 Yamaha GP1200 Waverunner.

As with all sonar systems in shallow marine waters, bubbles, sediments, and other detritus create noise that must be removed from the signal. The rapid sampling of the sonar allows significant interrogation of the estimated bottom returns to remove spurious signals. Figure 2 shows a typical raw and filtered sonar record (without GPS corrections). The basis for finding good data within, at times, a sea of noise is based on a conditional, expanding histogram feature extraction algorithm with limits that - if exceeded - flag the bad data. Some manual examination of the data stream is required to ensure no obvious spurious data points persist. In general, detection of the bottom between 1 and 10 *m* water depths is typically quire robust, particularly over sandy or hard-bottom substrates. Over softer material, the signal is attenuated more strongly at the bottom and the return is weaker, allowing more noise to enter the data stream. In deeper water greater than about 10 *m*, the attenuation increases and the signal to noise ratio goes down, again allowing more noise to enter the data stream. In any case, bottom detection is typically good on sandy beaches or hard bottom substrates to 25 *m* or so.

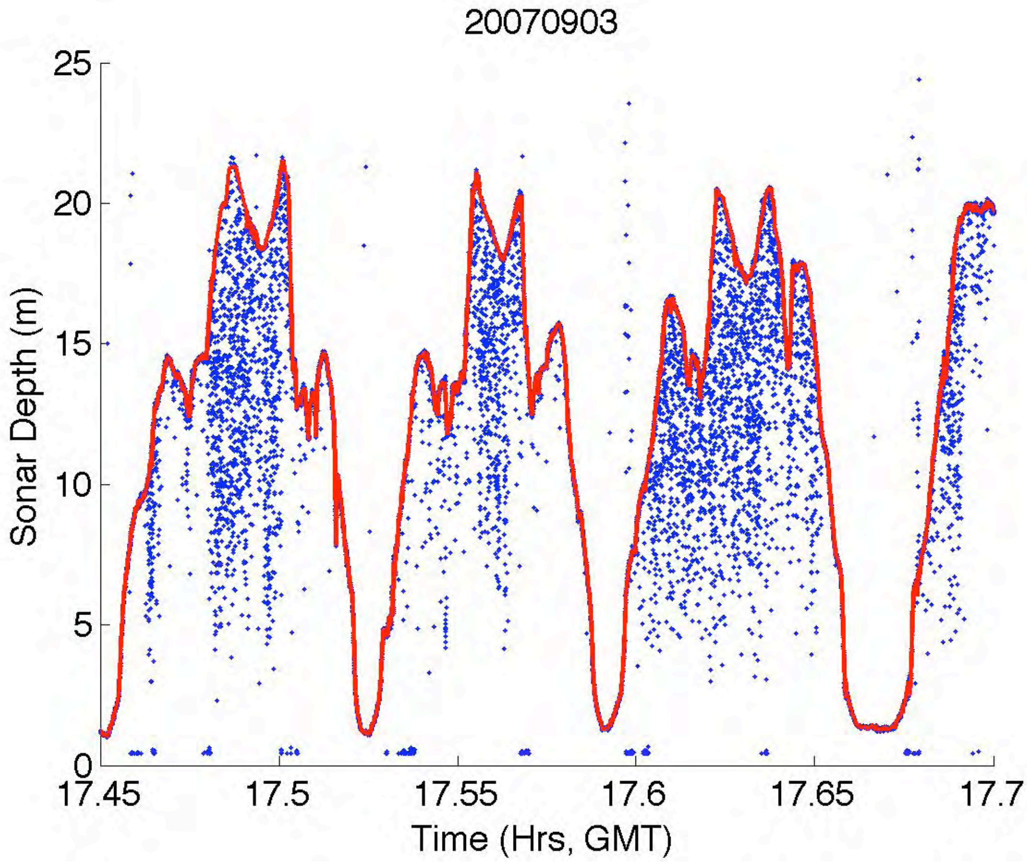

Fig. 2. Example raw (blue dots) and filtered (red line) sonar data. Depths are distances to the bottom from the sonar transducer.

Corrections for the speed of sound are made with the surface temperature measurements and assuming a constant salinity (obtained from other sources, typical conditions, or from the literature). Vertical variation in density is not considered, and thus leads to errors particularly in deeper water or under highly stratified conditions. Figure 3 shows a comparison of measured bottom depths between the CBASS (obtained at high tide) and an independent walking GPS survey (obtained six hours later at low tide) on a gently sloping southern California beach. Root-mean-square (RMS) errors are on the order of 5-6 *cm* with mean offsets of about 1 *cm*. Also shown is an inter-comparison between two coincidentally operating CBASS systems (with similar, but not identical components) out to 7 *m* water depths. RMS errors are about 7-8 *cm* with mean offsets of less than 1 *cm*. These results are similar to previous findings using other survey systems that utilize personal watercraft in the surf zone (Dugan, *et al*.,1999; Cote, 1999; MacMahan, 2001).

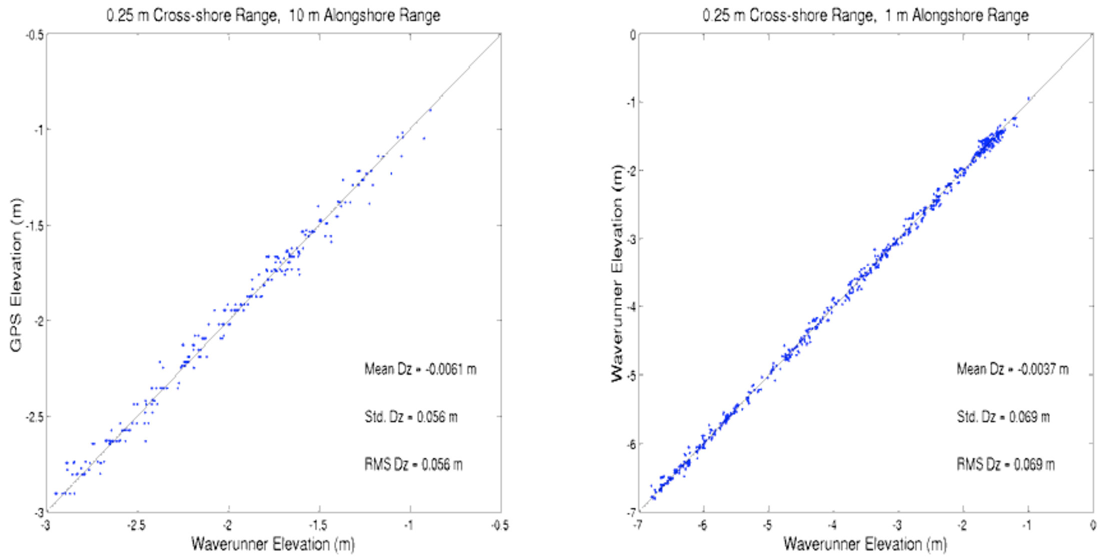

Fig. 3. (left panel) Comparison between high tide CBASS survey and low tide walking GPS survey. (right panel) Comparison between two CBASS survey systems. .

Sandy Beach Surveying at NCEX, 2003

The CBASS has been used extensively in shallow nearshore waters over the past 10 years. As an example, the CBASS was used to measure the bathymetry during the 2003 Nearshore Canyon Experiment held in southern California near Black's Beach (Figure 4). The bathymetry over a 3 *km* section of coastline was surveyed repeatedly over a 45 day period. A total of 29 days of surveys were conducted, each over about a 2-3 period at high tide to allow the maximum overlap with foreshore GPS-based surveys conducted at low tide. The conditions varied throughout the experiment with offshore significant wave heights ranging from 0.5 to 1.8 *m* and wave periods from about 7-12 *s*. Wave heights alongshore varied significantly owing to strong wave refraction over submarine canyons in the area that impinged closely on the nearshore. In some locations, particularly at the well-known Blacks Beach surf break, the wave heights could be twice that of neighboring locations, severely complicating the surveys by producing large breaking waves (that encouraged surfers to use the area for recreation) and strong currents. A total of 72 survey lines extending from near the shoreline to 10 *m* water depths and with 20-40 *m* alongshore spacings constituted a complete survey of the region, which often took 2 successive high tide periods to complete.

Fig. 4. CBASS in operation in the surf zone during NCEX.

Figure 5 shows examples of beach profiles from the beginning and end of the experiment. The changes in the bathymetry were restricted to water depths less than 6 *m*, and concentrated toward the center of the region not coincidentally where the largest waves were focused. The nature of the steep submarine canyons is also quite evident.

The principal difficulties in surveying in the surf environment were 1) high breaking waves that presented a danger to the operation of the vessel, 2) kelp and eel grass which clogged the waverunner intake and stalled the system potentially within the surf, 3) avoiding fixed instrumentation, frogmen, and surfers, 4) submerged rocks in a few areas toward the boundaries of the domain, 5) bubbles and sediment clouds that attenuated the sonar signal in shallow water, and 6) the steep canyon walls that reflected single sonic pulses at various depths.

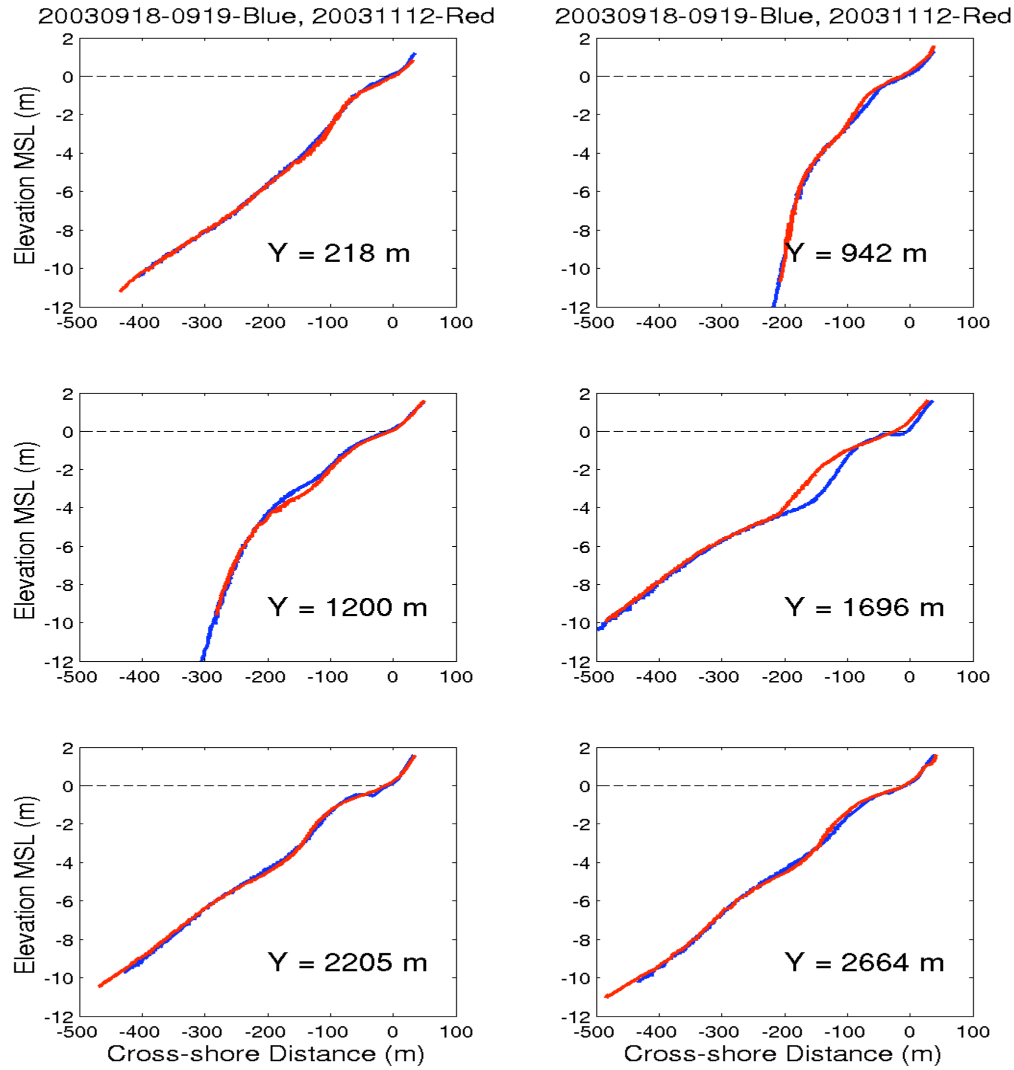

Fig. 5. Example profiles from the beginning (blue lines)) and end (red lines) of NCEX at specific alongshore locations (relative to a local benchmark).

Historical Surveys Along Lake Erie, 1876-2003

The CBASS was also used in 2002-2003 to conduct surveys along the southern Lake Erie shoreline to the northeast of Cleveland. In addition to a variety of detailed local surveys (not discussed herein), a set of 9 transect lines spanning about 18 *km* alongshore were surveyed with the CBASS and walking GPS surveys along the adjacent clifss, and subsequently compared with historical surveys along the same lines. The historical surveys were collected in 1876 and 1948 (by the US Army Corps of Engineers using spooled and lead lines), in 1970 (by the Ohio Dept. of Natural Resources, ODNR, using transits, wading, and fathometers), and in 1994 (by ODNR and the US Geological Survey using total stations and fathometers). The surveys were related to Lake Erie water levels that have been accurately recorded for more than 150 years and can be related to the International Great Lake Datum of 1985 (IGLD 85). Despite the wide range of survey tools utilized by the various agencies over the 127 year period, the surveys align at the location of the pin marks remarkably well.

Figure 6 shows an example of the surveys conducted by the various groups at one particular location. Clearly, the CBASS surveys extend far from shore exceeding 3 *km* in some locations and approaching 12-13 *m* water depths. Also, clearly evident is that even though the beach and cliff area has significantly eroded over time, the surveys overlap remarkably well at the top of the cliff where changes have been slight.

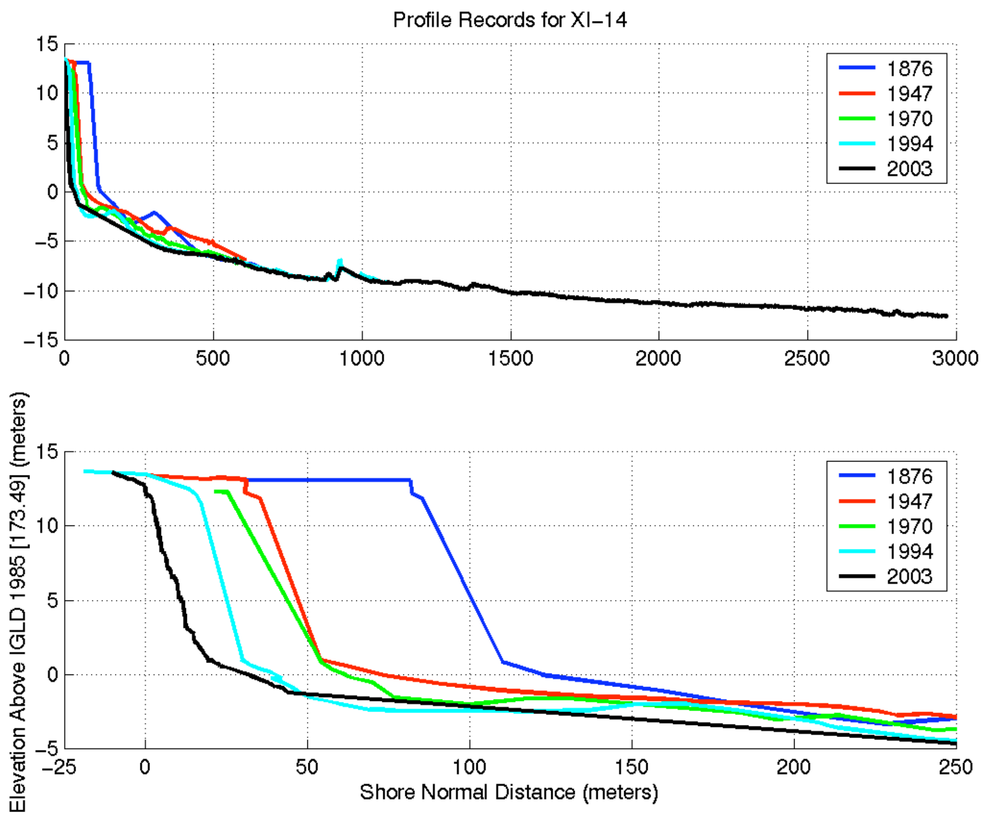

Fig. 6. (upper panel) All surveys for profile line XI-14 dating back to 1876, extending from the top of the bluff to well offshore (depth dependent on the survey method of each particular era). (lower panel) Expanded view of the nearshore and cliff areas showing the significant cliff retreat that has continued up to the present time.

The principal difficulties in surveying in this environment were 1) the very cold temperature during late fall surveys, and 2) submerged hazards that were difficult to detect during calm wave conditions (in fact at one time a hazard was contacted and a non-fatal puncture in the vessel hull occurred).

Shallow Surveys at Piscataqua Inlet, Portsmouth, NH, 2007

As part of the Common Data Set associated with Shallow Survey 2007, the CBASS was used to survey parts of the Piscataqua River Inlet, including Pepperell Cove and adjacent river channel, the shallow shelf around Garish Island, and the rocky regions near Ordiones Pt. (Figure 7). The survey area was conducted by 2 operators over a 9 day period, surveying primarily 5-6 hours about high tides. A total of 40.5 hours of surveys were conducted including 421 shore-normal lines at about 20 *m* alongshore spacing. A total of 385 *km* of survey line were transited encompassing a 10 *sq. km* area. Typical cross-shelf transects from the three regions are shown in Figure 8.

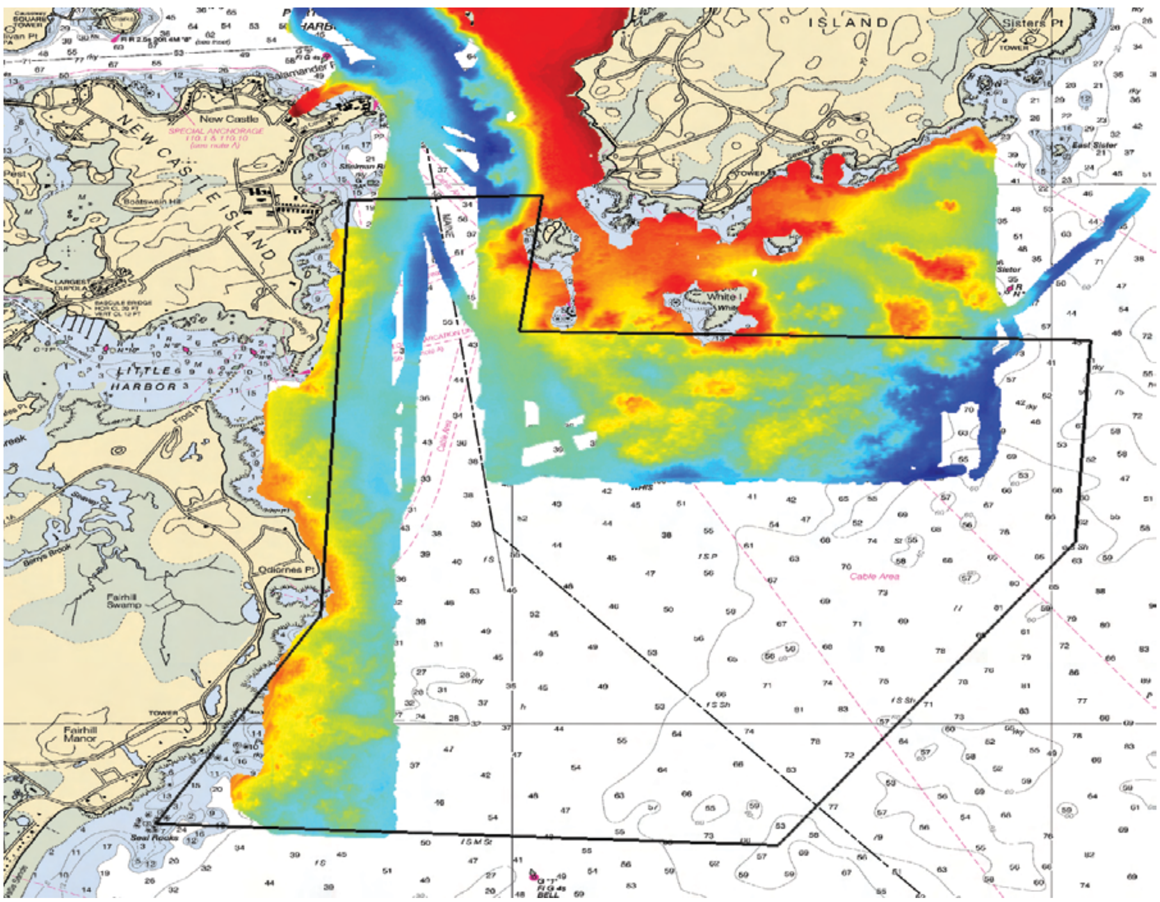

Fig. 7. Region near Piscataqua River Inlet surveyed by CBASS as part of the Common Data Set. Color depth scale ranges 1-25 *m*.

The conditions during the surveys were typically short period sea waves with a variety of wind conditions ranging from mild to moderately windy. The vessel operated at speeds ranging 1-20 *knots*, but typically around 5-7 *knots*, significantly faster than is typically done on sandy beaches with large breaking waves that limit the speeds at which the survey can progress. At times, significant hazards prevented rapid surveying, and careful operation was required, and in some cases the region was vacated owing to unknown, possible submerged rocks. In many instances the presence or absence of local lobster pots and floats was a reasonable indicator of safe or unsafe passage. In general, once the region was interrogated sufficiently, the survey could progress at a rapid pace.

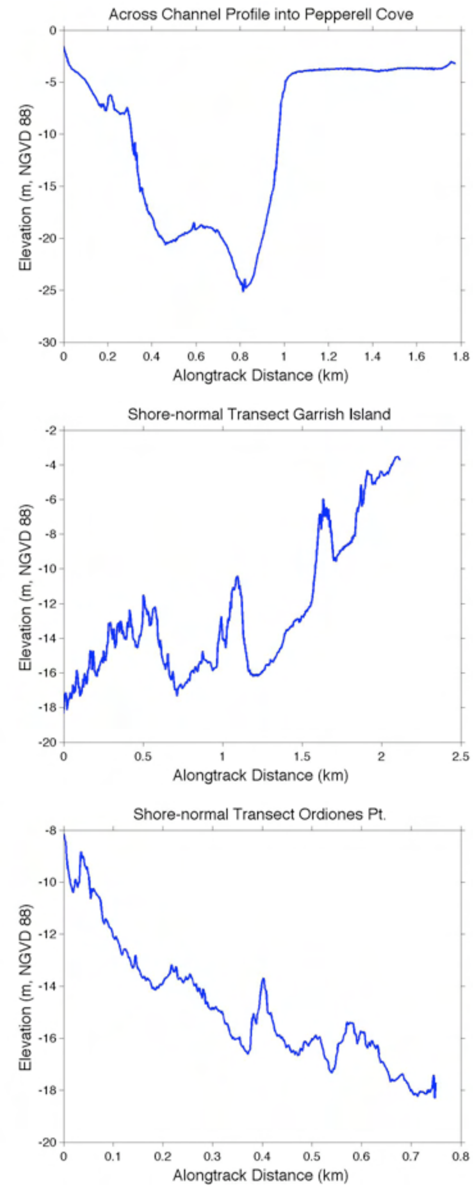

Fig. 8. Example profiles from (top) Pepperell Cove and river channel, (center) shelf at Garrish Island, and (bottom) Ordiones Pt.

Fig. 9. Example photograph of rocky hazards at Ordiones Pt.

The severe rocky environment of Ordiones Pt. (Figure 9) prevented the survey vessel from impinging too close to shore, and was generally limited to a 100-200 *m* from shore in depths around 5 *m*. The principal limitations for surveying in and around Piscataqua Inlet were 1) submerged rocks and hazards at all stages of the tide, and 2) avoiding local fisherman and lobster pots.

Conclusions

The Coastal Bathymetric Survey System, or CBASS, is a well tested survey tool in shallow marine and fresh water systems. Typical RMS errors over sandy substrates are 7-10 *cm* out to 10 *m* water depths. Although surveys are repeatable to depths of 25 *m*, absolute values depend on the vertical density structure of the water column. The CBASS is highly maneuverable, rugged, and reliable in the surf zone, and has proven to work well in rocky, hazardous waters when appropriate caution and operator experience is taken into consideration. The utility of using CBASS, or similar vessels, in shallow water environments has hightened the interest in incorporating other measurement capabilities, including those provided by multibeam and swath systems.

Acknowledgments

The CBASS was originally constructed by Chuck Worley, then of Scripps Institution of Oceanography (SIO), La Jolla, CA. Bill Boyd of SIO and EE Consulting, Inc., made the sonar. Fred Wright (SIO) wrote the data acquisition software. Ground truth walking GPS surveys were conducted by Linden Clarke, then of SIO. Jason Magalen conducted CBASS surveys conducted at NCEX and Lake Erie. Dennis Darnell (SIO) conducted many surveys on CBASS over the years, and assisted in modifications and construction of subsequent units. Don Guy (ODNR) was instrumental in the comparing the CBASS surveys with historical surveys along Lake Erie. Funding for the CBASS was provided by the California Dept. of Boating and Waterways, the Mellon Foundation, and the Office of Naval Research.

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