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On the Horizon:
Better Bottom Detection for areas of Sub-Aquatic Vegetation

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Abstract

Bottom detection methods in single beam echo sounding (SBES) are often less robust in areas with sub-aquatic vegetation. Due to current mapping efforts emphasizing near shore coverage for safety of navigation and the mission for alternative uses of hydrographic quality data with the Integrated Ocean and Coastal Mapping (IOCM) Center, there is a requirement for both robust bottom detection in areas with complex vegetation and delineation of the vegetated areas themselves. Vegetation can often be found growing in close proximity to rocks and other features of navigational significance and would provide valuable information to fisheries if prime fish habitats like eelgrass could also be mapped with the navigational hazards.

A bottom detection algorithm implemented in the program TracEd is being evaluated for handling bottom detections on eelgrass in the water column. This algorithm allows for detections of multiple returns in a full waveform trace for each ping. Each of these returns is then tagged as being associated to seafloor or water column features. Should this algorithm prove to be more robust in recognizing returns from vegetation and identifying the underlying bottom, a systematic approach for NOAA to more accurately determine depth in areas of sub-aquatic vegetation might be possible. A full waveform SBES dataset collected in New Hampshire's Great Bay Estuary is under analysis to determine whether bare earth can be distinguished from the eelgrass canopy in this area where eelgrass is common and well studied. Additionally, characteristics of the waveform necessary for bottom detection are also being evaluated for eelgrass mapping.

I. Introduction

A single beam echo sounder survey (SBES) was conducted in Great Bay by researchers from the Center for Coastal and Ocean Mapping (CCOM) during the summer of 2009. The purpose of the survey was to establish a bathymetric baseline for future re-survey to study channel migration; however, current variability in bottom detections from eelgrass beds would make comparisons with future surveys difficult. A screen capture of the real-time acquisition display seen below in Figure 1 shows bottom detections alternating between the eelgrass canopy and seafloor.

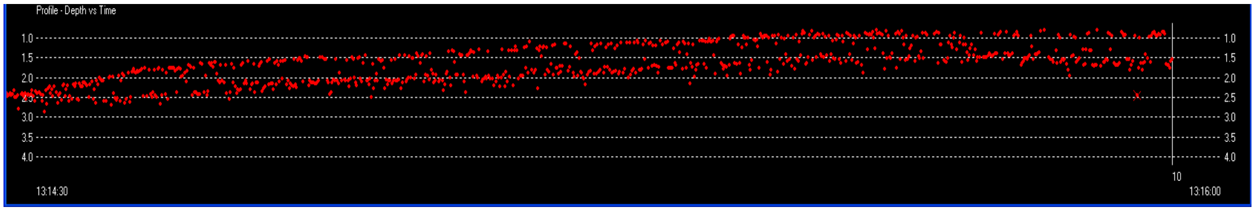

Figure 1: Bottom detections on both the eelgrass canopy and seafloor as seen in the Hypack profile window from R/V Limulus. (CCOM Great Bay Survey, 2009)

By determining a bare earth bathymetric model of Great Bay, estuarine studies of sediment deposition and re-working of the seabed could be more accurately evaluated without the depth variability from eelgrass detections.

Ultimately, the research outlined in this paper has two goals:

- Reprocess bottom detections scattered amongst the eelgrass canopy for bare earth detections with higher certainty for bathymetric purposes.
- Determine whether eelgrass beds in Great Bay New Hampshire can be mapped through textural analysis of waveform properties.

Both goals are to be achieved through the bottom detection process implemented in the software TracEd to achieve more accurate bottom picks. As an initial step, the researchers will display the rise time characteristic from the full waveform trace of the bottom return, as determined by TracEd, in the geographic information system ArcMap. The larger rise times are expected to correspond to eelgrass beds in Great Bay.

The next section of this paper highlights several NOAA hydrographic surveys where better knowledge of surveying in areas of sub-aquatic vegetation would have lead to less confusion and more accurate navigational products. Current practices stressing safety of navigation will be discussed along with expressing support of additional guidance for surveying in areas of vegetation.

The third section of this paper will briefly describe the ground truth comparisons that will occur between the TracEd rise times and historical eelgrass distributions. Extensive knowledge of eelgrass beds in Great Bay comes from the work of Dr. Fred Short and his colleges at Jackson Estuary Laboratory (JEL), University of New Hampshire (UNH). By evaluating the rise times from SBES returns in an area with knowledge of eelgrass distribution, statistical analysis can be conducted to determine how well rise times denote eelgrass beds for mapping.

Section four of this paper provides an overview of the TracEd algorithm by Dr. Semme Dijkstra. The methodology for more reliable bare earth bottom detection and eelgrass mapping was still in testing and development at the publication of this paper. The researchers are looking to draw attention to this area of study and start conversations for expanding current techniques for post processing of SBES to other methods of survey in areas of sub-aquatic vegetation.

The Great Bay dataset used in this study lends itself well to the goal of acquiring, managing, and integrating coastal mapping data for many uses. The phrase “map once, use many times” has been gaining ground with the hydrographic community in recent years. Project managers are beginning to ask whether their data could be of use to other groups, yet most organizations are presently unwilling or unable to commit additional resources to the task. This discussion aims to address the difficulties of acoustic surveying in areas of sub-aquatic vegetation and explore how characteristics of the full waveform signal can be better utilized for bottom detection and analysis with multiple missions.

II. Implications for NOAA in Echo Sounding

Due to the high acoustic impedance of gases, bubbles generated through photosynthesis and the gas filled channels of vegetation make vegetation at the seafloor strong acoustic reflectors (Wilson and Dunton, 2009). Numerous studies have also evaluated the effects of varying frequencies and grazing angles interacting with *Zostera marina*, commonly known as eelgrass, and other species of vegetation (Lyons and Pouliquen, 1998; McCarthy and Sabol, 2000). The acoustic response of sub-aquatic vegetation has been studied and use of side scan and interferometric sonar systems have been used to map eelgrass through seafloor classification methods. Although a plethora of acoustic mapping of sub-aquatic vegetation exists, little work has been done in developing procedures for the reprocessing of more robust bottom detections of bare seafloor in areas of vegetation.

NOAA’s Office of Coast Survey has experienced difficulties in dealing with the effects of sub-aquatic vegetation in bathymetric surveying. Hopefully, by the completion of this discussion, interest will be re-kindled in this area of acoustic research where little documentation exists. Mitigating the noise caused by sub-aquatic vegetation takes time and has often left shoal biased soundings from vegetation instead of actual seafloor depths in navigational products for the purposes of safety.

Descriptive reports filed with NOAA hydrographic surveys of shallow, interior waterways often include statements detailing dense vegetation covering the lake and river bottoms. The vegetation prevents the single beam echo sounders, used in conjunction with side scan sonars, from penetrating the vegetation and ensonifying the “true bottom” (NOAA Reports H11913 and F00542, 2008). Accepted procedure for evaluating depth data in these cases has been to study the depth soundings with the full single beam trace recorded in the Hypack BIN files. An example of the vegetation and false bottom detections displayed in Pydro's BIN viewer can be seen below in Figure 1. Pydro is the NOAA in-house software that displays the bottom picks (in red and highlighted below) with a digital trace of the data.

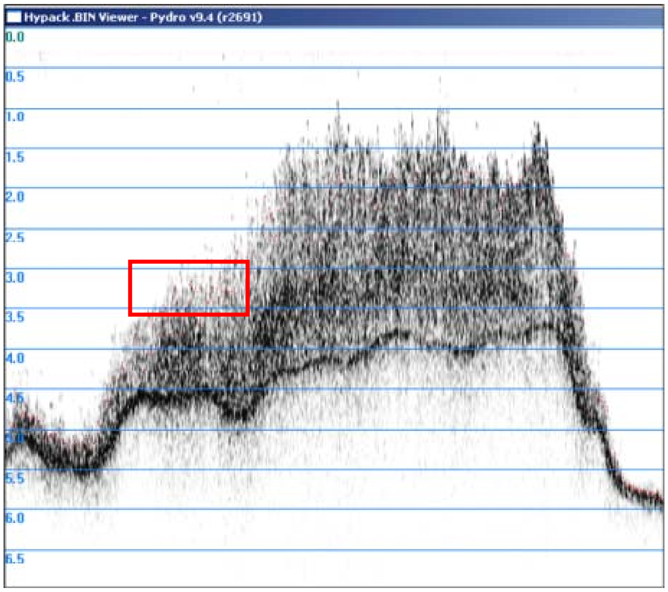

Figure 1: Sample screen capture of vegetation in BIN file with bottom detections on the grass from F00542 (2008). Vertical axis in meters.

The graphic in Figure 1 from survey F00542 is one example of confusion created between the field party and the review branch office; the survey was initially rejected in review and returned to the field. Dangers to Navigation (DtoN's) were submitted for charting and had to be recalled on account of the need to clarify that vegetation was present and for all parties to be reminded how to deal with surveys in areas of vegetation (NOAA Report F00542, 2008, personal communication LCDR Shepard Smith, March 31, 2008 and LT Olivia Hauser, January 13, 2009). Loss in processing and review time occurred due to the unusual nature of the survey compared to typical hydrographic submissions not located in areas of sub-aquatic vegetation.

In some cases, like in previously mentioned surveys F00542 and H11913, soundings from vegetation were charted due to the inability to determine whether or not rocks where concealed in the grass. The goal of NOAA nautical charts, above all, is to support safe navigation. NOAA surveys in coastal Alaska have also suffered noise introduced by sub-aquatic vegetation. Examples below in Figures 2 and 3 come from multibeam echo sounder (MBES) survey H11987 where noise caused by vegetation was also preserved and charted in the name of safe navigation. Vegetation could not be rejected because water column data or side scan imagery was not available to disprove the existence of hazards to navigation (NOAA Report H11987, 2009).

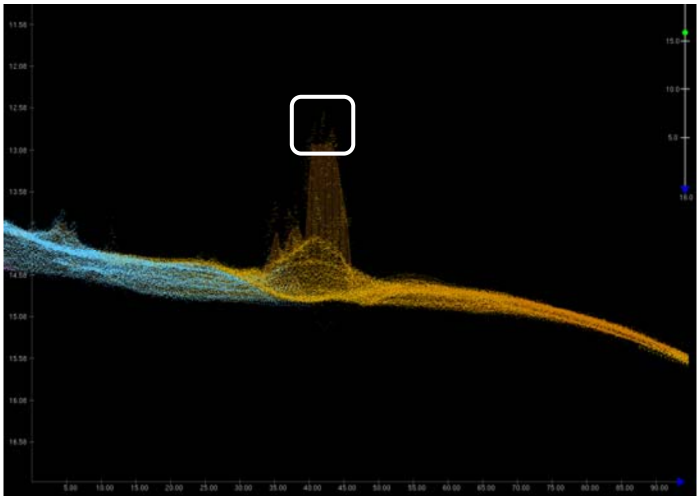

Figure 2: Surface only partially honoring MBES data, shoal sounding designated for safety of navigation (H11987, 2009). Data displayed in CARIS HIPS and SIPS 2-D editor with vertical exaggeration.

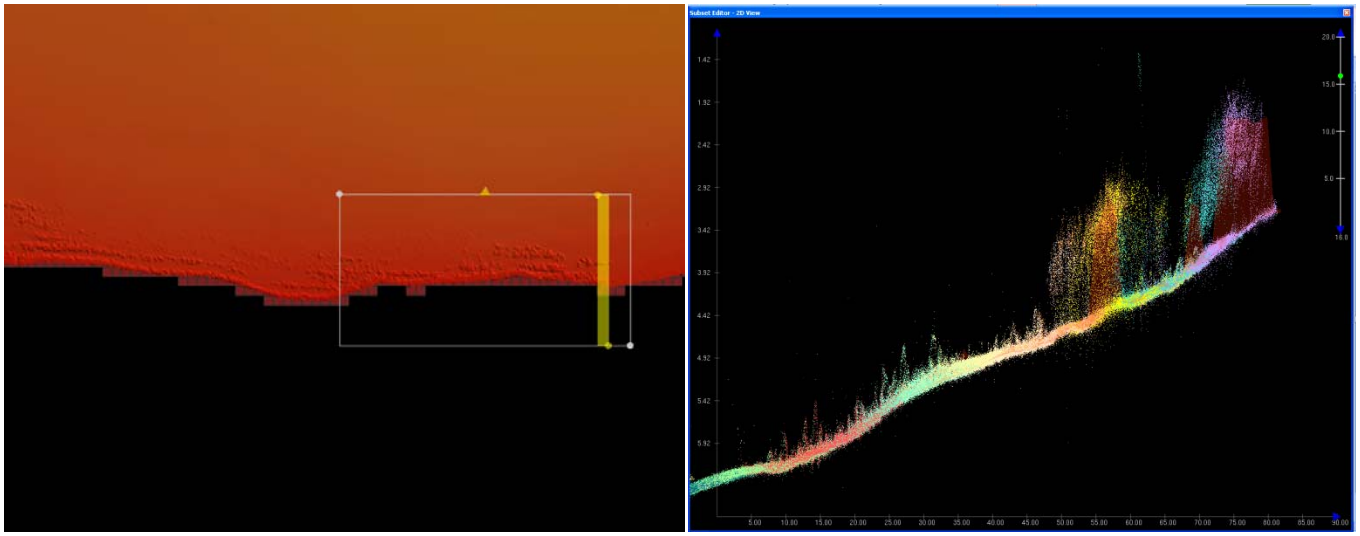

Figure 3: Suspected sub-aquatic vegetation left un-rejected and un-designated (H11987, 2009). Data displayed in CARIS HIPS and SIPS layout view (left) and 2-D editor (right) with vertical exaggeration.

As of early 2011, NOAA still has little documentation advising field units and review branches on practices when “noise,” created by vegetation, is present in surveys. Reference back to the Hydrographic Manual of 1976 explains the procedure for studying the analog trace in areas of vegetation and how great skill in studying the traces was required along with a lead line or sounding pole to supplement or replace echo soundings (Umbach, Sections 4.3.1 and 4.9.8.1). Not much has changed in technology relating to SBES besides the switch from analog to digital recording devices, yet minimal mention of vegetation occurring in surveys can be found in the present NOAA Field Procedures Manual (NOAA FPM, 2010, Section 4.2.4.2.6).

Although NOAA has made the ability to study the full waveform trace together with the bottom detections a priority for CARIS, their primary processing software; the researchers believe that vegetation on the seafloor should be an area of increased interest and documentation for NOAA for more accurate bare earth detection.

III. Historical Eelgrass Mapping in Great Bay

Fred Short of Jackson Estuary Laboratory with the University of New Hampshire has been studying eelgrass distribution in the Northern Atlantic for over twenty years. Short's work with eelgrass monitoring is world renowned through his participation with the Global Seagrass Monitoring Network as the organization's director.

Short conducted eelgrass mapping in the Great Bay Estuary (GBE) system for 1996, 1999, 2000, and 2001, reporting approximately 2,000 acres of eelgrass cover which remained relatively constant throughout the years. After 2002, the eelgrass mapping of Great Bay received financial support from the Piscataqua Region Estuaries Partnership (PREP) to digitize Short's recent work and commit to the annual monitoring of the estuary (Short, 2004).

The eelgrass of Great Bay has been established as essential habitat for juvenile fish and shellfish as well as providing food for waterfowl. Additionally, the grass has been shown to filter waters of nutrient runoff and suspended sediments while also stabilizing bottom sediments (Short, 2004; Pe'eri et al., 2008).

Annual eelgrass monitoring from 2002 through 2007 was conducted through the combination of ground truth observations and aerial photography. The consecutive surveys documented the steady decline in eelgrass biomass and distribution, along with providing ties to declining water clarity in the estuary (Short2007). Grants in 2007 provided Short and PREP the funding to collect and process a hyperspectral survey of GBE. Results of the AISA hyperspectral survey and subsequent analysis can be seen below in Figure 4. The imagery allowed for the mapping of nuisance macroalgae, lending support to the hypothesis that eutrophication of the estuary is responding to increased nutrients. Complications arose in identifying the spectra of submerged vegetation and macroalgae in GBE due to increased attenuation with depth; however, though a combination of ground truthing and expert opinions, the hyperspectral mapping was determined to show potential for management in coastal waters (Pe'eri et al., 2008).

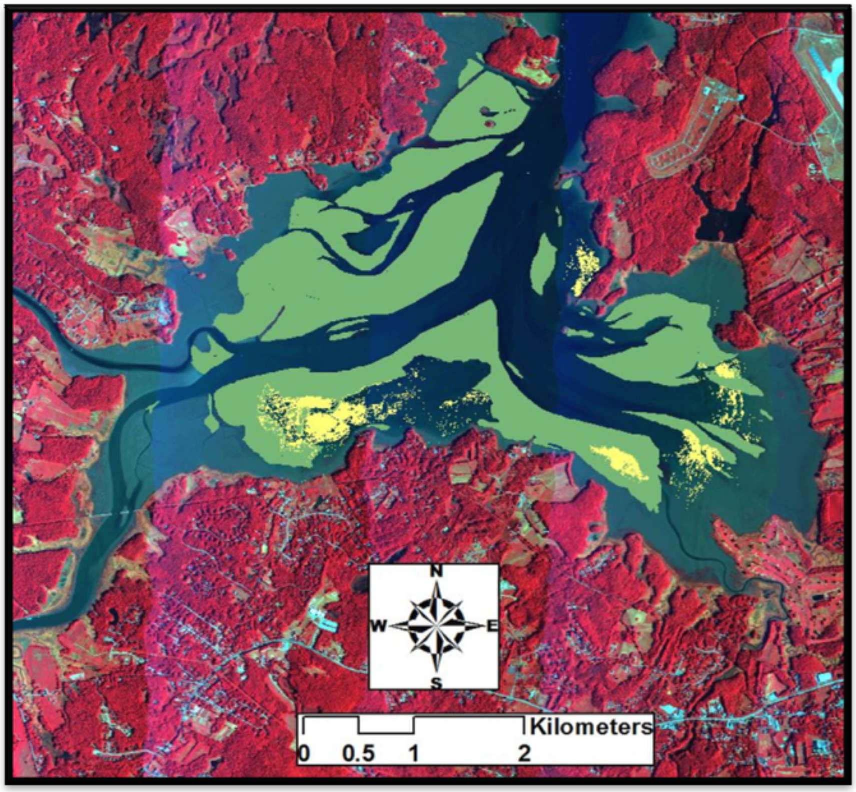

Figure 4: Areas highlighted in green represent eelgrass beds, while yellow represents macroalgae growth overlaying a hyperspectral survey mosaic flown August 2007. Mosaic is a false color image with channels R: 814nm, G: 670nm, and B: 527nm (Pe'eri et al., 2008).

All in all, the work of Fred Short and his colleague has provided an extensive digital dataset of eelgrass distribution in GBE. The eelgrass area features exist as shape files for evaluation in GIS software which will provide the ground truth portion for the SBES waveform analysis underway with the 2009 Great Bay dataset.

IV. Great Bay Analysis with TracEd

The SBES dataset of Great Bay was initially intended to create a baseline to study changes in the bathymetry of navigational channels and to map the eelgrass canopy with underlying substrate. Partial surveys exist for Great Bay from 1913 and 1955, however, due to insufficient quality assurances with historical survey practices, comparisons with historical data were not possible (Ward et. al., 2009). The recent survey took place during high tides throughout the months of July and August of 2009. Considering that the average depth of Great Bay varies from one to three meters at high tide, survey windows were limited to a few hours a day for safe navigation in shoal water and detection limitations of the echo sounder.

The bottom detection algorithm implemented in TracEd is designed to select multiple picks for each SBES trace. This capability allows for peaks throughout the entire return to be analyzed for feature detection rather than simply the bottom return – each feature detected will henceforth be referred to as a pick. Additionally, a set of descriptive features is extracted for each return allowing classification as associated to pelagic, benthic (seafloor) or sub-bottom targets.

One of the parameters extracted for each pick is the time separation between the leading edge and the maximum intensity of the return (after low pass filtering). Analyses of this separation for the bottom return allows for the detection of features such as aquatic vegetation and suspended sediment. In Great Bay, the dominant cause for increased separation values is the presence of eelgrass and thus TracEd could be used to map the presence and distribution of eelgrass in the system. As the presence of eelgrass minimally affects the speed of sound, the rise time may also be used as a measure of the distance from the eelgrass canopy to the bare earth (bottom) underneath by differencing the rise observed rise time with the expected rise time in the absence of eelgrass. Ability to measure eelgrass canopy height, in conjunction with underwater imagery in Great Bay, could also provide insight studying eelgrass movement due to currents for future field studies.

The methodology behind TracEd’s ability to consider multiple picks can be briefly summarized in the following steps:

1. Application of a median filter to remove noise while preserving edges of the pick
2. Leading edge detection, with subsequent analysis of the length of the features associated to the edges for the entire trace.
3. The response duration for the pick is used as quality control. If duration is less than the pulse length combined with the geometry of the transmitted and receive system allows, then the pick is flagged as suspect.
4. All the picks associated to a trace are analyzed for the likelihood of being a bottom return based on the Total Energy Content (TEC) of the pick, as well as its correlation in shape to previously accepted bottom picks, or in the absence thereof the modeled shape of the bottom return (if available). Note that when all gains and parameters of the signal have been applied, the greatest TEC is usually the correct bottom pick.
5. The pick designated as bottom is compared to a window whose center is determined by mean filtering the bottom returns and whose size is determined by analysis of first differences.
6. Additional flags are associated with the returns classifying them as seafloor, sub bottom- or water column features.

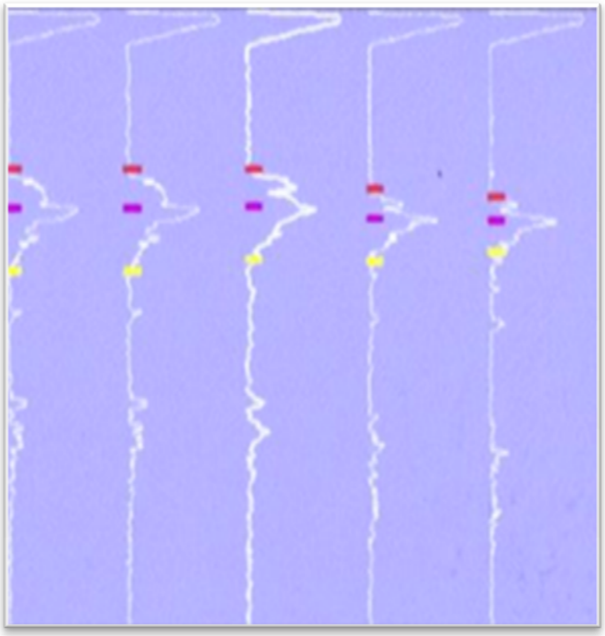

Figure 5: Example of five full waveform SBES traces displayed in TracEd (Dijkstra and Mayer, 2000). Red: leading edge, Purple: peak amplitude, Yellow: trailing edge.

Once the bottom detection process is complete, the rise time from the break point to the peak amplitude for picks classified as water column features can be exported from TracEd. The rise times can be brought into ArcMap geo-referenced for comparisons with the eelgrass distribution layers as seen above in Figure 4.

V. Conclusions

NOAA’s IOCM Coordinator, Roger Parsons, identified three areas of attention as the National Ocean and Coastal Mapping (OCM) action pan at the Oregon Seafloor Mapping Workshop (2008). In partnership with the work being conducted by Fred Short and PREP, our undergoing research addresses the first two goals of tool development and OCM community building to maximize national mapping efficiencies. Should the TracEd algorithm prove more robust in recognizing returns from vegetation and identifying the underlying bottom, a systematic approach for NOAA to more accurately determine depth in areas of sub-aquatic vegetation might be possible. Additionally, the study of rise time for eelgrass mapping is one waveform characteristic expected to show promise for bed delineation, thereby achieving the goal of multi-mission analysis of acoustic data for bathymetry and habitat mapping.

The researchers are excited to continue with TracEd analysis of the Great Bay dataset. Dijkstra is currently updating software for the new Odom file format while planning a brief imagery and ground truth study with Beduhn to obtain physical measurements of eelgrass canopy height with concurrent SBES data logged. Those results will be combined with the analysis described in this paper as Beduhn’s directed research in partial fulfillment of the Master’s Degree program in Ocean Mapping from CCOM of the University of New Hampshire.

Acknowledgements

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