ELSEVIER

Marine Geology 133 (1996) 241–248

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

Performance of a sonar altimeter in the nearshore

Edith L. Gallagher [a], William Boyd [a], Steve Elgar [b], R.T. Guza [a], Brian Woodward [a]

[a] *Center for Coastal Studies 0209, Scripps Institution of Oceanography, La Jolla, CA 92093, USA*
[b] *School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA 99164-2752, USA*

Received 12 April 1995; accepted 22 February 1996

Abstract

A 1 MHz sonar altimeter with automatic gain control is shown to provide accurate estimates of the distance between the instrument and the seafloor. Laboratory experiments indicate that distance estimates degrade slightly when the bottom is rough or sloped and when sediment is suspended in the water column. Results from field tests, both within and seaward of the surf zone, show some degradation owing to a combination of suspended sediment and bubbles, bed undulations, and perhaps the dynamic nature of the sand bottom under waves. Seaward of the surf zone the bottom can be located within ± 2 cm nearly continuously, whereas inside the surf zone the bottom can be located only intermittently and the accuracy decreases to ± 3 cm. A 300 m long cross-shore transect of 16 altimeters was deployed from the shoreline to about 4 m depth for 3 months in summer–fall 1994 near Duck, NC. Results show that the altimeters are robust and can usually provide estimates of the seafloor position every few minutes even in the surf zone during large storms.

1. Introduction

Sonar altimeters can be used to estimate the location of the seafloor by measuring the time for an acoustic pulse to travel to the seafloor and back, and converting to a distance with the theoretical sound speed. Sonar altimeters mounted on fixed frames have been used to investigate nearshore bedforms (Dingler et al., 1977; Dingler and Clifton, 1984), to measure accretion and erosion in intermediate water depth (8 m) (Wright et al., 1986a,b), and to estimate the height of current meters above a sandy continental shelf (Grant et al., 1983). Owing to the severe attenuation and scattering of the sonar beam by suspended sand and bubbles associated with breaking waves in very shallow water, sonar altimeters mostly have been deployed seaward of the surf zone. Even in water 8 m deep, the performance of sonar altimeters can be poor during storms (Green and Boon, 1988). In the present study, laboratory and field tests of a sonar altimeter that can locate the seafloor with uncertainties of a few centimeters through bubbly and turbid surf zone waters are described. Automatic gain control (AGC) is used to accommodate large fluctuations in the acoustic propagation properties of the water column, thus improving the bottom-locating capability of the altimeter. A post-processing algorithm rejects spurious sonar returns from suspended sand and bubbles. Preliminary results from a field deployment demonstrate that the altimeter can monitor nearshore bathymetric evolution on both relatively small (megaripples, lengths of 1–10 m and heights

PII S0025-3227(96)00018-7

of 10–50 cm) and large (sand bars, lengths of 100–200 m and heights of a few meters) spatial scales for several months with little maintenance.

2. The altimeter

The altimeter consists of a 2.54-cm diameter transducer (V302-SB Videoscan immersion transducer manufactured by Panametrics, Inc.) and its electronics housed in a 7-cm diameter, 35-cm long PVC tube. The transducer beamwidth of approximately 3.4° results in a 6-cm diameter footprint at 1.0 m range. A 1 MHz acoustic pulse (duration 10 μsec) is transmitted 25 times per second, with return echoes detected after each pulse. Because the transducer vibrates after the pulse is sent, and early reflections can be noisy, the incoming signal is blocked for 270 μsec, corresponding to a minimum detectable distance to the sea floor of approximately 20 cm. The maximum range varies from approximately 180 cm in turbid, bubbly water to more than 250 cm in clear water.

The strength of the bottom reflection can vary as the concentration of bubbles and suspended sediment in the water column fluctuates (e.g., with the passage of bores and/or sediment clouds), and thus an altimeter that uses a fixed threshold to detect the bottom echo is ineffective in the surf zone. Using AGC, the instrument gain is adjusted (and applied to the subsequent pulse) to maintain an approximately constant peak voltage regardless of attenuation and scattering in the water column (Fig. 1). A threshold voltage for detecting the bottom is set just below this constant level, and the travel time of the first return above the threshold (Fig. 1) is used to calculate the distance to the seafloor (the dependence of sound speed on water temperature, measured with a colocated thermistor, is accounted for in post-processing).

Although bottom location estimates discussed here are based on travel times sampled at 2 Hz, sample rates, threshold voltages, and AGC response characteristics are adjustable. Incorrect estimates of the distance to the bottom can occur when the assumption that the strongest echo comes from the seafloor is violated, when the effects of bubbles on sound speed are not negligible, and when there are very large variations between the successive (25 Hz) return pulses (i.e., successive return pulses are similar in Fig. 1). A schematic block diagram of the AGC altimeter electronics is shown in Fig. 2.

3. Laboratory tests

The altimeter was suspended about 90 cm above the smooth metal bottom of a laboratory tank filled with sea water. The mean distance to the bottom estimated with the altimeter was within the few mm accuracy of an independent distance estimate and had a resolution (scatter) of ± 1 mm, approximately equal to the acoustic wavelength (~ 1.5 mm) and close to the theoretical resolution of the instrument (~ 0.75 mm). The scatter of the estimates increased to ± 2 mm when a level bed of sand grains (diameter ~ 1 mm) covered the bottom, probably because of the uneven reflecting/scattering surface of the grains.

On a sloping bed, the first return from the bottom could be from the higher portions of the footprint, resulting in an underestimate of the average distance to the bed (Dingler, 1974 and Green and Boon, 1988). Although the shape of artificially steep bedforms is qualitatively reproduced when the altimeter is translated across them (Fig. 3), the narrow troughs (with widths similar to the 6 cm diameter footprint) are truncated (positions 158 and 175 cm, Fig. 3) and the narrow peaks are smoothed (positions 148 and 165 cm, Fig. 3).

The scatter (ie, the thickness of the band of returns from the bottom) was about ± 7.5 mm, compared to ± 2 mm for the flat, compacted sand bed, possibly owing to returns from the vertical extent of the footprint or to a change in the scattering properties of the bed because of dilation of the sand during construction of the ripples. The ~ 2 cm offset error (Fig. 3) is comparable to the accuracy of the manual surveys (done with a plumb bob suspended from a string).

To determine the effect of suspended sediment on the bottom-detection capability of the altimeter, tests were performed in an elutriator, a cylindrical flow channel in which water is pumped vertically

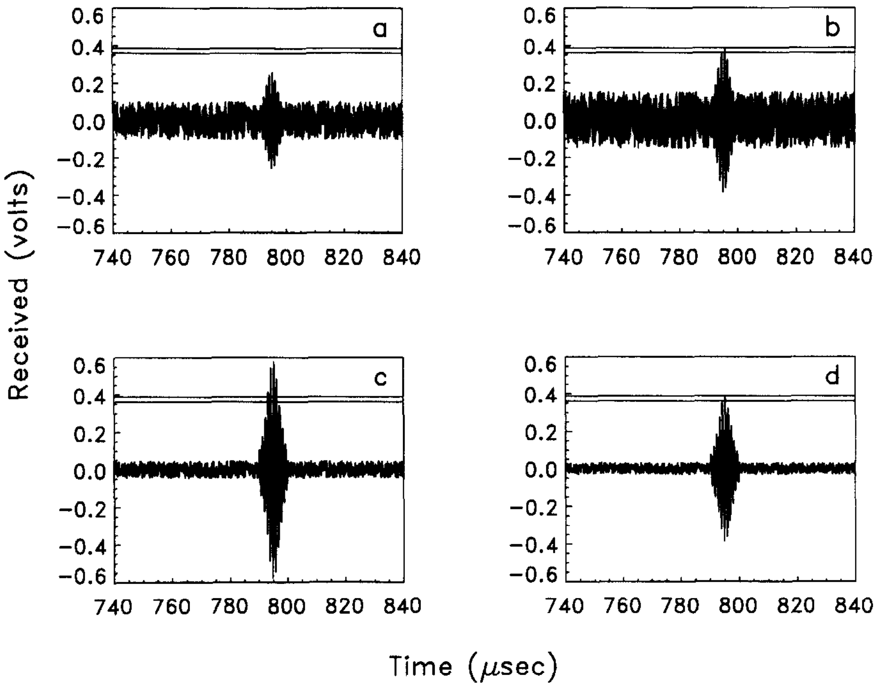

Fig. 1. Received acoustic signal strength versus time. A pulse (10 μs duration) of 1 MHz sound, transmitted by the altimeter at $t=0$, is reflected from the seafloor 60 cm below and received at $t \sim 795$ μs. A weak return pulse is shown before (a) and after (b) gain adjustment to increase the signal level. A strong reflected pulse received by the altimeter is shown before (c) and after (d) gain adjustment to reduce the signal level. The AGC constant voltage (0.389 V) and the detect threshold voltage (0.361 V) were chosen by trial and error.

upward to suspend sediment. Tests were performed for a range of sediment grain diameters (0.1–10 mm). Larger grain sizes in suspension degraded the bottom-finding capability relative to smaller grain sizes. When the grain size is comparable to, or larger than, the acoustic wavelength (~1.5 mm), the acoustic pulse will be reflected, as opposed to being scattered from smaller grains (Urick, 1983). Strong reflections from larger grains in the water column are effective at masking the true bottom location.

4. Field tests

Field tests were conducted seaward of the surf zone in about 3-m water depth near the Scripps Institution of Oceanography. The significant wave height ranged from 38 to 62 cm. Divers observed that the upper layer of sand was often moving in response to wave-orbital velocities and that orbital ripples often covered the seafloor near the altimeter. Divers also observed that scour from the support frame did not extend into the altimeter footprint. Altimeter estimates of the distance to the undisturbed sand bottom had about ±2 cm scatter (0–11 min, Fig. 4), compared to ±0.5 cm scatter when a smooth metal plate was placed on the sand below the altimeter and leveled by pressing it into the bed (11–30 min, Fig. 4). After the plate was removed, the scatter of the bottom location estimates (±1 cm) was reduced relative to the scatter from the undisturbed sand (±2 cm), possibly owing to compaction of dilated sand during leveling of the plate. Removal of the plate did not result in relaxation of the 2 cm sand compression. Between minutes 25 and 29 (Fig. 4) sand was released from a container, suspending sediment in the water column between the altimeter and the plate. There were many false returns from the water column, but the bottom location is still apparent.

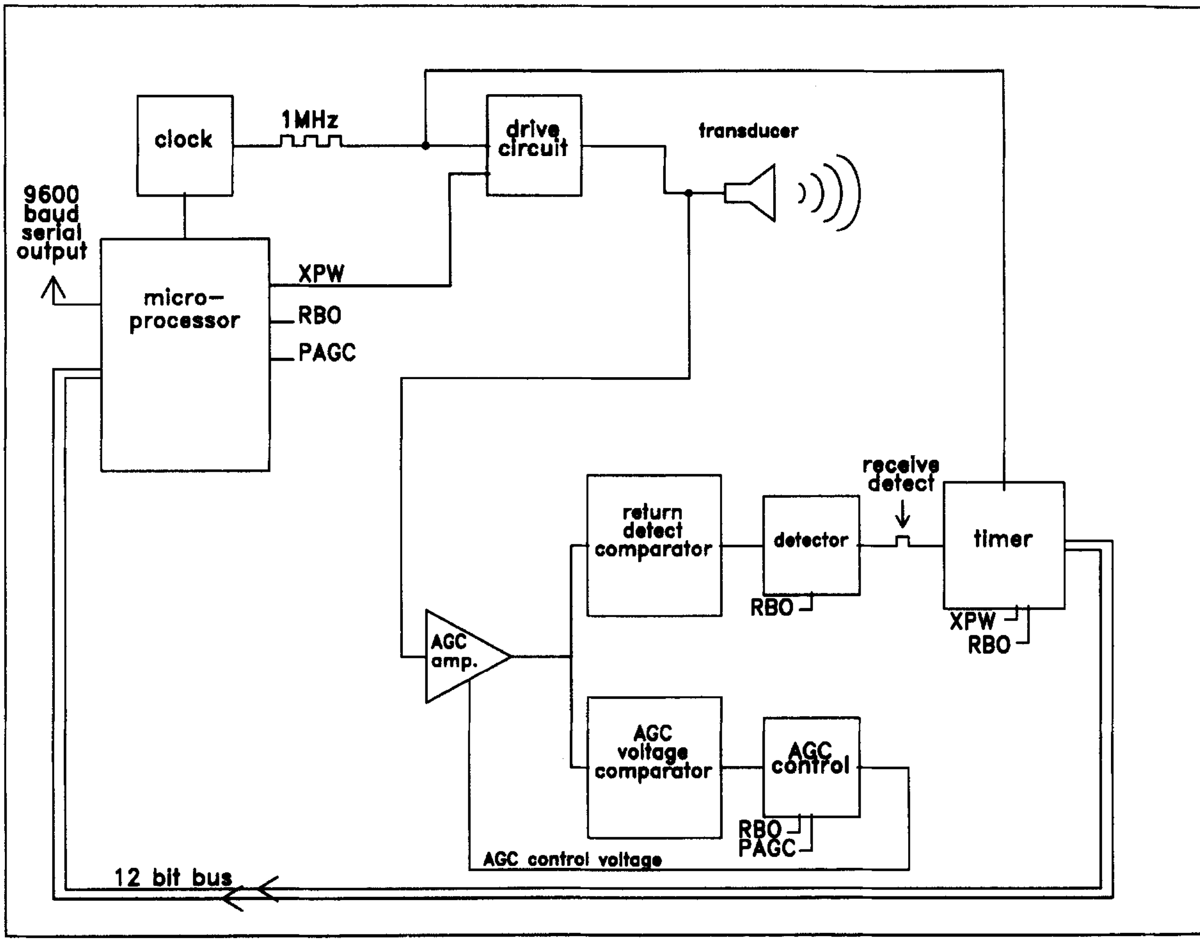

Fig. 2. Block diagram of the automatic gain control (*AGC*) sonar altimeter circuitry. *XPW* is the transmitted pulse, *RBO* is the receiver blank-out pulse, and *PAGC* is the AGC control pulse.

The performance of the AGC altimeter was superior to that of a colocated nonAGC altimeter. At best, the nonAGC altimeter accurately located the bottom 85% as often as the AGC altimeter. During turbid conditions when the bottom was more difficult to locate, 33% of the AGC altimeter estimates were accurate, compared to 1% of the nonAGC altimeter estimates.

Bottom location estimates for 1.2 days during a surf zone field test (mean water depth from 0 to 150 cm depending on tidal stage) are shown in Fig. 5. Although breaking-wave induced bubbles and suspended sand produce a large number of errant returns from the water column, the seafloor position is distinguishable as the dark band of dots (width about ± 3 cm) between approximately 60 and 80 cm below the fixed altimeter. Most of the errant returns fall between 20 and 25 cm. When the return signal noise floor is similar in magnitude to the bottom return it may be amplified to the detect threshold through adjustment of the gain by the AGC (Fig. 1), resulting in an (incorrect) estimate at, or near, the minimum detectable distance, 20 cm. During low tide (eg, day 20.1–20.3 and beginning again at day 21.2) the altimeter was above the water surface, producing the "black snow" of dots with no distinguishable seafloor location.

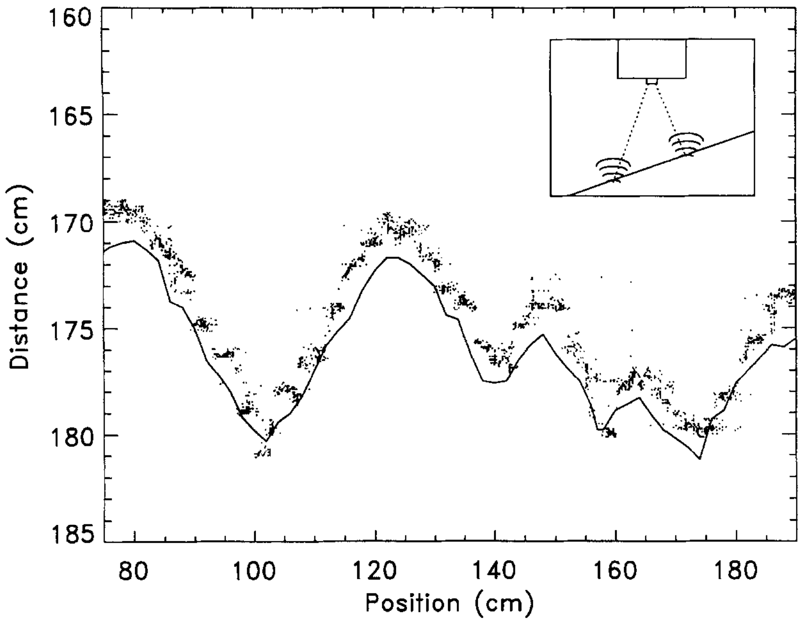

Fig. 3. Distance of the sonar altimeter above a sand bed versus position along the centerline of a laboratory tank. Each point represents a sonar altimeter estimate and the solid line represents a manual survey (approximately ± 2 cm accuracy). Inset: footprint of altimeter on a sloped surface.

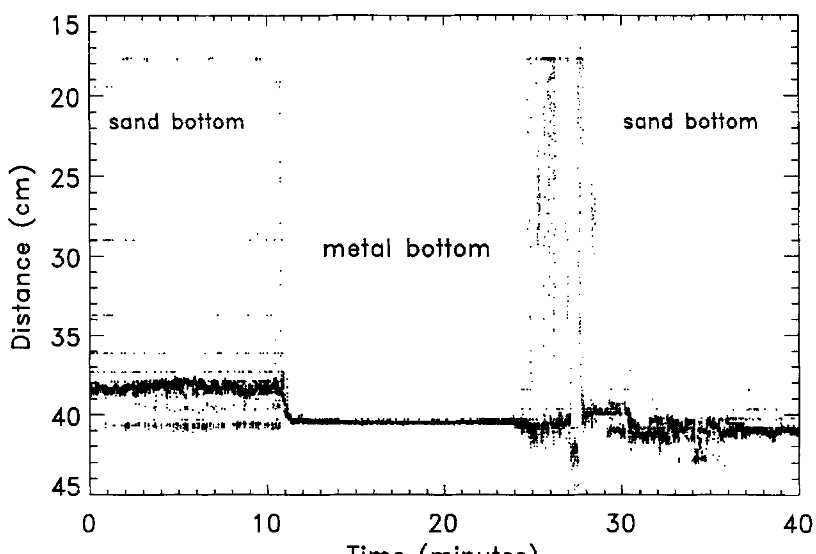

Fig. 4. Distance of the sonar altimeter above the bed seaward of the surf zone (3 m water depth) versus time. Each point represents an altimeter estimate (every 0.5 s). The seafloor was a natural sand bed from time = 0 until time = 11 min, when a smooth metal plate was leveled on the sand below the altimeter. At time = 25 min a container of sand was emptied above the metal plate, partially filling the water column with suspended sand. The smooth plate was removed at time = 30 min.

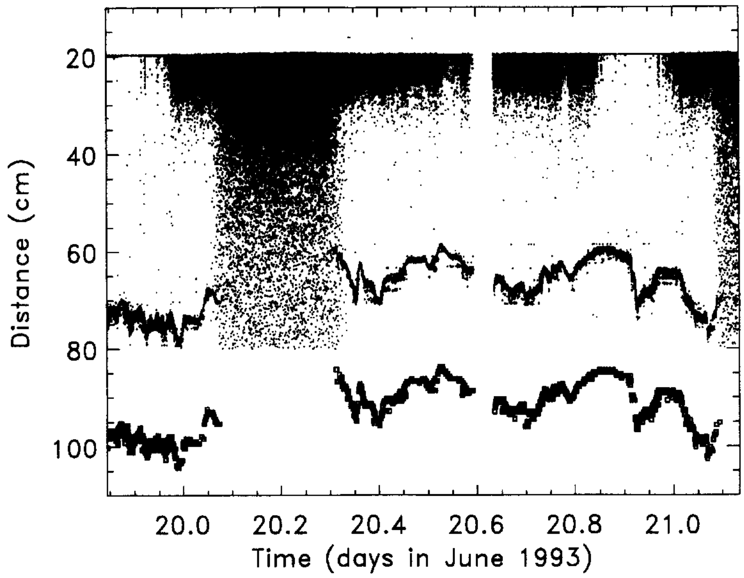

Fig. 5. Distance of the sonar altimeter above the seafloor in the surf zone versus time. The dots represent raw altimeter estimates every 0.5 s. The (fluctuating) seafloor position is distinguishable as the dark band of dots between approximately 60 and 80 cm. At low tide (e.g., between about 20.1 and 20.3 days) the altimeter was out of the water, producing the "black snow" of dots with no distinguishable seafloor location. The squares (offset 25 cm for clarity) represent the 32-s estimates from the bottom-finding algorithm.

5. Bottom-finding algorithm

Although as many as 70% of the sonar returns can be erroneous, especially in the surf zone, the seafloor is often readily detectable by eye (e.g., Fig. 5). To routinely process the raw, 2 Hz sonar returns, an algorithm has been developed that provides accurate estimates of the bottom location every 32 seconds. First, a histogram with 2-cm wide distance bins is constructed from 256 s of 2 Hz samples. The distance bin with the most occurrences (excluding bins less than 25 cm, which contain most of the false returns) provides a rough estimate of the distance to the seafloor. The 256-s record is then subdivided into eight 32-s records, and a histogram with 0.5 cm-wide bins (within ± 20 cm of the maximum of the 256-s histogram) is constructed for each. The maxima of the 32-s histograms provide estimates of the distance to the seafloor every 32 s. The estimates of the bottom location used here had a minimum of 5 (100) points in the peak of the 32-s (256-s) histogram. Distance estimates from the bottom-finding algorithm for the surf zone data in Fig. 5 are shown offset by 25 cm. The parameters used in the algorithm were determined by trial and error using data from the field tests and a subsequent 3-month long field deployment (discussed below). The algorithm only failed during the most energetic conditions in the surf zone.

6. Preliminary results from a 3-month long field deployment

For approximately 3 months in summer-fall 1994, 16 AGC sonar altimeters colocated with current meters, pressure gages, and thermistors were deployed along a cross-shore transect extending from the shoreline to about 4-m water depth near Duck, NC. The altimeters were quite robust, with only one electronic failure. No additional maintenance was required other than occasional cleaning of biological growth and vertical adjustment to keep the altimeters within the operating range (25–200 cm above the seabed).

The elevation of the seafloor (relative to mean sea level) in the surf zone over an 80-day period estimated by one AGC sonar altimeter is shown in Fig. 6. Between days 56 and 63 the offshore

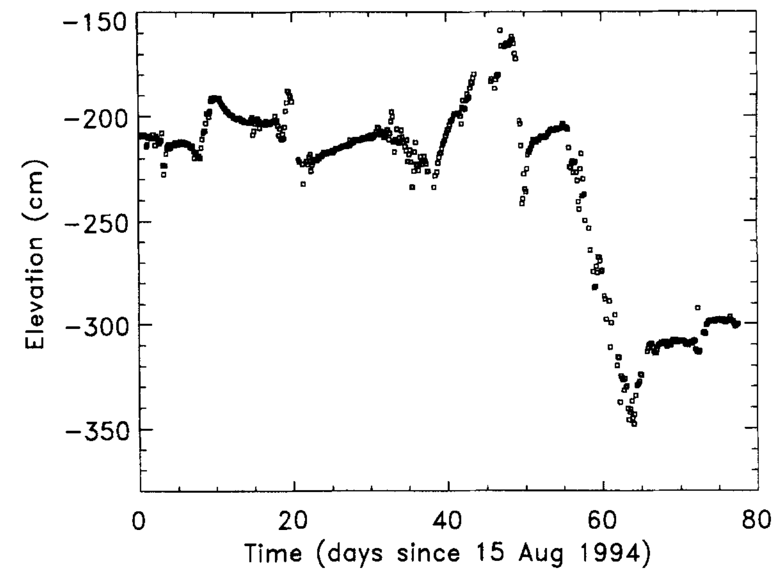

Fig. 6. Elevation of the seafloor (relative to mean sea level) in the surf zone estimated by a sonar altimeter mounted on a fixed frame near cross-shore position 220 m (see Fig. 7) versus time. Each symbol is a 3-hr average estimate of the seafloor elevation.

significant wave height reached 4 m and the sand bar moved offshore, resulting in 1.5 m of erosion at this location (cross-shore distance = 220 m in Fig. 7) and nearly 1 m of accretion further offshore (cross-shore distance = 320 m in Fig. 7).

The cross-shore transect contained a dense, two-dimensional array of 7 AGC altimeters located in about 2-m water depth (cross-shore distance = 170 m in Fig. 7). Four days of observations from 3 sonars closely spaced along the cross-shore leg of the array are shown in Fig. 8. The 20 cm fluctuations during day 59 and 60 were migrating mega-

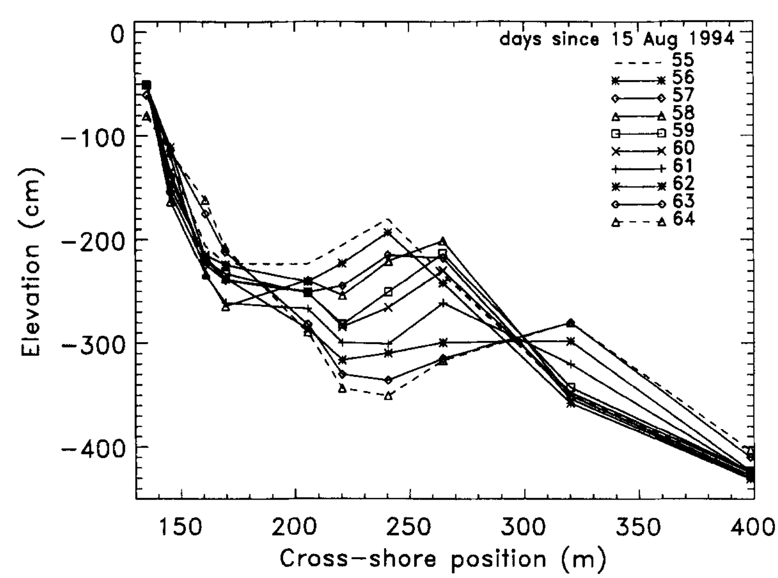

Fig. 7. Elevation of the seafloor (relative to mean sea level) estimated by sonar altimeters versus cross-shore position. The symbols are 3-hr average elevations (1300–1600 hrs) between days 55 (dashed curve) and 64 (dashed curve with triangles).

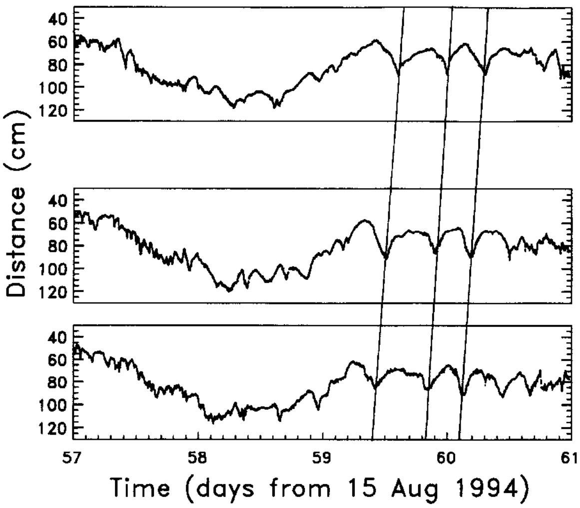

Fig. 8. Distance of the seafloor below 3 fixed sonar altimeters (located near cross-shore position 170 m, Fig. 7) versus time. Each point represents a 32-s estimate of the bottom location. The altimeters are separated by 80 cm (upper to middle panel) and 60 cm (middle to lower panel) in the cross-shore direction. The slopes of the 3 nearly vertical lines connecting the "troughs" of the bedforms suggest a migration speed of about 30 cm/hr toward the beach (along the array axis).

ripples, and the slopes of the 3 nearly vertical lines connecting the "troughs" of the bedforms correspond to a cross-shore migration speed of about 30 cm/hr toward the beach.

7. Conclusions

Automatic gain control has improved the ability to estimate the seafloor location with a downward looking 1 MHz sonar altimeter. Coupled with a bottom-finding algorithm, the altimeter can accurately (±3 cm) estimate the seafloor location about twice per minute, even in the surf zone where energetic breakers and strong currents produce bubbles and dense suspensions of sediment. A field deployment of 16 altimeters near Duck, NC demonstrated that this robust sensor requires little maintenance over several months.

Acknowledgments

This research was supported by the Office of Naval Research (Coastal Dynamics and AASERT graduate student support) and the National Science Foundation (Coastal Ocean Processes program). The Hydraulics Laboratory of the Scripps Institution of Oceanography provided construction and testing facilities. The US Army Corps of Engineers Field Research Facility provided excellent logistical support. Dr. Bradley Werner made valuable comments.

References

Dingler, J.R., 1974. Wave-formed ripples on nearshore sands. Thesis. Univ. Calif., San Diego, 136 pp. (unpublished).

Dingler, J.R., Boylls, J.C. and Lowe, R.L., 1977. A high-frequency sonar for profiling small-scale subaqueous bedforms. Mar. Geol., 24: 279–288.

Dingler, J.R. and Clifton, H.E., 1984. Tidal-cycle changes in oscillation ripples on the inner part of an estuarine sand flat. Mar. Geol., 60: 219–233.

Grant, W.D., Williams, A.J., Glenn, S.M., Cacchione, D.A. and Drake, D.E., 1983. High frequency bottom stress variability and its prediction in the CODE Region. Woods Hole Oceanogr. Inst. Tech. Rep., 83-19, 71 pp.

Green, M.O. and Boon, J.D., 1988. Response characteristics of a short-range, high-resolution digital sonar altimeter. Mar. Geol., 81: 197–203.

Urick, R.J., 1983. Principles of Underwater Sound. McGraw-Hill, New York, 423 pp.

Wright, L.D., Nielsen, P., Shi, N.C., and List, J.H., 1986a. Morphodynamics of a bar-trough surf zone. Mar. Geol., 70: 251–285.

Wright, L.D., Boon, J.D., Green, M.O. and List, J.H., 1986b. Response of the mid-shoreface of the southern Mid-Atlantic Bight to a "northeaster". Geomar. Lett., 6: 153–160.