CHAPTER 313

DELILAH, DUCK94 & SandyDuck: Three Nearshore Field Experiments

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Abstract

Two major field experiments have recently been conducted, and a third is being planned, at Duck, NC, along the mid-Atlantic coast of the USA, to investigate nearshore dynamic processes. Named DELILAH, DUCK94, and SandyDuck, these experiments take advantage of logistical efficiency and relatively uncomplicated, open-coast field conditions provided by the Field Researeh Facility of the US Army Engineer Waterways Experiment Station. DELILAH occurred in 1990, and emphasized hydrodynamics measurements. DUCK94, in 1994, added measurements of sediment transport and morphologic evolution, and was planned as a comprehensive pilot study for SandyDuck, the most ambitious experiment in the series, scheduled for 1997. Scientific motivation, instrumentation plans, participants, and representative climatic conditions of DELILAH and DUCK94 are described, as are sources of further information and data.

Introduction

Sinee 1979, the Coastal and Hydraulic Laboratory (formerly the Coastal Engineering Research Center) of the US Army Engineer Waterways Experiment Station has hosted a series of increasingly complex, multi-investigator, multi-agency nearshore field experiments at its Field Research Facility (FRF) located in Duck, North Carolina, USA. Two recent experiments, *DELILAH* and *DUCK94*, and a planned third experiment, *SandyDuck*, all evolved from scientific and pragmatic successes of prior work at this site, and have the basic objectives of improving fundamental understanding and modeling of surf zone physics. The emphasis in DELILAH was surf zone hydrodynamics in the presence of a changing barred bathymetry. DUCK94 and SandyDuck have added components to resolve sediment transport and morphologic evolution at bedform scales from ripples to nearshore bars. DUCK94 was designed as a pilot effort to test instruments and procedures required for the more comprehensive *SandyDuck* experiment. The purpose of this paper is to summarize the two completed experiments, including participants, environmental

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conditions, data collected, and data availability, and thereby suggest the plan for the future experiment.

DELILAH

The DELILAH (***D**uck **E**xperiment on **L**ow-frequency and **I**ncident-band **L**ongshore and **A**cross-shore **H**ydrodynamics*) design (Figure 1) was to make surf zone hydrodynamics measurements to augment directional wave measurements being made in 8-m water depths by the FRF and in 13-m depths during the concurrent SAMSON (***S**ources of **A**mbient **M**icro-**S**eismic **O**cean **N**oise*) experiment (Herbers & Guza, 1994; Nye & Yamamoto, 1994). By agreement among investigators, DELILAH objectives were:

> *To measure the wave- and wind-forced three-dimensional nearshore dynamics with specific emphasis on infragravity waves, shear waves, mean circulation, set-up, runup, and wave transformation, and to monitor bathymetric response to these processes.*

Table 1 lists DELILAH investigators, their organizations at the time of the experiment, and general areas of scientific interest.

The DELILAH array of in situ instruments (Figure 1) consisted of a primary

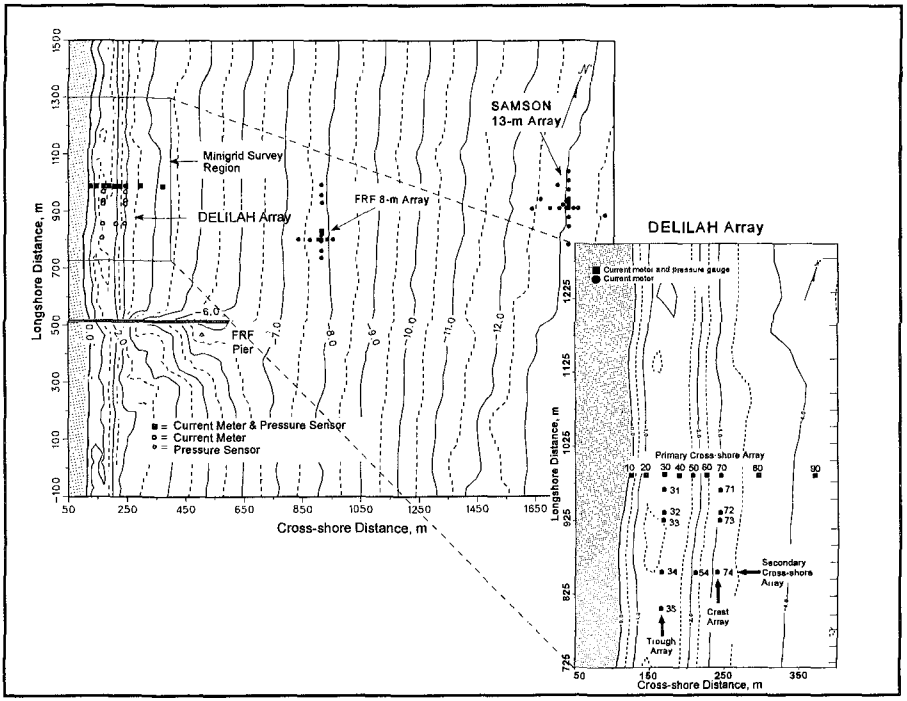

Figure 1. Instrument array locations during the SAMSON & DELILAH experiments

cross-shore array of nine current meters to obtain mean and fluctuating currents, with collocated pressure gauges to enable directional wave measurements. A secondary cross-shore array of three current meters provided long-shore redundancy. Longshore coverage was provided by an array of six current meters in the nearshore trough, and a second array of five current meters located just seaward of the inner bar crest. Instruments were provided by the Naval Postgraduate School (NPS), Scripps Institution of Oceanography (SIO), and the FRF. The DELILAH array was designed by E. B. Thornton, J. M. Oltman-Shay, and P. A. Howd, with Dr. Thornton having primary responsibility for data collection.

Table 1. DELILAH Participants

US Army Engineer Waterways Experiment Station William Birkemeier - morphology Kent Hathaway - runup, infragravity waves, morphology, remote sensing Charles Long - incident and reflected directional wave spectra Nicholas Kraus - longshore currents Jane Smith - vertical current profile, 2-D circulation Todd Walton - runup Edward Thompson - surf beat modeling
Naval Postgraduate School Edward Thornton, Katie Scott - mean circulation, shear waves, rip currents
Naval Research Laboratory Dennis Trizna - radar measurements of waves and currents
Oregon State University Rob Holman - morphology, runup, shear waves, infragravity waves, video remote sensing Peter Howd - infragravity waves, morphology Tom Lippmann - morphology, infragravity waves, video remote sensing Todd Holland (also with the US Geological Survey) - runup, cusp formation
Scripps Institution of Oceanography Robert Guza - cross-shore and longshore currents, infragravity waves, wave transformation, (also SAMSON PI)
Northwest Research Associates Joan Oltman-Shay - shear waves, infragravity waves (also SAMSON PI)
Washington State University Steve Elgar - incident and reflected directional wave spectra (also SAMSON PI)

Additional instruments augmented information from the stationary, in situ array. A mobile sled equipped with a vertical array of five current meters, a pressure gauge, and a surface-piercing wave staff was deployed by J. M. Smith and K. K. Hathaway. Seven video cameras operated by R. A. Holman recorded swash and ocean surface images in the surf zone. D. B. Trizna used five Naval Research Laboratory (NRL) radar systems for remote sensing of waves, currents, and bathymetry. Bathymetric changes were measured daily by the FRF in the 550-m by 400-m minigrid area (Figure 1) using the Coastal Research Amphibious Buggy (CRAB).

A wide range of conditions were encountered during the 21 days of data collection (Figure 2). A short-duration wave event on 1-2 October was followed by several days of low waves ($H_{mo} < 1$ m). On 9-12 October, a "southeaster" built waves of about 2-m height, and induced north-flowing longshore currents that peaked near 1.5 m/s. Passage of Hurricane Lili well offshore on 12-14 October resulted in 2.5-m swell under low-wind conditions. Following Lili, moderately energetic waves and currents continued until the end of the experiment.

In the above conditions, nearshore bathymetry underwent significant changes. Figure 3

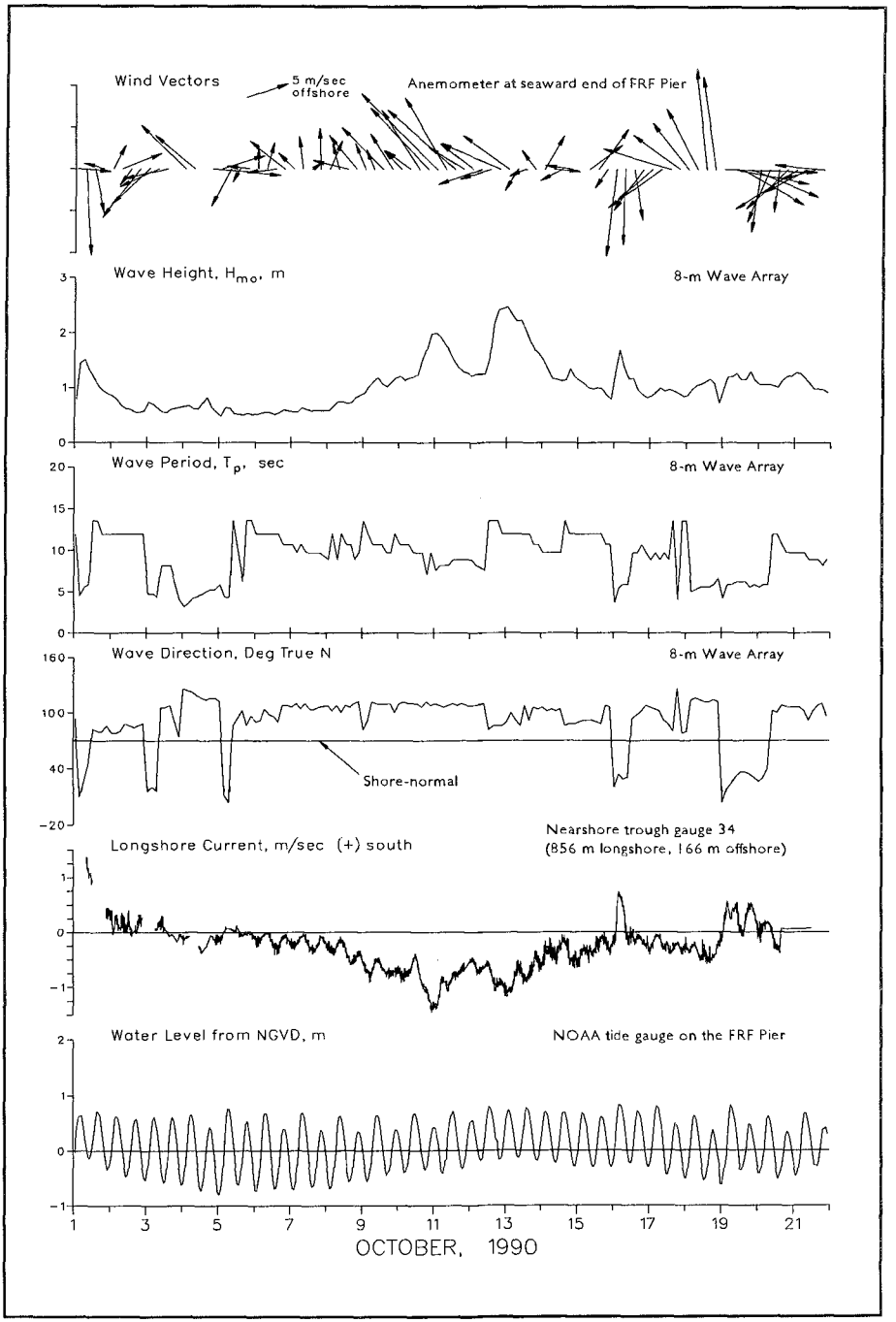

Figure 2. Conditions during DELILAH

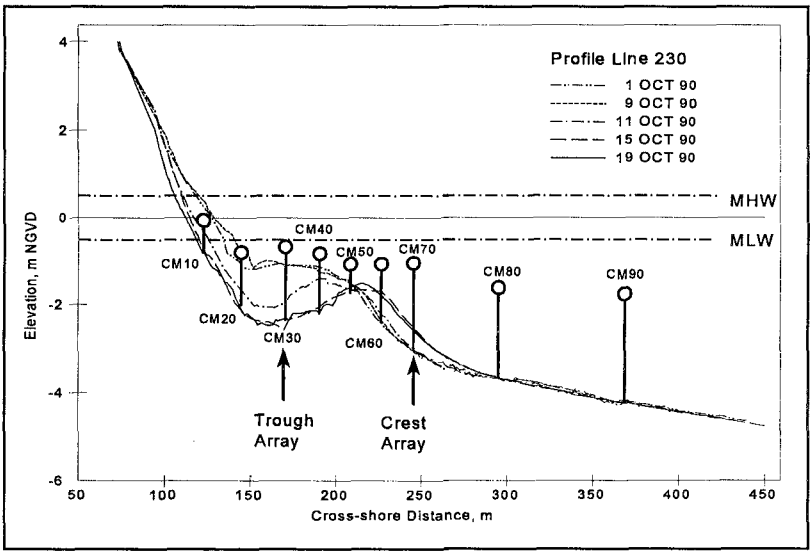

Figure 3. Profile change adjacent to the DELILAH cross-shore array

shows bathymetric profiles along the primary cross-shore array at five times during the experiment, illustrating the offshore migration of the nearshore bar, and notably the extensive deepening of the nearshore trough on 10-13 October. The CRAB surveys also revealed the presence of megaripples in the nearshore trough and on the seaward bar flank. Figure 4 illustrates four of the 20 minigrid surveys. Vertical lines in this figure indicate current meter locations. Bar topography undulated rhythmically in the alongshore direction until 9 October, when it began to assume a more uniform, linear shape. It reached maximum uniformity by 11 October, and retained this shape through the end of the experiment. Well correlated with shoal parts of the nearshore bathymetry in Figure 4 are time exposures of breaking waves patterns shown in Figure 5. Such remote images are used to extend spatial and temporal coverage provided by measured bathymetry.

DUCK94

Success of DELILAH, and the evident need for more detailed information about sediment transport and morphologic evolution that results from hydrodynamic forcing, initiated interest in further field work to be supported by the US Army Corps of Engineers, ONR, and the US Geological Survey. A plan for two additional field experiments developed. The first, DUCK94, was intended as a test run for new instrumentation, a more formal experiment organization, and more complicated logistics in preparation for SandyDuck, the second experiment. DUCK94 was scheduled for August and October 1994 to take advantage of the synergy offered by the National Science Foundation's Coastal Oeean Processes (CoOP) experiment (Butman, 1994), being conducted at the FRF during that time. The following focus topics were established as fundamental to improved understanding of surf zone sediment transport:

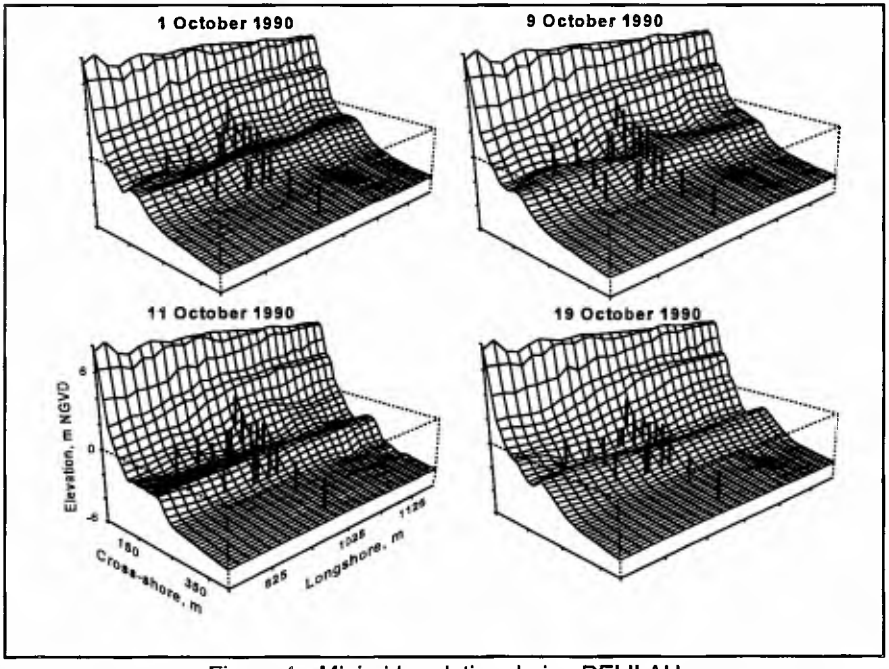

Figure 4. *Minigrid* evolution during DELILAH

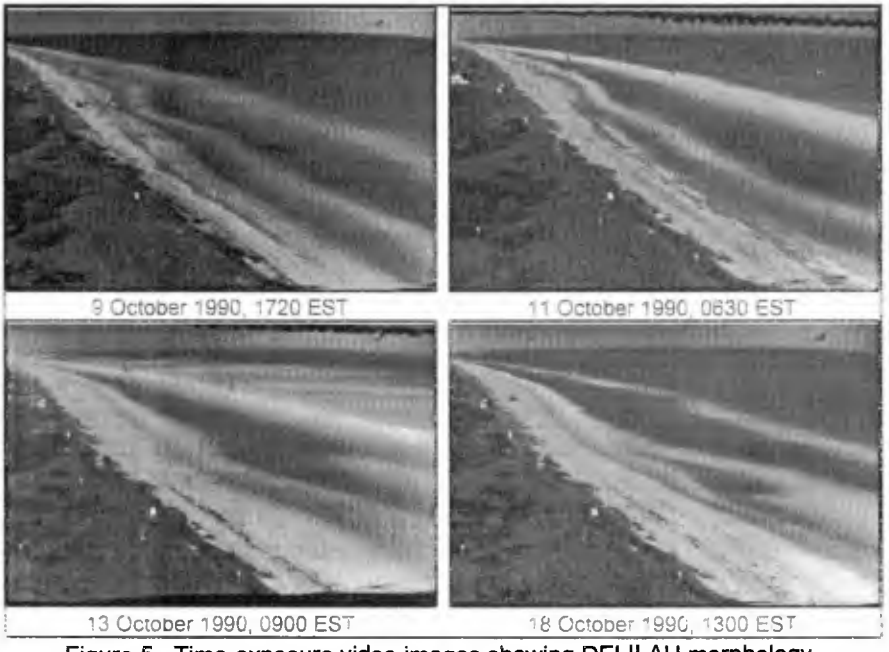

Figure 5. Time-exposure video images showing DELILAH morphology.

a. small and medium scale sediment transport and morphology;
b. wave shoaling, wave breaking, and nearshore circulation;
c. swash processes including sediment motion.

Considerable interest was expressed for DUCK94. Table 2 lists the 19 organizations that conducted 31 experiments involving more than 100 scientists, students, and technicians. Instrument measurements were complemented by observations from ground- and aircraft-based radar and video systems. Table 3 lists the 31 basic studies, along with the principal investigators, their primary focus areas, and experiment durations. The extensive instrumentation resulted from consideration of relevant measurement scales required to address SandyDuck science objectives. Guidance was provided by using measured velocity data from DELILAH and sediment transport modeling. Based on this analysis, a general nearshore instrumentation array was designed (Birkemeier & Thornton, 1994). The full array, shown in Figure 6, was used during the October phase of DUCK94. An abbreviated form of this array was used in the August segment of the experiment. Formal dates for DUCK94 were 8-24 August and 1-24 October, though some investigations (Table 3) of various durations were underway between June and November.

Table 2. DUCK94 Participating Organizations

Agencies	1	US Army Engineer Waterways Experiment Station
	2	United States Geological Survey
	3	Office of Naval Research
	4	Naval Research Laboratory
	5	Naval Postgraduate School
Universities	6	Dalhousie University (Canadian)
	7	Duke University
	8	Oregon State University
	9	North Carolina State University
	10	Memorial University of Newfoundland (Canadian)
	11	Scripps Institution of Oceanography
	12	University of Delaware
	13	University of East-Anglia (United Kingdom)
	14	University of Florida
	15	University of Miami
	16	University of Washington
	17	Washington State University
Companies	18	Areté Associates
	19	Neptune Sciences, Inc.

A wide variety of instrumentation was used in DUCK94. Conventional total-station surveying techniques were used in subaerial morphology studies (29, referring to investigations by experiment number in Table 3), minigrid surveys (15), and positioning of all stationary instruments. Central to the main layout were cross-shore arrays of instrument clusters (11), each containing an electromagnetic current meter, a pressure gauge, an acoustic altimeter, and a thermometer (Fedderson, et al.,1997). The altimeters permitted the first comprehensive real-time measurements of bottom changes (8) (Gallagher, Elgar & Guza, 1997). A large number of suspended sediment concentration gauges were deployed, including optical backscattering sensors (16, 22, 26, 30), and less intrusive fiber-optic backscattering sensors (1). The Coherent Acoustic Sediment Probe (Stanton & Thornton, 1997) was mounted on a mobile sled along with eurrent meters, pressure gauges, scanning sonars, and void fraction sensors (20, 25, 26). The Sensor Insertion System,

Table 3. DUCK94 Experiments
(number in parens refers to organization from Table 2)

No.	Investigators	Experiment Title	Participating Months	Wave Shoaling	Nearshore Circulation	Boundary Layers	Swash Processes	Small Scale Sediments	Meso/Macro Morphology	Water Properties
1	Beach(8), Holman, Stamberg	Sedimant dynamics in the nearshore environment	Aug,Oct		X	X		X		
3	Church(4), Elgar, Guza	Mine scour, burial, and migration as a function of wave and current forcing	Sap				X			
4	Draka(9), Smith	Nearshore sedimentary structures	Aug,Oct					X		
5	Dugan(17)	Airborna remote sansing of the environment in tha littoral zona	Oct	X	X					
6	Earla(18)	Real-time buoy directional wave measurements for driving surf zone numerical models	Aug,Oct	X						
7	Earle(18), Walsh, Boyd	Scanning radar altimeter sea surface topography & high resolution directional wave measurements	Oct	X						
8	Elgar(16)	Temporal and spatial variability of tha bathymetry of a natural beach	Aug,Oct						X	
10	Graber(14), Shay, Haus	An invastigation of surfaca currants and internal waves over the inner and mid-shelf	Oct	X	X					
11	Herbers(5), Elgar, Guza, O'Reilly	Surface gravity waves and nearshore circulation	Aug,Oct	X	X					
12	Haines(2), Gelfenbaum	Vertical structure of mean currents & turbulent stresses in the nearshore boundary layer	Aug,Oct		X	X				
13	Hanes(13), Vincent	Near bed intermittent suspension	Aug,Oct		X			X		
14	Hanes(13)	Remote vidao measurement of mesoscale nearshore processes	Aug,Oct				X		X	
15	Hathaway(1), Leffler	Rip current mapping and minigrid surveys	Aug,Oct		X				X	
16	Hay(6), Bowen	Sediment suspension, local morphology, and bubbles	Oct		X			X	X	X
17	Holman(8), Holland, Plant	Foreshore dynamics	Aug,Oct				X			
18	Howd(7), Hathaway	Procasses of shorafaca profila adjustment	Aug,Oct		X				X	
19	Jensen(1)	Evolution of wave spectra in shallow water	Aug,Oct	X						
20	Lippmann(11), Thornton, Stanton, Su	Spatial distribution of wave breaking and turbulance	Aug,Oct	X		X				X
21	Long(1)	Wind wave frequency-direction spectral measuraments	Aug,Oct	X						
22	Miller(1)	Longshore sediment transport during storms	Aug,Oct					X		
23	Fabre(19), Wilson, Earle	Wave and surf generated ambient noisa measurements	Aug,Oct							X
24	Staubla(1), Smith, Birkemeier	Sediment dynamics and profile intaractions sampling experiment	Aug,Oct					X		
25	Thornton(5), Dingler	Small-scale morphology in the nearshore	Aug,Oct					X	X	
26	Thornton(5), Stanton	Suspended and bedload sediment transport	Aug,Oct		X			X		
27	Trizna(4)	Radar remote sensing of nearshore processes: bar morphology, directional wave spectra, infragravity waves, wave breaking	Aug,Oct	X	X				X	
28	Walkar(4)	Hyparspactral optical characterization of surf zone bottom/resuspended sediment	Aug					X		X
29	Werner(10), Elgar	Swash zone morphology: field manipulation and simulation	Jun,Sap				X		X	
30	Whita(1)	Field tasts of sadiment transport theories	Aug,Oct		X			X		
31	Livingston(3), Wolf, Pasewark	Wava and surf noise measurements: supplamentation	Oct							X

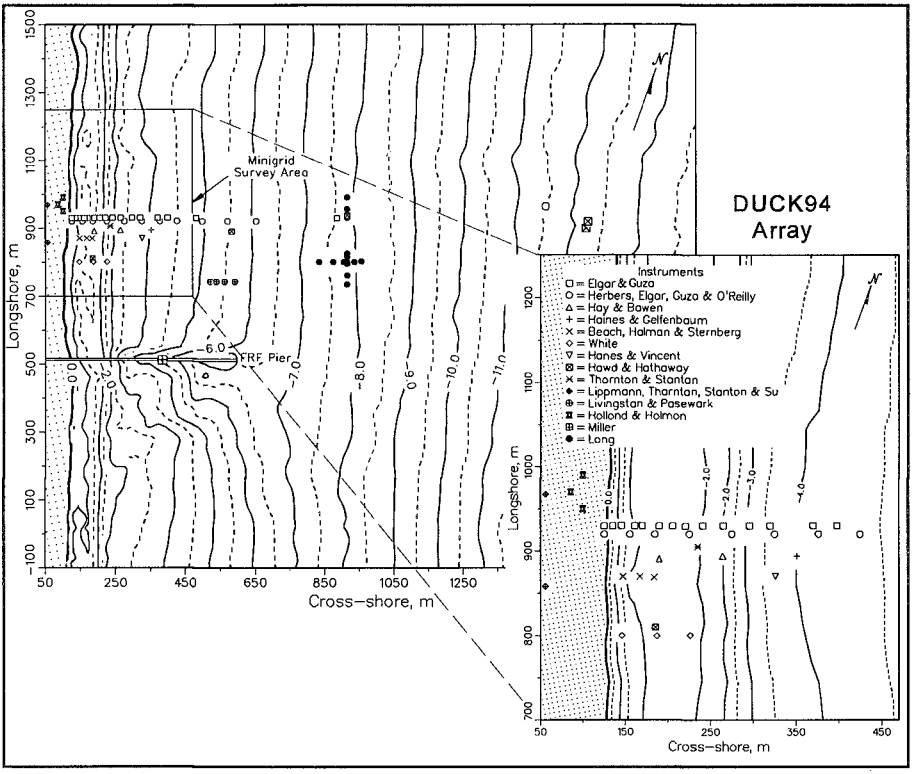

Figure 6. DUCK94 Instrument layout identified by investigator

located on the FRF pier, provided a stable, mobile platform for sediment transport measurements during high-energy conditions (1, 22). In situ (16) and CRAB-mounted (25) side-scan sonars provided observations of bottom bedforms, including megaripples. Most array positions included one or more current meters (1, 3, 11, 12, 13, 15, 16, 18, 22, 26, 30). Incident wave conditions were monitored with directional wave buoys (6, 19), and a direction-sensing array of pressure gauges (21).

Dynamics measurements were complemented by a series of geologic studies that included surface sediment samples (24) (Stauble & Cialone, 1997), short cores, box cores, and vibracores (4). Several remote sensing systems were used. Surf zone and swash processes were observed with tower-mounted video systems (14, 17, 20). Observations were also made with land-based marine radar systems (27), coherent radar systems (10), airborne synthetic aperture radar, topographic lidar, visible and hyperspectral light imaging, and scanning radar altimetry (5, 7, 28). Three studies examined fundamental nearshore acoustie behavior (16, 23, 31).

Environmental conditions during the October phase of DUCK94 are illustrated in Figure 7. Two high-wave events occurred. The first was on 2-4 October, wherein wave

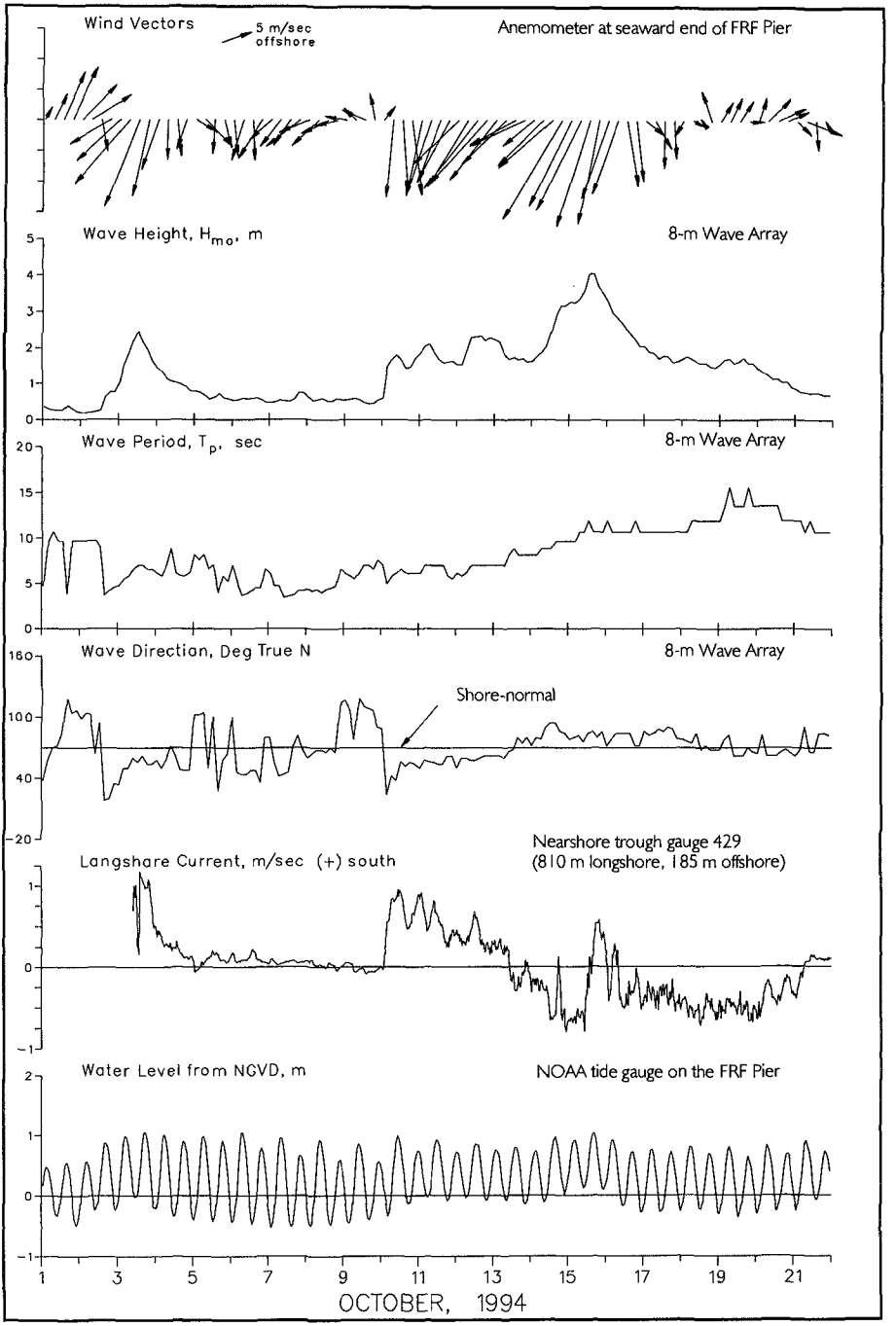

Figure 7. Conditions during the October phase of DUCK94

heights exceeded 2.5 m. Wave heights reached 4.5 m during the second storm, an eight-day event beginning on 10 October. During the larger storm, large bottom changes were accompanied by a complex nearshore circulation pattern wherein wave-driven currents in the surf zone were opposed by strong wind-driven longshore flows offshore. As shown in Figure 7, currents in the nearshore trough changed from about 1 m/s to the south at the beginning of the storm on 10 October to about 1 m/s to the north just prior to the peak of the storm on 15 October.

Figure 8 illustrates four of the 12 minigrid surveys collected during October. Following a pattern similar to that observed in DELILAH, the bar moved offshore and became more linear in the initial part of the 10 October storm. High waves prevented daily surveys until 21 October, when the survey revealed that a very large rip channel had developed. Evolution of this channel is evident in video time exposure images depicted in Figure 9. Sequences of profile data through the region of the rip are shown in Figure 10, where it is seen that the bar crest moved 100 m seaward, causing 1.2 m of deposition at its most seaward observed location on 18 October. By 21 October, the bar crest had begun migrating landward.

DUCK94 data are being analyzed, and research results are beginning to appear in the literature. Preliminary findings were discussed at a post-experiment meeting (summarized by Long & Sallenger, 1995), where adequacy of the DUCK94 experiment plan was also evaluated in preparation for SandyDuck.

SandyDuck

SandyDuck will take place from 22 September to 31 October 1997. Most of the core DUCK94 experiments are being repeated, with improvements based on experience gained in DUCK94, both in keeping with the basic tenets of physics research, and to take advantage of two major improvements in the basic experiment design. DUCK94 revealed that nearshore dynamics is far less uniform alongshore than had previously been assumed. Consequently, instruments will be added to expand longshore coverage of currents, bottom changes, and sediment transport. Missing from all Duck experiments has been accurate, spatially detailed measurements of sea surface elevation, the gradient of which is an O(1) force in the surf zone. As the second change in the experiment plan, new instruments will be deployed to resolve this very important component of nearshore dynamics.

Further Information and Data Availability

More information about these experiments can be found on the World Wide Web at http://frf.wes.army.mil under the heading "projects." Summary data and statistics from DELILAH are available through the above web site, or via anonymous FTP at ftp://frf.wes.army.mil/pub/delilah. A DELILAH summary report will be published in 1997 by the US Army Engineer Waterways Experiment Station, Vicksburg, MS.

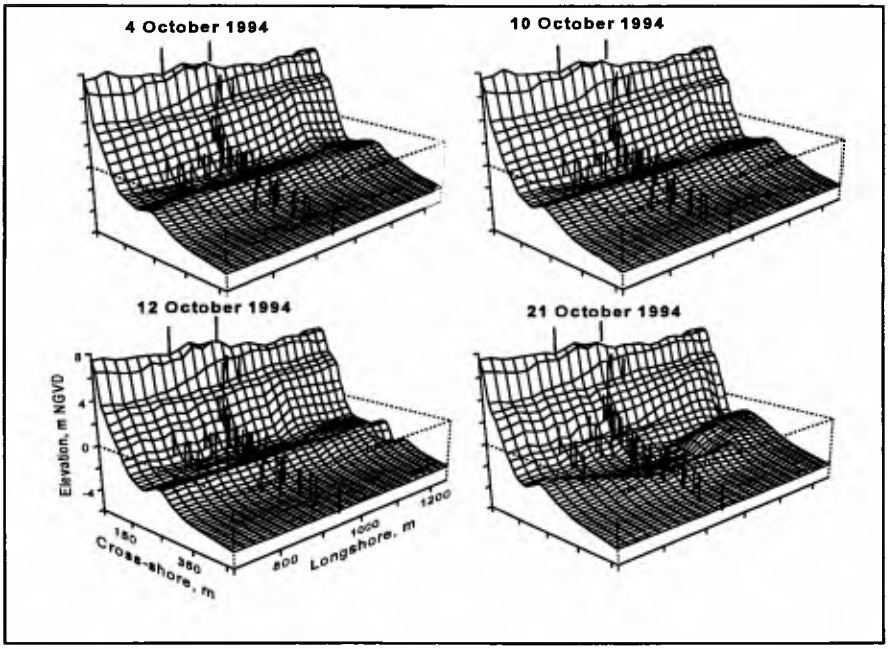

Figure 8. Minigrid evolution during DUCK94

Figure 9. Time-exposure images showing DUCK94 morphology

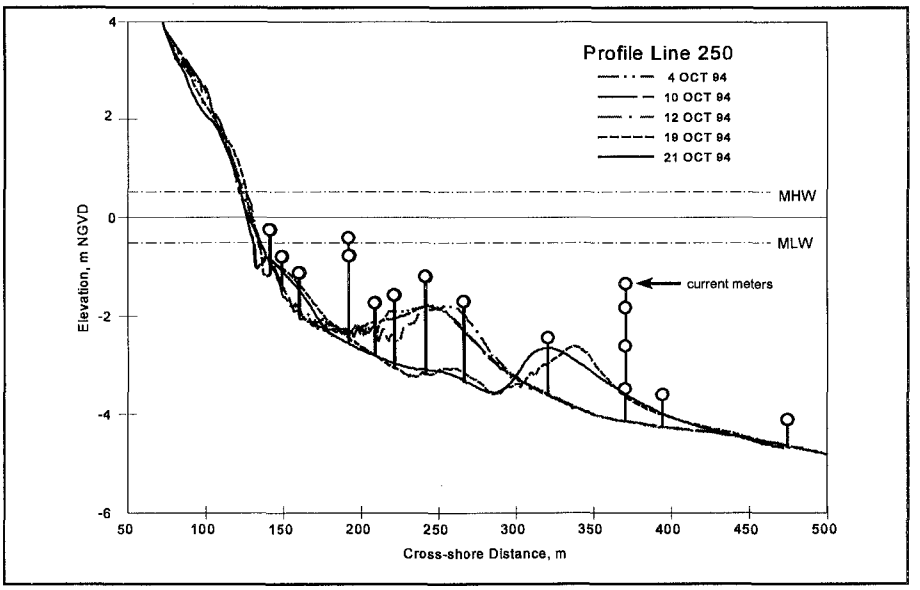

Figure 10. Profile change along the Elgar & Guza cross-shore array during DUCK94

Data from DUCK94 are not yet generally available. The investigators have agreed on a data sharing policy that offers protection of data by collecting investigators, encourages collaboration, and provides for eventual public release. This policy is:

a. global release of all data three years after the experiment;
b. responsible investigators will be identified when data sets are used by others;
c. prior to three-years, data shared by agreement between individual investigators;
d. any manuscript based on shared data must be approved by all responsible investigators prior to submission;
e. no third-party data dissemination;
f. principal investigators control use of their data.

An extensive discussion of the DUCK94 experiments, including tables listing sensors, data sets, and a summary of results, findings and publications, is available through the above web site. It is anticipated that DUCK94 data will become generally available late in 1998, and that SandyDuck data will be released near the turn of the century.

Acknowledgments

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