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Field Research Facility: A User's Guide to the Survey Lines Dataset

William A. Birkemeier and Michael F. Forte

July 2019

Coastal and Hydraulics Laboratory

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Coastal Ocean Data Systems Program
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July 2019

Field Research Facility: A User's Guide to the Survey Lines Dataset

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Final report

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Abstract

This report summarizes 44 years of beach-nearshore profile survey data collected at the Field Research Facility (FRF). The FRF is operated by the Coastal Observations and Analysis Branch of the Coastal and Hydraulics Laboratory, one of the laboratories of the U.S. Army Engineer Research and Development Center.

The 1,110 surveys collected between 1974 and 2018 provide a unique temporal and spatial record of beach and nearshore change under a wide variety of conditions (waves, tides, currents, etc.) that have been monitored by the FRF data collection program.

Over the years, the collection methods evolved from manually reading and recording each survey position to continuously recording Global Positioning System observations. Each method is presented along with its strengths, weaknesses, accuracy, and error sources. As the equipment has changed, the consistency and overall accuracy has improved.

The intent of this report is to document the FRF survey program as a guide for future data collectors and users of these data.

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Preface

This study was conducted for the U.S. Army Corps of Engineers under the Coastal Field Data Collection Program, Project No. 9DF3CF. The technical monitor was Dr. J. P. Waters.

Over the years, the work of collecting survey data was performed by many individuals whose efforts resulted in this unique coastal dataset. Significant contributors include Mr. Gene Bichner, Mr. Bill Birkemeier, Ms. Harriet Chesi, Mr. Michael Dominguez, Mr. Michael Forte, Mr. Daniel Freer, Mr. Bill Grogg, Mr. Peter Howd, Mr. Charles Judge, Mr. Guan-hong Lee, Mr. Michael Leffler, Mr. Curtis Mason, Mr. H. Carl Miller, Mr. Rob Mitchell, Mr. Jason Pipes, Mr. Mark Preisser, Ms. Judy Roughton, Ms. Francis Sargent, Ms. Rebecca Savage, Mr. Brian Scarborough, Mr. Raymond Townsend, Mr. Steve Underwood, and many others. The work was performed by the Coastal Observations and Analysis Branch of the Flood and Storm Protection Division, U.S. Army Engineer Research and Development Center – Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication of this report, Dr. J. P. Waters was Chief, Coastal Observations and Analysis Branch; Dr. Cary Talbot was Chief, Flood and Storm Protection Division; and Mr. Charles E. Wiggins was the Technical Director for the Navigation Program.

The Deputy Director of ERDC-CHL was Mr. Jeffrey E. Eckstein, and the Director was Dr. T. V. Wamsley

COL Ivan P. Beckman was the Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

1.1 Background

The Field Research Facility (FRF), is a coastal observatory established in 1977 and located on the Atlantic Ocean near Duck, NC. The FRF is operated by the Coastal Observations and Analysis Branch (COAB) of the Coastal and Hydraulics Laboratory (CHL), one of the laboratories of the U.S. Army Engineer Research and Development Center (ERDC). One of theFRF missions is to collect concurrent coastal process and response data to improve the understanding and ability to model nearshore dynamics. Process data include waves, tides, and currents along with local weather; response data include topographic and bathymetric surveys.

Figure 1-1. The Lighter Amphibious Resupply Cargo, 5-ton (LARC-V) (left) and Coastal Research Amphibious Buggy (CRAB) (right).

The surveys consist of repetitively mapping a series of cross-shore *profile lines*. Under the Beach Evaluation Program (BEP), dune and beach surveying began at the FRF in 1974, prior to the construction of the research pier and facilities. The first nearshore survey was conducted in 1978 as part of the Duck-X experiment. Nearshore surveys followed again in 1979 and 1980. Regular and more frequent surveys began with the arrival of the CRAB in October 1980. The CRAB is a 10-meter (m)-tall motorized tripod that can drive offshore (Figure 1-1). Survey data collected using the 10 m long amphibious LARC-V began in 1999 (Figure 1-1). Most of the survey data were collected using electronic total stations that measure distance, zenith, and azimuth angles. Starting in 1981, a Zeiss Elta-2s®, which required the CRAB to stop, was used. It was replaced in 1990 by a Geotronics Geodimeter 140T®, which allowed continuous

tracking of the CRAB. Use of a real-time kinematic Global Positioning System (RTK-GPS) with the CRAB and the LARC-V began in 1996.

Through 2018, 1,110 surveys have been collected with over 17,000 individual cross sections. They comprise an accurate, comprehensive spatial and temporal coastal survey dataset.

Of the 185 currently defined profile lines, two sets of lines have been routinely surveyed. Lines 1097 and 1006, located ~500 m north of the FRF research pier, and lines 1 and -91, located ~500 m to the south, are known as the *4-Lines* (previously referred to and published as lines 58, 62, 188, and 190). These 4-Lines have been most frequently surveyed (there are 790 surveys of Line 1097). A series of 15–33 profile lines, which include the 4-Lines, are typically surveyed monthly. They are referred to as *monthly surveys*. These lines are located close enough together to allow three-dimensional (3D) contour maps to be created. There are 351 monthly surveys. The routine surveys are complemented by special surveys to the north and south of the FRF property and by experiment surveys. During seven major experiments from 1982 to 1998, a sub-region located north of the FRF research pier and known as the *minigrid* was surveyed approximately daily. Table 1-1 summarizes the available surveys. Each of these data sets provides different opportunities for coastal dynamics research.

Table 1-1. Summary of available FRF surveys: 1974–2018.

Project	Start Date	End Date	Number of Profiles per Survey	Surveys through 2018	Monthly Surveys
FRF Survey Line Dataset	1974	continuing	varies 1-131	1,110	351
Beach Evaluation Program	1974	1978	17-27	157	
FRF Experiments					
DUCK82	1982	1982	15	23	7
DUCK85	1985	1985	18	45	19
SuperDuck'86	1986	1986	20	24	14
DELILAH	1990	1990	20	19	19
DUCK94	1994	1994	18	45	18
SandyDuck'97	1997	1997	20	54	43
DUCK98	1998	1998	20	5	4

Over the years, people, equipment, software, and survey techniques have changed along with the accuracy, workflow, documentation, coordinate system, vertical datum, and error types. Digital data formats and storage media have changed. One consequence was that written documentation and data files were scattered (e.g., notebooks, file boxes, floppy disks, CDs, the Web) and were at risk of being lost.

1.2 Objective

The objective of this report is to document the FRF surveys data, data collection methods, and the data conversion effort. It updates earlier published information about the surveys and adds additional information and detail. The report is designed as a guide for anyone who contributes to the dataset in the future or uses the data in their research.

To protect and preserve this important national archive, in 2014 the COAB was charged with developing a Field Research Facility Data Integration Framework (FDIF), providing a modern discoverable archive with easily accessible information for strategic analysis and reporting. To accomplish this, COAB partnered with the U.S. Army Corps of Engineers (USACE), Mobile District, Spatial Data Branch and Applied Science Associates.

The Field Research Facility Survey Lines Dataset Project is an activity conducted under FDIF to take a comprehensive look at the survey data with the intent of updating and standardizing the formats, compiling an inventory of available surveys, and assembling all supporting documents and data files.

The main tasks were the following:

- Recompute the coordinate location of each point based on an update of the origin of the FRF local coordinate system.
- Compute and add geographic and North Carolina state plane coordinates to each survey point along with the local FRF coordinates, using metric units.
- Adjust the vertical datum from NGVD29 to NAVD88.
- Update the data format to a comma separated value (CSV) ASCII format.
- Combine and renumber the separate 4-Line, monthly and experiment datasets so there is a single CSV file for every survey with a new, unique survey number.

- Rename the files using a consistent format that is more descriptive than the original 8-character filenames.
- Establish and implement a consistent set of profile line numbers based on their longshore distance (FRF coordinate) in meters.
- Compile an inventory of all known cross-section surveys done at the FRF.
- Scan to pdf format all paper records documenting the collection of the data.
- Compile a folder set, organized by year and survey date, that includes all raw and analyzed data, supporting field notes and plots.
- Create ISO 19115 compliant metadata for the dataset, which includes supporting information for each of the seven surveying techniques used.

1.3 Approach

This report is organized into eight chapters. Chapter 2 presents the fundamentals of the FRF survey program. Chapter 3 discusses nearshore survey errors in general. Chapters 5 to 7 cover the different survey techniques used based on the survey platform: Sea-Sled, CRAB, or LARC-V. Chapter 8 discusses and summarizes the surveys collected during the field experiments. Appendices provide information about abbreviations used (Appendix A), the FRF coordinate system and profile lines (Appendix B), a list of known papers that have been published using FRF survey data (Appendix C), and the inventory of surveys (Appendix D).

2 Field Research Facility (FRF) Survey Fundamentals

This chapter presents basic information about the FRF surveys including details about the local coordinate system, the vertical datum, survey line locations and length, temporal and spatial coverage, and data formats.

The coordinate system in use was first established by the Wilmington District of the USACE when it laid out the construction of the pier. The original profile numbering system was established by the Coastal Engineering Research Center (CERC) in 1972 when the BEP laid out a series of 69 profile lines from Duck, south to Oregon Inlet, NC (Birkemeier et al. 1985).

Because survey data are labor and time consuming to collect and because the beach changes during a multi-day survey, a major requirement is to survey as quickly as possible the areas most likely to change. Based on the early surveys with the CRAB, the bar/trough zone (less than ~4 m depth) is most dynamic and varies alongshore while deeper contours are more shore parallel and slower to change under normal conditions. Consequently, survey line lengths are varied alongshore so all lines cover the most active zone but only some lines extend to the full extent of the survey (1 kilometer [km] for the CRAB, 2 km for the LARC). By varying the line lengths, it is possible to optimize the survey time and to provide complete coverage of the survey area. Similarly, it was determined that the dune portion of the profile, which is tedious to survey, typically changes slowly (except during storms), so it is less frequently surveyed.

2.1 Units of measure

All survey data have always been reported in meters, and the data files discussed here are in meters. However, data were collected in survey feet until ~1996 when Global Positioning System (GPS) instruments were adopted. Units of feet were more convenient to use because the pier was constructed in feet (pier bents are exactly 40 feet [ft] apart), profile lines were spaced exactly 150 ft apart, and navigation guidance provided to the CRAB driver worked better in feet. Because of early data filename limits (eight characters), when working with older files, units of measure may not always be clear. However, it is usually easy to determine by looking at the coordinates and elevations in the file.

2.2 FRF coordinate system

FRF surveys use a local Cartesian coordinate system that was established after the site was acquired in 1972.

2.2.1 Horizontal coordinates

The origin of the FRF coordinate system is located behind the dune line near the southern boundary of the FRF property. The baseline of the system (cross-shore distance = 0.0) is aligned 18.1465 degrees (deg) west of True North and aligns almost exactly with the front of the FRF garage. Distance is positive to the north, along the baseline, and positive offshore. The FRF research pier is oriented at 90 deg to the baseline. Figure B-1 and Table B-1 in Appendix B include information about the early FRF monumentation.

The original control was of third-order accuracy, sufficient to establish an internally consistent, local coordinate system. Geographic and State Plane Coordinates were also established (relative to NAD27) for each established benchmark (usually capped pipes and concrete monuments with brass disks), but these were seldom used. However, with the arrival of GPS technology, which natively collects geographic coordinates, a conversion algorithm from geographic coordinates to the local FRF coordinates was required.

The first conversion program was developed in 1991 and used extensively to convert GPS observations to and from FRF coordinates. Because the 1991 conversion used constants of meter/degree latitude and meter/degree longitude, accuracy decreases with distance from the FRF origin. The values of these constants and the location of the origin were updated in 2010, which improved conversion results.

Because all pre-GPS surveys were done from the FRF pier, using the alignment of the pier to define the orientation of the FRF coordinate system, the actual location of the FRF origin and the baseline were never used except to initially establish the control points on the pier. Recognizing that the alignment of the pier was critical to an accurate conversion, in 2014 a careful GPS survey (relative to NAD83) was conducted of the pier and the FRF origin. The results were used to refine the FRF coordinate system in geographic and North Carolina state plane coordinates. The updated values are listed in Table 2-1. A conversion from

state plane to and from FRF coordinates, both Cartesian coordinate systems, is straight forward and recommended over a conversion of FRF to/from geographic coordinates, using the constants in Table 2-1.

In updating the data set to include geographic and state plane coordinates, pre-GPS surveys, which were collected in FRF coordinates, were directly converted using the 2014 origin values in Table 2-1. Data that were collected using GPS had to be first be re-converted back to geographic coordinates using the 1991 or 2010 values and then converted using the 2014 values.

Table 2-1. Evolution of the FRF coordinate system origin.

	1980-1995 (NAD27)	2010 revision (NAD83-86)	2014 (NAD83-2011)
Origin Latitude	36.177602465	36.177597325	36.177597484
Origin Longitude	-75.749689583	-75.749685725	-75.749685973
m/degLat	110,959.306	110,962.357	110,963.357
m/degLon	89,946.657	89,955.864	89,953.364
GridAngle (deg)	18.1418	18.1391	18.1465
Angle FRF to Lat/Lon (deg True North)	71.8582	71.8609	71.8535
Angle FRF to State Grid	69.9800	69.9800	69.9747
FRF Origin Northing (m)	274,093.698	274,093.139	274,093.156
Easting (m)	901,951.338	901,951.703	901,951.680

2.2.2 Vertical datum

Survey elevations were originally collected relative to the NGVD29. This changed on 1 November 2006 when elevation data began to be collected relative to the NAVD88. All data have now been converted to NAVD88, which is noted in the filename. Original files are unchanged, and the datum may not be noted in the original field notes. Subtract 0.293 m from an elevation in NGVD to convert to NAVD88.

Because the National Oceanic and Atmospheric Administration (NOAA) operates tide station 8651370 located at the end of the FRF research pier, NOAA has maintained a network of elevation benchmarks on the FRF property including a first-order mark buried near the flagpole. They also annually check the level of the pier deck to make sure that it has not changed. Based on surveys from 1978 to 2014, the pier deck has not changed (to an accuracy of 1 centimeter [cm]). That is important as surveys with the range-azimuth systems used the pier deck to determine

instrument height. The elevation of the deck is 7.74 m or 25.42 ft relative to NGVD and 7.46 m or 25.46 ft relative to NAVD88.

In 2004, the National Geodetic Survey of NOAA established Station NCDU under the Continuously Operating Reference Station program. This station is a continuously operating GPS base station that provides differential GPS data to support FRF surveys and provides a robust measure of long-term vertical ground movement at the FRF.

2.3 Spatial coverage

The surveys are conducted over a series of pre-established profile lines, which extend from the dune to varying distances offshore.

2.3.1 Profile lines

Each profile line was assigned a unique number. The original profile numbers increased toward the south, opposite to the FRF coordinate system. The numbering scheme was a holdover from the beginning of the program when the profile lines from the CERC-BEP program were combined with the construction lines established by the USACE, Wilmington District (SAW). The SAW lines were established at 45.72 m (150 ft) intervals around the research pier. Some of these lines were combined with the BEP lines to create a set of lines that nominally cover the 1,000 m oceanfront of the FRF property at ~45 m spacing, with closer-spaced lines added around the pier to better resolve the bathymetry under it (Birkemeier et al. 1985).

Profile lines were initially numbered by adding a "0" to the CERC-BEP line numbers (16 became 160), which allowed nine line numbers to be added between the CERC-BEP lines, and these were used to number the SAW lines and to add some additional lines. Table B-1 in Appendix B lists the original lines and their designations.

Lines numbered 300 and above referred to profile lines that were surveyed shore-parallel (not cross-shore), providing data between the lines that helps in generating bathymetry contours. Shore-parallel survey lines were collected only during three surveys (19810717, 19821016, and 19970405).

Revised profile numbering. The region covered by FRF surveys has expanded extending from 8 km south of the research pier to 6 km north.

Many different profile lines have been surveyed, and the original numbering scheme had become unworkable. Consequently, as part of the FDIF conversion, the original profile numbers have been replaced with their FRF longshore coordinate, rounded to the nearest meter. This allows new lines to be added as close as every 1 m.

Shore parallel lines and "just driving around while surveying lines" are given a profile line number of "0", which identifies it is as not being a cross-section transect but keeps it in the dataset.

Table B-2 in Appendix B is a list of the profile lines that have been surveyed at least once, with their original profile numbers, baseline locations, geographic coordinates, and North Carolina state plane coordinates.

2.3.2 4-Line and monthly surveys

Figure 2-1 illustrates the layout and varied length of the profile lines that make up the monthly survey. The more frequently surveyed 4-Lines are labeled (-91, 1, 1006, and 1097). The track lines shown in Figure 2-1 are from the 1 February 2000 survey and were optimized for the CRAB.

Figure 2-1. The monthly survey profile lines with the 4-Line profile lines labeled. Note the varied cross-shore lengths (actual coverage from 1 February 2000).

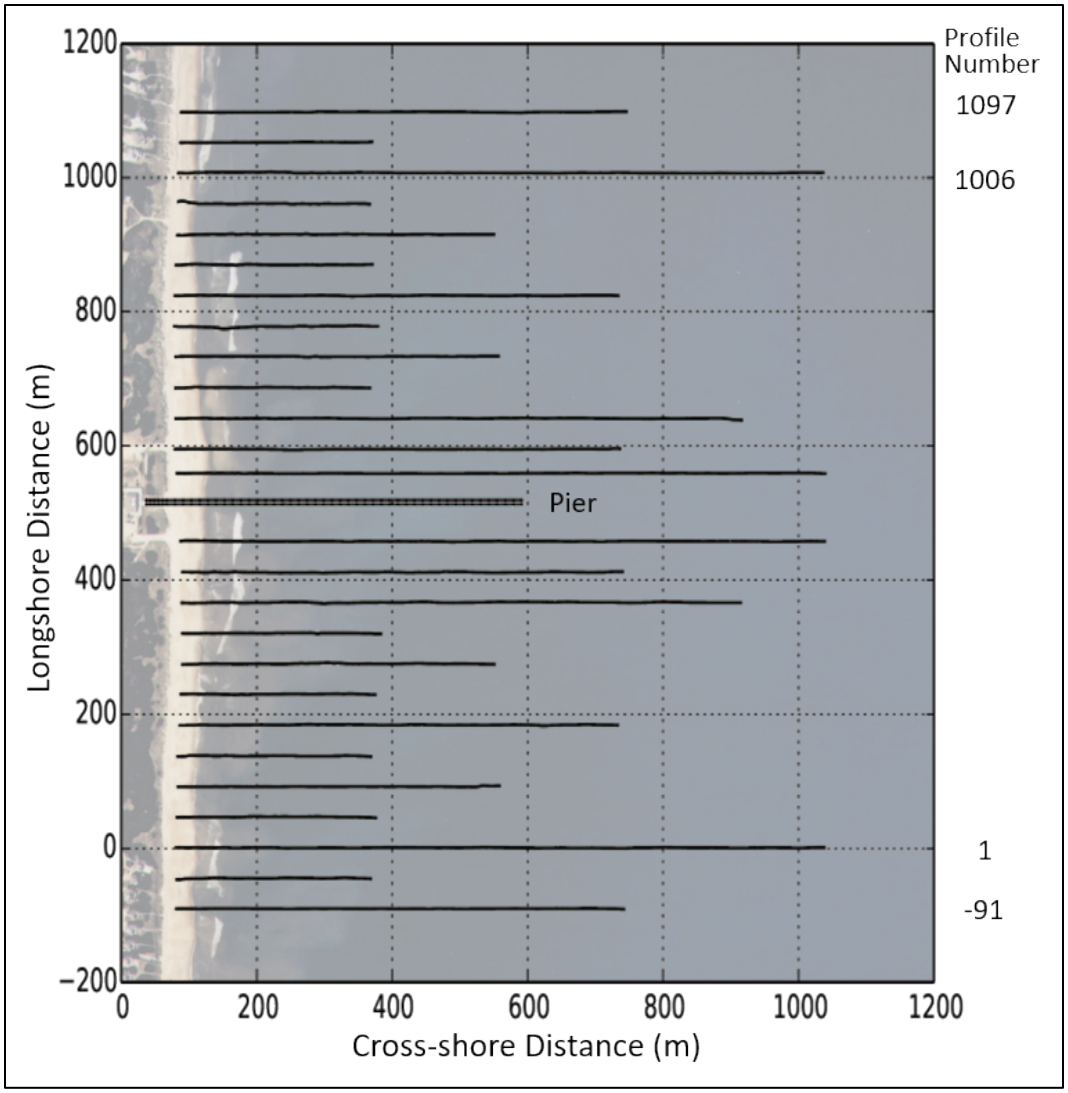
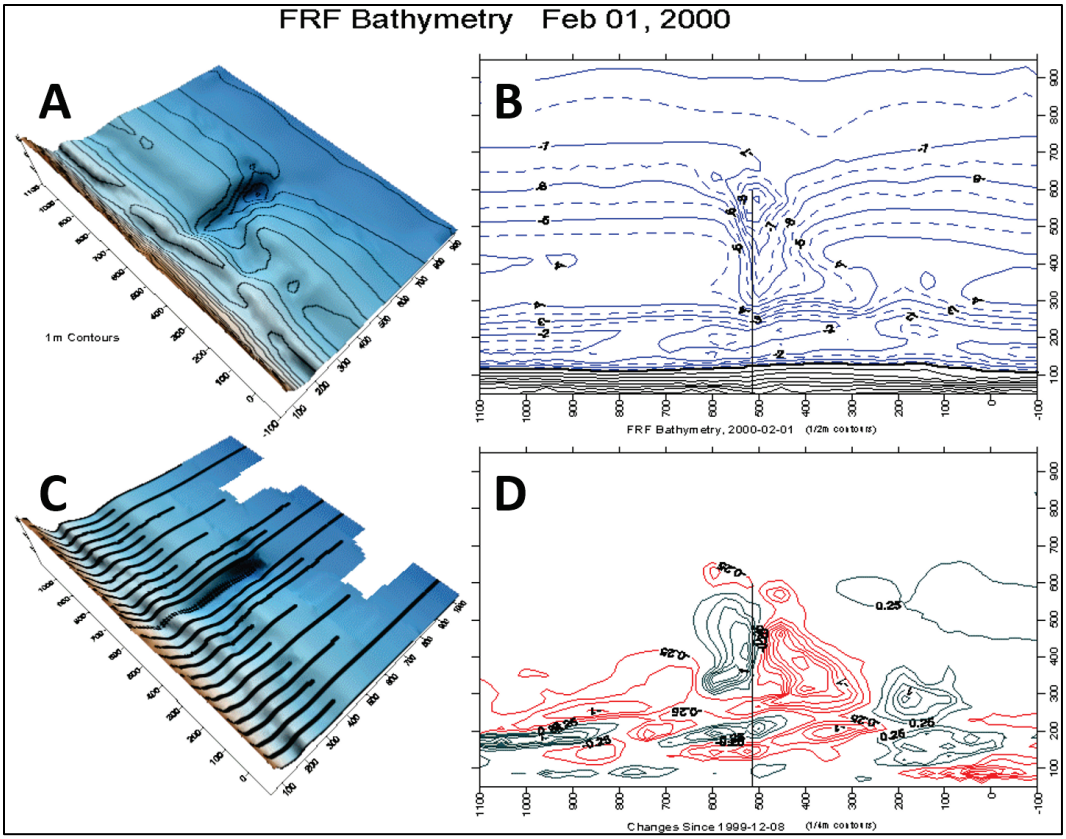


Figure 2-2 shows four views of this survey. Panel A is a surface map; Panel B a contour map; Panel C overlays the track line data on the surface in Panel A; and Panel C is a contour diagram of the change since the previous survey (8 December 1999). Notice in Panel C how the varying cross-shore line lengths resolve the 3D nature of the surface with more coverage nearshore and less coverage offshore where the contours become more shore parallel. The data also resolve the deep scour trough associated with the pier. This trough is the dominate feature in the data, and as discussed by Miller et al. (1983), the size and shape of the scour feature changes, particularly after storms.

Figure 2-2. A four-panel plot showing the bathymetry surrounding the FRF (A, B), the 28-line coverage of the area (C), and a diagram showing the changes since the previous survey (D).



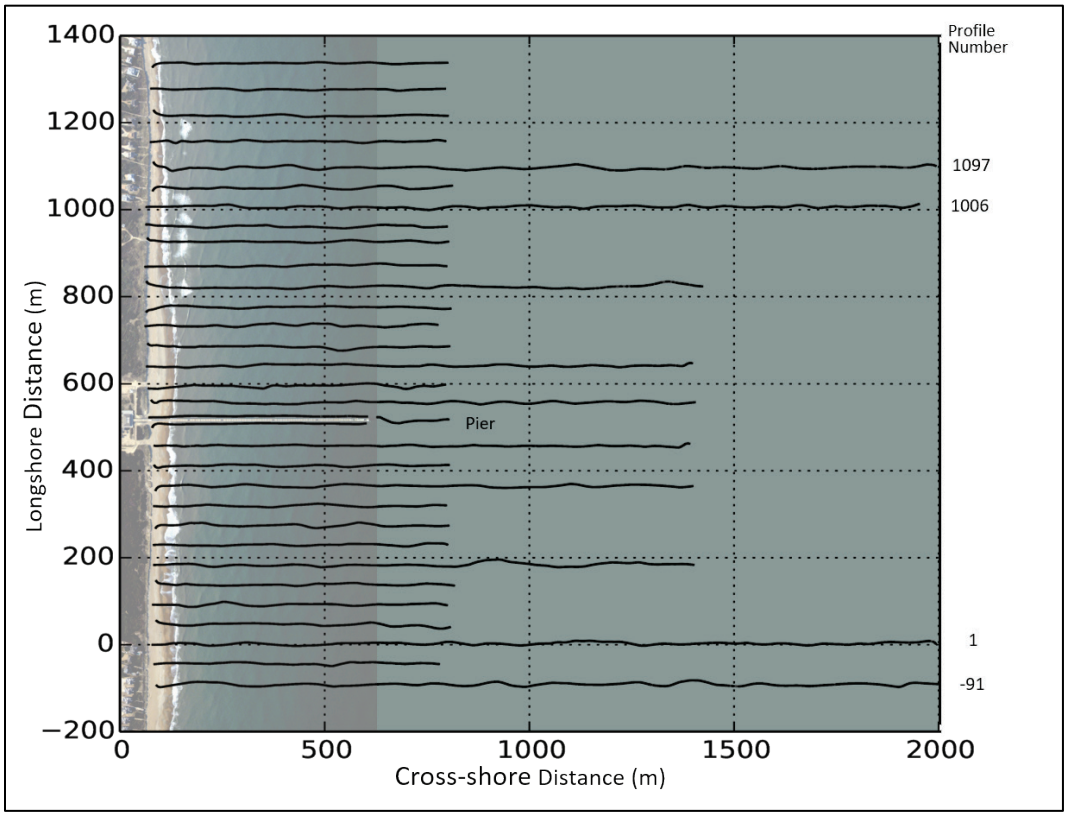
Line 1006 and line 1 are located at the northern and southern edges of the FRF property and are the primary survey lines. They are located sufficiently away from the pier to be outside of the complex morphology around the pier. They extend to the full operating distance of the CRAB to ~950 m offshore and ~8.5 m in depth. Lines 1097 and -91, located an additional ~90 m (north and south, respectively) from lines 1 and 1006, are useful to confirm observed changes on the primary lines. They are usually surveyed on the return trip to the beach and are typically ~150 m shorter in length than the primary lines. Because lines 1 and 1006 are equidistant from the FRF pier and on opposite sides, they can be used to compare north and south cross-shore changes. The entire monthly survey can be used to compare erosion and deposition on opposite sides of the pier.

Varying the lengths of the lines allows a monthly survey with the CRAB to be completed in 2 days. Since the LARC-V can complete the same amount of surveying in a one-third of the time and is not depth limited, in September 1999 line lengths were adjusted, and some were extended to

2 km offshore. Figure 2-3 illustrates the line lengths and lines being surveyed with the LARC-V.

The number of lines surveyed has varied depending on the conditions and coverage desired. The minimum number of 16, which is every other line, equals the maximum number of lines the CRAB could survey in a day, good for a quick pre-storm survey. During 2008–2009, nine surveys were collected of a series of 27 profile lines located north of the FRF between lines 1006 and 3353 as part of the MORPHOS[1] experiment, a useful data set for measuring change away from the FRF. Beginning in 2016 and continuing, four additional lines to the north were added to the monthly survey, extending the coverage north by 240 m to 1,337 m. From August 2017 to August 2018, 10 more lines were added (43-line surveys) to extend the coverage to 4,156 m north to monitor a 90,000 m^3 beachfill placed by the town of Duck beach adjacent to and just north of the FRF property.

Figure 2-3. Map of the 33 monthly survey lines surveyed by the LARC showing the extended line lengths and coverage. The 4-Lines are indicated on the right (track line data shown from the 7 July 2017 survey).



[1] Modeling Relevant Physics Of Systems

2.3.3 Pier surveys

Because the contours around the research pier are too steep and dangerous for the CRAB to survey (in 1987, it fell over while working too close to the pier), the bathymetry under the pier was surveyed using a traditional sounding technique. A fiberglass tape with a weight tied to the end, typically a diving weight, is lowered to the bottom, pulled tight, and then the distance to the top of the pier deck is read and recorded on a paper form. There are 49 stations, one located at the midpoint between every pier bent. Line 520 is the north edge of the pier, 514 is the south edge, and line 517 is the centerline. Pier soundings were typically collected within a few days of each survey. Waves and strong currents could affect individual data points or prevent the soundings from being collected. Starting in April 2006, the pier soundings were discontinued, and line 524 on the north side and line 509 on the south side were added and surveyed using the LARC-V. These lines are within approximately 5 m of the pier. Line 517, extending seaward from the end of the pier, was also added to resolve the scour around the end of the pier.

Because the scour feature is so important, inclusion of the pier lines is critical to resolving this feature in contour and 3D plots. There are ~32 monthly surveys where the pier lines were not surveyed. To properly include these surveys in comparisons, either the area around the pier should be avoided or some measure of the missing pier surveys should be patched in. The patch could be from an earlier survey or by using the mean pier profile shape from several recent surveys.

2.3.4 Data point spacing and gaps

The interval between data points varies with the technique used. Average spacing for the surveys using the Zeiss Elta-2s where the CRAB had to stop for each data point was 20.6 m whereas the average spacing for the continuous tracking Geodimeter 140T and GPS systems is 2.7 and 2.6 m, respectively, which is a clear improvement.

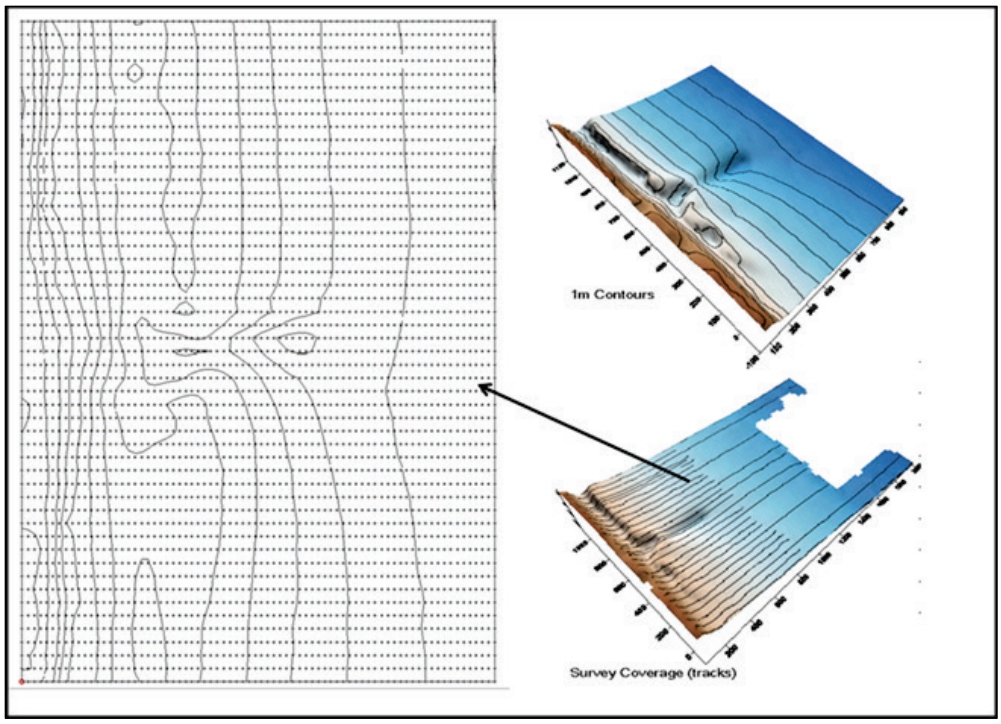
Users should be aware that gaps in the data exist, the result of missed points, GPS dropouts, offline errors, bad weather, and collection problems. Short data gaps on straight portions of the profile, beyond approximately 400 m, can typically be ignored or interpolated through. However, gaps inside of 400 m, particularly between the beach and nearshore, can be

significant and should not be interpolated through. Cross-section and plan-view symbol plots can be helpful in identifying gaps.

2.3.5 The contour map challenge

One objective of the monthly survey is to create a contour map (Figure 2-4). Map generation is challenging using profile lines since there are no data between the lines and closely spaced data along the lines. Moreover, varying line lengths and spacing, data gaps, and steep bottom slopes challenge typical gridding routines. What seems to work best in gridding monthly survey data is to use rectangle search boxes that are aligned with the FRF coordinates (shore parallel) and are long in the alongshore direction (~profile line spacing) and short in the cross-shore direction (~10 m). Because lines -91 and 1097, which anchor the edges of the contour map, are surveyed 100–150 m shorter than the primary lines (1 and 1006), the offshore corners of the survey region will often show a data gap. Also, care must be taken to preserve a data gap around the pier if the pier survey lines are not included, as most routines will grid right through this narrow area. Plant et al. (2002) address errors associated with resolving bathymetry with cross-section data using FRF surveys as an example.

Figure 2-4. Example of interpolated, regularly spaced data points and grid contours for a monthly survey.



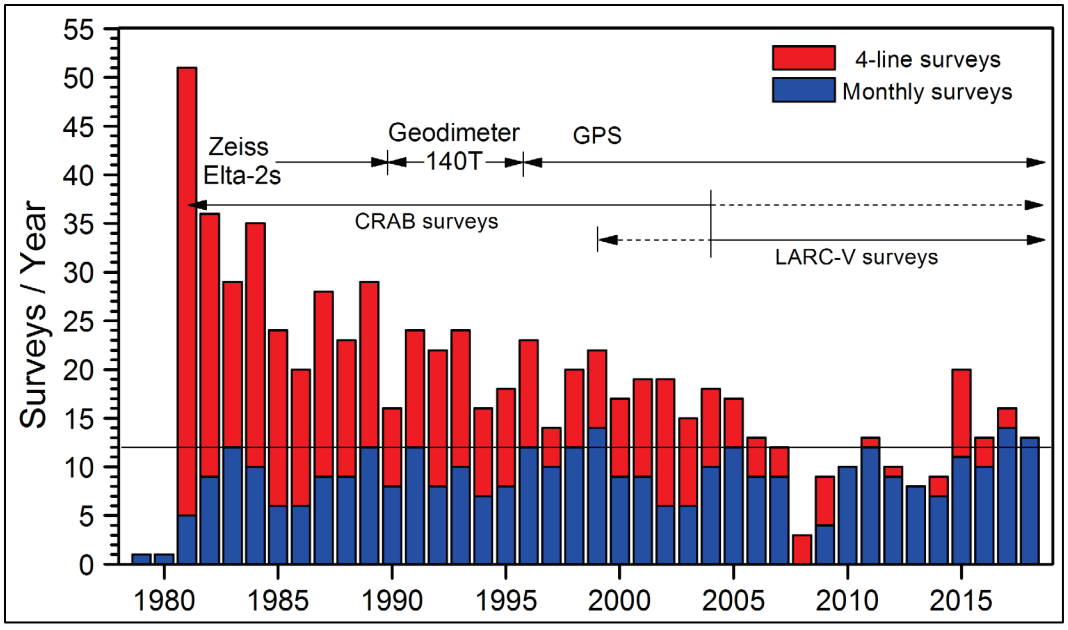
Ideally, the point data should first be interpolated to extend each of the lines to their full length prior to gridding. This would reflect the shore-parallel nature of the contours seaward of the sandbar zone. Each short line should first be extended based on the two adjacent lines, and then the middle length lines should be extended based on their adjacent lines. Using this approach would produce the highest-quality depth grid ready for contouring.

2.4 Temporal coverage

FRF surveys started in 1974, and as of 2018, 1,110 surveys have been collected, an unprecedented temporal record. The most surveyed lines are line 1097 (790 surveys) and line 1006 (789 surveys). Unfortunately, there were known surveys that have been lost, such as those from the Duck-X experiment in 1978. Included in the data and discussed in Chapter 4 are the monthly, weekly, and daily beach surveys from 1974 to 1978 conducted under the CERC BEP (Birkemeier et al. 1985).

This section discusses the temporal coverage from 1980 to 2018. Figure 2-5 shows the available data for the 4-Line and monthly surveys. Appendix D provides additional details for these surveys and all other surveys including the date, number of profiles surveyed, which profiles were surveyed, and the method used.

Figure 2-5. Frequency of 4-Line and monthly surveys at the FRF.



Since a survey may take multiple days, a sequential *survey number* is assigned to each survey. The survey number is also useful if multiple surveys of one or more lines are collected on the same day (as happened during the DUCK85 experiment). Surveys are also referred to by date, where the date is the earliest day of data collection. During the reanalysis effort documented here, all surveys were renumbered starting with a survey number of 200. By starting with 200, the 138 beach surveys of the BEP (Birkemeier et al. 1985) could be included within this dataset along with any other early surveys, should they be recovered.

In 1981 with the arrival of the CRAB and the Zeiss Elta-2s, the surveying intent was to document natural beach evolution at time intervals that were appropriate to capture the changes resulting from fast-developing storms. Since it is relatively easy to survey following a storm, but difficult to anticipate one in advance, it was decided to conduct 4-Line surveys every other week, before a storm if possible, and within a day or so after any event that changes were expected to have occurred. Every second 4-Line survey would be part of the monthly survey, a schedule that would result in a minimum of 24 4-Line and 12 monthly surveys per year.

Temporal coverage is best during the early years with 95 4-Line surveys in the first 2 years and 20 or more 4-Line surveys in 15 of the first 19 years (1981–1999). Survey coverage varies annually with no monthly surveys in 2008 and just six 4-Line surveys in 2009. With one exception, a 4-Line survey in 2011, all non-experiment surveys from 2010 to 2018 are monthly surveys.

Potential users of these data should carefully evaluate which data, if any, is most appropriate for their research. These are some considerations:

- Zeiss Period, 1981–1990 - more frequent surveys (290 total) but fewer data points per line so nearshore sandbar surveys are not fully resolved
- Geodimeter 140T, 1990–1995 – reasonably frequent surveys (115 total) with well-resolved sandbars; sometimes problematic data (see Section 6.4)
- GPS, 1996–present – fewer surveys/year, well-resolved sandbars with the CRAB, less so with the LARC; consistent accuracy since unlike the Zeiss and Geodimeter 140T, GPS accuracy is independent of distance.

Please refer to the specific sections on each survey method for more details and explanation concerning data quality.

2.5 Dune surveys

The dune portion of the profile extends from behind the dune (approximately 46 m from the baseline) to the toe of dune (~76 m from the baseline). Because the dune cannot be traversed by the CRAB or LARC-V, it must be walked by someone carrying a level rod prism pole or GPS antenna. The surveyor moves across the dune stopping at regular intervals and breaks in slope.

Except for a few exceptions, the dune portion of the profile was surveyed at the same time as the beach-nearshore part until 21 August 1985. At that time, it was realized that since the surveyor did not always follow the same transect or survey the same points, the data began showing significant dune change even though the dune was well vegetated and stable. The frequent surveys were also carving a path into the dunes, artificially changing their cross-section. It was therefore decided to survey the dune portion of the profiles seasonally (quarterly) to minimize impact on the dune vegetation and to reduce discrepancies due to slight shifts of the transect being walked.

The beach-nearshore portion of the profile starts at the toe of the dune with the LARC-V or CRAB backing up to get as close as possible to the base of the dune — but still leaving a gap of ~10–15 m. After each survey, the dune and beach-nearshore are combined in processing — sometimes resulting in an odd break in slope where they meet, especially if the beachface has eroded or accreted since the dune was surveyed.

Although the intent was for quarterly surveys of the dune, the time between dune surveys varied and increased to as long as 4 years. Table 2-2 lists the days when the dune portions of the profile lines were surveyed. It also lists available aerial and terrestrial Coastal Lidar and Radar Imaging System lidar data that could supplement the survey data. The dune surveys have been included only in surveys within 90 days of these dates, so many surveys do not have a dune portion. The 90 days implies that for this period of change, the dune was unchanged. Dune data were not always inserted into all surveys within 90 days. During the experiment surveys (see next section), the dune was typically surveyed once and used throughout, reflecting an unchanging dune. Inserted dune points are

identified in the data files by a "0" time so they are easily identified and removed if desired.

Table 2-2. FRF dune survey dates.

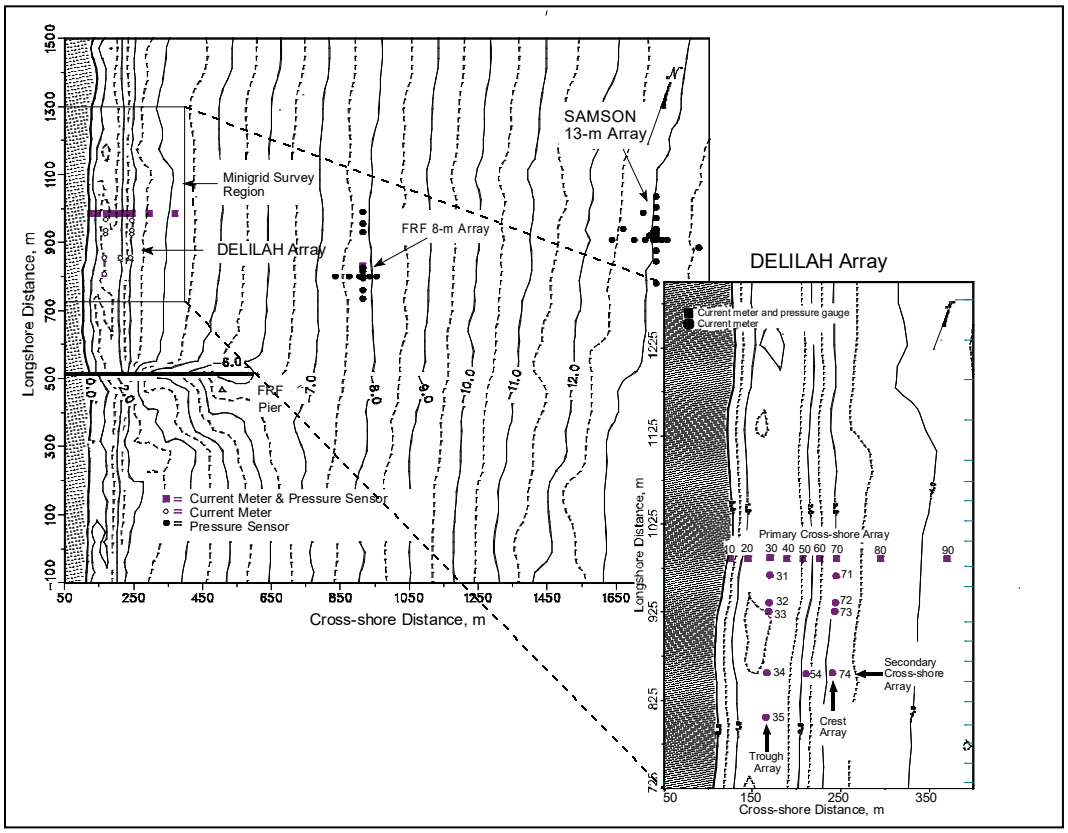
Year	Available Dune/Topo Survey Dates							
1981	dune was surveyed along with the beach/nearshore							
1982	with 1 exception, the dune was surveyed along with the beach/nearshore							
1983	with 1 exception, the dune was surveyed along with the beach/nearshore							
1984	with 3 exceptions, the dune was surveyed along with the beach/nearshore							
1985	19850214	19850326	19850424	19850906	19850928	19851106	19851219	
1986	19860103	19860106	19860113	19860416	19860612	19860903	19861206	
1987	19870106	19870318	19870408	19870721	19871207			
1988	19880607	19880921	19881112	19881121				
1989	19890317	19890818	19891102					
1990	19900122	19900706	19901003					
1991	19910423	19910819	19911107					
1992	19920530	19921027						
1993	19931103							
1994	19940125	19940728	19941022	19941222				
1995	19950814							
1996	19961009							
1997	19970624					Available Aerial Lidar		
1998	19980807							19980901
1999	19990909					19990909	19990918	19991006
2000								
2001								20010103
2002	20020128							
2003	20030818	20030923						
2004	20041007							
2005	20050511	20051021	20051116					20050824
2006	20060202	20060728	20061115	20061213				
2007	20070402	20070628	20070816	20071105				
2008	20080215	20080411	20080805	20080930	20081031	20081112	20080317	20080914
2009	20090721	20090811						20090816
2010								
2011								
2012	20120810	20121106						20121105
2013								20130925
2014	20140429	Available CLARIS lidar						
2015								
2016								
2017								
2018	20180919	20181213						

2.6 Experiment surveys

Surveys conducted during each of the seven experiments are discussed in detail in Chapter 8. There are similarities between them that are summarized here, to highlight the potential value of these surveys to researchers.

All the experiments were conducted in the fall, and during each one, a small minigrid survey region was established north of the pier where it was open to storm waves from the Northeast. A sample minigrid from the 1990 DELILAH experiment is shown in Figure 2-6. In each minigrid, the profile line spacing was ~25 m, approximately half of the monthly spacing, so spatial coverage is tighter. Surveys are more frequent, usually daily, so the temporal coverage is more comprehensive.

Figure 2-6. Sample minigrid survey region, from DELILAH 1990.



Complementing the detailed surveys were extensive observations of the local dynamics within and around the minigrid: waves, tides, and currents.

Because they were more closely spaced than the usual survey lines, profile lines established during experiments were at the time given unique 200 series line numbers. Existing lines from the monthly survey within the minigrid were included and also renumbered. Experiment survey numbers were numbered sequentially starting with the first survey as survey "1".

As part of the FDIF efforts, the experiment profile lines have been renumbered to their FRF alongshore coordinate, rounded to whole meters,

and the surveys have been renumbered to be in sequence with the overall survey data set, allowing all surveys to be combined. Experiment data filenames include the experiment name.

2.7 Survey data, files, formats, and supporting documents

This section addresses details about the data archive itself: useful details for understanding, finding. and using these data.

2.7.1 Data file content, format, and filename

The data are stored in separate CSV ASCII data files, one survey per file. This file includes all the profile lines surveyed, which are sorted by profile number and distance offshore. Each row is a single data point, and there are 14 columns of information; there is no header record. Rows are of variable length but have a maximum length of ~125 characters. For each data point, three coordinates are included.

Column headers/variable names (not included in the file)

Locality, Profile, Survey Number, Latitude, Longitude, Northing, Easting, FRF_offshore, FRF_longshore, Elevation, Ellipsoid, Date, Time, Time_sec.

Data Columns

1. Locality Code (3 character) - "FRF"; Experiments use DK, SD, DE, BD, etc.
2. Profile Number (integer)
3. Survey Number (integer) - sequential since initial survey
4. Latitude (decimal degrees)
5. Longitude (decimal degrees)
6. Northing (decimal meters) - NAD83 North Carolina State Plane Coordinate
7. Easting (decimal meters) - NAD83 North Carolina State Plane Coordinates
8. FRF offshore coordinate: distance offshore from the local baseline, in meters
9. FRF longshore coordinate: distance alongshore from the local origin, in meters

10. Elevation - relative to the North American Vertical Datum (NAVD88), in meters
11. Ellipsoid – optional; if used, this is the geographic ellipsoid of the survey point
12. Date - date data point was collected (YYYYMMDD)
13. Time (hhmmss or hhmmss.sss): Time data point was collected - in Coordinated Universal Time (UTC)
14. Time_sec: Time (UTC) data point was collected in seconds past midnight

Each filename includes descriptive information about the content — the filename includes seven fields, separated by underscores, with details about the contents of the file:

- Location (FRF)
- Survey Date (YYYYMMDD)
- Survey Number (XXXX)
- Survey Job (FRF or Experiment designation)
- Vertical Datum (NAVD88)
- Vessel used (CRAB, LARC-V, etc.)
- Survey Instrument (Level, Zeiss, Geodimeter, GPS, etc.)
- Time Base (UTC)
- Version Date (vYYYYMMDD) representing the date that the data in the file were updated.

Sample filename

FRF_20080107_1025_MORPHOS_NAVD88_LARC_GPS_UTC_v20151115.csv

2.7.2 Notes on data values

Date value. The date marking each data point is the date that point was collected, with some exceptions. Sometimes the weather precluded the full offshore extent of the profile line to be surveyed, and data from a previous or later survey may be patched in to facilitate comparisons and contour map generation. Dates on those added points retain their correct dates. Data from the dune portion of the profile may also be from a different date (see section 2.5), but those points may be marked with the date of the beach/nearshore survey date. The first point is always given that date — since the first point is usually used to establish the date of the survey.

Time value. Because surveys take hours or sometimes days to conduct, the exact time that a data point is collected is not a critical value and was seldom included in survey data files. However, with the adoption of GPS, very precise time values have been recorded. Prior to 2015, time was recorded relative to Eastern Standard Time (EST) or Eastern Daylight Time (the field notes are not always clear). Before GPS, the start time of each profile line was recorded and hand entered during processing. That time was then assigned to all points in the survey. If a time was not known, then a time of 1200 was entered. All times were converted to UTC (as noted in the filename) by adding 5 hours (1200 EST becomes 1700 UTC). One exception: a time of "0" is used to denote an inserted dune or offshore point, useful to identify and remove those points if so desired.

Coordinate values. Coordinate values are derived and resulted from a work flow that varied with the survey method used (see Chapters 4–7). Pre-GPS surveys were collected relative to FRF coordinates, and the Geographic and NC State Plane coordinates were computed from the FRF coordinates. GPS data were collected using the HYPACK, Inc., HYPACK® software, which collects in Geographic and computes NC State Plane. FRF coordinates were then computed from the Geographic coordinates, and post-2014 from the NC State Plane coordinates. Prior to the adoption of the present data format in November 2010, only the computed FRF coordinates were saved, not the observed Geographic and NC State Plane coordinates.

As of 2018, there are 1,110 FRF data files that vary in size from a single profile line with 37 points to a survey with 131 profile lines and 120,000 data points. Total size of all files is ~620 megabytes of data.

2.7.3 Supporting files and folders

The FRF Survey Line Dataset is supported by a collection of folders, one per survey organized by year and survey date. Each folder holds all available documents, raw data, early processed files, plots and other files used in creating the final coordinate data file. These files can be used to track the evolution of the data, including steps taken, data deleted, and adjustments made, if any. If the raw data are available, it should be possible to recompute the final coordinate values, but in practice this may be difficult considering the various techniques used, transformations applied, and editing required. Most, but not all, editing is documented in included notes or in log books.

Unfortunately, not all raw files could be found, so there are surveys where only the original processed data file is available, and in some cases only the distance and elevation data pairs (not the longshore coordinate) were originally saved. The column "Raw Data Available" in Appendix D indicates if the original raw survey data are available.

From 1980 to 2006, notes on every survey were logged on a paper form, and paper plots were printed, and handwritten notes were often written on them. These paper documents have been scanned and included in the appropriate folder for each survey. Post 2006, notes were kept electronically in a spreadsheet that documents the data collection but not the data processing. Available notes, file types, and formats vary with the collection technique used.

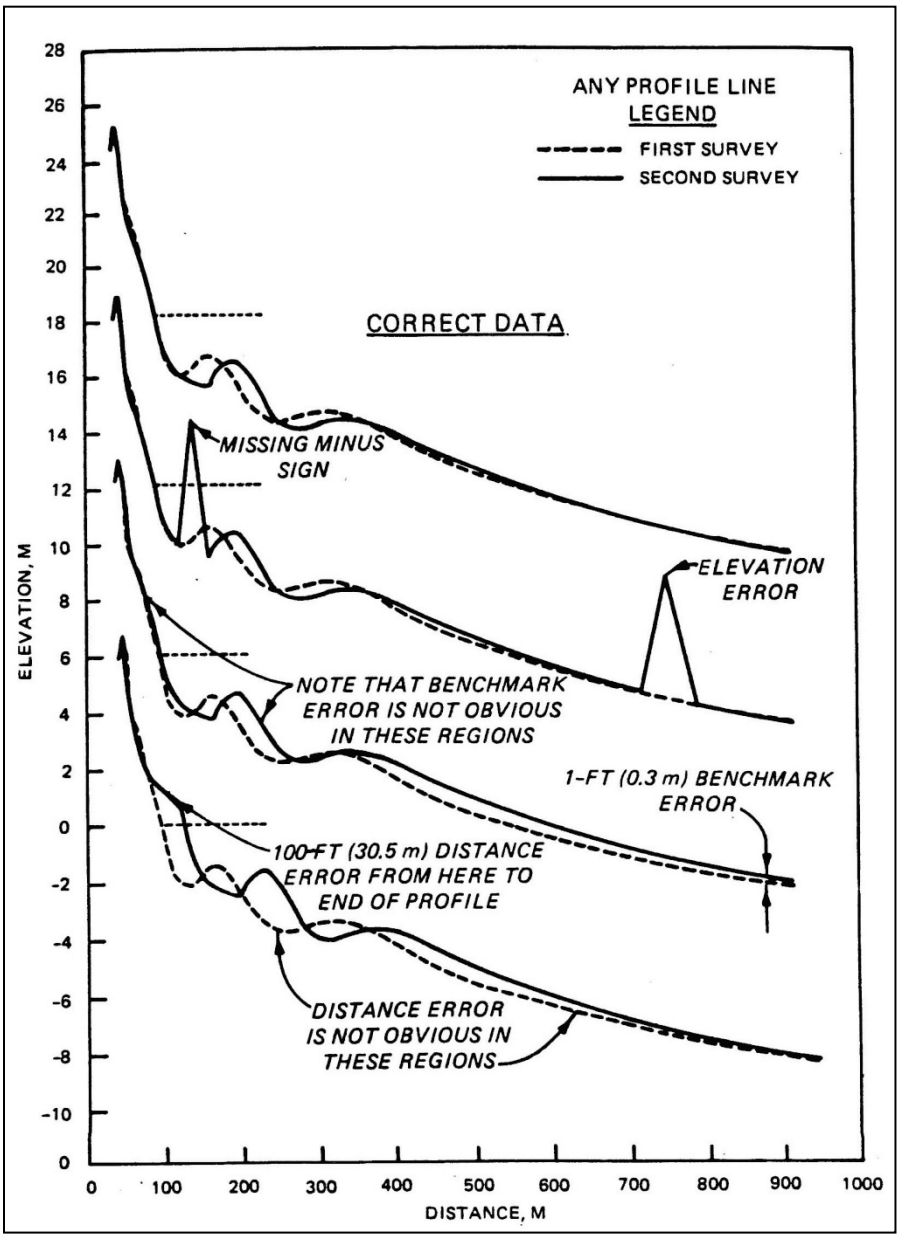
2.8 Reports published using these data

These survey data have been often used in published research examining nearshore morphology evolution and relating morphology response to coastal processes. Many are seminal reports on nearshore morphology. Appendix C lists over 80 publications. When publishing research using these data, use this report as a citation for the data.

3 Errors in Beach-Nearshore Surveys

A goal of the survey program has been to collect surveys of sufficient accuracy to resolve small volume changes over the length of a profile line. That determination requires a vertical and horizontal accuracy of a few centimeters, sustained over many surveys and many years — a significant challenge. Figure 3-1 shows typical survey errors.

Figure 3-1. Schematic showing typical survey errors.



Every observed or measured quantity contains errors resulting from a variety of sources, and hence a measurement is seldom exact. One of the important functions of the surveyor is to collect measurements that are correct within known limits of precision and that satisfy the requirements of the computations that will use the collected data (shoreline change, volume change, bar movement, etc.). This process requires knowledge of the sources of errors, an understanding of the effect of various errors on the observed quantities, and a familiarity with the procedures necessary to minimize errors.

Errors usually arise from three sources: operational errors, instrument errors, and external errors. Operational errors involve the procedures used to conduct a survey. Instrument and software errors result from limitations of the instruments or devices with which measurements are taken. External errors arise from the variations of nature such as temperature, humidity, wind, and gravity. These errors along with how they were identified are discussed in general below and as they pertain to the different survey methods in Chapters 4–6.

In general, the evolution of the surveying methods at the FRF has been toward steady improvement, reducing or eliminating errors.

3.1 Operational errors

Operational errors can result from improper stationing of an instrument, which results in a systematic error that affects all collected points. A small horizontal stationing error may be hard to detect and have little real impact, but an elevation error will affect volume computations and may overwhelm real change. With optical instruments, misaiming the instrument at the target will also result in an error, but only to individual points. These single point errors may be easy to identify and remove, or not. Misaligning the optical instrument with the FRF grid results in a rotation of the FRF coordinate system and horizontal offset errors, which are opposite in sign north and south of the instrument.

The LARC-V data have unique operational errors because, unlike the CRAB, which allows for a direct measure of coordinates, the final coordinates from the LARC-V result from a computed combination of GPS, echosounder, sound speed sensor, and motion sensor, each with its own accuracy, errors, and precision. Given these same data, two software programs may compute different coordinates.

A different type of operational error results when topographically important points, such as the bar crest or trough, are missed. This can be a problem with the CRAB-Zeiss and LARC-V surveys, but it is less of a problem with the CRAB surveys with the Geodimeter and GPS, as long as there are no gaps in coverage.

Operational errors can also result from procedural lapses such as a misread stadia reading, a misaimed total station, or an incorrectly transcribed number. When using the Zeiss, the tilt of the CRAB had to be hand-entered into the instrument, which was usually not a problem. However, removing that entry before the next shot was a constant problem. In general, those systems that require less human interaction have fewer operational errors.

3.2 Instrument errors

Instrument errors are related to the accuracy, precision, and unique idiosyncrasies of the instruments themselves. RTK-GPS data accuracy is dependent on the number of satellites and their geometry; the vertical accuracy of a total station decreases with distance and is related to the accuracy in range and angle; optical systems will give a reading, even if misaimed at the target.

3.3 External errors

The electronic survey instruments are sensitive to atmospheric variation since they use the speed of light to determine distance and optical aiming to measure the angles. The instruments allow for rough adjustment for these variables. During the summer months heat shimmer and temperature gradients near the land-sea interface may also affect the accuracy of angular measurements. There is no quantitative feel for these sorts of errors other than they appear to be negligible relative to other types of errors; they may explain some instrument systematic offshore changes amounting to several centimeters during the summer months that do not appear to be related to the dominant processes. GPS data are less affected by temperature variation but are affected by weather and the atmosphere, which may result in unquantified errors on specific surveys.

An additional but unquantified source of error results from the thermal expansion and contraction of the CRAB frame and its liquid-filled tires. Although its height is routinely measured on land, any height difference

when fully submerged is unknown. It is suspected that it may be on the order of 3 to 6 cm (0.1 to 0.2 ft) between summer and winter extremes but that it occurs gradually. This amount of variation combined with the slight uncertainty of the over hundreds of different instrument setups and atmospheric conditions results in a survey noise level that obscures small bed level changes along the offshore reaches of the profiles.

3.4 Error identification and correction

Errors in the data are most easily recognized through comparison with earlier and later surveys. In general, each newly collected survey is compared during processing to the previous one. Typically, the data are error free. If not, the comparison usually shows possible individual point or systematic errors. Obvious errors are removed (see Figure 3-1). Subtle point errors or small systematic errors can present a real challenge to resolve. Often the field notes help, as can a comparison with a later survey. These surveys extend far enough offshore where change is typically small and slowly varying. Based on the offshore data, it is known that real profiles at the FRF do not shift vertically one survey and then back the same amount the next survey (assuming the time between surveys is ~months, not years).

Errors observed offshore can usually be verified and corrected using vertical reference checks made during every survey, typically a point in the FRF parking lot for the GPS system and one or two permanently mounted prisms for the optical systems.

Corrections made to the data consist of deletion of points and subtraction or addition of biases. The biases can be constant or gradual. An error in measuring the height of the CRAB or of the instrument results in a constant offset while improper leveling of an optical instrument results in a gradual vertical error that increases with distance.

Corrections made to the data are recorded in the processing notes and logs, although not all changes have been recorded. GPS data do not suffer from the same problems as the earlier methods. Problems with the LARC-GPS survey caused by echosounder dropouts, particularly in resolving the shape of longshore sandbar, are noted in text files in the survey folder.

3.5 Accuracy of the survey system

Quantifying and maintaining accuracy has been a consistent part of the survey program, with each change in the system prompting new comparisons with the previous method. The overall accuracy was first established with the Zeiss Elta-2s, which is a first-order survey instrument. The distance accuracy of the Elta-2s is ±2 cm in rapid measurement mode, and the angle accuracy is ±0.6 inch (in.) for an absolute vertical accuracy of ±1.5 cm at 1,000 m. Under ideal survey conditions, vertical accuracy based on repetitive surveys with the CRAB was found to be ±2.1 cm or under normal conditions ~±3 cm (Howd and Birkemeier 1987b).

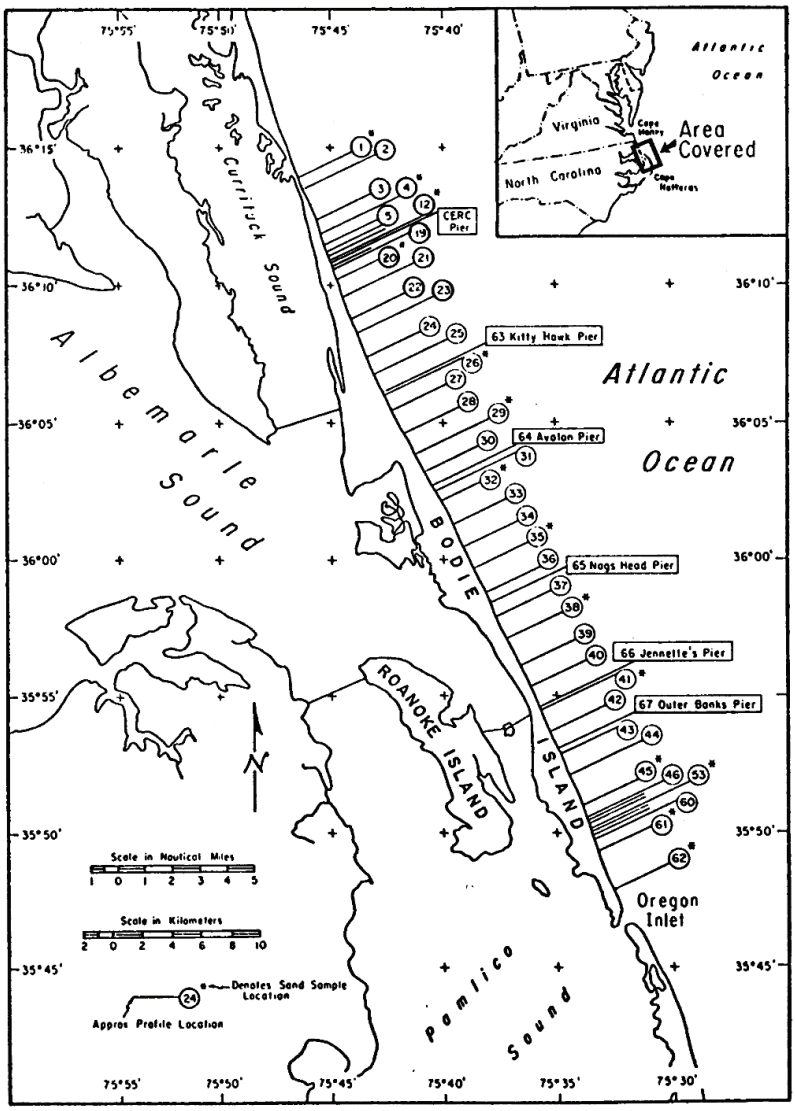
Later survey methods were compared to surveys with the CRAB using the Zeiss Elta-2s and found to be of similar accuracies.

Data prior to December 1981 were saved only to whole feet in distance and tenths-of-a-foot in elevation (normal accuracy for beach profile survey data at the time). Because of the greater accuracy of the CRAB/Zeiss data, subsequent data were stored to 0.1 ft in distance and 0.01 ft in elevation. This precision has an impact on the overall accuracy of the data.

4 Coastal Engineering Research Center-Beach Evaluation Program (CERC-BEP) Beach Surveys: 1974–1978

In 1974, the BEP of the CERC, the predecessor organization to the CHL of the ERDC, established a series of 69 profile lines along the Dare County, North Carolina, oceanfront (Figure 4-1). The surveys were coincident with the development of the FRF; surveys began in May 1974, prior to construction.

Figure 4-1. CERC-BEP Dare County profile lines. An * marks sand sample profiles. (from Birkemeier et al. 1985)



The data from these lines is discussed in Birkemeier et al. (1985). Well-documented permanent concrete monuments were established at the origin of each profile line.

All surveys were done under contract by professional surveyors using an automatic level to measure elevation and a survey tape to measure distance relative to the origin (Figure 4-2). Surveys were done in feet relative to the NGVD29 datum and extended from behind the dune to wading depth (-0.6 m). Sand samples were collected from the dune and across the beachface on 14 of the profile lines. Field notes were reduced by hand to distance-elevation pairs that were then keypunched onto 80-column Hollerith computer cards.

Figure 4-2 . Beach survey using an elevation rod and automatic level.

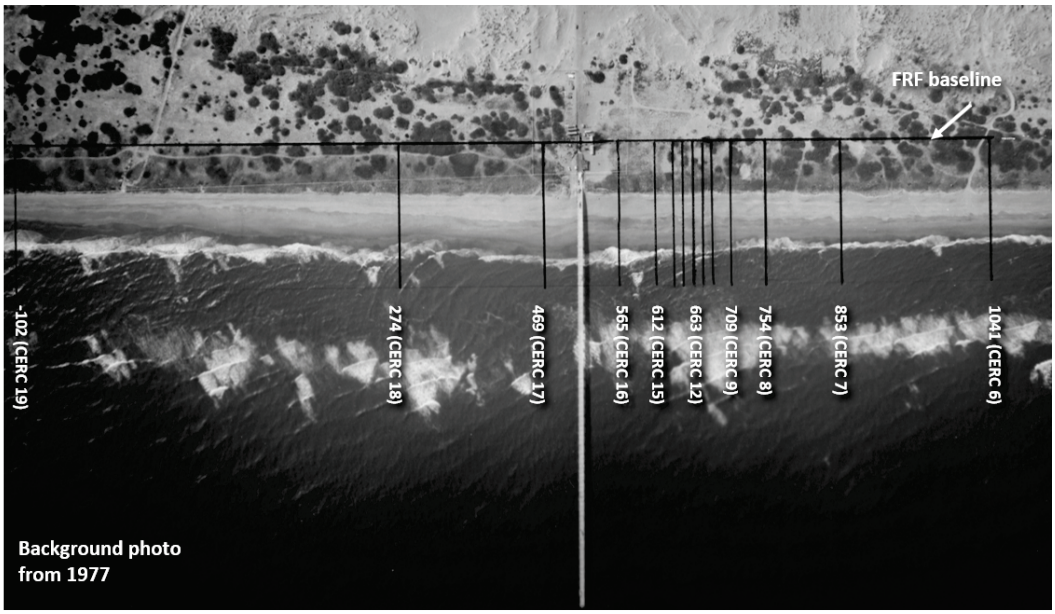
As with the other FRF survey data, these data were converted to NAD83 horizontal coordinates and NAVD88 vertical datum. NC State Plane and Geographic coordinates were computed and added to the cross-section coordinates.

The overall data set is referred to as the Dare County NC-BEP surveys. Profile lines 1-25 were converted to the FRF coordinate and profile numbering system and included in the FRF survey data archive using project name CERC. Relative to the FRF coordinate system, these lines

extend from -7,900 m south of the FRF to 6,275 m north. The locations of these lines are documented in the tables in Appendix B.

Besides providing a record of the beach and dune configuration in 1974, before the construction of the FRF, these surveys include unique temporal and spatial features. They were originally designed to answer questions concerning how frequently to survey and how closely spaced profile lines should be. There are 141 surveys from 6 May 1974 to 24 January 1977. These were followed by 27 surveys of five profile lines from 9 November 1977 to 28 March 1978 located 800 to 7,900 m south of the pier, south of the monthly survey boundary. Within the first 141 surveys are monthly, weekly, and daily surveys of the 25 lines. Monthly and weekly surveys include the full dune, back to the benchmark; daily surveys start at the base of the dune. Three sets of 31 daily surveys were collected starting 20 January 1975, 8 August 1975, and 21 April 1976 (winter, summer, spring). These surveys can be used to examine high-frequency temporal variation of the beach. The distance between the survey lines was varied to examine the alongshore variation in beach response. The most closely spaced lines (CERC 8 to CERC 16) were located north of the FRF pier (Figure 4-3) and extended outward. For comparison, a similar set of closely spaced lines with the same varying temporal coverage was located in Nags Head, NC, between profile lines 46 and 60 (Figure 4-1).

Figure 4-3. The CERC profile lines located around the FRF pier.



These surveys predate and include the construction of the FRF pier. Beginning 7 July 1976, additional lines were added to the surveys to include each side of the pier (see Section 2.3.3). The surveys from 10 July 1976 to 17 December 1976 covered the first phase of construction (extending 243 m from the baseline); surveys from 6 January 1977 to 24 January 1977 covered the full length of the pier.

Appendix D tabulates the CERC surveys, including the date of each survey and which profile lines were surveyed.

5 Sea-Sled and Boat Surveys: 1979 and 1980

The earliest nearshore surveys in the dataset are from the fall of 1979 and 1980. Twenty-two lines were surveyed in 1979, and in October 1980, 24 lines were surveyed in advance of the Atlantic Remote Sensing Land-Ocean Experiment. For these surveys, the profile lines were located 3–4 km north and south of the pier. Figure 5-1 shows the Langley and McDonald Sea-Sled on the beach in 1980.

Figure 5-1. Langley and McDonald Sea-Sled on the beach in 1980.

Both surveys were done under contract to Langley and McDonald of Virginia Beach, VA, and each profile line was surveyed in three parts: beach, nearshore, and offshore. The beach portions were surveyed to wading depth (-0.5 m) using conventional level and tape techniques. The nearshore was surveyed out to 600 m using a sea-sled with a graduated mast, which was pulled offshore by a boat and winched back to shore by means of a cable (Figure 5-1). The offshore was surveyed using an analog echosounder mounted on a boat. A Motorola Mini-Ranger® system provided horizontal position information for the sled and boat. The Mini-Ranger can collect position data with an accuracy of ±3–5 m (or better) depending on geometry and range. The echosounder was calibrated vertically on each range line by overlapping the data with the sled for 30 m

(only at a single depth). Because wave motion was not completely removed from the echosounder portion of the survey, it is less accurate vertically than the beach and sled portions. Adjusting the fathometer data to match the sled data also would not completely remove depth changes resulting from speed of sound changes in deeper water. All surveying was done in cross-section coordinates and then converted to FRF coordinates.

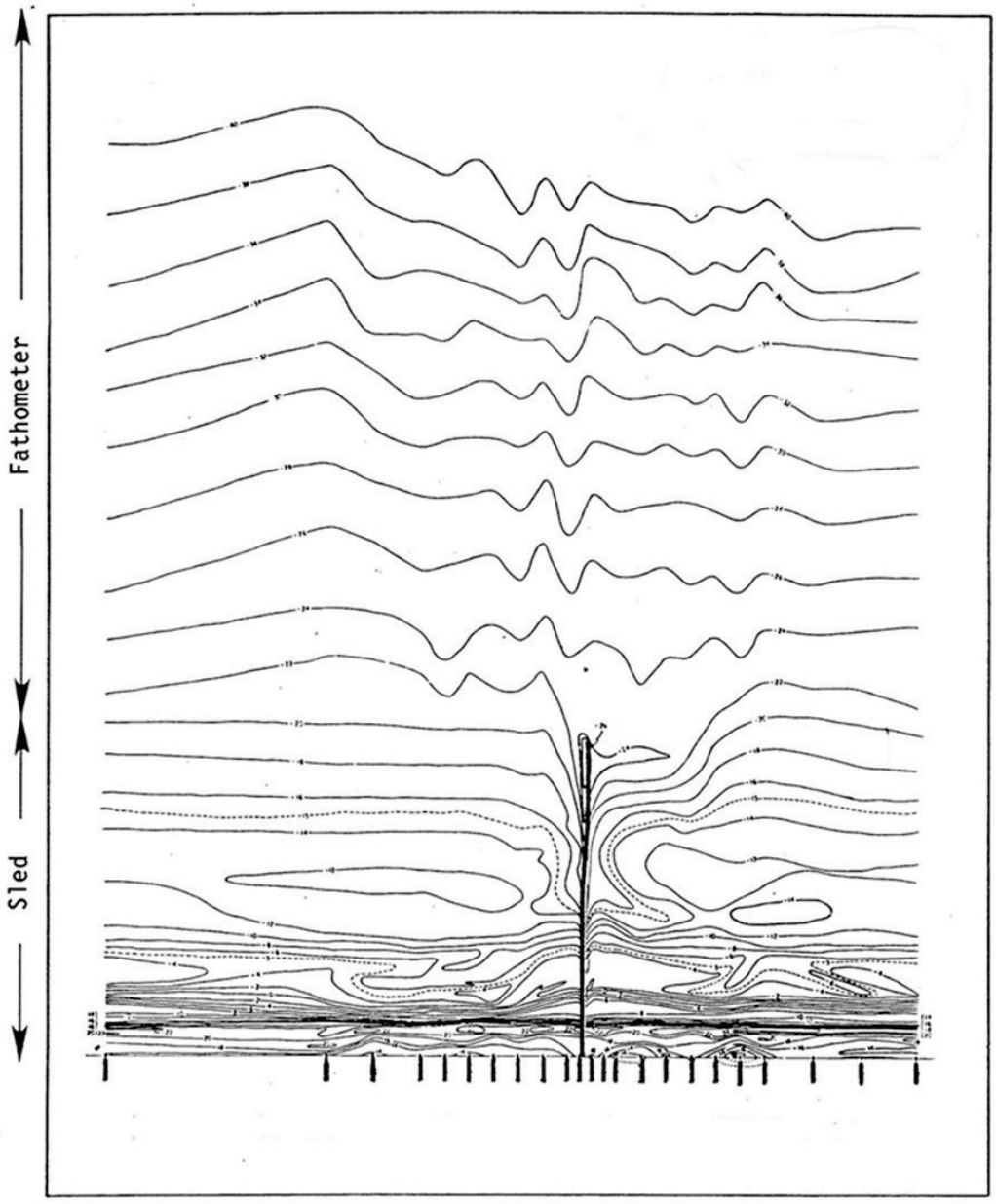
The profile lines cover ~6.5 km alongshore and extend from behind the primary dune line to at least 600 m with selected lines surveyed to ~3 km offshore (17 m isobath NAVD88).

The dune and beach, or topographic, portion of the profile was surveyed using a level for elevation and a tape for distance. The level was also used to measure the elevation of the sled as it was pulled toward shore using a truck-mounted winch with a cable marked every 6.1 m. Each time a mark came to the winch (as the sled was winched in), the elevation of the sled was read with the level. The sled was then moved to the next line, and a swimmer on a jet ski returned the cable to the boat, which pulled the sled offshore

Beach and sled data were collected manually and recorded in field books. The fathometer data were recorded on a paper chart that was manually interpreted. All data were reduced, recorded onto a paper data form, and keyed into a coordinate ASCII file.

A contour map of the data is shown in Figure 5-2. Note the change in curvature in the shape of the contours between the inshore sled portion of the surveys and the offshore, boat portion. From later surveys, it is known that offshore contours are generally straight and shore parallel. The curvature in the offshore contours is enhanced by the closely spaced profile lines and small vertical errors in bottom depth.

Figure 5-2. Contour map of the October 1980 survey (profile line locations indicated by vertical lines at the bottom of the plot).



Besides the updated ASCII data file, the supporting archive for these surveys include scanned documents of contract paperwork and the distance-elevation log sheets.

6 Coastal Research Amphibious Buggy (CRAB) Surveys: January 1981–Present

Surveys conducted using the CRAB and four different survey instruments are discussed in this chapter. Sections 6.1 – 6.5 are adapted from Howd and Birkemeier (1987b) and Lee and Birkemeier (1993).

6.1 The CRAB

The CRAB (Figure 6-1) was originally described in Birkemeier and Mason (1984). Built by the SAW, this unique three-wheeled vehicle was modeled after a vehicle originally built by Marine Travelift & Engineering of Sturgeon Bay to monitor beach nourishment projects. That vehicle is still in use, owned and operated by the Great Lakes Dredge and Dock Company.

Figure 6-1. The CRAB during the early level and stadia surveys.

The CRAB consists of a tripod of 20.3 cm schedule-80 aluminum tubing, connected at the base by horizontal members 2.1 m above the ground, with an operations platform 10.6 m above the ground. It is 7.6 m between the center of the rear wheels and 9.0 m from the front wheel to the rear axle. The tires are 157 cm in diameter and 71 cm wide. Power was supplied by a 39.5 kilowatt Volkswagen® engine that was later updated to a small

Kubota® diesel. The engine drives a variable stroke hydraulic pump. This pump transfers hydraulic fluid at 5.5 × 106 Newton/m² or higher to hydraulic motors at each of the wheels. The variable stroke feature of the pump allows an infinitely variable gear ratio in either forward or reverse and constant engine speed. For strength and corrosion resistance, all hydraulic lines are made of stainless steel, except for short flexible sections at the front steering wheel. Originally open deck, a cabin was added in 1986 to protect the operator and equipment.

Total vehicle weight is approximately 8,200 kilograms; although it appears top heavy, the liquid-filled tires and wide wheelbase make it very stable. It has passed a 20 deg tilt test and is designed to withstand even steeper angles.

During a survey, the CRAB averages 2.3 km/hour. The maximum significant wave height considered for safe operation is ~1.5 m, based primarily on rescue concerns if it were to break down under higher waves. On a few occasions, the CRAB has been operated during higher waves (>2 m), and the operator felt one of the wheels being briefly lifted off the bottom. During the experiments, the CRAB was used to survey and to pull instrumented sleds offshore during higher wave conditions (Figure 6-2). It stayed in shallow water and did not go seaward of the nearshore bar and operated without problems.

Figure 6-2. The CRAB operating in high waves during DELILAH.

The tracks of the CRAB have been observed in a side-scan record, but close inspection by divers indicate that the large tires have a negligible effect on a hard rippled sand bottom. No adjustment is made for sinking in the sand. Scour around the tires has been observed in areas of active wave breaking or strong currents if the CRAB stops moving. The CRAB cannot be used on soft silty or steeply sloped bottoms.

When the CRAB is used for surveys, its height allows highly accurate topographic surveys techniques to extend offshore. Since a set of reflecting prisms or a GPS antenna is mounted directly above and centered over the back two wheels, it averages the elevation between the wheels. The most critical measurement for accurate surveys with the CRAB is the height of the prism or antenna above the ground. During a survey, the CRAB tilts, particularly on the steep slopes of the sub-aerial beach. Because of its height, the tilt affects the measured elevation. Depending on the system used, the tilt was either observed or estimated.

6.2 Stadia and level Surveys: January 1981–June 1981

From January to June 1981, the position and elevation of the CRAB were determined using an automatic level located on the beach, to read a 12.3 m high stadia board attached to the CRAB (Figure 6-1). This system was slow and sensitive to a wide range of errors. Primary sources of error included out-of-level instrument, stadia reading errors, field book and transcription errors, and instrument stationing errors. Estimated horizontal accuracy was from ±0.3 to ±3 m. Vertical accuracy was estimated to vary from ±0.03 to ±0.6 m. Single points may have been in greater error.

Errors tended to increase with distance from the station. This resulted from the increased difficulty in reading the stadia board and the greater impact of out-of-level errors. Because of these errors, data collected prior to June 1981 end approximately 600 m offshore. Points farther offshore were of questionable accuracy and were dropped.

Although of inferior quality to later surveys, the stadia survey data have been retained in the data set because of the unusual configuration of the profile lines at the time, which is accurately represented.

6.3 Zeiss Elta-2s Surveys: July 1981–April 1990

To improve the speed and accuracy of the surveys, a Zeiss Elta-2s electronic surveying instrument with automatic data recording was used after June 1981.

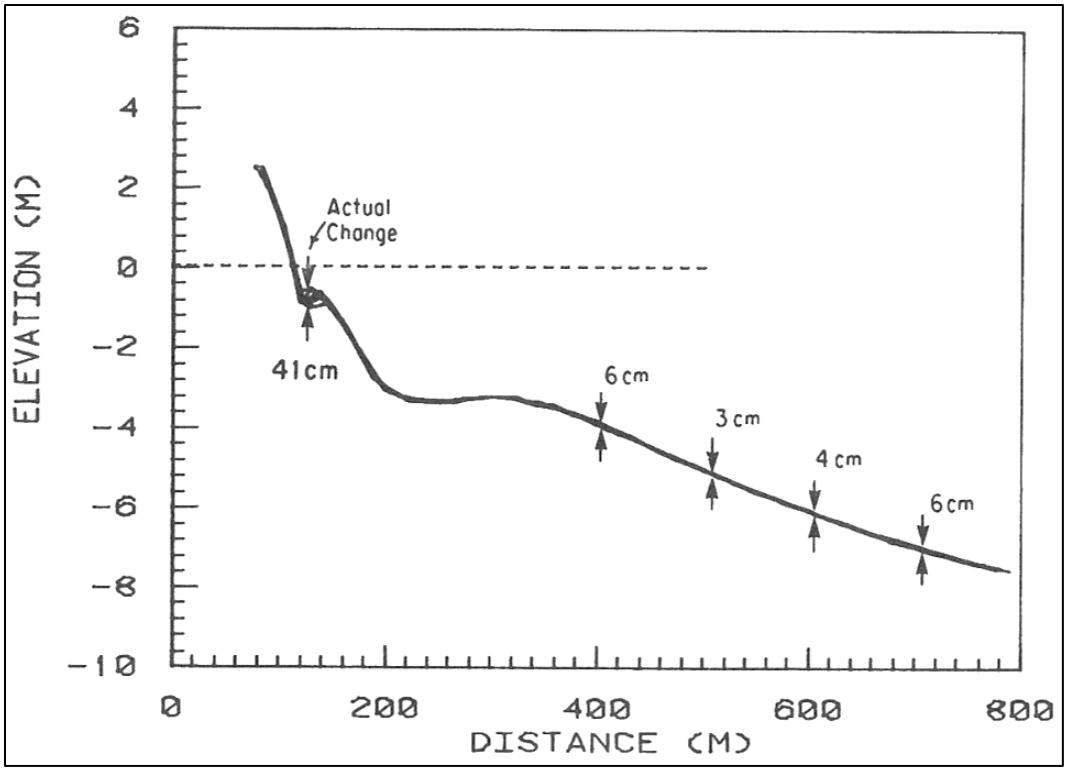
6.3.1 The Zeiss Elta-2s

The Zeiss Elta-2s (Figure 6-3) incorporates a first-order electronic theodolite, distance meter, microprocessor, rechargeable power supply, and interchangeable solid state memory module in one compact unit. When optically aimed at a reflecting prism on the CRAB, the instrument uses a collimated infrared beam to measure the distance and the electronic theodolite to measure both horizontal and vertical angles. The microprocessor then uses these measurements plus the coordinates of the instrument to compute X, Y, and Z Cartesian coordinates of the ground point under the CRAB (corrected for earth curvature).

Figure 6-3. The Zeiss Elta-2s Electronic Total Station.

The high accuracy of the system is shown in Figure 6-4 (Birkemeier and Mason 1984), which shows 10 repetitive surveys of a profile line collected over a 2-day period under near ideal conditions. While there is movement of the nearshore bar during the survey period, the stability of the offshore zone is of greater interest. Seaward of 220 m, the average range in elevation was 5 cm. The standard deviation of the 10 elevations for a given distance was usually less than 2 cm.

Figure 6-4. Result of 10 repetitive surveys, maximum vertical difference shown.



In operation, the Zeiss was set up over a point of known coordinates on the FRF pier deck over the south railroad track. The instrument height was measured from the pier deck, and the azimuth of the FRF coordinate system was established by aligning the instrument with the south rail at the end of the pier. A permanent single prism located at a known coordinate near the end of the pier (approximately 500 m away) was used to check the stationing of the instrument before a survey began. Only aproximately 10 seconds are required to aim, shoot, and record each survey point. Because the actual coordinates of each point are displayed, the CRAB can be kept on line to within ±1.5 m through radio communications between the CRAB driver and the instrument operator. The dune portion of the profile was surveyed using a single prism mounted on a pole. A round aluminum plate, mounted on the bottom of the pole, prevented it from sinking in the sand (Figure 6-5).

Figure 6-5. Conducting a CRAB survey with the Zeiss Elta-2s (left); using a prism pole for a dune survey (right).

Survey points were selected based on the timed travel of the CRAB. More points were taken close to shore where the profile is more complex. Once the survey was complete, the solid state memory was removed from the Zeiss, and the data were transferred to either a mainframe or desktop computer through a Zeiss interface (Figure 6-6). Because the operator has only to aim the instrument at the prism, instrument reading errors and field book entry errors are eliminated.

Figure 6-6. Processing Zeiss survey data through a terminal to a mainframe computer in 1981. Zeiss interface on the right.

A unique feature of the Zeiss system is its ability to accept and record an additional piece of information (up to seven digits) with every survey point. This was used to manually enter the angular tilt of the CRAB, which

was measured with two orthogonal tilt meters. If the tilt was greater than 4 deg, the CRAB driver would radio the Zeiss operator who would then enter the tilt angles into the instrument. The angles were then automatically accounted for during processing of the data.

The Zeiss Elta-2s creates a simple ASCII data file with one point per data line in FRF coordinates. Optionally, a second line per point could be recorded with the raw distance and angle data. However, with limited memory on board, this option was seldom used.

6.3.2 The Interactive Survey Reduction Program (ISRP)

ISRP is a FORTRAN program developed at the FRF to read in the Zeiss data file and to produce a new output file. ISRP was used to assign profile and survey numbers and included the capabilities to interactively plot, compare, and edit individual points and entire surveys. Eventually ISRP was able to resolve typical Zeiss errors even including graduated vertical adjustments and rotated coordinates.

6.3.3 Zeiss survey errors

Several types of instrument and operational errors can occur with the Zeiss. A common type of operator error was caused by the instrument being triggered to begin a reading before properly centering the scope on the prisms. This short cut, of triggering then sighting, results in the recording of incorrect azimuth and zenith angles and a point in error. Errors affecting single points were usually easy to detect and remove.

Errors from misaligning the instrument to the coordinate system and from movement of the tripod were eliminated after August 1985 when two permanent fixed instrument mounts were established, one on the pier and one on the roof of the facility. A protective dome was added over the roof mount to protect the instrument and operator from heat and weather (Figure 6-7). Permanent prisms were located at known coordinates and used to check and recheck the instrument stationing during the survey. If the measured location of a prism was outside certain tolerances, ±6 cm horizontal or ±1.5 cm vertical, the instrument was re-stationed.

Figure 6-7. Roof dome added in 1985 to protect the Zeiss Elta-2s from heat and weather.

From approximately 14 December 1982 until 9 February 1983, the Zeiss Elta-2s was intermittently producing questionable results that appeared as a systematic vertical error. From 24 February 1983 through 28 March 1983, the instrument was being repaired, and alternate methods were employed. These included the use of the stadia board and automatic level to determine elevation and a Motorola Mini-Ranger® positioning system to determine offshore distance (24 February to 3 March 1983). A loaner Zeiss instrument was also employed (22 March to 28 March 1983).

Because this was an unusually active period of profile response with several significant storms occurring, the data during this period have been retained in the data set. They do accurately reflect the changes in profile configuration that occurred, but the horizontal and vertical accuracies are less than those for the other CRAB/Zeiss data.

6.4 Geotronics Geodimeter 140T Surveys: May 1990–May 1994

Starting in May 1990, FRF surveys were conducted using an auto-tracking optical system, the Geotronics Geodimeter 140T. With the auto-tracking ability, the CRAB could move continuously while position information was obtained every 2 to 3 m. Data were collected on a shore-based personal computer, and steering information was radioed by the instrument operator to the driver. The DELILAH experiment surveys in the fall of 1990 were the first real production surveys with the instrument.

6.4.1 The Geotronics Geodimeter 140T

The Geodimeter 140T (Figure 6-8) consists of an electronic theodolite, distance meter and tracker. The system is designed to track the position of a moving object with a servo unit that moves the instrument horizontally and vertically. The angle and distance measuring units are both mechanically and electronically connected to a top-mounted tracker unit. The initial aiming of the instrument is controlled by a joystick. Once locked onto the prism array mounted on the CRAB, the Geodimeter 140T continues to follow it as the CRAB moves.

Figure 6-8. The Geodimeter 140T mounted on the FRF pier. The small orange box on the top of the instrument is the tracker.

The stated operating range of the Geodimeter 140T is 5.5 km with a single circular prism array; horizontal accuracy is ±10 millimeters NCDU in tracking mode. The angle accuracy is ±3 second (compares to ±0.6 second with the Zeiss), and vertical accuracy is ±1.5 cm at 1,000 m.

Using the Geodimeter 140T, it took an average of 25 minutes to survey one profile line, with survey points being obtained every 2–3 meters. An important advantage of the auto-tracking system was the ability to accurately map the complex shape of the nearshore sand bars and to detect small features that were not observed in the Zeiss surveys, as well as to improve overall survey speed.

When the Geodimeter 140T was used, topographic points covering the dune were typically collected with a prism pole and the Zeiss Elta-2s.

6.4.2 The Read Geodimeter (RG) 7 Program

The Geodimeter 140T outputs an ASCII stream of polar coordinates to a computer connected by a serial cable. This data stream was captured by the (RG) program, a custom FORTRAN program developed at the FRF. Eventually reaching version RG7, the RG program collected the raw data, computed FRF coordinates, and provided real-time display of the CRAB position, which was radioed to the CRAB operator to help keep the CRAB online. The RG program also allowed entry of a vertical angle error used to correct the alignment between the tracker and the optical scope of the instrument. After a survey, the file output by the RG program was converted using Read_RG6, another custom program, into a data format that ISRP could read in. As with the Zeiss data, ISRP was used to edit and create the final survey data file (see Section 6.3.2).

6.4.3 Geodimeter 140T errors and accuracy

While the Geodimeter 140T brought welcome improvements in coverage and speed, it had several idiosyncrasies that were not fully understood initially.

The Geodimeter 140T is a Geodimeter 140 electronic total station with an added tracker unit and servo motors. One of its problems arose from the separation of the tracking unit from the angle measurement unit. For accurate vertical measurements, the two units must be perfectly parallel. While there is a procedure to calibrate the alignment of the tracker, it was easier and more accurate to measure the angle between them using a distant mounted prism of known elevation and applying that correction to the data. Unfortunately, the angle can change during a survey, likely caused by differential heating of the instrument. Although checks of the vertical angle correction were made, they were not always made frequently

enough to fully remove the error. The vertical error increases with distance from the instrument. At a distance of 1,000 m, a 20-second angle error results in a vertical error of 10 cm.

Another error results from the instrument shifting out of level, also likely caused by differential heating of the instrument and its mount. Some of this movement is compensated for by an auto-leveling system, and it is designed to stop acquiring data if the instrument tilts outside the range of the compensator. However, this applies only for the horizontal compensation and not for the vertical. Consequently, if tilted, the instrument will continue to collect bad vertical data with no indication except for the bubble level on the instrument being off. Because the operator watches a computer screen, and not the instrument, a tilted instrument could be undetected. From the beginning, this error was minimized by sheltering the Geodimeter with an umbrella or by setting it up in the roof dome (Figure 6-7). Frequently sighting and re-sighting a prism of known location was also used as a setup check and for computing corrections. Unfortunately, during the first year of use, some of the out-of-level errors were wrongly corrected for by adjusting the vertical angle correction between the tracker and optical unit, which added to the error. Once the tilt error was fully understood, a program of frequent level checks was instituted.

If the amplitude of the tracker, which is adjustable, was improperly tuned, the instrument would oscillate slightly as it tried to lock onto the center on the prism. This results in jagged data with oscillatory amplitude of a few centimeters. Although the data appear to follow the true profile shape somewhat, the oscillations are not necessarily centered on the true profile, so they cannot be simply averaged out. At its worst, the tracker would drift completely away from the prism and temporarily lock onto a horizontal position above the prism for a short distance before reacquiring the prism center. This would result in a "step function" appearance to the data. These errors and their appearance in the data should not be confused with megaripples — rough sections of the profile typically found in the trough or on the outer flank of the sandbar, distinctive from other sections of the profile, which are smooth. Data affected by these oscillations affect the entire profile line with no smooth regions. Major changes caused by the tracker drift were identified by overlaying all surveys of each profile line and deleting points that fell outside the overall envelope or had a "step" shape to them when compared to subsequent surveys of the same line.

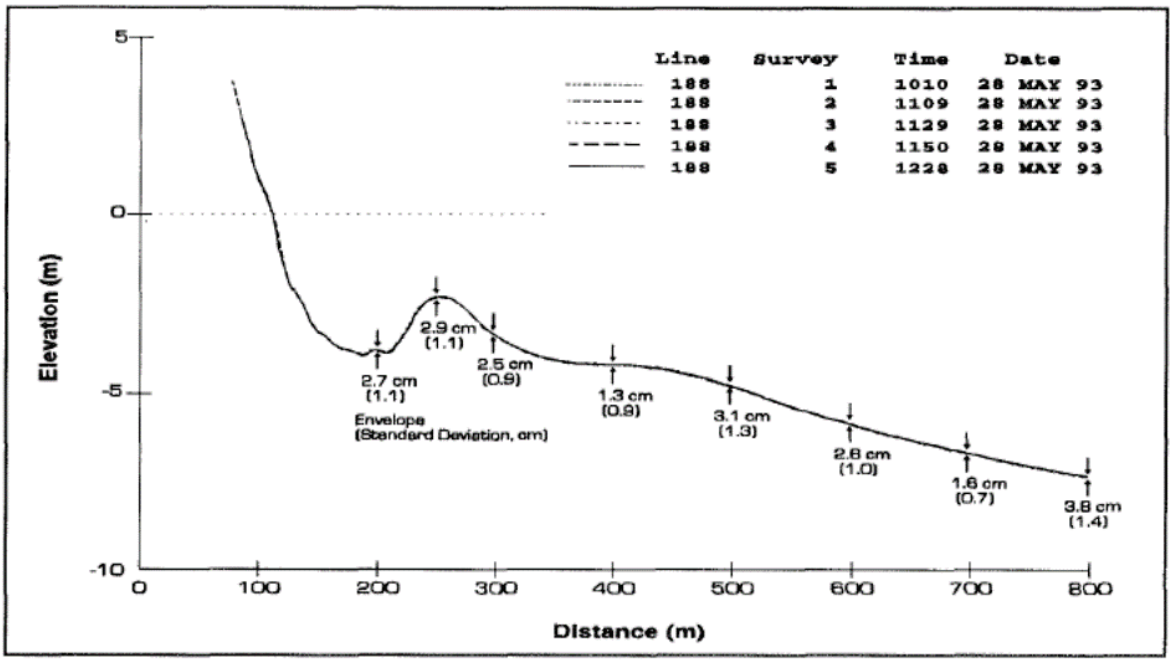
While these Geodimeter errors are unfortunate, their impact on the survey data is seldom greater ±15 cm in the vertical and is typically less than ±10 cm.

A final problem is interference from sunlight, which can overwhelm the tracker power. This problem affected early morning surveys of lines south of the pier. The problem was eliminated by surveying northern lines first.

Because of the height of the prism, data affected by the tilt of the CRAB on steep parts of the profile (particularly the foreshore and the sandbar slopes) were adjusted automatically using an iterative technique in the analysis. The measured slope was used as a first guess to adjust the data points both horizontally and vertically. A new slope was then determined and applied. On a 10 deg slope typical of the beachface, the tilt can result in a +20 cm vertical adjustment to the data.

Lee and Birkemeier (1993) report on the accuracy of the Geodimeter 140T using real surveys. Figure 6-9 shows the results of five repetitive surveys of line 188 (now Line 1) with vertical ranges of 1.3 to 3.8 cm and standard deviations varying from ±0.7 to ±1.4 cm, with the greatest difference being at the farthest point. They also estimated the operational accuracy of the surveys by measuring the variation in the far offshore (800 m) where the bottom is relatively stable. A running mean filter was used to filter out the real sea bottom change from the survey noise. Using a running mean of five consecutive surveys to filter out the real variation, they computed the standard deviation of the residuals, which is the variance of the elevation to the five survey running mean, at ±2.11 cm and ±2.71 cm for the Zeiss surveys and the Geodimeter surveys, respectively.

Figure 6-9. Five repetitive surveys of Line 188 using the CRAB and the Geodimeter 140T (Lee and Birkemeier 1993).



6.5 Geodimeter 140T with HYPACK: June 1994–July 1996

From June 1994- July 1996, the HYPACK, Inc., HYPACK hydrographic survey software was used to log the data stream from the Geodimeter 140T and to provide the steering information, which the operator radioed to the CRAB driver. This was a change from using RG7. It used a Windows environment and added real-time navigation information in graphical form.

There was no other change to the surveys, just the adoption of a new software package, new software driver for the Geodimeter 140T, and a different computation of FRF coordinates from the observed polar coordinates.

6.6 GPS surveys: August 1996–August 1999 (and individual surveys later)

The next significant upgrade to the FRF surveys was in August 1996, the switch to an RTK-GPS system, which is still in use (as of 2019) whenever the CRAB is used for surveying. The switch to GPS changed the surveying from a two-person operation to a single CRAB operator who drives the CRAB and runs the HYPACK data collection and navigation software.

6.6.1 Trimble RTK differential GPS system

The Trimble® dual frequency RTK-GPS system utilizes a Trimble 4000 or R7 receiver as a base station along with Trimble 4000, 4700, R7, or 5700 receivers as rovers. The base station is set up over a known control point within the survey area. The known latitude, longitude, and elevation are fed into the base station memory. The base station then computes its location using signals from five to nine satellites. By comparing this reading to the known reading, the base station can calculate a correction that is then sent via radio in real time to the rover receivers. The GPS sampling rate is set at 1 hertz (Hz), which is the basic sample rate of the GPS system. Higher rates are possible on the rover, but since rover positions above 1 Hz are extrapolated, the elevation accuracy (±2 cm) is obtained at this rate (1 Hz) while still maintaining sufficient coverage at typical CRAB survey speeds (1.6 knots).

Position accuracy also depends on the quality of the satellite geometry during the survey, defined as a PDOP[1] value of 4 or less, and the continuity of the radio communications between the base and rover. Communication dropouts result in the system switching from kinematic to differential, with an associated loss in vertical and horizontal accuracy. Radio repeaters are used to ensure continuous communications. Distances between base station and rover are kept to less than 10 km to ensure that both units are seeing the same satellite constellation and that there is minimal impact of variation in the ellipsoid across the survey region.

In operation, the GPS antenna for the rover station on the CRAB is mounted on the same staff used for the reflecting prisms required by Zeiss Elta-2s and Geodimeter 140T, at a measured height above the ground (see Figure 6-10). Similarly, a GPS antenna on a pole is used with a backpack-mounted GPS rover to survey the dune.

[1] Position Dilution of Precision

Figure 6-10. The GPS antenna mounted above a ring of reflecting prisms on the CRAB.

6.6.2 HYPACK

Since the HYPACK software works with different surveying equipment, it was relatively easy to switch from using the Geodimeter 140T to the RTK-GPS system as the same navigation line files that define the FRF profile lines could be used.

There were, however, some significant changes that had to be made including mounting the GPS receiver and a computer in the CRAB so the driver could operate HYPACK and navigate using the screen information (Figure 6-11). In addition, since the HYPACK/GPS system collects natively in geographic coordinates and outputs in geographic and NC state plane coordinates, but not FRF coordinates, processing software had to be developed to read the HYPACK output files and to create an ISRP-compatible FRF coordinate file.

Figure 6-11. The HYPACK computer mounted in the cab of the CRAB. The GPS receiver is mounted directly overhead in a weather-proof box.

This was done using FORTRAN Program FRFGPS, which became GPSmax in 2004, when HYPACK changed to HYPACKMax. GPSmax assigned profile and survey numbers to each line, patched in a file of dune points, and adjusted for the tilt of the CRAB. ISRP was used for editing, but as an old disk operating system program, it could not be updated for use with Windows® PCs. In 2001, ISRP3, a new Windows version of ISRP developed in Visual Basic, began to be used to edit the CRAB-GPS survey data.

6.6.3 CRAB GPS accuracy and errors

Under ideal satellite and atmospheric conditions, the horizontal accuracy of an RTK position is ±1 cm ±1 parts per million (ppm) based on the distance to the base station. Vertical accuracy is ±2 cm±2 ppm. Since the maximum distance to the base station was ~2 km, the vertical accuracy of the GPS positions is ±2.4 cm.

The RTK-GPS elevation accuracy is comparable to that of the Zeiss Elta-2s and the Geodimeter 140T, but unlike those systems the accuracy does not vary with location if the rover station is within 10 km of the base station and the satellite geometry is acceptable. This range allows for significant improvement in the overall accuracy and robustness of the data, with no reduction in accuracy over the outer portion of the profile where bottom changes are small and difficult to resolve, relative to the vertical error in

the system. Errors that can still occur include systematic vertical errors resulting from an incorrect antenna height on the CRAB or unacceptable satellite geometry, which degrades the accuracy.

There are 154 surveys (through 2018) that use the CRAB-GPS system, and these should be the best at resolving, in detail, the complex curves that define the shape of the inshore sandbars and the small but important changes offshore. In fact, these surveys can be used to quantify the range of natural variation that occurs and the result used to qualify the earlier surveys with the Zeiss Elta-2s and Geodimeter 140T.

7 Lighter Amphibious Resupply Cargo, 5-ton (LARC-V) Surveys: September 1999–Present

The CRAB with RTK-GPS is the most robust and accurate system for collecting beach-nearshore surveys, but it has some significant limitations. It is slow, depth limited, not transportable, and requires a hard, mildly-sloping bottom. These limitations were addressed in September 1999 when the LARC-V started to be used for surveying.

The goal of the system was to match the accuracy of the CRAB, possible only because of the availability of RTK-GPS and precision digital echosounders.

7.1 LARC-V

The LARC-V is the smallest of a class of amphibious vessels developed and operated by the Army in the 1950s and used in the Korean and Vietnam Wars. They are 10.7 m long, diesel powered, 4-wheel drive, and able to carry 5 tons. It is capable of speeds in water of 8 knots (15 km/hr) and 26 knots (48 km/hr) on land. Though out of production, they are still in use today. LARC-Vs are known for their seaworthiness, particularly in breaking waves. To facilitate surveying, the FRFs LARC-V is equipped with a 220/110 volt diesel generator, expanded cabin space, and air conditioning. The cabin space provides counter space for the computers and allows for the pilot and surveyor to be in close contact during a survey (Figure 7-1).

Figure 7-1. LARC-V interior and exterior view.

7.2 The survey system

Previous boat-mounted survey systems were unable to filter out wave motion and had to adjust for changing tides. They were therefore limited to vertical accuracies of ~30 cm (1 ft). The LARC-V system overcomes the wave and tide problems by using the RTK-GPS system combined with a motion sensor to determine the precise location (x, y, z, t) and movement (heave, pitch, roll) of the LARC-V, and a depth sounder to determine the depth (d) and time (t). This system can be used on any floating platform, but the LARC-V has the unique ability of being able to operate on the beach, over shallow shoals, in breaking waves, and offshore.

7.2.1 The components of the LARC-GPS survey system

The system consists of the following:

- RTK-GPS using Trimble 4000, 5700, 4700 dual-frequency receivers for horizontal and vertical positioning, configured for 1-second updates (see Section 6.6.1)
- Knudsen 320B/P Echosounder with a 200 kHz 9˚ transducer and a close-proximity option that allows depth measurement as shallow as 10 cm
- HYPACK Inc's HYPACK Max software for data logging and navigation
- Data collection laptop computer
- Optionally, a TSS DMS 3-25 motion sensor to measure heave, pitch and roll
- CTD (conductivity, temperature, depth) profiler to determine the speed of sound in water or a sound speed sensor
- Trimble TDC-1 handheld data logger for collecting RTK-GPS data across the dune and on the beach, since replaced with a tablet PC running HYPACK
- Fathomax data processing software that analyses the HYPACK Max data files, and creates the final X, Y, Z data file, which are edited using ISRP3.

In operation, the pilot steers the LARC-V over a pre-defined course of profile lines at a speed of approximtely 7 km/hour (4 knots). The HYPACK navigation system provides real-time position information to a computer monitor in the LARC-V, which enables the pilot to accurately steer the line. A typical line begins at the foot of the dune and extends offshore to a predetermined depth or distance. Topographic points are determined by

the height of the antenna above the ground. Once the LARC-V is floating, the echosounder is used. Since echosounder data are affected by density changes in the water column, the speed of sound is collected, either from the LARC-V periodically during the day with the CTD, or from the end of the FRF pier to a depth of -7 m on the day of survey. While the LARC-V can operate under higher wave conditions, air entrainment in the surf zone limits surveying to conditions with waves generally less than 1 m.

Data points are collected on average every 2.5 m. Topographic survey points (TOPO) of the beach and dune, above the elevation reached by the LARC-V, are collected with a walking backpack-mounted Trimble RTK-GPS system. As described in Section 2.5, TOPO points may be added from an earlier time period.

7.2.2 Knudsen Mini Echosounder

Because accurate depth information is needed as soon as the LARC-V enters the water and the tires are no longer in contact with the ground, the Knudsen Mini Echosounder has a close-proximity option that allows depth measurement as shallow as 10 cm. The echosounder transducer is mounted ~37.0 cm from the ground on the LARC-V, which is as close a reading as is required for the surveying done using the LARC-V system. The 9-degree (deg) beam width of the Knudsen 200 kHz transducer equates to a bottom measuring patch 0.6 m diameter at 4 m depth and 1.3 m at 8 m depth. This is a much smaller measuring patch than the CRAB, which averages across its 7.6 m rear axle. The transducer is mounted between the front wheels of the LARC-V directly below the GPS antenna. This location minimizes the bubbles that form and pass under the LARC-V as it transits breaking waves in the surf zone. Unfortunately, in this location the transducer may come out of the water as the LARC-V powers through breaking waves as it drives offshore, which creates gaps in the depth data. This does not happen when the LARC-V is traveling toward shore, with the waves. Note that the direction of survey can be identified in the data using the time or seconds past midnight variable.

Echosounder accuracy is ±1 cm ±0.1 percent of the depth value, which is typically less than 10 m. The Knudsen Mini Echosounder is sampled at a rate of 10 Hz. This high sample rate is important because the objective of the analysis software is to determine the depth at the exact moment that the 1 Hz RTK-GPS data are acquired. This 10 to 1 oversampling of the

depth, relative to the RTK-GPS data stream helps insure that a quality 1 Hz interpolation of the depth data can be obtained.

Knowing the RTK-GPS and echosounder accuracy, and assuming the errors are independent, then a vertical error budget for the system can be computed using the following equation:

$$\Delta Z = \sqrt{\sqrt{GPS^2(\Delta Sounder)^2 + Sounder^2(\Delta GPS)^2}}$$

With the errors for the GPS and sounder as stated above: GPS = 2 cm, ΔGPS = 0.15 cm, Sounder = 1 cm, ΔSounder = 0.7 cm gives a ΔZ = ±2.4 cm. This is an ideal, random accuracy, different from a sound speed, systematic or offset errors that can significantly affect overall data accuracy.

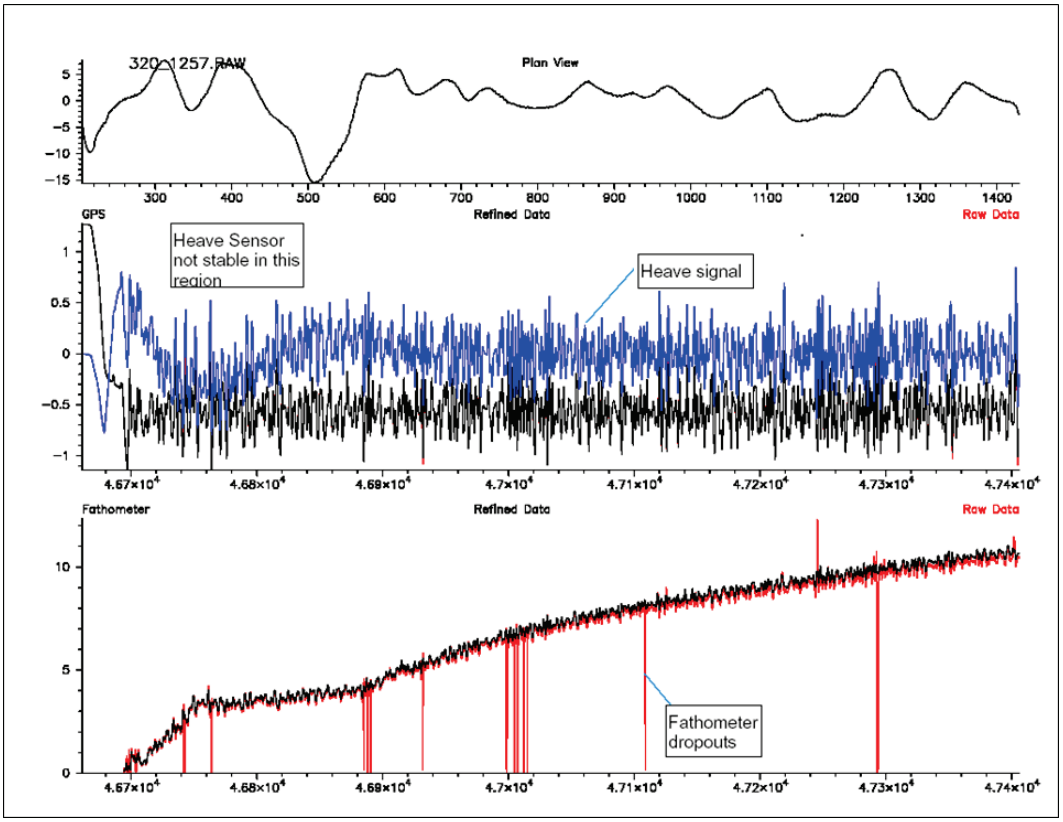
7.3 Survey data analysis with Fathomax

Fathomax is a custom-built FORTRAN program that combines the RTK-GPS and echosounder data to remove the motion of the LARC-V due to the waves and the changing tide level. The survey software also adjusts the measurements to changes in speed of sound over the survey area. The final product is a data file with horizontal coordinates in the geographic, state-plane and FRF coordinate systems, and a Z coordinate relative to the local vertical datum (NAVD88). The analysis software has evolved over time and accomplishes these tasks:

- Separates and filters the RTK-GPS and echosounder data streams
- Adjusts echosounder data for the speed of sound profile
- Corrects the echosounder data for drift of the data collection computer's clock
- Separates topographic (over land) points from bathymetric (in water) points
- Optimizes the match between the RTK-GPS and echosounder data in time
- Interpolates an echosounder reading for each RTK-GPS point
- Optionally smooths the final elevation data
- Creates an X, Y, Z output file.

Figure 7-2 is an example of the raw data that is collected. The horizontal position from the GPS receiver is shown in the top panel. The GPS elevation and the heave signal, which should follow the GPS signal, is shown in the middle panel. The echosounder depth is in the bottom panel. The raw echosounder trace (in red) can be quite noisy with frequent dropouts, particularly in the shallowest region where the sandbar occurs. Fathomax uses several routines to filter through the dropouts, producing a clean bottom trace (black line). Even though it is usually clear to the eye which data points are the bottom and which ones are noise, it is a numerical challenge to correctly identify non-bottom points. So, an alternative which works is to help Fathomax along by first using the echosounder editor in HYPACK to remove obvious non-bottom soundings. This technique was found to work so well that in 2015, it was decided to reanalyze many of the LARC-GPS surveys using this technique, greatly improving the quality of the surveys over shallow sandbars.

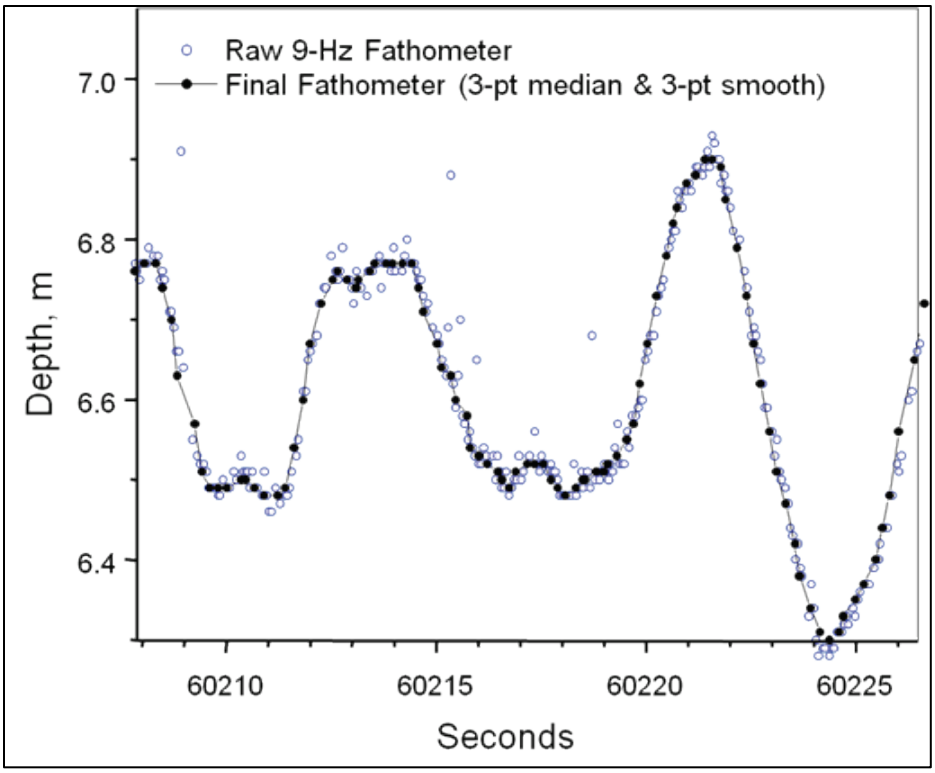
Figure 7-2. Example GPS and echosounder data from a cross-shore transect.



The first step in the Fathomax process is to separate the GPS and echosounder data and to filter out spurious echosounder data caused by bubbles in the surf zone or from the transducer coming out of the water in

larger waves. This filtering is shown in Figure 7-3. Original data are shown as blue circles and the final, edited data are shown as the solid black line.

Figure 7-3. Raw and filtered fathometer sounder data



The Echosounder data are then adjusted for the speed of sound using either a constant value or the most recent sound speed profile, which is preferred.

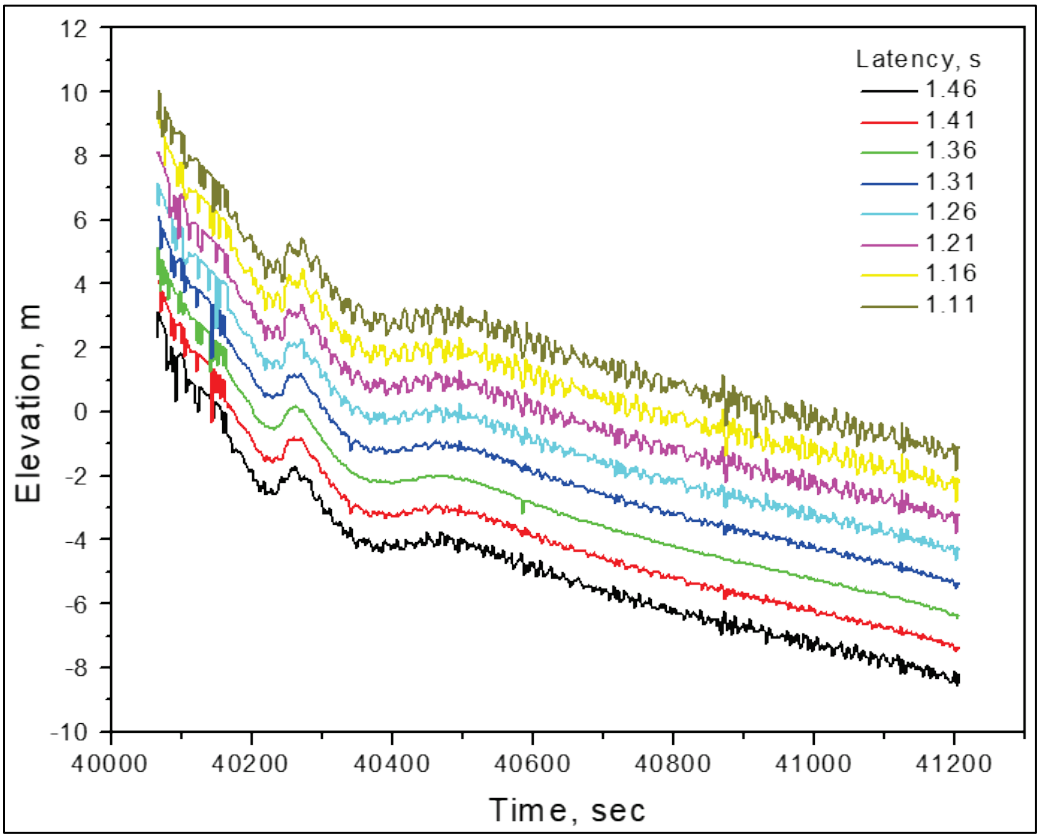
To remove the wave motion, it is imperative that the GPS and echosounder data be accurately time-stamped. The GPS data stream is precisely stamped with the GPS clock time. However, the echosounder data are stamped with the real-time clock of the collection PC. Because PC clocks drift (it can be ~0.25 second in 10 minutes), the drift must be accounted for. Since HYPACK stamps GPS points with both GPS time and PC clock time, the drift of the PC clock is computed and used to adjust the echosounder data time stamp.

Land points are separated from over-water points by first precisely determining when the LARC-V is floating. This is done by first computing the average and standard deviation for all over-water GPS elevations (echosounder depth >1.5 m). Points above the computed average, plus one

standard deviation are considered to be land points. The elevation of land points is computed based on the height above the ground of the GPS antenna on the LARC-V.

Once the over-water points are identified, the echosounder and GPS data are first adjusted based on pitch and roll (if the motion sensor is used) and then aligned in time. This is accomplished by dynamically adjusting the time (or *latency*) of the GPS data, relative to the echosounder data, until a best fit based on bottom smoothness is obtained. As can be seen in Figure 7-4, the computation of the latency is quite sensitive, with hundredths of a second having an impact. The green line with a latency of 1.36 second has the least remaining wave action and is best fit.

Figure 7-4. The effect on depth of varying latency between GPS and echosounder values.

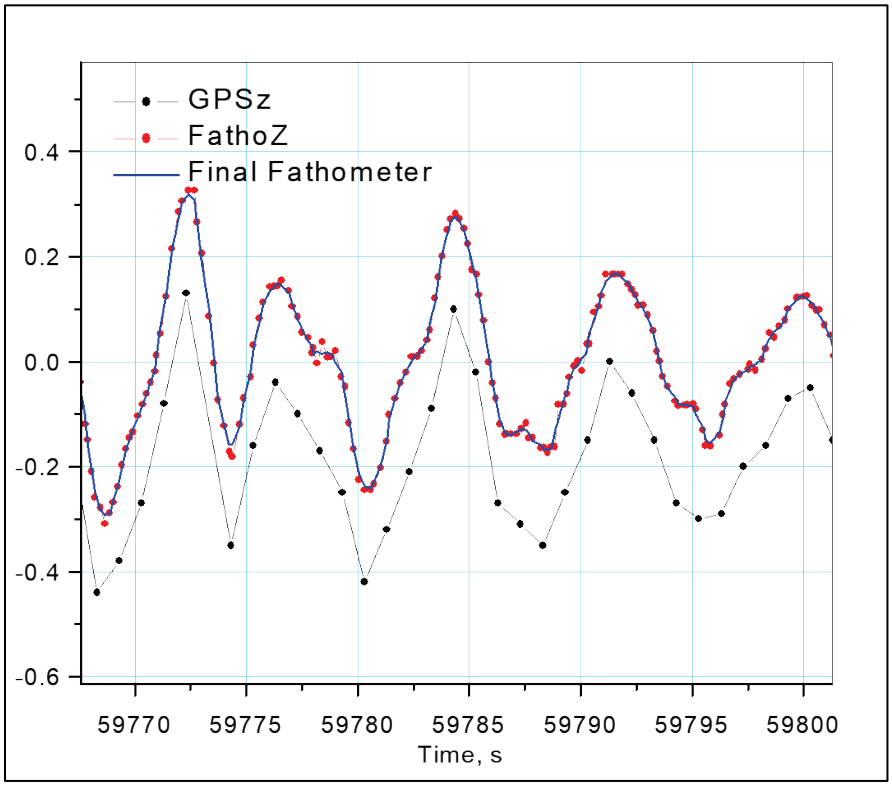


Because the latency is dependent on the timing between instruments and computers, one might assume that it would be a constant value for a set of equipment, but that is not the case; a new latency value is computed for each survey line. Upgrades in GPS equipment and computer speed have reduced latency values from ~1.4 s to less than ~0.1 s, a significant improvement.

A segment of properly aligned GPS and echosounder data is shown in Figure 7-5. Even after filtering, there are many more echosounder points than GPS data. Once aligned, the two echosounder points, which bound the GPS point in time, are used to interpolate a depth coincident with the GPS point, and a final elevation is computed.

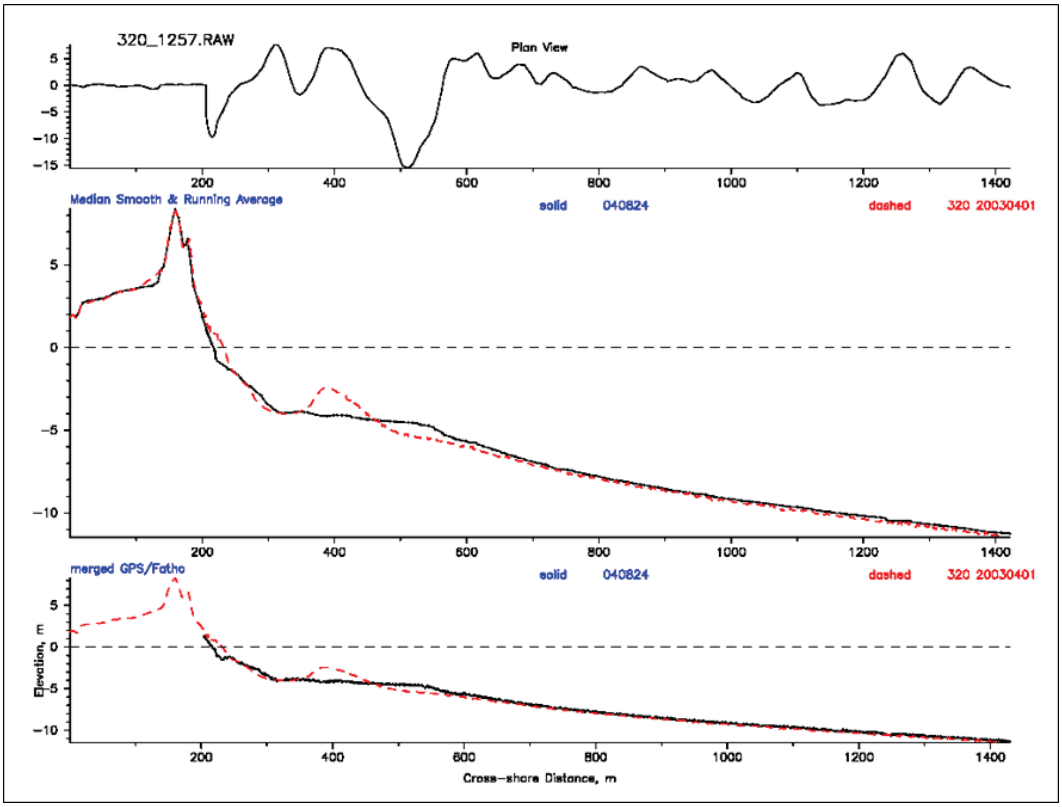
Note that doing the opposite, interpolating a GPS point for every echosounder point, would increase overall point density but result in noisy, erroneous data because the interpolated points would not correctly reflect the wave motion that occurred.

Figure 7-5. A segment of properly timed GPS and echosounder data.



Since not all motion is removed by this process, the final data are optionally smoothed with a median smooth, a moving average, or a combination of the two. Individual cross sections may receive additional editing outside of Fathomax to remove offline points and spikes that survived the automatic checks. The resulting final cross-section plot for the data shown in Figure 7-2, is shown in Figure 7-6.

Figure 7-6. Final cross-section (black line) based on the raw data in Figure 7-2. Note added dune points in the middle panel. Dash red line is an earlier survey.

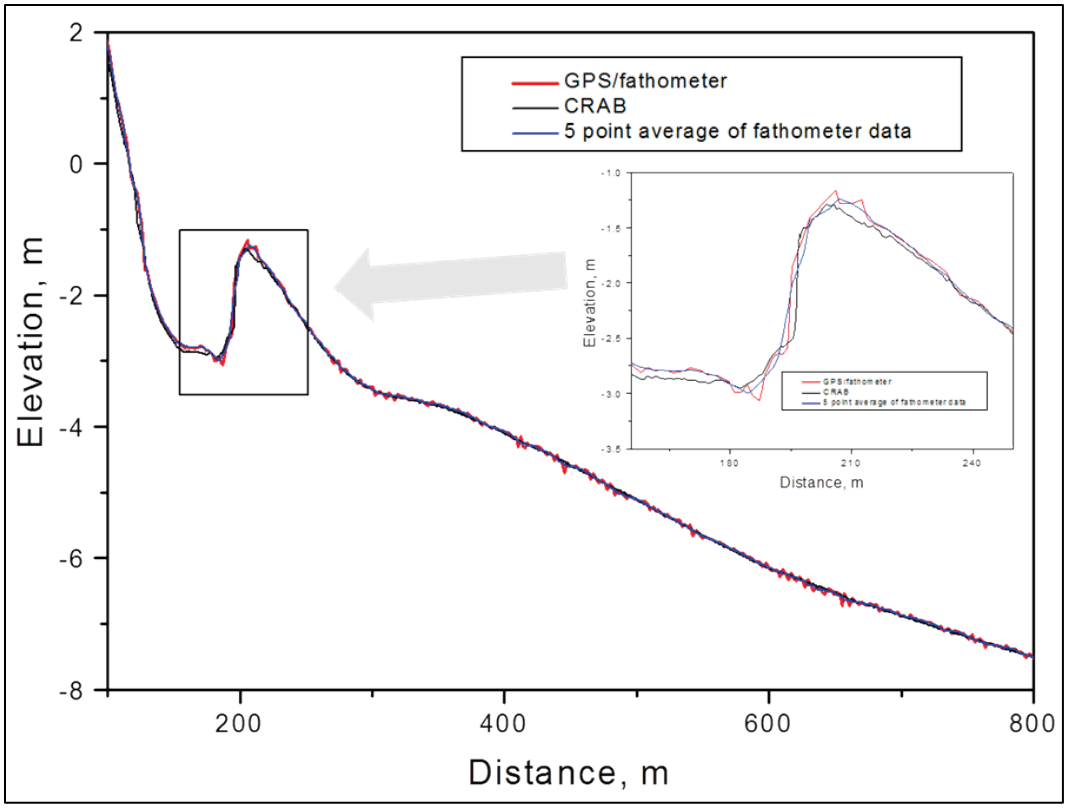


Use of a motion sensor for measuring heave, pitch, and roll is considered optional at the FRF where the depths are less than 15 m, and usually less than 10 m. A typical LARC-V pitch of 2 deg over a depth of 15 m results in a depth difference of just 2 cm which is within the error of the system. However, in deeper water or on a different craft, use of a motion sensor is strongly recommended. If available, pitch and roll are used in the depth computation. Heave, which tracks the GPS vertically, is infrequently used to fill significant gaps in the GPS data.

7.4 Accuracy, errors, discussion

The goal of the LARC-GPS surveys is data of similar accuracy to the CRAB-GPS data. This is obtainable as shown in the comparison in Figure 7-7 between a LARC-GPS survey with a CRAB-GPS data. There are small differences around the bar crest and trough. Offshore, the match is very good, and surveys with the CRAB and LARC-V are routinely intermixed. In a series of five repetitions, root-mean-square error was found to average 3.1 cm, varying from 6.4 cm in the trough to 2.2 cm on the shoreface

Figure 7-7. Comparison of LARC-GPS survey to CRAB-GPS survey. The red line shows some remnant wave signal which is removed using a 5 -point moving average (blue line).



8 Experiment Surveys

There were seven major collaborative field experiments held at the FRF from 1981 to 1998 where a subregion known as the minigrid was surveyed or lines within the minigrid were surveyed (see Figure 2-6). Although each experiment was different, there was commonality in the surveys:

- Number of profiles: ~20
- Offshore extent: ~400 m
- Profile Spacing: ~25 m
- Survey Interval: ~daily
- Survey Schedule: September/October
- Long-term FRF profiles included: 2 to 8.

Collectively they represent a unique set of highly resolved beach/nearshore data that complement and expand the temporal coverage of the long-term data.

In this chapter, the profile lines used and the available surveys are tabulated along with any relevant details for each experiment. Not discussed here, but important to the use of these data, is the fact that each experiment included an array of instruments, deployed within the minigrid on deep jetted pipes.

The survey data from these experiments have been converted to the 2014 FRF coordinate system in NAD83 and NAVD88 using the data format described in Section 2.7.1. Profile line and survey numbers have also been updated.

8.1 DUCK82, 1982

An overview of the DUCK82 experiment is provided by Mason et al. (1985). Unique to DUCK82 was a sled that could be pulled off and onshore and used to survey line 235 independent of the conditions. The other lines were surveyed using the CRAB and Zeiss system (see Section 6.3). Table 8-1 lists the profile lines that were surveyed, and Table 8-2 summarizes the available surveys including seven minigrid surveys.

Table 8-1. DUCK82 survey lines.

Profile Line	Exp. Profile Number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane (NAD83)		Geographic	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
DUCK82							
1143	200		1143.00	275,167.054	901,560.277	36.1873856985	-75.7536441382
1120	205		1120.14	275,145.576	901,568.105	36.1871899358	-75.7535649654
1097	210	58	1097.28	275,124.098	901,575.933	36.1869941731	-75.7534857931
1074	215		1074.42	275,102.620	901,583.761	36.1867984104	-75.7534066211
1052	220	59	1051.56	275,081.142	901,591.589	36.1866026476	-75.7533274495
1029	225		1028.70	275,059.664	901,599.417	36.1864068847	-75.7532482783
1006	230	62	1005.84	275,038.187	901,607.245	36.1862111217	-75.7531691075
983	235		982.98	275,016.709	901,615.073	36.1860153587	-75.7530899370
960	240	63	960.12	274,995.231	901,622.901	36.1858195956	-75.7530107670
937	245		937.26	274,973.753	901,630.729	36.1856238324	-75.7529315973
914	250	66	914.40	274,952.275	901,638.557	36.1854280692	-75.7528524280
892	255		891.54	274,930.797	901,646.385	36.1852323059	-75.7527732591
869	260	67	868.68	274,909.319	901,654.214	36.1850365425	-75.7526940906
845	265		845.82	274,887.841	901,662.042	36.1848407791	-75.7526149225
823	270	73	822.96	274,866.363	901,669.870	36.1846450156	-75.7525357548

Table 8-2 . Available Surveys from the DUCK82 experiment.

DUCK82 Surveys				Profile Line Numbers/FRF Alongshore Distance (m)													
Date	Survey Number	Profiles Surveyed	Other Profiles	1143	1120	1097	1074	1052	1029	1006	983	960	940	914	892	869	845	823
19820914	286	15	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19821003	288	1									■							
19821007	289	14		■	■	■	■	■	■	■	■		■	■	■	■	■	■
19821010	290	1									■							
19821010	291	1									■							
19821011	292	1									■							
19821011	293	1									■							
19821012	294	1									■							
19821012	295	1									■							
19821013	296	13		■	■	■	■	■	■	■	■			■	■	■	■	■
19821013	297	1									■							
19821014	298	3				■				■	■							
19821014	299	1									■							
19821014	300	1									■							
19821015	301	16	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19821016	302	4	12			■				■	■							■
19821017	303	14		■	■	■	■	■	■	■		■	■	■	■	■	■	■
19821019	304	15	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19821020	305	1									■							
19821020	306	1									■							
19821021	307	1									■							
19821022	308	15	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

8.2 DUCK85, 1985

An overview of DUCK85 is provided by Howd and Birkemeier (1987c) and Birkemeier et al. (1988). The DUCK 85 surveys are unique in that they include the only night surveys ever conducted by the CRAB, including one

day with five repetitive surveys and several days with four. Night surveying was not conducted during the October phase of the experiment.

All surveys were conducted using the CRAB and Zeiss system (see Section 6.3). Table 8-3 lists the profile lines that were surveyed, and Table 8-4 summarizes the 45 available surveys including 19 minigrid surveys.

Table 8-3. DUCK85 survey lines.

Profile Line	Exp. Profile Number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane (NAD83)		Geographic	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
DUCK85							
1234	180		1234.44	275,252.966	901,528.964	36.1881687482	-75.7539608330
1189	195		1188.72	275,210.010	901,544.620	36.1877772235	-75.7538024849
1166	197		1165.86	275,188.532	901,552.449	36.1875814610	-75.7537233113
1143	200		1143.00	275,167.054	901,560.277	36.1873856985	-75.7536441382
1120	205		1120.14	275,145.576	901,568.105	36.1871899358	-75.7535649654
1097	210	58	1097.28	275,124.098	901,575.933	36.1869941731	-75.7534857931
1074	215		1074.42	275,102.620	901,583.761	36.1867984104	-75.7534066211
1052	220	59	1051.56	275,081.142	901,591.589	36.1866026476	-75.7533274495
1029	225		1028.70	275,059.664	901,599.417	36.1864068847	-75.7532482783
1006	230	62	1005.84	275,038.187	901,607.245	36.1862111217	-75.7531691075
983	235		982.98	275,016.709	901,615.073	36.1860153587	-75.7530899370
960	240	63	960.12	274,995.231	901,622.901	36.1858195956	-75.7530107670
937	245		937.26	274,973.753	901,630.729	36.1856238324	-75.7529315973
914	250	66	914.40	274,952.275	901,638.557	36.1854280692	-75.7528524280
892	255		891.54	274,930.797	901,646.385	36.1852323059	-75.7527732591
869	260	67	868.68	274,909.319	901,654.214	36.1850365425	-75.7526940906
845	265		845.82	274,887.841	901,662.042	36.1848407791	-75.7526149225
823	270	73	822.96	274,866.363	901,669.870	36.1846450156	-75.7525357548
777	275	76	777.24	274,823.407	901,685.526	36.1842534883	-75.7523774204
731	280	85	731.52	274,780.451	901,701.182	36.1838619608	-75.7522190876

Table 8-4. Available surveys from the DUCK85 experiment.

DUCK85 Surveys				Profile Line Numbers/FRF Alongshore Distance (m)																				
Date	Survey Number	Profiles Surveyed	Other Profiles	1234	1189	1166	1143	1120	1097	1074	1052	1029	1006	983	960	940	914	892	869	845	823	777	731
19850903	398	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850909	400	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850911	401	1											■										
19850911	402	13		■	■		■	■	■	■	■	■	■	■	■	■	■						
19850911	403	1											■										
19850912	404	18		■	■		■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■
19850912	405	1											■										
19850912	406	1											■										
19850912	407	2							■				■										
19850912	408	2							■				■										
19850912	409	2							■				■										
19850912	410	2							■				■										
19850913	411	2							■				■										
19850913	412	2							■				■										
19850913	413	6		■	■		■	■	■				■										
19850913	414	2							■				■										
19850913	415	8							■		■	■	■	■	■	■	■						
19850914	416	2							■				■										
19850914	417	2							■				■										
19850914	418	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850914	419	2							■				■										
19850914	420	2	2						■				■										
19850915	421	2							■				■										
19850915	422	2							■				■										
19850915	423	2							■				■										
19850915	424	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850916	425	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850916	426	4							■		■		■		■								
19850917	427	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850917	428	2							■				■										
19850918	429	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850919	430	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850920	431	19		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19850925	432	8	2						■		■		■		■		■		■		■	■	
19850928	433	11	20	■			■		■		■			■	■		■		■		■	■	■
19851015	434	18	2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
19851016	435	1												■									
19851019	436	18		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
19851020	437	18		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
19851021	438	11		■	■		■		■		■		■	■	■		■		■		■		
19851021	439	2											■	■									
19851022	440	11		■	■		■		■		■		■	■	■		■		■		■		
19851023	441	18		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
19851024	442	2	2										■	■									

8.3 SuperDuck, 1986

Crowson et al. (1988) and Birkemeier et al. (1989) provide an overview of the SuperDuck experiments and a summary of the collected data, respectively. All surveys were conducted using the CRAB and Zeiss system (see Section 6.3). Table 8-5 lists the profile lines that were surveyed, and Table 8-6 summarizes the 24 available surveys including 14 minigrid surveys.

Table 8-5. SuperDuck, 1986 survey lines.

Profile Line	Exp. Profile Number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane (NAD83)		Geographic	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
SuperDuck 1986							
1326	165		1325.88	275,338.878	901,497.652	36.1889517969	-75.7542775341
1280	170		1280.16	275,295.922	901,513.308	36.1885602727	-75.7541191828
1234	180		1234.44	275,252.966	901,528.964	36.1881687482	-75.7539608330
1189	195		1188.72	275,210.010	901,544.620	36.1877772235	-75.7538024849
1166	197		1165.86	275,188.532	901,552.449	36.1875814610	-75.7537233113
1143	200		1143.00	275,167.054	901,560.277	36.1873856985	-75.7536441382
1120	205		1120.14	275,145.576	901,568.105	36.1871899358	-75.7535649654
1097	210	58	1097.28	275,124.098	901,575.933	36.1869941731	-75.7534857931
1074	215		1074.42	275,102.620	901,583.761	36.1867984104	-75.7534066211
1052	220	59	1051.56	275,081.142	901,591.589	36.1866026476	-75.7533274495
1029	225		1028.70	275,059.664	901,599.417	36.1864068847	-75.7532482783
1006	230	62	1005.84	275,038.187	901,607.245	36.1862111217	-75.7531691075
983	235		982.98	275,016.709	901,615.073	36.1860153587	-75.7530899370
960	240	63	960.12	274,995.231	901,622.901	36.1858195956	-75.7530107670
937	245		937.26	274,973.753	901,630.729	36.1856238324	-75.7529315973
914	250	66	914.40	274,952.275	901,638.557	36.1854280692	-75.7528524280
892	255		891.54	274,930.797	901,646.385	36.1852323059	-75.7527732591
869	260	67	868.68	274,909.319	901,654.214	36.1850365425	-75.7526940906
823	270	73	822.96	274,866.363	901,669.870	36.1846450156	-75.7525357548
777	275	76	777.24	274,823.407	901,685.526	36.1842534883	-75.7523774204

Table 8-6. Available surveys from the 1986 SuperDuck experiment.

SuperDuck 1986 Surveys				Profile Line Numbers/FRF Alongshore Distance (m)																			
Date	Survey Number	Profiles Surveyed	Other Profiles	1325	1280	1234	1188	1165	1143	1120	1097	1074	1051	1028	1005	982	960	937	914	891	868	822	777
19860903	464	20	20	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19860912	465	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19860918	466	2	2								■				■								
19860920	467	8												■	■	■	■	■	■	■	■		
19860926	468	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19860930	469	2													■	■							
19861002	470	1														■							
19861006	471	20	2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19861007	472	1														■							
19861008	473	1														■							
19861009	474	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19861010	475	9		■	■	■	■	■	■		■		■		■								
19861011	476	14		■	■	■	■		■		■		■		■	■	■		■		■	■	■
19861012	477	14		■	■	■	■		■		■		■		■	■	■		■		■	■	■
19861013	478	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19861014	479	18		■	■	■	■		■	■	■		■	■	■	■	■	■	■	■	■	■	■
19861015	480	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19861016	481	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19861017	482	3	1				■				■				■								
19861018	483	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19861020	484	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19861021	485	2			■										■								
19861022	486	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

8.4 DELILAH, 1990

The DELILAH experiment in the fall of 1990 is summarized by Birkemeier et al. (1997a). It was unique in that there was a companion wave experiment, SAMSON, which deployed a directional wave gauge at a depth of 13 m (see Figure 2-6), which required accurate knowledge of the surrounding bathymetry. The deep bathymetry, beyond the range of the

CRAB, was collected prior to the experiment using a sea-sled towed behind the LARC-V. DELILAH was also the first operational use of the Geotronics Geodimeter 140T. (DELILAH data are available online.)

A series of 20 profile lines were surveyed every day during DELILAH beginning 1 October and continuing throughout the experiment. The lines were spaced approximately 25 m apart near the instruments and 50 m apart elsewhere. Profile lines and their locations are listed in Table 8-7. All lines extended from the base of the dune to approximately 375 m offshore, except during the high wave period on 13 October 1990. The dune section of each profile line was surveyed at the beginning of the experiment. To provide continuity between surveys, the dune data points were added to each survey (the dunes were unaffected by waves and tides during the experiment).

Table 8-7. DELILAH survey lines.

Profile Line	Exp. Profile Number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane (NAD83)		Geographic	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
DELILAH 1990							
1280	170		1280.16	275,295.922	901,513.308	36.1885602727	-75.7541191828
1234	180		1234.44	275,252.966	901,528.964	36.1881687482	-75.7539608330
1189	195		1188.72	275,210.010	901,544.620	36.1877772235	-75.7538024849
1166	197		1165.86	275,188.532	901,552.449	36.1875814610	-75.7537233113
1143	200		1143.00	275,167.054	901,560.277	36.1873856985	-75.7536441382
1120	205		1120.14	275,145.576	901,568.105	36.1871899358	-75.7535649654
1097	210	58	1097.28	275,124.098	901,575.933	36.1869941731	-75.7534857931
1074	215		1074.42	275,102.620	901,583.761	36.1867984104	-75.7534066211
1052	220	59	1051.56	275,081.142	901,591.589	36.1866026476	-75.7533274495
1029	225		1028.70	275,059.664	901,599.417	36.1864068847	-75.7532482783
1006	230	62	1005.84	275,038.187	901,607.245	36.1862111217	-75.7531691075
975	235		976.89	275,010.981	901,617.161	36.1859631552	-75.7530688250
951	240		950.98	274,986.639	901,626.032	36.1857412903	-75.7529790991
937	245		937.26	274,973.753	901,630.729	36.1856238324	-75.7529315973
914	250	66	914.40	274,952.275	901,638.557	36.1854280692	-75.7528524280
892	255		891.54	274,930.797	901,646.385	36.1852323059	-75.7527732591
869	260	67	868.68	274,909.319	901,654.214	36.1850365425	-75.7526940906
845	265		845.82	274,887.841	901,662.042	36.1848407791	-75.7526149225
823	270	73	822.96	274,866.363	901,669.870	36.1846450156	-75.7525357548
796	275		797.05	274,842.021	901,678.742	36.1844231502	-75.7524460318
777	280	76	777.24	274,823.407	901,685.526	36.1842534883	-75.7523774204
754	285		754.38	274,801.929	901,693.354	36.1840577246	-75.7522982538
731	290	85	731.52	274,780.451	901,701.182	36.1838619608	-75.7522190876

All DELILAH surveying was conducted with either the Zeiss Elta-2s total station or the Geotronics Geodimeter 140-T auto-tracking total station. Problems developed with each of these instruments, and it is important to understand what the problems were and their impact before using the DELILAH survey data.

Table 8-8 summarizes the 19 available DELILAH minigrid surveys.

Table 8-8. Available surveys from the DELILAH experiment.

DELILAH Surveys			Profile Line Numbers/FRF Alongshore Distance (m)																						
Date	Survey Number	Profiles Surveyed	1280	1234	1189	1166	1143	1120	1097	1074	1052	1029	1006	977	951	937	914	892	869	846	823	797	777	754	732
19900919	586	21	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	
19901001	587	20	■	■	■		■		■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■
19901002	588	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901003	589	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901004	590	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901005	591	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901006	592	19	■	■			■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901007	593	19	■	■	■		■		■	■	■		■	■	■		■	■	■	■	■	■	■	■	■
19901008	594	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901009	595	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901010	596	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901011	597	18	■	■	■		■		■	■	■	■	■		■			■	■	■	■	■	■	■	■
19901012	598	19	■	■	■		■		■	■		■	■	■	■		■	■	■	■	■	■	■	■	■
19901013	599	12	■	■	■		■		■		■		■		■		■		■		■		■		
19901014	600	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901015	601	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901016	602	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901017	603	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901018	604	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
19901019	605	20	■	■	■		■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■

One interesting feature that was measured for the first time at the FRF was large bedforms, or megaripples, that developed along some of the profile lines in the nearshore trough and seaward of the bar. These features are large enough to be felt by the wheels of the CRAB and are reflected in the data (the CRAB surveys the average elevation between the two back wheels). Because they appeared repeatedly from day to day, and were observed by the CRAB operators, there is convincing evidence that these features are not the result of the Geodimeter oscillations (see Section 6.4.3).

13 m deep survey. The first 13 m deep survey using the towed sled was conducted on 1 May 1990, followed by subsequent surveys on 2, 8, and 27 August 1990. All of the surveys were conducted with the Geodimeter 140-T, which was located on the end of the FRF pier and which tracked the sled as it was towed behind the LARC-V

The final 13 m deep bathymetry data were acquired on six different dates and include sled data from the three dates given above and CRAB survey data from the 6 September 1990 FRF monthly survey and a preliminary minigrid survey on 19 September 1990. Unfortunately, the CRAB and sled data do not overlap well, resulting in discontinuities where the data sets meet. The difference is usually less than 20 cm, but the effect is quite pronounced on the bathymetric chart and on specific cross sections (an

explanation for the discontinuities is given below). The most serious discontinuity, and the largest data gap, is around the 8 m pressure gauge array location. Neither the CRAB nor the sled was driven through the 8 m array. A special deepwater parallel pass was made alongside the array with the CRAB, but not until January 1991. To fill the data gaps in a reasonable way, a very large *search* area had to be defined in the gridding routine, which was used to plot the data. This has the adverse effect of overly smoothing all of the data, particularly the irregular bottom found in the 10 to 13 m depth south of the pier.

Problems with the sled were also encountered. These resulted from the sled tilting sideways, while on a turn, or backward when under tow. During the surveys on 2 and 8 August, strong currents caused the sled to tilt sideways when it was under tow. Consequently, these surveys were not used in the final data set unless they provided the only coverage of an area. Sled tilt results in a vertical error, which can show up as either a bump or a hole. If the tilt occurred gradually, it was difficult to identify and correct.

Because of these problems, the data processing included rechecking and recomputing the data points based on a reanalysis of the vertical angle correction data for each day (any out-of-level errors were not corrected for). Data with nearby coverage from the same or different days were overlaid and compared. The plan view and the cross-section view of each profile line were examined, and suspect points, indicated by wide variations in depth between adjacent points, were removed. Where data from two surveys overlapped and did not match well, data that best fit the rest of the data were retained. Confidence in a particular survey was determined by the overall smoothness of the data (no Geodimeter oscillation) and from the frequency and quality of the vertical angle error checks. Most of the data from the 1 May 1990 and the 27 August 1990 surveys were kept. Data were deleted if there was evidence of sled tilt. Finally, the large gap in the data at 1280 m longshore and 900 m cross-shore was filled with data from 1,100 m in the longshore. To reduce the total number of points, only the median depth value of every three data points along a line was kept (limited by a maximum allowable distance and vertical change). Still, the raw data file includes over 10,000 points. Note that all of the errors described in the 13 m deep survey section result in less than 30 cm vertical error at the outer edge of the survey region.

During the 2015 reanalysis, the deep sled data were incorporated into the survey data from 6 September 1990 with most of the sled data being assigned a profile number of "0", indicating non-cross-shore data. The DELILAH minigrid data from 19 September 1990 was not included (different than in the original processing).

8.5 DUCK94, 1994

An overview of the DUCK94 experiment from the fall of 1994 is provided in Birkemeier and Thornton (1994) and by Birkemeier et al. (1997b). All surveys were conducted using the CRAB and the Geotronics Geodimeter 140T with HYPACK software (see Section 6.4). Table 8-9 lists the profile lines that were surveyed, and Table 8-10 summarizes the 45 available surveys including 18 minigrid surveys. DUCK94 Experiment data are available online.

Table 8-9. DUCK94 survey lines.

Profile Line	Exp. Profile Number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane (NAD83)		Geographic	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
DUCK94							
1234	180		1234.00	275,252.550	901,529.116	36.1881649595	-75.7539593007
1189	195		1189.00	275,210.271	901,544.525	36.1877796012	-75.7538034465
1143	200		1143.00	275,167.052	901,560.277	36.1873856792	-75.7536441304
1097	210	58	1097.00	275,123.833	901,576.029	36.1869917569	-75.7534848159
1074	215		1074.42	275,102.618	901,583.762	36.1867984104	-75.7534066211
1052	220	59	1052.00	275,081.554	901,591.439	36.1866063978	-75.7533289662
1029	225		1029.00	275,059.944	901,599.315	36.1864094364	-75.7532493103
1006	230	62	1006.00	275,038.335	901,607.191	36.1862124749	-75.7531696547
983	235		983.00	275,016.726	901,615.067	36.1860155134	-75.7530899996
960	240	63	960.00	274,995.116	901,622.943	36.1858185518	-75.7530103449
937	245		940.00	274,976.325	901,629.792	36.1856472808	-75.7529410802
905	250	66	905.00	274,943.441	901,641.777	36.1853475563	-75.7528198677
880	255		880.00	274,919.953	901,650.338	36.1851334674	-75.7527332879
860	260	67	860.00	274,901.162	901,657.186	36.1849621961	-75.7526640244
838	265		840.00	274,882.371	901,664.035	36.1847909249	-75.7525947612
818	270	73	818.00	274,861.701	901,671.569	36.1846025264	-75.7525185720
796	275		795.00	274,840.092	901,679.445	36.1844055643	-75.7524389200
777	280	76	785.00	274,830.696	901,682.869	36.1843199286	-75.7524042889
754	285		754.00	274,801.570	901,693.485	36.1840544577	-75.7522969327
742	287		742.00	274,790.296	901,697.594	36.1839516948	-75.7522553757
731	290	85	732.00	274,780.901	901,701.018	36.1838660590	-75.7522207449
709	295		708.60	274,758.915	901,709.031	36.1836656712	-75.7521397092

Table 8-10. Available surveys from the DUCK94 experiment.

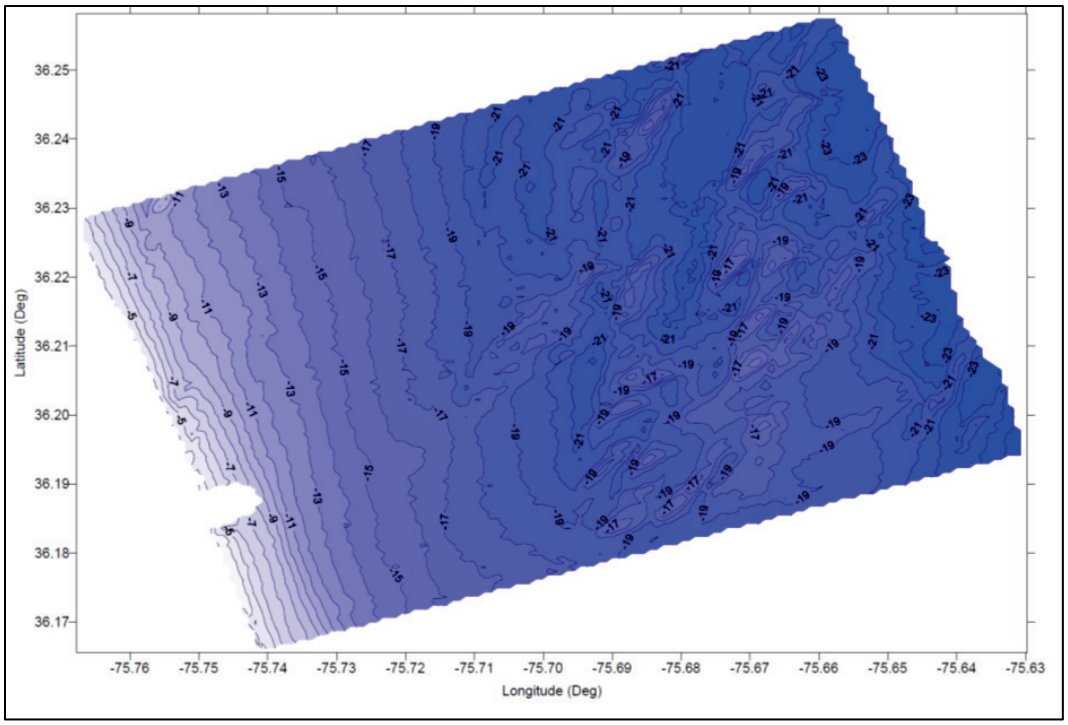
DUCK94 Surveys				Profile Line Numbers/FRF Alongshore Distance (m)																					
Date	Survey Number	Profiles Surveyed	Other Profiles	1234	1189	1143	1097	1074	1052	1029	1006	983	960	937	905	880	860	838	818	796	777	754	742	731	709
19940701	689	7			■	■		■	■				■				■				■				
19940708	690	18		■	■	■		■		■		■	■	■	■	■	■	■	■	■	■	■	■	■	■
19940714	691	1												■											
19940715	692	1												■											
19940721	693	1												■											
19940722	694	1												■											
19940730	695	8	12							■	■	■	■		■	■		■		■					
19940803	696	8		■	■	■				■							■			■		■			■
19940808	697	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940810	698	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940812	699	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940814	700	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940816	701	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940818	702	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940820	703	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940825	704	6										■	■	■	■	■	■								
19940907	705	18	4	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940909	706	6										■	■	■	■	■	■								
19940914	707	6										■	■	■	■	■	■								
19940916	708	6										■	■	■	■	■	■								
19940921	710	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19940924	711	6										■	■	■	■	■	■								
19940926	712	6										■	■	■	■	■	■								
19940928	713	1																■							
19940930	714	4										■	■	■	■										
19941003	715	10										■	■	■	■	■	■	■	■	■	■				
19941004	716	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19941005	717	20		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19941006	718	4										■		■	■	■									
19941007	719	18		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■		■		■		■
19941008	720	18		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■		■		■		■
19941009	721	18		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■		■		■		■
19941010	722	18		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■		■		■		■
19941011	723	12		■		■		■		■	■		■	■	■		■		■				■		■
19941012	724	14		■	■	■		■		■	■		■	■	■		■		■		■		■		■
19941013	725	7										■	■	■	■	■	■	■							
19941014	726	12				■		■	■	■	■	■	■	■			■	■			■				■
19941015	727	12									■	■	■	■	■	■	■	■	■		■		■		■
19941016	728	10										■	■	■	■		■	■	■		■		■		■
19941017	729	10										■	■	■	■		■	■	■		■		■		■
19941018	730	10										■	■	■	■		■	■	■		■		■		■
19941019	731	16			■	■		■	■	■	■	■	■	■	■		■	■	■		■		■		■
19941020	732	18		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■		■		■		■
19941021	733	19		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■		■		■
19941026	734	6	2									■	■	■	■	■	■								

The minigrid was composed of 18 profile lines spaced approximately 25 m apart near the instruments and 50 m apart elsewhere. All lines extended from the base of the dune to approximately 400 m offshore. The dune section of each profile line was only surveyed at the beginning of the experiment. To provide continuity between surveys, the dune data points were automatically added to each survey.

Offshore multibeam survey. In August 1994, the Naval Research Laboratory (NRL) sponsored an offshore multibeam swath survey to

support wave transformation studies under the Coastal Ocean Processes Experiment, which took place coincident with DUCK94. The Multibeam survey was conducted during a few days in mid-August 1994 by C&C Technologies, Inc., using a ~10 m long boat equipped with RTK-GPS for horizontal position and a multibeam sonar. Coverage of 100% was obtained of an area 7 km alongshore by 10 km offshore. Approximately 950,000 points were collected. Because of the deployed DUCK84 experiment instrumentation, the minigrid area and just seaward of it was not surveyed. A separate multibeam survey of approximately 70,000 points was also collected as a detailed survey around the FRF research pier extending to ~800 m offshore (Figure 8-1). FRF cross sections were extracted from the multibeam data and included as part of the FRF DUCK94 minigrid survey of 14 August 1994. Because these data were added in 2016 and because the data were collected under contract to NRL, few details about the equipment used and initial data processing done by C&C Technologies are available. The data are unique in that they cover the widest area and extend farther offshore than any other FRF survey.

Figure 8-1. Contour map of the multibeam survey, courtesy of Arête Assoc. The gap near shore indicates the location of the minigrid survey area.



8.6 SandyDuck, 1997

An overview of the SandyDuck experiment from the fall of 1997 is provided by Birkemeier et al. (1997b). All surveys were conducted using the CRAB and the Trimble® RTK-GPS using HYPACK software (see Section 6.6). Table 8-11 lists the profile lines that were surveyed, and Table 8-12 summarizes the 54 available surveys including 43 minigrid surveys.

Table 8-11. SandyDuck, 1997 survey lines.

Profile Line	Exp. Profile Number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane (NAD83)		Geographic	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
SandyDuck 1997 and DUCK98							
1280	1		1280.16	275,295.922	901,513.308	36.1885602727	-75.7541191828
1234	2		1234.14	275,252.680	901,529.069	36.1881661381	-75.7539597774
1189	3		1189.03	275,210.297	901,544.516	36.1877798337	-75.7538035405
1143	4		1143.00	275,167.054	901,560.277	36.1873856985	-75.7536441382
1097	5	58	1096.98	275,123.812	901,576.037	36.1869915630	-75.7534847375
1060	6		1060.10	275,089.161	901,588.666	36.1866757324	-75.7533570069
1025	7		1025.04	275,056.228	901,600.669	36.1863755626	-75.7532356109
975	8		975.06	275,009.263	901,617.787	36.1859474942	-75.7530624914
937	9		935.13	274,971.748	901,631.460	36.1856055612	-75.7529242082
895	10		894.89	274,933.947	901,645.237	36.1852610178	-75.7527848706
865	11		865.02	274,905.882	901,655.466	36.1850052204	-75.7526814237
845	12		843.99	274,886.123	901,662.668	36.1848251180	-75.7526085891
800	13		801.93	274,846.603	901,677.072	36.1844649131	-75.7524629208
767	14		767.49	274,814.243	901,688.866	36.1841699625	-75.7523436426
742	15		742.19	274,790.474	901,697.529	36.1839533173	-75.7522560318
712	16		712.01	274,762.123	901,707.862	36.1836949090	-75.7521515328
682	17		682.14	274,734.059	901,718.091	36.1834391108	-75.7520480900
640	18	135	640.08	274,694.539	901,732.494	36.1830789050	75.7519024267
594	19		594.06	274,651.297	901,748.255	36.1826847665	-75.7517430430
565	20		565.10	274,624.091	901,758.170	36.1824367984	-75.7516427693

Table 8-12 Available surveys from the 1997 SandyDuck experiment.

SandyDuck 1997 Surveys:				Profile Line Numbers/FRF Alongshore Distance (m)																			
Date	Survey Number	Profiles Surveyed	Other Profiles	1280	1234	1189	1143	1097	1060	1025	975	937	895	865	845	800	767	742	712	682	640	594	565
19970623	792	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970729	793	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970807	794	16						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970815	795	16	11					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970821	796	16						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970828	797	16						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970906	798	16						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970913	799	15						■	■	■		■	■	■	■	■	■	■	■	■	■	■	■
19970916	800	10	13	■		■		■		■		■		■			■		■		■		■
19970922	801	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970923	802	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970924	803	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970925	804	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970926	805	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970927	806	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970928	807	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970929	808	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19970930	809	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971001	810	2										■	■										
19971002	811	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971003	812	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971004	813	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971005	814	2										■			■								
19971006	815	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971007	816	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971008	817	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971009	818	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971010	819	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971011	820	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971012	821	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971013	822	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971014	823	19	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■
19971015	824	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971016	825	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971017	826	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971018	827	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971019	828	9							■		■		■		■		■		■		■	■	■
19971020	829	10			■		■		■		■		■		■		■		■		■		■
19971021	830	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971022	831	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971023	832	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971024	833	20	12	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971025	834	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971026	835	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971027	836	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971028	837	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971029	838	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971030	839	20		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19971031	840	1	5															■					
19971106	841	7									■	■	■	■	■	■	■						
19971109	842	2									■					■							
19971111	843	5									■	■	■		■	■							
19971121	844	1													■								
19971124	845	10	11								■	■	■	■	■	■	■	■	■	■			

In terms of surveys, SandyDuck was the most ambitious of the experiments, with the most temporal and spatial coverage. (SandyDuck Experiment data are available online.)

8.7 DUCK98, 1998

DUCK98 was a minor experiment conducted at the FRF September-October 1998. It reused the SandyDuck profile lines to collect minigrid surveys. All surveys were conducted using the CRAB and the Trimble RTK-GPS using HYPACK software (see Section 6.6). Table 8-13 lists the profile lines that were surveyed and Table 8-14 summarizes the five available surveys including four minigrid surveys.

Table 8-13. DUCK98, 1998 survey lines.

Profile Line	Exp. Profile Number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane (NAD83)		Geographic	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
SandyDuck 1997 and DUCK98							
1280	1		1280.16	275,295.922	901,513.308	36.1885602727	-75.7541191828
1234	2		1234.14	275,252.680	901,529.069	36.1881661381	-75.7539597774
1189	3		1189.03	275,210.297	901,544.516	36.1877798337	-75.7538035405
1143	4		1143.00	275,167.054	901,560.277	36.1873856985	-75.7536441382
1097	5	58	1096.98	275,123.812	901,576.037	36.1869915630	-75.7534847375
1060	6		1060.10	275,089.161	901,588.666	36.1866757324	-75.7533570069
1025	7		1025.04	275,056.228	901,600.669	36.1863755626	-75.7532356109
975	8		975.06	275,009.263	901,617.787	36.1859474942	-75.7530624914
937	9		935.13	274,971.748	901,631.460	36.1856055612	-75.7529242082
895	10		894.89	274,933.947	901,645.237	36.1852610178	-75.7527848706
865	11		865.02	274,905.882	901,655.466	36.1850052204	-75.7526814237
845	12		843.99	274,886.123	901,662.668	36.1848251180	-75.7526085891
800	13		801.93	274,846.603	901,677.072	36.1844649131	-75.7524629208
767	14		767.49	274,814.243	901,688.866	36.1841699625	-75.7523436426
742	15		742.19	274,790.474	901,697.529	36.1839533173	-75.7522560318
712	16		712.01	274,762.123	901,707.862	36.1836949090	-75.7521515328
682	17		682.14	274,734.059	901,718.091	36.1834391108	-75.7520480900
640	18	135	640.08	274,694.539	901,732.494	36.1830789050	75.7519024267
594	19		594.06	274,651.297	901,748.255	36.1826847665	-75.7517430430
565	20		565.10	274,624.091	901,758.170	36.1824367984	-75.7516427693

Table 8 14. Available surveys from the DUCK98 experiment.

DUCK98 Surveys				Profile Line Numbers/FRF Alongshore Distance (m)																	
Date	Survey Number	Profiles Surveyed	Other Profiles	1280	1234	1189	1143	1097	1060	1025	975	937	895	865	845	800	767	742	712	682	640	594
19980915	864	18	2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
19980925	865	4	0				■		■				■					■				
19980929	866	20	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19981005	867	20	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
19981015	868	20	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

9 Summary

Forty-four years of beach-nearshore profile data collected at the FRF are presented. These data are unique in that they cover the most active part of the profile from the dune out past the surf zone. They offer a rare look at the dynamic and often surprising changes that naturally occur in the nearshore zone. The data should be useful to coastal engineers and researchers who need to understand the dynamic nature of the nearshore zone.

Over the years, the collections methods have evolved from manually reading and recording each survey point to the use of highly sophisticated, accurate, and continuously collected RTK-GPS observations. Similarly, the platforms for collection have evolved from the use of sea-sleds to the slow but accurate CRAB and to the fast and capable amphibious LARC-V. Each of the methods used has been presented along with their strengths, weaknesses, accuracy, and error sources. Even as the equipment has changed, the overall accuracy, of a few centimeters vertically, has been sustained.

The intent of this report is to document the FRF survey program as a guide for future contributors and users of these data.

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Appendix A: Abbreviations

- **2d**—Two-dimensional survey data composed only of distance offshore and elevation/depth
- **3d**—Three-dimensional survey data composed only of distance offshore, longshore and elevation/depth

- **ASCII**—American Standard Code for Information Interchange

- **BEP**- Beach Evaluation Program, a beach surveying program of CERC from the 1960s and 1970s.

- **CEERD-HF**— U.S. Army Corps of Engineers, Engineer Research and Development Center, Flood and Storm Protection Division
- **CEERD-HF-A**— U.S. Army Corps of Engineers, Engineer Research and Development Center, Flood and Storm Protection Division, Coastal Observations and Analysis Branch
- **CERC**— U.S. Army Corps of Engineers Coastal Engineering Research Center (predecessor to CHL)
- **CESAM**— U.S. Army Corps of Engineers, Mobile District
- **CESAM-OP-J**— U.S. Army Corps of Engineers, Mobile District, Operations Division, Spatial Data Branch
- **CHL**—Coastal and Hydraulics Laboratory, one of the laboratories of ERDC
- **COAB**—Coastal Observation and Analysis Branch
- **CODS**—Coastal Ocean Data Systems
- **CORS**— Continuously Operating Reference Station. CORS is an NGS program of continuously operating GPS stations.
- **CRAB**—Coastal Research Amphibious Buggy
- **CTD**—Conductivity, Temperature, and Depth observation

- **DELILAH**—the *Duck Experiment on Low-frequency and Incident-band Longshore and Across-shore Hydrodynamics*, an experiment held at the FRF in the fall of 1990,
- **DMS**—Dynamic Motion Sensor
- **DOS** – Disk Operating System, the original operating system on PC computers

- **EDT**— Eastern Daylight Time
- **ERDC**—U. S. Army Engineer Research and Development Center

- **ERDC-CHL**—U. S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory
- **EST**— Eastern Standard Time

- **FDIF**—Field Research Facility Data Integration Framework
- **FGDC**—Federal Geographic Data Committee
- **FRF**—Field Research Facility
- **ft**—Feet

- **GIS**—Geographic Information System
- **GPS**—Global Positioning System

- **HYPACK®** — A Hydrographic Package of software for collecting hydrographic survey data available from HYPACK, Inc.

- **ISO**—International Organization for Standardization
- **ISO 19115**—defines the schema required for describing geographic information and services by means of metadata. It provides information about the identification, the extent, the quality, the spatial and temporal aspects, the content, the spatial reference, the portrayal, distribution, and other properties of digital geographic data and services.
- **ISRP**— Interactive Survey Reduction Program, a custom FORTRAN program developed at the FRF to interactively process and graph survey data. Used from 1981 to ~2000. Replaced by ISRP3 a similarly named Visual Basic program developed by Terry Lease in 2001.

- **JPG**—Joint Photographic Experts Group (file format)

- **km**—kilometers

- **LARC**—Lighter Amphibious Resupply Cargo
- **LARC-V**—Lighter Amphibious Resupply Cargo, 5 ton

- **m**—meters
- **MB**—Megabyte
- **MORPHOS**- Modeling Relevant Physics of Sedimentation, a 2005-2009 project of ERDC-CHL

- **NAD27**—North American Datum of 1927

- **NAD83**—North American Datum of 1983
- **NAVD88**—North American Vertical Datum of 1988
- **NDIF**—Navigation Data Integration Framework
- **NGS**— the NOAA National Geodetic Survey
- **NGVD29** –National Geodetic Vertical Data of 1929
- **NOAA**— National Oceanic and Atmospheric Administration

- **PNG**—Portable Graphics Network (file format)
- **POC**—Point of Contact

- **RMS error** —Root Mean Square error
- **RTK-GPS**—Real-Time Kinematic Global Positioning System

- **SAMSON**—Sources of Ambient Micro-Seismic Ocean Noise, an experiment, held at the FRF in 1990
- **SAW**— South Atlantic, Wilmington, the US Army Engineer District, Wilmington located in Wilmington, NC.

- **TOPO**—Topographic (land-based) elevation and position data
- **TR**—Technical Report
- **TSS**—Teledyne TSS

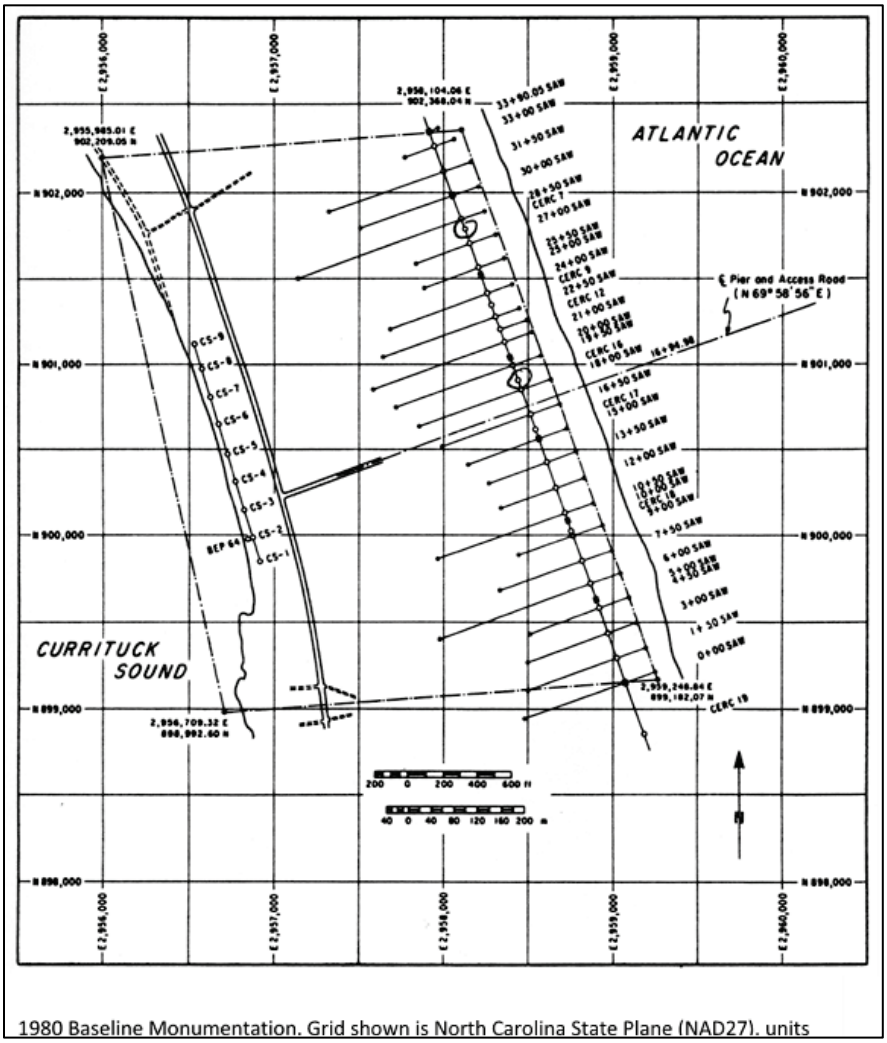
- **USACE**—U.S. Army Corps of Engineers
- **UTC**—Coordinated Universal Time

- **XML**—eXtended Markup Language

Appendix B: FRF Control and Profile Line Locations

This appendix documents the 185 profile lines in the FRF survey dataset. Figure B-1 below is a 1980 map showing the baseline, survey lines, and FRF property corner locations. All profile lines run parallel to the pier centerline at 69.975 deg east of True North. Table B-1 lists control information for the 1980 monumentation, updated in 2014 to NAVD88 and NAD83. Table B-2 lists the FRF profile lines and their origins.

Figure B-1. 1980 Baseline monumentation. Grid shown is North Carolina State Plane (NAD27); units are in survey feet (from Birkemeier et al. 1985).



1980 Baseline Monumentation. Grid shown is North Carolina State Plane (NAD27). units

Table B-1. 1980 FRF baseline monumentation (updated in 2014).

Profile Number	Pre-2015 Profile	Pre-1980 Designation	Distance Along Baseline (ft)	Distance Along Baseline (m)	Distance from FRF Pier Centerline (ft)	Distance from FRF Pier Centerline (m)	Elevation (NGVD) (ft)	Elevation (NGVD) (m)	Elevation (NAVD88) (m)	Monument Type[2]	North Carolina SP (NAD83) Northing (m)	North Carolina SP (NAD83) Easting (m)	Geographic From CorpsCon6 (NAD83) Latitude	Geographic From CorpsCon6 (NAD83) Longitude
4240	25	CERC A[1]	13,910.00	4,240	12,220	3,720	12.55	3.825	3.532	C1	278,050.25	900,422.63	36.213689644	-75.765240635
3193	30	CERC 3[1]	10,480.00	3,190	8,780	2,680	13.41	4.087	3.794	C1	277,079.79	900,821.19	36.204831542	-75.761162751
2184	40	CERC 4	7,163.73	2,183.51	5,468.75	1,666.88	15.85	4.831	4.538	C1	276,144.65	901,203.97	36.196296036	-75.757248205
1422	50	CERC 5[3]	4,663.73	1,421.51	2,968.75	904.88	14.79	4.508	4.215	C1	275,428.72	901,464.91	36.189770682	-75.754608736
1280		new in 1979	4,237.98	1,291.74	2,543.00	775.11					275,306.80	901,509.34	36.188659407	-75.754159277
1166		new in 1979	3,827.98	1,166.77	2,133.00	650.14					275,189.39	901,552.14	36.187589239	75.753726457
1097	58		3,600.00	1,097.28	1,905.02	580.65					275,124.10	901,575.93	36.186994173	-75.753485793
1052	39		3,450.00	1,051.56	1,755.02	534.93					275,081.14	901,591.59	36.186602648	-75.753327450
1041	60	CERC 6	3,413.73	1,040.51	1,718.75	523.88	12.36	3.767	3.474	D	275,070.76	901,595.37	36.186507977	-75.753289162
1033	61	SAW 33+90.05	3,390.05	1,033.29	1,695.07	516.66	14.45	4.404	4.111	C	275,063.97	901,597.85	36.186446168	-75.753264165
1006	62	SAW 33+00	3,300.00	1,005.84	1,605.02	489.21	13.15	4.008	3.715	P1	275,038.19	901,607.25	36.186211122	-75.753169107
960		SAW 31+50	3,150.00	960.12	1,455.02	443.49	12.52	3.816	3.523	P1	274,995.23	901,622.90	36.185819596	-75.753010767
914	66	SAW 30+00	3,000.00	914.40	1,305.02	397.77	14.70	4.481	4.188	P1	274,952.27	901,638.56	36.185428069	-75.752852428
869	67	SAW 28+50	2,850.00	868.68	1,155.02	352.05	12.36	3.767	3.474	P1	274,909.32	901,654.21	36.185036543	-75.752694091
850	70	CERC 7	2,788.73	850.01	1,093.75	333.38	12.92	3.938	3.645	CI	274,891.77	901,660.61	36.184876617	-75.752629416
823	73	SAW 27+00	2,700.00	822.96	1,005.02	306.33	13.14	4.005	3.712	P1	274,866.36	901,669.87	36.184645016	-75.752535755
777	76	SAW 25+50	2,550.00	777.24	855.02	260.61	12.00	3.658	3.365	P1	274,823.41	901,685.53	36.184253488	-75.752377420
762	78	SAW 25+00	2,500.00	762.00	805.02	245.37	12.33	3.758	3.465	C	274,809.09	901,690.74	36.184122979	-75.752324643
755	80	CERC 8	2,476.23	754.76	781.25	238.13	12.75	3.886	3.593	C1	274,802.28	901,693.23	36.184060935	-75.752299552
732	85	SAW 24+00	2,400.00	731.52	705.02	214.89	12.24	3.731	3.438	P1	274,780.45	901,701.18	36.183861961	-75.752219088
709	90	CERC 9	2,319.98	707.13	625.00	190.50	12.51	3.813	3.520	CI	274,757.54	901,709.53	36.183653094	-75.752134623
686	95	SAW 22+50	2,250.00	685.80	555.02	169.17	13.26	4.042	3.749	P1	274,737.50	901,716.84	36.183470433	-75.752060756
686[3]	100	CERC 10	2,241.86	683.32	546.88	166.69	13.31	4.057	3.764	C1	274,735.16	901,717.69	36.183449186	-75.752052164
671	110	CERC 11	2,202.80	671.41	507.82	154.78	14.99	4.569	4.276	C1	274,723.98	901,721.76	36.183347232	-75.752010935
663	120	CERC 12	2,163.73	659.51	468.75	142.88	12.50	3.810	3.517	C1	274,712.79	901,725.84	36.183245252	-75.751969696
648	130	CERC 13	2,124.66	647.60	429.68	130.97	13.04	3.975	3.682	C1	274,701.60	901,729.92	36.183143272	-75.751928456
640	135	SAW 21+00	2,100.00	640.08	405.02	123.45	16.14	4.919	4.626	P1	274,694.54	901,732.49	36.183078905	-75.751902427
640[3]	140	CERC 14	2,085.60	635.69	390.62	119.06	13.45	4.100	3.807	C1	274,690.42	901,734.00	36.183041318	-75.751887227
612	150	CERC 15	2,007.48	611.88	312.50	95.25	12.88	3.926	3.633	C1	274,668.04	901,742.15	36.182837410	-75.751804770
610	151	SAW 20+00	2,000.00	609.60	305.02	92.97	13.10	3.993	3.700	C	274,665.90	901,742.93	36.182817886	-75.751796874
594	155	SAW 19+50	1,950.00	594.36	255.02	77.73	13.80	4.206	3.913	P1	274,651.58	901,748.15	36.182687377	-75.751744099
564		CERC 16	1,851.23	564.26	156.25	47.63	14.18	4.322	4.029	C1	274,623.30	901,758.46	36.182429568	-75.751639846
558	160		1,830.00	557.79	135.02	41.15					274,617.22	901,760.68	36.182374154	-75.751617437
549	161	SAW 18+00	1,800.00	548.64	105.02	32.01	15.76	4.804	4.511	P1	274,608.63	901,763.81	36.182295848	-75.751585772
539	162	B	1,769.98	539.49	75.00	22.86	16.05	4.892	4.599	P2	274,600.03	901,766.94	36.182217490	-75.751554086
526	163		1,725.00	525.78	30.02	9.15	17.77	5.416	5.123		274,587.15	901,771.63	36.182100084	-75.751506609
520	164	CERC 68	1,704.98	519.68	10.00	3.05	North side of the pier			NP	274,581.42	901,773.72	36.182047828	-75.751485478
517	165	SAW 16+94.98	1,694.98	516.63	0.00	0.00	17.56	5.352	5.059	D	274,578.55	901,774.77	36.182021726	-75.751474923
514	166	CERC 69	1,684.98	513.58	-10.00	-3.05	South side of the pier			SP	274,575.69	901,775.81	36.181995624	-75.751464368
503	167	SAW 16+50	1,650.00	502.92	-44.98	-13.71	19.04	5.803	5.510	P1	274,565.67	901,779.46	36.181904319	-75.751427447
494		C	1,619.98	493.77	-75.00	-22.86	17.55	5.349	5.056	P2	274,557.07	901,782.60	36.181825961	-75.751395761
491	168		1,610.00	490.73	-84.98	-25.90					274,554.22	901,783.64	36.181799911	-75.751385227
480	169		1,575.00	480.06	-119.98	-36.57	16.65	5.075	4.782	P1	274,544.19	901,787.29	36.181708555	-75.751348285
469	170	CERC 17	1,538.73	469.01	-156.25	-47.63	14.11	4.301	4.008	C1	274,533.81	901,791.08	36.181613883	-75.751310002
457	171	SAW 15+00	1,500.00	457.20	-194.98	-59.43	15.10	4.602	4.309	C1	274,522.72	901,795.12	36.181512790	-75.751269123
419	173	D	1,375.00	419.10	-319.98	-97.53	16.97	5.172	4.879	P2	274,486.92	901,808.17	36.181186516	-75.751137188
411	174	SAW 13+50	1,350.00	411.48	-344.98	-105.15	14.89	4.538	4.245	P1	274,479.76	901,810.78	36.181121261	-75.751110801
395	175	E	1,295.00	394.72	-399.98	-121.91	14.71	4.484	4.191	P2	274,464.01	901,816.52	36.180977700	-75.751052750
366	176	SAW 12+00	1,200.00	365.76	-494.98	-150.87	17.59	5.361	5.068	P1	274,436.80	901,826.43	36.180729731	-75.750952481
320	178	SAW 10+50	1,050.00	320.04	-644.98	-196.59	16.15	4.923	4.630	P1	274,393.85	901,842.09	36.180338201	-75.750794162
305	179	SAW 10+00	1,000.00	304.80	-694.98	-211.83	15.70	4.785	4.492	C	274,379.53	901,847.31	36.180207691	-75.750741389
274[3]	180	CERC 18	913.73	278.51	-781.25	-238.13	14.36	4.377	4.084		274,354.82	901,856.31	36.179982509	-75.750650336
274	181	SAW 9+00	900.00	274.32	-794.98	-242.31	14.23	4.337	4.044	P1	274,350.89	901,857.74	36.179946671	-75.750635845
229	182	SAW 7+50	750.00	228.60	-944.98	-288.03	16.24	4.950	4.657	P1	274,307.94	901,873.40	36.179555140	-75.750477529
183	183	SAW 6+00	600.00	182.88	-1,094.98	-333.75	14.16	4.316	4.023	P1	274,264.98	901,889.06	36.179163609	-75.750319214
152	184	SAW 5+00	500.00	152.40	-1,194.98	-364.23	13.48	4.109	3.816	C	274,236.34	901,899.49	36.178902589	-75.750213672
137	185	SAW 4+50	450.00	137.16	-1,244.98	-379.47	14.76	4.499	4.206	P1	274,222.02	901,904.71	36.178772078	-75.750160902
91	186	SAW 3+00	300.00	91.44	-1,394.98	-425.19	15.10	4.602	4.309	P1	274,179.07	901,920.37	36.178380547	-75.750002590
46	187	SAW 1+50	150.00	45.72	-1,544.98	-470.91	14.90	4.542	4.249	P1	274,136.11	901,936.02	36.177989015	-75.749844281
1	188	SAW 0+00	0.00	1.00	-1,694.98	-516.63	15.14	4.615	4.322	C1	274,094.10	901,951.34	36.177597484	-75.749685973
-46	189		-150.00	-45.72	-1,844.98	-562.35					274,050.20	901,967.34	36.177205951	-75.749527666
-91	190		-300.00	-91.44	-1,994.98	-608.07					274,007.24	901,982.99	36.176814419	-75.749369361
-102		CERC 19	-336.27	-102.50	-2,031.25	-619.13	16.14	4.919	4.626	C1	273,996.86	901,986.78	36.176719746	-75.749331083
-229		new in 1979	-766.02	-233.48	-2,461.00	-750.11	14.79				273,873.79	902,031.63	36.175598004	-75.748877549
-366		new in 1979	-1,258.02	-383.45	-2,953.00	-900.08	14.79				273,732.89	902,082.99	36.174313773	-75.748358334
-864	200	CERC 20	-2,836.27	-864.50	-4,531.25	-1,381.13	16.05	4.892	4.599	C1	273,280.93	902,247.71	36.170194165	-75.746692898
-1769	207	F[1]	-5,720.00	-1,740	-7,420.00	-2,260	16.44	5.011	4.718	C1	272,479.65	902,612.09	36.162869257	-75.742937274
-3317	220	CERC 22[1]	-10,870.00	-3,310	-12,570.00	-3,830	19.16	5.840	5.547	C1	271,021.46	903,200.95	36.149560627	-75.736928884

1 - Monument not on the baseline, distance along baseline is approximate

2 - Monument types: C-concrete; C1-concrete with front and rear pipes; D-monument destroyed; NP-north pier edge; P1-capped galvanized pipe with front and rear pipes; P2-pipe with front pipe only; SP-south pier edge.

3 - Duplicate profile number used

Adapted from Table 4 in: Birkemeier, W. A., Miller,H.C, Wilhelm, S.D., DeWall, A.E. and Gorbics, C.D., 1985. *User's Guide to CERC's Field Research Facility*. Instruction Report CERC-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS, 136p.

Table B-2. FRF Profile line origins (monthly survey lines indicated in green).

Profile Line Number	Early FRF number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane 2014 FRF origin, NC SP NAD83		Geographic From Corps Con 6 (NAD83)	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
-7900	CERC 25		-7899.70	266,670.778	904,656.916	36.1099403804	-75.7223549285
-6235	CERC 24		-6235.05	268,235.115	904,086.762	36.1242004312	-75.7281113863
-4516	CERC 23		-4515.54	269,850.187	903,498.117	36.1389225935	-75.7340566791
-3314	CERC 22		-3313.78	270,979.515	903,086.510	36.1492167454	-75.7382151796
-2233	CERC 21		-2233.00	271,995.160	902,716.338	36.1584744702	-75.7419559706
-1741	CERC F	297	-1741.00	272,457.414	902,547.860	36.1626879263	-75.7436588173
-1500			-1500.00	272,683.844	902,465.333	36.1647518232	-75.7444930003
-1350			-1350.00	272,824.775	902,413.968	36.1660364025	-75.7450122229
-1200			-1200.00	272,965.706	902,362.602	36.1673209788	-75.7455314621
-1050			-1050.00	273,106.638	902,311.237	36.1686055522	-75.7460507179
-864	CERC 20		-864.00	273,281.392	902,247.544	36.1701984191	-75.7466946181
-853	230	28	-853.00	273,291.727	902,243.777	36.1702926208	-75.7467326990
-701	220	23	-701.00	273,434.538	902,191.727	36.1715943149	-75.7472589172
-594	212	212	-594.00	273,535.068	902,155.087	36.1725106373	-75.7476293573
-549	210	18	-549.00	273,577.348	902,139.677	36.1728960060	-75.7477851524
-503	208	208	-503.00	273,620.567	902,123.925	36.1732899383	-75.7479444111
-457	206	206	-457.00	273,663.786	902,108.173	36.1736838702	-75.7481036714
-411	204	204	-411.00	273,707.005	902,092.421	36.1740778019	-75.7482629333
-366	202	12	-366.00	273,749.284	902,077.012	36.1744631696	-75.7484187344
-320	200	200	-320.00	273,792.503	902,061.260	36.1748571007	-75.7485779994
-274	198	198	-274.00	273,835.722	902,045.508	36.1752510316	-75.7487372659
-244	197	8	-244.00	273,863.908	902,035.235	36.1755079429	-75.7488411362
-229	196	196	-229.00	273,878.001	902,030.098	36.1756363985	-75.7488930716
-183	194	194	-183.00	273,921.220	902,014.346	36.1760303288	-75.7490523412
-137	192	192	-137.00	273,964.439	901,998.594	36.1764242588	-75.7492116123
-102	CERC 19		-102.00	273,997.323	901,986.609	36.1767239880	-75.7493327979
-91	190	190	-91.00	274,007.658	901,982.842	36.1768181886	-75.7493708850
-46	189	189	-46.00	274,049.937	901,967.433	36.1772035544	-75.7495266968
1	188	188	1.00	274,094.096	901,951.338	36.1776060473	-75.7496894351
46	187	187	46.00	274,136.375	901,935.928	36.1779914126	-75.7498452499
91	186	186	91.00	274,178.654	901,920.519	36.1783767776	-75.7500010662
137	185	185	137.00	274,221.873	901,904.767	36.1787707059	-75.7501603466
183	183	183	183.00	274,265.092	901,889.015	36.1791646340	-75.7503196286
229	182	182	229.00	274,308.311	901,873.263	36.1795585619	-75.7504789122
274	181	181	274.00	274,350.591	901,857.853	36.1799439258	-75.7506347346
320	178	178	320.00	274,393.809	901,842.101	36.1803378531	-75.7507940212
343	177	177	343.00	274,415.419	901,834.225	36.1805348166	-75.7508736651
366	176	176	366.00	274,437.028	901,826.349	36.1807317801	-75.7509533094
389	175	175	389.00	274,458.638	901,818.473	36.1809287435	-75.7510329541
411	174	174	411.00	274,479.308	901,810.940	36.1811171432	-75.7511091363
434	172	172	434.00	274,500.917	901,803.064	36.1813141065	-75.7511887818
457	171	171	457.00	274,522.527	901,795.188	36.1815110697	-75.7512684276
469	CERC 17		469.00	274,533.801	901,791.079	36.1816138330	-75.7513099821
480	169	169	480.00	274,544.136	901,787.312	36.1817080328	-75.7513480738
509	167	167	509.00	274,571.383	901,777.381	36.1819563775	-75.7514484979
514	166	166	513.59	274,576.081	901,775.669	36.1819991955	-75.7514658124
517	165	165	517.00	274,578.899	901,774.642	36.1820248864	-75.7514762012
520	164	164	519.69	274,581.718	901,773.614	36.1820505772	-75.7514865899
534			534.00	274,594.871	901,768.820	36.1821704600	-75.7515350700
524	163	163	524.00	274,585.476	901,772.245	36.1820848316	-75.7515004416
546	161	161	546.00	274,606.146	901,764.711	36.1822732309	-75.7515766260
554			554.00	274,613.662	901,761.972	36.1823417200	-75.7516043500
558	160	160	558.00	274,617.420	901,760.602	36.1823759942	-75.7516181813
565	20		565.00	274,623.997	901,758.205	36.1824359394	-75.7516424219

Table B-2. (cont.). FRF profile line origins.

Profile Line Number	Early FRF number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane 2014 FRF origin, NC SP NAD83		Geographic From Corps Con 6 (NAD83)	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
572			572.00	274,630.574	901,755.808	36.1824958500	-75.7516666400
576	157	157	576.00	274,634.332	901,754.438	36.1825301390	-75.7516805144
584			584.00	274,641.848	901,751.699	36.1825986600	-75.7517082000
594	155	155	594.00	274,651.244	901,748.274	36.1826842838	-75.7517428478
604			604.00	274,660.639	901,744.850	36.1827699300	-75.7517774800
612	CERC 15		612.00	274,668.156	901,742.110	36.1828384285	-75.7518051814
617	154	154	617.00	274,672.853	901,740.398	36.1828812465	-75.7518224964
624			624.00	274,679.430	901,738.001	36.1829411900	-75.7518467500
640	135	135	640.00	274,694.463	901,732.522	36.1830782091	-75.7519021453
648	CERC 13		648.00	274,701.979	901,729.783	36.1831467179	-75.7519298494
663	115	115	663.00	274,716.072	901,724.646	36.1832751717	-75.7519817946
671	CERC 11		671.00	274,723.589	901,721.907	36.1833436804	-75.7520094988
682	17		682.00	274,733.924	901,718.140	36.1834378799	-75.7520475922
686	95	95	686.00	274,737.682	901,716.770	36.1834721342	-75.7520614443
709	86	86	709.00	274,759.291	901,708.894	36.1836690967	-75.7521410944
712	16		712.00	274,762.110	901,707.867	36.1836947874	-75.7521514836
731	85	85	731.00	274,779.961	901,701.361	36.1838574954	-75.7522172819
742	287		742.00	274,790.296	901,697.594	36.1839516948	-75.7522553757
747	82		747.00	274,794.994	901,695.882	36.1839945127	-75.7522726911
754	285		754.00	274,801.570	901,693.485	36.1840544577	-75.7522969327
767	14		767.00	274,813.785	901,689.033	36.1841657842	-75.7523419530
777	76	76	777.00	274,823.180	901,685.609	36.1842514200	-75.7523765840
796	275		795.00	274,841.031	901,679.102	36.1844141279	-75.7524423832
800	74	74	800.00	274,844.789	901,677.733	36.1844483821	-75.7524562356
818	270	73	818.00	274,861.701	901,671.569	36.1846025264	-75.7525185720
823	73	73	823.00	274,866.399	901,669.857	36.1846453442	-75.7525358877
838	71		838.00	274,880.492	901,664.720	36.1847737977	-75.7525878349
845	12		845.00	274,887.069	901,662.323	36.1848337427	-75.7526120769
853	69		853.00	274,894.585	901,659.584	36.1849022512	-75.7526397822
860	260	67	860.00	274,901.162	901,657.186	36.1849621961	-75.7526640244
865	11		865.00	274,905.860	901,655.474	36.1850050140	-75.7526813402
869	67	67	869.00	274,909.618	901,654.105	36.1850392682	-75.7526951929
880	255		880.00	274,919.953	901,650.338	36.1851334674	-75.7527332879
892	255		892.00	274,931.227	901,646.229	36.1852362301	-75.7527748461
895	10		895.00	274,934.046	901,645.201	36.1852619208	-75.7527852357
905	250	66	905.00	274,943.441	901,641.777	36.1853475563	-75.7528198677
914	66	66	914.00	274,951.897	901,638.695	36.1854246283	-75.7528510365
927			927.00	274,964.111	901,634.243	36.1855359400	-75.7528961000
937	65	65	937.00	274,973.507	901,630.819	36.1856215901	-75.7529306905
951	64		951.00	274,986.660	901,626.025	36.1857414798	-75.7529791757
960	63	64	960.00	274,995.116	901,622.943	36.1858185518	-75.7530103449
975	8		975.00	275,009.209	901,617.806	36.1859470050	-75.7530622936
983	235		983.00	275,016.726	901,615.067	36.1860155134	-75.7530899996
1006	62	62	1006.00	275,038.335	901,607.191	36.1862124749	-75.7531696547
1021	61		1021.00	275,052.428	901,602.054	36.1863409281	-75.7532216040
1025	7		1025.00	275,056.186	901,600.685	36.1863751822	-75.7532354571
1029	225		1029.00	275,059.944	901,599.315	36.1864094364	-75.7532493103
1036			1036.00	275,066.521	901,596.918	36.1864693700	-75.7532735300
1041	CERC 6		1041.00	275,071.219	901,595.206	36.1865121989	-75.7532908698
1052	59	59	1052.00	275,081.554	901,591.439	36.1866063978	-75.7533289662
1060	6		1060.00	275,089.070	901,588.699	36.1866749061	-75.7533566727
1074	215		1074.00	275,102.224	901,583.905	36.1867947956	-75.7534051592
1097	58	58	1097.00	275,123.833	901,576.029	36.1869917569	-75.7534848159
1120	57		1120.00	275,145.443	901,568.153	36.1871887181	-75.7535644729
1127			1127.00	275,152.019	901,565.756	36.1872486700	-75.7535886800

Table B-2. (cont.). FRF profile line origins.

Profile Line Number	Early FRF number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane 2014 FRF origin, NC SP NAD83 Northing (m)	NC State Plane 2014 FRF origin, NC SP NAD83 Easting (m)	Geographic From Corps Con 6 (NAD83) Latitude	Geographic From Corps Con 6 (NAD83) Longitude (W)
1143	56	56	1143.00	275,167.052	901,560.277	36.1873856792	-75.7536441304
1157			1157.00	275,180.206	901,555.483	36.1875056100	-75.7536926500
1166	197		1166.00	275,188.662	901,552.401	36.1875826402	-75.7537237883
1189	54	54	1189.00	275,210.271	901,544.525	36.1877796012	-75.7538034465
1203	53		1203.00	275,223.425	901,539.731	36.1878994905	-75.7538519343
1217			1217.00	275,236.578	901,534.937	36.1880193900	-75.7539003900
1234	52	52	1234.00	275,252.550	901,529.116	36.1881649595	-75.7539593007
1257	51		1257.00	275,274.160	901,521.240	36.1883619203	-75.7540389601
1277			1277.00	275,292.951	901,514.391	36.1885331900	-75.7541082300
1280	50	50	1280.00	275,295.769	901,513.364	36.1885588810	-75.7541186199
1303	49		1303.00	275,317.379	901,505.488	36.1887558416	-75.7541982801
1326	48	48	1326.00	275,338.988	901,497.612	36.1889528022	-75.7542779406
1337			1337.00	275,349.323	901,493.845	36.1890469700	-75.7543159900
1349	47		1349.00	275,360.598	901,489.736	36.1891497627	-75.7543576016
1372	46	46	1372.00	275,382.207	901,481.860	36.1893467231	-75.7544372629
1391	45		1391.00	275,400.058	901,475.354	36.1895094295	-75.7545030704
1410	44	44	1410.00	275,417.910	901,468.847	36.1896721359	-75.7545688782
1422	CERC 5		1422.00	275,429.184	901,464.738	36.1897748978	-75.7546104411
1437	43		1437.00	275,443.277	901,459.602	36.1899033501	-75.7546623949
1463	42	42	1463.00	275,467.705	901,450.698	36.1901260007	-75.7547524486
1506	40	40	1506.00	275,508.106	901,435.974	36.1904942304	-75.7549013846
1511			1511.00	275,512.803	901,434.261	36.1905370200	-75.7549187200
1554	38	38	1554.00	275,553.204	901,419.537	36.1909052772	-75.7550676404
1600	35	35	1600.00	275,596.423	901,403.785	36.1912991968	-75.7552269704
1646	34	34	1646.00	275,639.642	901,388.033	36.1916931160	-75.7553863020
1692	32	32	1692.00	275,682.860	901,372.281	36.1920870351	-75.7555456352
1703	31		1703.00	275,693.195	901,368.514	36.1921812330	-75.7555837368
1737	30	30	1737.00	275,725.140	901,356.871	36.1924723903	-75.7557015061
1783	28	28	1783.00	275,768.359	901,341.119	36.1928663088	-75.7558608423
1803	27		1803.00	275,787.150	901,334.270	36.1930375776	-75.7559301194
1829	26	26	1829.00	275,811.578	901,325.367	36.1932602270	-75.7560201801
1875	24	24	1875.00	275,854.797	901,309.615	36.1936541449	-75.7561795195
1903	22		1903.00	275,881.104	901,300.027	36.1938939209	-75.7562765094
1953	21		1953.00	275,928.081	901,282.905	36.1943220920	-75.7564497072
2003	20		2003.00	275,975.058	901,265.783	36.1947502628	-75.7566229068
2103	18		2103.00	276,069.012	901,231.540	36.1956066034	-75.7569693115
2184	CERC 4		2184.00	276,145.115	901,203.803	36.1963002384	-75.7572499047
2203	16		2203.00	276,162.966	901,197.296	36.1964629428	-75.7573157236
2303	14		2303.00	276,256.920	901,163.053	36.1973192808	-75.7576621431
2397			2397.00	276,345.237	901,130.864	36.1981242600	-75.7579878300
2403	13		2403.00	276,350.875	901,128.809	36.1981756175	-75.7580085699
2503	12		2503.00	276,444.829	901,094.566	36.1990319528	-75.7583550042
2603	10		2603.00	276,538.783	901,060.322	36.1998882869	-75.7587014458
2693			2693.00	276,623.342	901,029.503	36.2006589700	-75.7590132900
2703	9		2703.00	276,632.737	901,026.079	36.2007446196	-75.7590478948
2803	8		2803.00	276,726.691	900,991.835	36.2016009511	-75.7593943511
2903	7		2903.00	276,820.645	900,957.592	36.2024572812	-75.7597408148
3003	6		3003.00	276,914.599	900,923.348	36.2033136100	-75.7600872859
3053	5		3053.00	276,961.577	900,906.227	36.2037417739	-75.7602605243
3153	4		3153.00	277,055.531	900,871.983	36.2045981007	-75.7606070064
3193	CERC3		3193.00	277,093.112	900,858.286	36.2049406311	-75.7607456014
3241			3241.00	277,138.210	900,841.849	36.2053516600	-75.7609119000
3253	3		3253.00	277,149.485	900,837.740	36.2054544262	-75.7609534960
3353	2		3353.00	277,243.439	900,803.496	36.2063107504	-75.7612999929
3453	1		3453.00	277,337.393	900,769.253	36.2071670733	-75.7616464972

Table B-2. (cont.). FRF profile line origins.

Profile Line Number	Early FRF number	Original FRF Number	FRF Coordinate Longshore (m)	NC State Plane 2014 FRF origin, NC SP NAD83		Geographic From Corps Con 6 (NAD83)	
				Northing (m)	Easting (m)	Latitude	Longitude (W)
3550			3550.00	277,428.529	900,736.037	36.2079977200	-75.7619825700
3605			3605.00	277,480.203	900,717.203	36.2084686815	-75.7621731978
3755			3755.00	277,621.135	900,665.837	36.2097531604	-75.7626929849
3858			3858.00	277,717.907	900,630.567	36.2106351900	-75.7630498800
3905			3905.00	277,762.066	900,614.472	36.2110376363	-75.7632127886
4055			4055.00	277,902.997	900,563.107	36.2123221092	-75.7637326089
4156			4156.00	277,997.891	900,528.521	36.2131869800	-75.7640826400
4240	CERC A		4240.00	278,076.812	900,499.756	36.2139062884	-75.7643737434
4355			4355.00	278,184.860	900,460.376	36.2148910461	-75.7647722993
4505			4505.00	278,325.791	900,409.011	36.2161755101	-75.7652921694
4655			4655.00	278,466.722	900,357.646	36.2174599712	-75.7658120561
4805			4805.00	278,607.653	900,306.281	36.2187444292	-75.7663319594
4955			4955.00	278,748.585	900,254.915	36.2200288843	-75.7668518793
5105			5105.00	278,889.516	900,203.550	36.2213133365	-75.7673718158
5269	CERC 2		5269.00	279,043.601	900,147.391	36.2227176674	-75.7679402987
5405			5405.00	279,171.378	900,100.820	36.2238822318	-75.7684117386
5555			5555.00	279,312.309	900,049.455	36.2251666751	-75.7689317249
5705			5705.00	279,453.241	899,998.089	36.2264511153	-75.7694517278
5855			5855.00	279,594.172	899,946.724	36.2277355526	-75.7699717474
6275	CERC 1		6275.00	279,988.779	899,802.901	36.2313319611	-75.7714278905

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Appendix D: Summary of FRF Surveys: 1974-2018

An inventory of each survey with the details about the profile lines surveyed has been created as part of this re-analysis and is included in this appendix available on the web site of the FRF.

Included in the following pages is a summary of surveys for the period of 1974-2018. Vertical color bands highlight the monthly profile lines and the FRF pier line. Listed wave data are for the first day of each survey and are typically from a wave buoy at the FRF located in ~17 m water depth.

The following columns of information are included:

1. Project/Experiment
2. Survey date for the first day of surveying
3. Survey number
4. Number of profile lines surveyed
5. Vehicle used (Topo, SLED, CRAB, LARC, etc.)
6. Instrument used (Level, Zeiss, Geodimeter, GPS, etc.)
7. Collection software (ISRP, RG7, HYPACK)
8. Raw data availability (yes or no)
9. Significant wave height on the first day of surveying
10. Peak wave period on the first day of surveying
11. The number of other, non cross-shore. Profile lines surveyed.

In the remaining columns, one for each profile line, a ■ is used to mark each profile line included in that survey.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
meters	3.2808398950131	feet
meters	3.2808334366796	survey feet
survey feet	0.3048006	meters

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14. ABSTRACT
This report summarizes 44 years of beach-nearshore profile survey data collected at the Field Research Facility (FRF). The FRF is operated by the Coastal Observations and Analysis Branch of the Coastal and Hydraulics Laboratory, one of the laboratories of the U.S. Army Engineer Research and Development Center.
The 1,110 surveys collected between 1974 and 2018 provide a unique temporal and spatial record of beach and nearshore change under a wide variety of conditions (waves, tides, currents, etc.) that have been monitored by the FRF data collection program.
Over the years, the collection methods evolved from manually reading and recording each survey position to continuously recording Global Positioning System observations. Each method is presented along with its strengths, weaknesses, accuracy, and error sources. As the equipment has changed, the consistency and overall accuracy has improved.
The intent of this report is to document the FRF survey program as a guide for future data collectors and users of these data.

15. SUBJECT TERMS
Beaches—Statistics, Beaches—Surveys, Coastal engineering, Data sets, Duck (N.C.), Oceanography

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