CHAPTER 257

A Comprehensive Field Study of Tidal Inlet Processes at Ponce de Leon Inlet, Florida

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1 Introduction

Traditional coastal engineering concerns at tidal inlets include navigation and channel maintenance. Today coastal engineers are faced with new concerns such as adjacent shoreline impacts, water quality, and wetlands preservation. The development of new engineering tools to address these problems depends on improved understanding of tidal inlet processes. A necessary component of this research is comprehensive field measurement of the complex hydrodynamic and sedimentation processes at tidal inlets (Mehta, 1995).

The field measurement work unit of the Coastal Inlets Research Program (CIRP) of the US Army Corps of Engineers is a coordinated effort to acquire a comprehensive data set of physical inlet processes. The measurements will be used to evaluate and refine existing process models and motivate new predictive methods. A wide range of approaches must be served by common measurements. These include physical, numerical, analytical, empirical, semi-empirical, and hybrid models. Field data are required for development, calibration, and validation.

This paper describes the planning, site selection, and design of the study. Preliminary results from the first year of data collection are presented. It is intended as a reference for investigators using the data. Problems as well as successes are described so that future studies will hopefully improve on the efforts described here.

2 Planning

2.1 Measurements

The Ponce study is the first major long term field study of a tidal inlet since the General Investigations of Tidal Inlets program (G.I.T.I.) of the 1970s. It is also the first to benefit from the major improvements in instrumentation and computer technology since that time. However a tidal inlet remains a difficult environment for field studies. The same conditions that cause hazardous navigation impact the installation and survivability of instrumentation. Rapid changes in bedforms

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make siting of in-situ gages difficult and mandate frequent surveys. The variety of measurements required to describe all of the interacting processes still exceeds todays measurement capabilities.

Careful planning of field experiments is required to match limited resources with conflicting needs. Approaches to field experiments are affected by the technical discipline and research interests of various investigators. For example, there is not a consensus on whether it's best to study a single inlet intensively or study several inlets with limited measurements.The planning of the Ponce experiment reflects the evolution of research from traditional tidal hydraulics problems to problems of decadal or longer time scales such as impacts on adjacent shorelines from dredging and other engineering activities. Today there is more emphasis on these longterm geomorphologic responses and the sediment transport processes that drive them. Measurement technology has improved in the areas of hydrodynamics but unfortunately, progress in sediment transport measurements has been much slower.

The approach which led to the Ponce study was based on applying an engineering design method to the field studies. Study proposals and measurement requirements documents were developed by each investigator. The requirements focussed on the end use of the data, rather than specific gages or surveys. Based on requirements, experiment plans were developed which attempted to meet as many requirements as possible. Gages and surveys were prioritized by the number and technical value of requirements they satisfied. The decision to initially concentrate on comprehensive measurements at a single inlet was based on cost/benefit analysis. There remains a need to examine variability between different types of inlets, but this will be left to future studies. The planning resulted in the following types of measurements:

- Water levels at the open coast, outer throat, inner throat, and back bay open boundaries.
- Directional wave measurements in the offshore, ebb shoal, and throat areas.
- Current measurements in the throat and on the ebb shoal.
- Wind velocity and barometric pressure.
- Bathymetry
- Beach profiles on the ocean side
- Sediment samples
- Long term monitoring of shoreline, breaker lines, and the shoals.
- Regular and post-storm aerial photography.

2.2 Site selection

Since the CIRP is a national program, there were many possible field study sites. The selection was based on technical merit by using a formal analysis that matched technical and operational requirements with the characteristics of candidate inlet field sites. Each investigator developed requirements for hydrodynamic and sedimentary characteristics of the study inlet. Operational and cost factors were also considered for each inlet.

The set of all U.S. inlets was reduced to 12 candidate inlets by establishing minimum requirements. From the research viewpoint, availability of historical data was a major factor. Relevance as demonstrated by real world problems representative of those faced by the Corps was important. Finally the inlet should have a manageable physical size for field operations.

A weighted requirements matrix analysis was employed to compute separate metrics for technical and operational characteristics of the candidate inlets. In the case of the technical requirements, the field study requirements were used to compute the weights. For operational and cost factors, weights were assigned based on a consensus of senior field technicians and project engineers.

The candidate inlets were ranked by operational score, technical score, and a combined score which was normalized to provide equal weight to the operational and technical factors. Separately each candidate inlet was evaluated to determine it's suitability for physical modeling. The major factor in this evaluation was the scale factor necessary to represent the inlet in available facilities. For some inlets, factors such as tide range and wave generation requirements were also important.

The results of the formal analysis ranked Ponce de Leon Inlet, Fl. highest. The recommendation was reviewed and accepted by all investigators, program managers, and sponsors. Experience during the first year of the field study has supported the selection. Ponce is a tidal inlet typical of the east coast of the U.S. It has a jettied entrance with a visible north jetty and a south jetty covered with sand. The design channel is $5m$ deep and $70m$ wide. Historically, the inlet has undergone significant evolution due to engineering activity and natural response. A substantial set of historic data is available (USAE Jacksonville District, 1993). Present engineering problems include dangerous navigation, potential breach locations, severe scour along the inside of the north jetty, inner bank erosion, and jetty sand bypassing problems. Many unique operational advantages at Ponce have been important in achieving a successful monitoring effort. These include undeveloped land south of the inlet, the Coast Guard Station close by, and a single tall condominum building near the inlet which was ideally sited for video monitoring. Ponce is a dynamic inlet which can be expected to undergo measureable changes during the lifetime of the study.

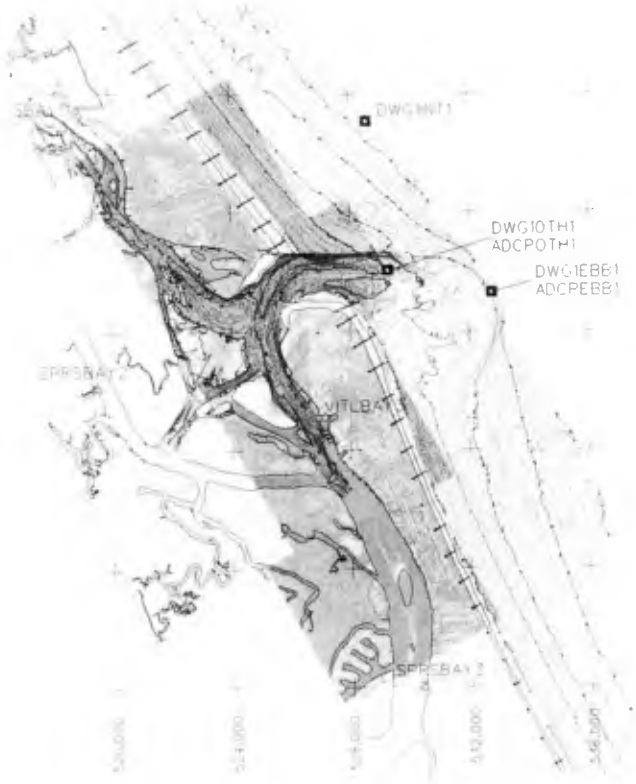

Figure 1: Ponce Inlet long term field measurements.

3 Instrumentation

3.1 Hydronamic gages

Figure 1 shows the layout of the long term instrumentation at Ponce. There are directional wave gages at three sites on the ocean side of the inlet. The site **DWG1INT1** is intended as a reference for incident waves. The gage is located in $14m$ of water north of the inlet in an area where the bottom contours are relatively parallel. The site **DWG1EBB1** is located on the face of the ebb shoal in approximately $7m$ of water. The site in the outer throat of the inlet is **DWG1OTH1**. Each of these sites has a DWG-1 (Howell, 1992) directional wave gage. The DWG-1 is a short-baseline pressure gage array. The pressure gages are Paros Digiquartz which provide accurate water level information. *PUV* type directional wave gages using electro-magnetic current meters were not used because of the high cost and difficulty of the regular cleaning. The Ponce area is regularly visited by shrimp trawlers, making the trawler resistant design of the

DWG1EBB1	Ebb Shoal	29deg 04.565min N, 80deg 53.902min W
DWG1INT1	North of Inlet	29deg 05.462min N, 80deg 54.620min W
DWG1OTH1	Outer Inlet Throat	29deg 04.605min N, 80deg 54.489min W
SPRSBAY1	Deepwater Marina	29deg 05.453min N, 80deg 56.432min W
SPRSBAY2	Utility Company (W)	29deg 03.944min N, 80deg 56.332min W
SPRSBAY3	Riverview Restaurant (S)	29deg 02.266min N, 80deg 54.299min W
VITLBAY3	Coast Guard Station	29deg 03.776min N, 80deg 54.909min W

Table 1: Map coordinates of the principle gage sites.

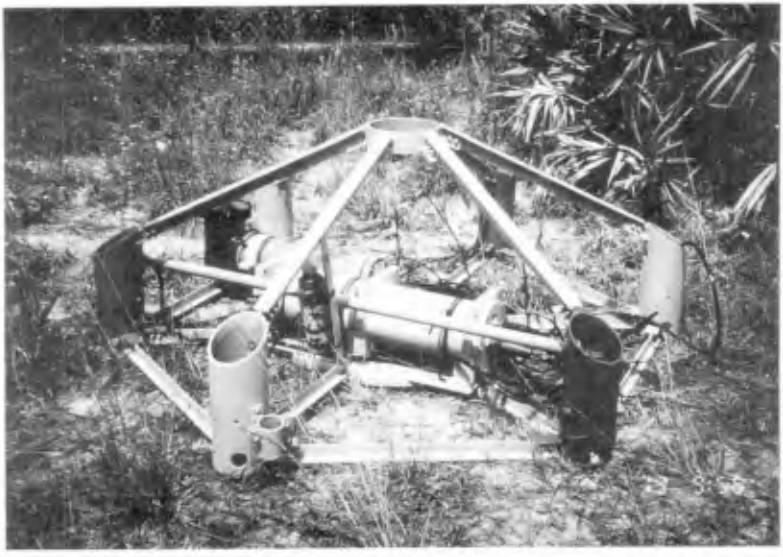

Figure 2: DWG-1 directional wave gage modified with a colocated ADCP (top right). Continuous digital time series data from both instruments are transmitted on a single cable.

Gage type	Sample period	Resolution
Directional Wave Gages	0.2-sec	2-mm
Current Profiler	1-sec	$1 - cm/sec$
Bay Water Levels	360-sec	1-cm

Table 2: Sampling periods for the hydrodynamic measurements. Record lengths are approximately continuous.

DWG-1 advantageous.

The ebb shoal site and the inlet throat site also have RDI [2] broadband 1200kHz Acoustic Doppler Current Profilers (ADCP) located on the same mounting pod as the DWG-1. Figure 2 shows the right angle upward looking style ADCP used. The ADCP is configured for continuous real time output at a $1Hz$ sample rate and $1m$ vertical bins. The combined DWG-1 and ADCP share the same cable for both power and data output. All data recording is continuous, real-time via the cable. The internal recording modes of the instruments are not used.

Water level data in the inner bay is provided by Paros Digiquartz pressure sensors. The sensors are mounted in a steel protective sleeve sleeves are attached to a fixed length pipe which is used to mount the sensors to a pile. The top of the pipe has a reference mark which can be surveyed to establish the datum for the water levels. Both the offshore water levels (from the DWG-1) and the inner bay water levels use absolute pressure sensors which require compensation for barometric pressure. Another Paros sensor is used as the principle barometric pressure measurement and is recorded simultaneously with the water level sensors. A backup barometric measurement is available from the meteorological station installed on the north beach[3]The meteorological station is provided by the Battelle institute. A standard stilling well tide gage is located at the Coast Guard Station (**VITLBAY3** in Figure 1). This gage uses an air acoustic sensor and provides a check on the air pressure corrections and datums for the pressure water level sensors.

Datums for the offshore water levels obtained from the DWG-1 wave gages were not surveyed like the inner bay gages. Instead data analysis of six months of data was used to estimate the datums. The technique is based on an iterative minimization of the residuals between the Coast Guard Station tide gage (**VITLBAY3** and the offshore water levels. The technique selects data windows at slack water when the inner and outer water levels approach equality. The method produces accuracies comparable to that obtained with conventional surveys. Details of the method will be provided in a future publication.

Table 1 lists the locations of the principle measurement sites.

[2]RD Instruments, see `http://www.adcp.com/` for additional information.

[3].

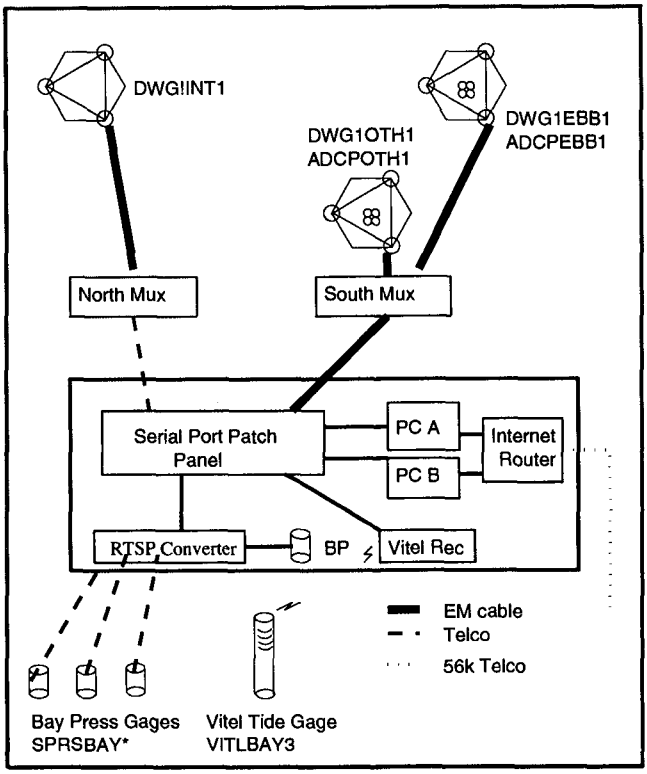

Figure 3: Diagram of the Ponce hydrodynamic gage data acquisition system.

3.2 Time series data acquistion

Table 2 gives the sample rates and resolution of the measurements. All data are acquired continuously. However some of the routine analysis use shorter record lengths. For example directional wave spectra are computed using 34 minute records windowed from the available 59 minute records.[4] All data analyses are performed at least hourly. Data from all of the time series gages are logged by a single computer located in a leased trailer at the Coast Guard Station. The trailer is connected to the Internet via a 56k Baud leased line to the Jacksonville COE District office in Jacksonville. Figure 3 shows the layout of the connections from the gages to the central logging computer. Most of the connections are through

[4]A variety of analysis products are produced from the Ponce data. Users should check the analyses parameters used for the particular product rather than relying on the general description here.

cable installed for the experiment or local leased telephone lines. This design was used instead of radio telemetry because experience in previous projects has shown that wireline installations provide higher data return at a lower maintenance cost than telemetry. Another reason for use of a central computer facility was the desire to preposition the infrastructure that would be required for a larger short term experiment. Without this requirement a design based on several outdoor Remote Transmission Units (RTUs) could have been used.

All of the data logged by the central computer are acquired through serial ports. The computer is a standard industrial rackmount PC computer. A multiport serial card is installed to provide extra ports. There are three identical computers installed. Two of the computers are operational all of the time and have the serial data arriving continuously. Logged data from one of the computers is transferred over the Internet link to a computer in Vicksburg which is configured with a standard data acquisition, analysis and storage system known internally as PMAS (McKinney and Howell, 1996). Should a failure of the principal computer occur, data are automatically acquired from the backup computer. The third computer is installed and tested, but disconnected from power, network, and serial lines. It can be manually configured to replace either of the two operating computers. This mode is used to protect this machine from lightning surges which overpower the surge protection devices.

The software for the PC compatible computers logs the data from each serial port to files. The Posix compliant Linux[5] operating system provided most of the building blocks for the system. Customized code was implemented primarily with shell scripts. Procedures too complex for shell scripts were implemented as Ada programs using the freely available GNAT Ada compiler[6]. The software is configured to operate completely unattended. Status information is available at any time on-site or remotely using the *finger* command. Automated email messages are sent to advise of any unusual situation or error. A status monitor implemented as a shell script runs continuously on the computer in Vicksburg. It uses a combination of the *finger* and *traceroute* commands to detect problems at the site and network outages. Automated email messages are also sent by the Vicksburg monitor computer to warn of problems.

3.3 Problems and performance

The general performance of the hydrodynamic monitoring system has been very good. The data acquisition system has achieved over 99% reliability. The ebb shoal directional wave gage and ADCP experienced a cable failure during the March 1996 storm. The failure was caused by incomplete disassembly of the instrument by unauthorized divers. The instrument located in the throat of the

[5]A freely available Unix like operating system which runs on PCs. See `http://www.li.org/` for additional information.

[6]GNAT is a the Free Software Foundation Ada 95 compiler. See `http://www.gnat.com/` for additional information.

Figure 4: The SHOALS helicopter Lidar bathymetric system. The Pod on the bottom of the helicopter contains the laser, scanner, and optics. The computers and operator's consoles are located inside the helicopter.

inlet has experienced periodic burial by sand. The directional wave gage continued to yield useful data. However the sand cover which ranged from 1-2m rendered the ADCP data unuseable. Relocation of these instruments is under consideration. Some problems have been encountered with the Vitel tide gage in setting its range to accomodate the extreme highs and lows of the water levels. These problems have been easily corrected but compromise the peak tide data until correction. After an initial period of working with the telephone company to debug the leased telephone lines, the bay pressure tide gages have been very reliable.

Data analysis of the wave and water level gages has been generally routine. However the Ponce system is our first experience with continuous time series data from multiple ADCPs. Automated analysis and quality control software was not available at the beginning of the study. Development of this software is underway, but will require extensive effort before its performance is comparable with existing wave and tide measurement software. ADCPs have the potential to provide details of both mean and orbital velocities, as well as suspended sediment concentrations. As better analysis tools become available these measurements should become feasible.

4 Spatial monitoring and surveys

4.1 Bathymetry

The Ponce study is fortunate to have available a powerful new tool for coastal engineering work, the helicopter Lidar bathymetric system. The system developed by the Corps of Engineers is known as SHOALS. Irish *et al.*(1996) in this Proceedings provides a detailed description of the SHOALS system and its use for monitoring volume changes at inlets. Figure 1 shows bathymetry obtained from the SHOALS system. The detailed and rapid coverage provided by the laser system allow the details of the complex bottom topography of the inlet system.

A Lidar system operates by measuring the time difference between the reflection of a laser light pulse from the water surface and the bottom. Scanning the laser allows coverage of a $100m$ swath as the helicopter moves across the survey area. Figure 4 shows a photograph of the SHOALS system mounted on the survey helicopter. The accuracy of SHOALS is continually being evaluated and improved. Experience at Ponce shows that accuracies are already comparable with that of traditional fathometer surveys. Improved GPS technology now allows SHOALS to survey the above water portions of the beach profile. The accuracies of this capability are currently under evaluation.

The main limitation of Lidar technology is dependence on water clarity. At Ponce there have been periods where surveys could not be performed because the water was too turbid. Turbidity problems were most severe near the throat and in the back bay. Turbidity can be caused by a variety of weather conditions. These include storms which suspend large quantities of sediment. The rapid survey capability of SHOALS makes it ideal as a post-storm survey tool, however turbidity will prevent its use during the storm and the recovery period immediately afterwards.

4.2 Shoreline response

Monitoring of the long term shoreline response is performed using previously developed techniques. Data are acquired from

- Color digital aerial photography
- Wading beach profiles
- Continuous video monitoring

The aerial photography and beach profiles are combined with the SHOALS bathymetry in a Geographic Information System (GIS) database. Once in the GIS, standard tools such as differencing and volume change mapping are applied. As longer records become available, the GIS will be used as a tool to help manage the spatial data and facilitate correlations with the hydrodynamic forcing.

Figure 5: Video photo looking out from the top of the condominium toward the inlet channel and jetties. The photo is a result of a timed exposure which causes the breaker lines to appear as white streaks.

Potential development of inlet response models require long term data of shoreline position that is sampled more frequently than annual or semiannual beach surveys. One approach that has been applied to beaches on the open coast is video monitoring. Konicki and Holman (1996) describe the technique in a paper in this Proceedings. For the Ponce experiment, five video cameras were mounted on top of a condominium on the south side of the inlet. The cameras provide views of the up and down coast beach, the throat, ebb shoal, and flood shoal. Figure 5 shows an unrectified view from one camera of the channel and jetties. The photo is the result of a six minute time averaged exposure. Averaging highlights wave breaking zones as white bands. By processing many such photos, shoreline, bar, and shoal positions may be tracked.

The usefulness of the video data has not yet been demonstrated. Long term records and substantial efforts in data analysis are required. If successful, results from this monitoring will appear in future publications.

5 Sample storm data

Figure 6 shows waves from both the offshore gage and the wave gage in the throat of the inlet. This storm occurred in March 1996 and was unusual in that the wind

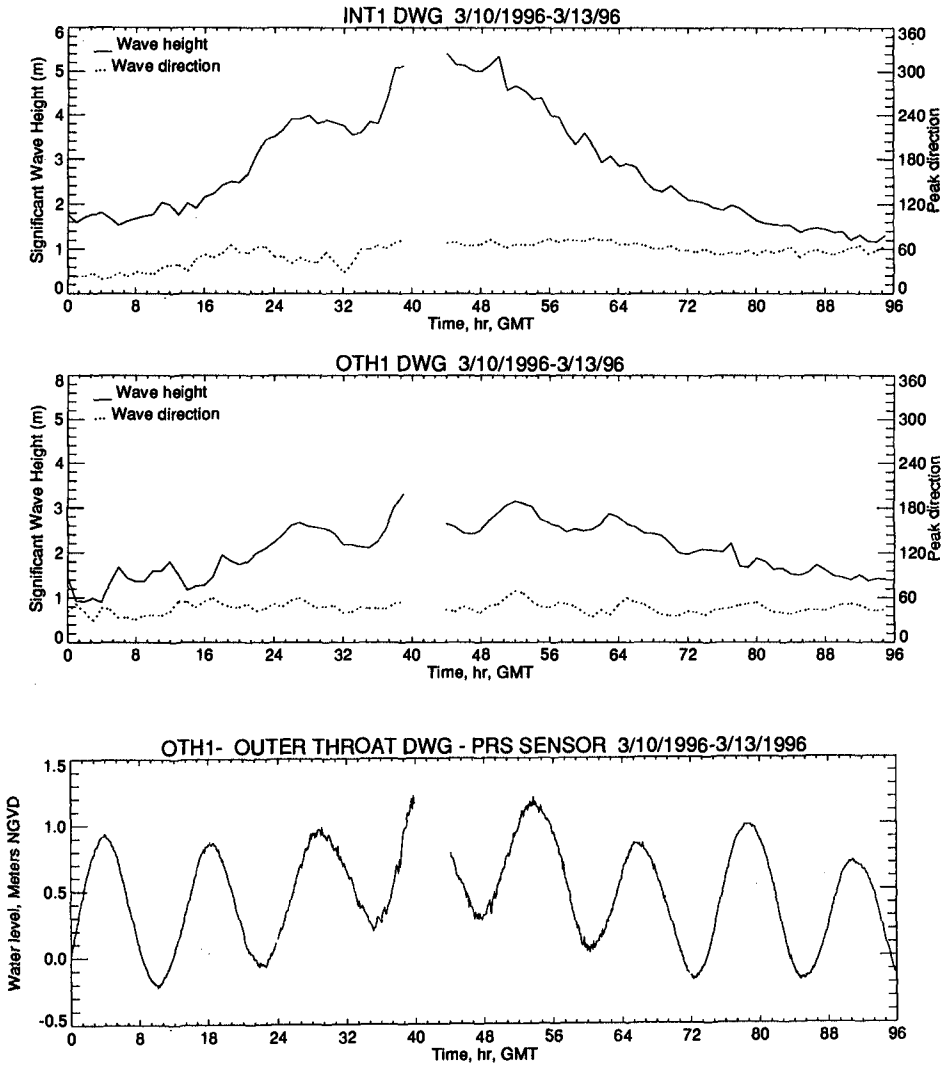

Figure 6: Inlet wave shoaling during a large storm. Note the modulation of wave height by water level in the throat (**OTH1**).

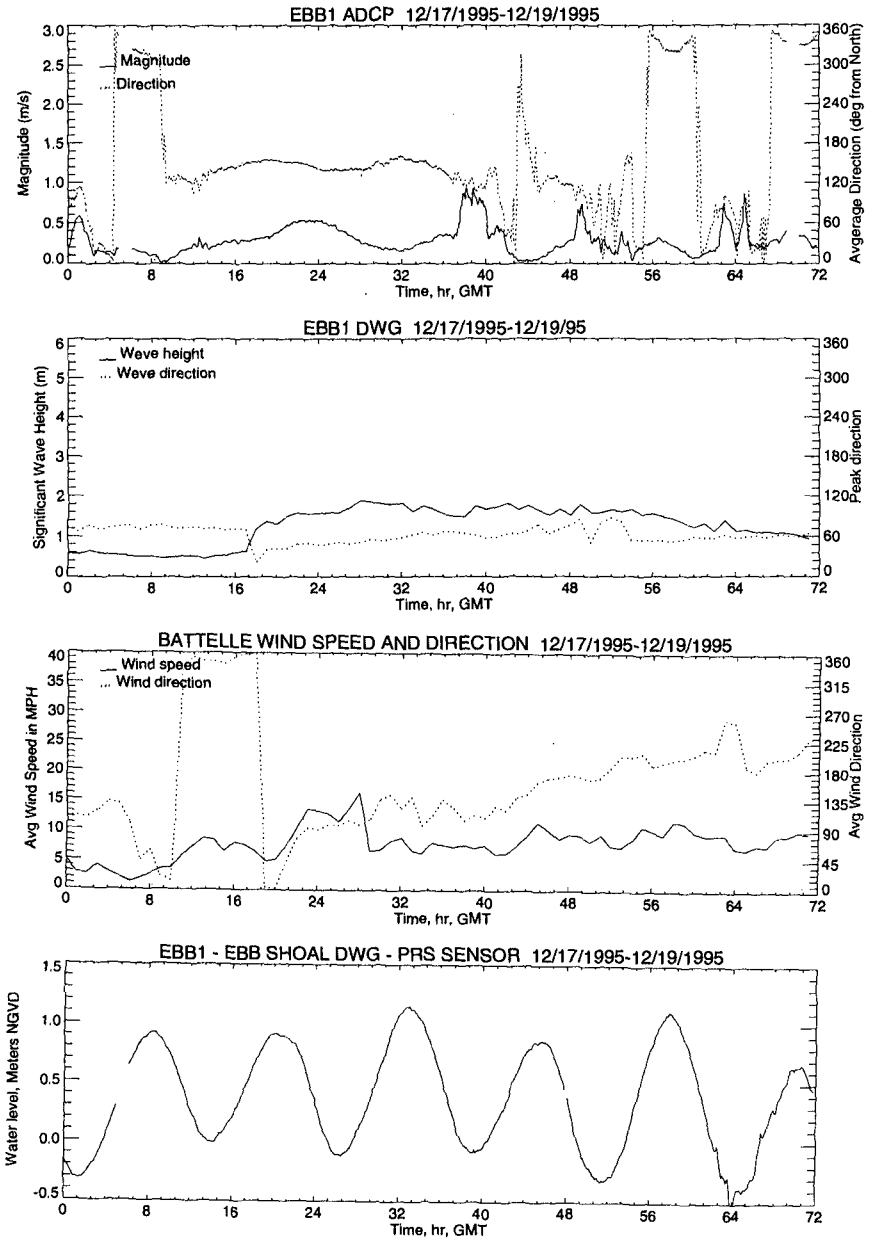

Figure 7: Ebb shoal waves and currents. Note the wind and waves driven currents as well as tidal currents.

direction stayed fairly constant as can be seen by the wave direction. The throat waves show both the effects of shoaling and the sheltering of the north jetty. The modulation of the wave height by the tide confirms the importance of water levels and tidal currents in predicting waves in inlets.

Figure 7 shows vertically averaged mean currents on the ebb shoal during a moderate Nor'easter. The beginning and end of the record show tidal currents dominant as is the ambient condition. As the wind and wave directions change, the tidal component of the mean current is strongly influenced.

Additional data analysis is currently underway and will be reported by the program investigators. The data already acquired provide confirmation of the complexity of the hydrodynamic and sedimentary processes at Ponce inlet.

6 Acknowlegements

Many people made important contributions to this study. Bill Grogg, Trap Puckette, Sam Corson, Pat McKinney, Rhonda Lofton, Kent Hathaway, Jeff Lillycrop, and Tom Martin all played key roles. The U.S. Coast Guard Station, the Inlet Condominium, the Battelle Paint testing facility, and many other public and private land owners made their property and facilities available. This work was supported by the Coastal Inlets Research Program of the US Army Corps of Engineers. Permission for publication was granted by the Chief of Engineers.

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