DIRECTIONAL WAVE AND CURRENT MEASUREMENTS DURING HURRICANE HUGO

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ABSTRACT

Wave and Current measurements during extreme dynamic sea conditions has always been a difficult task. Survivability of the instruments and their moorings has been, at best, tenuous. When data is collected, the reduction and processing time is usually lengthy, requiring the use of main frame computers.

This paper describes the mooring, set-up, and results obtained from an S4 Current Meter deployed adjacent to an underwater habitat during the passage of HURRICANE HUGO. The S4 was deployed on a simple bottom mount in 60 feet of water. The instrument was programmed to record one second samples of vector current speed and wave data for 18 minutes every two hours. Three days of data were recorded covering the onset and passage of HUGO. The data was retrieved and preliminary processing was completed using a 386-based PC. Mooring details and the storm affects on the mooring will be described. Sample processing results of directional wave spectra will be presented to demonstrate what can be accomplished using off the shelf state-of-the-art instruments and personal computers.

INTRODUCTION

The National Undersea Research Center at Farleigh Dickinson University, under the sponsorship of NOAA, maintains an underwater habitat positioned 60 feet below the surface between two coral-covered walls on the sand plain of a submarine canyon off St. Croix in the Virgin Islands. The research goals of NURC-FDU are to contribute to the further understanding of marine coastal ecosystems. Of the many data measurements utilized in this endeavor, wave and current measurements are used to describe forces present in the canyon as related to the benthic ecology. The passage of HURRICANE HUGO directly over St. Croix presented an unusual opportunity to collect directional wave and current data under extreme conditions.

On 15 September 1989, St. Croix was placed under a Hurricane Watch which was later upgraded to a Hurricane Warning. An S4 Current Meter had been deployed five meters from the West wall of Salt River Submarine Canyon at a depth of 60 feet in support of scientists from the University of Cinncinatti studying sediment transport. The scientific mission, which was to have begun on Friday, 15 September, was cancelled and preparations were made to secure for a possible hurricane. On Saturday, 16 September, the S4 Current Meter was recovered, and the data collected for the mission was retrieved. The S4 was then re-programmed to collect data on the storm.

OVERVIEW OF THE S4 CURRENT METER

The S4 Current Meter is solid state electromagnetic current meter housed in a 25cm diameter spherical enclosure with no protruding sensors. The instrument may be programmed and data retrieved via a standard RS232C serial connection to a terminal or computer. The S4 is a true vector averaging instrument, sampling at a one half second rate. The user may program the averaging period, on time duration, and recording interval. Options installed on the instrument used for ths deployment included 256K bytes of CMOS non-volatile memory, 70 meter depth sensor with 14 bit resolution, conductivity, and temperature. Conductivity and temperature were not used for the purposes of this deployment. For further information on the theory and operation of the S4 Current Meter refer to 'THE DEVELOPMENT OF A SPHERICAL ELECTROMAGNETIC CURRENT METER' by Lawson et al[1].

INSTRUMENT SETUP AND DEPLOYMENT

The meter was programmed to record one second averages of the half second sample rate for 18 minutes every two hours. This was done to provide adequate data for later analysis using special Directional Wave Processing Software developed at InterOcean Systems, and to best utilize the 256K memory of the S4 Current Meter over the greatest time. Measurements of current velocity, current direction, depth, and conductivity were collected.

At 1500 hours on 16 September, Glenn Taylor and William Thorn dove in choppy seas to deploy the S4. The meter was mounted on a cement baseplate, weighing 60 pounds, with a PVC pipe extending upward. The mooring rod was secured to the PVC pipe with a bolt. The baseplate was secured to a coral reef outcropping up the canyon from the meter. The Current Meter pad-eye was secured with a separate line which was tied to a canyon navigation line. The baseplate was located on the sand floor of the canyon at a depth of approximately 60 feet of seawater (18.5 meters), 12 feet (four meters) out from where the West canyon wall meets the sand floor of the canyon.

Figure 5 is a photo of the S4 being installed on the cement baseplate. Figures 1 and 2 are maps showing the location of St. Croix and the Salt River Canyon. Figures 3 and 4 are charts of the S4 location in the Salt River Canyon.

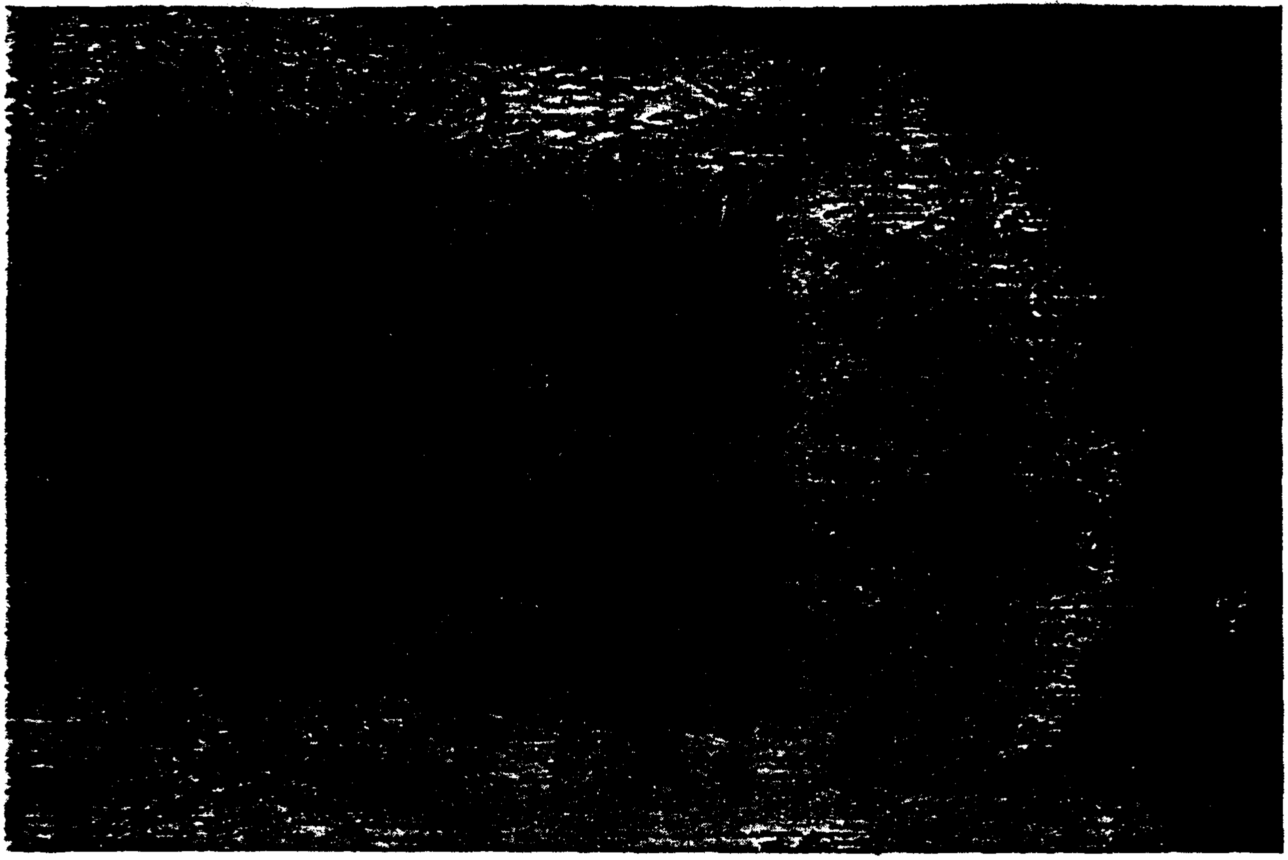


Figure 1

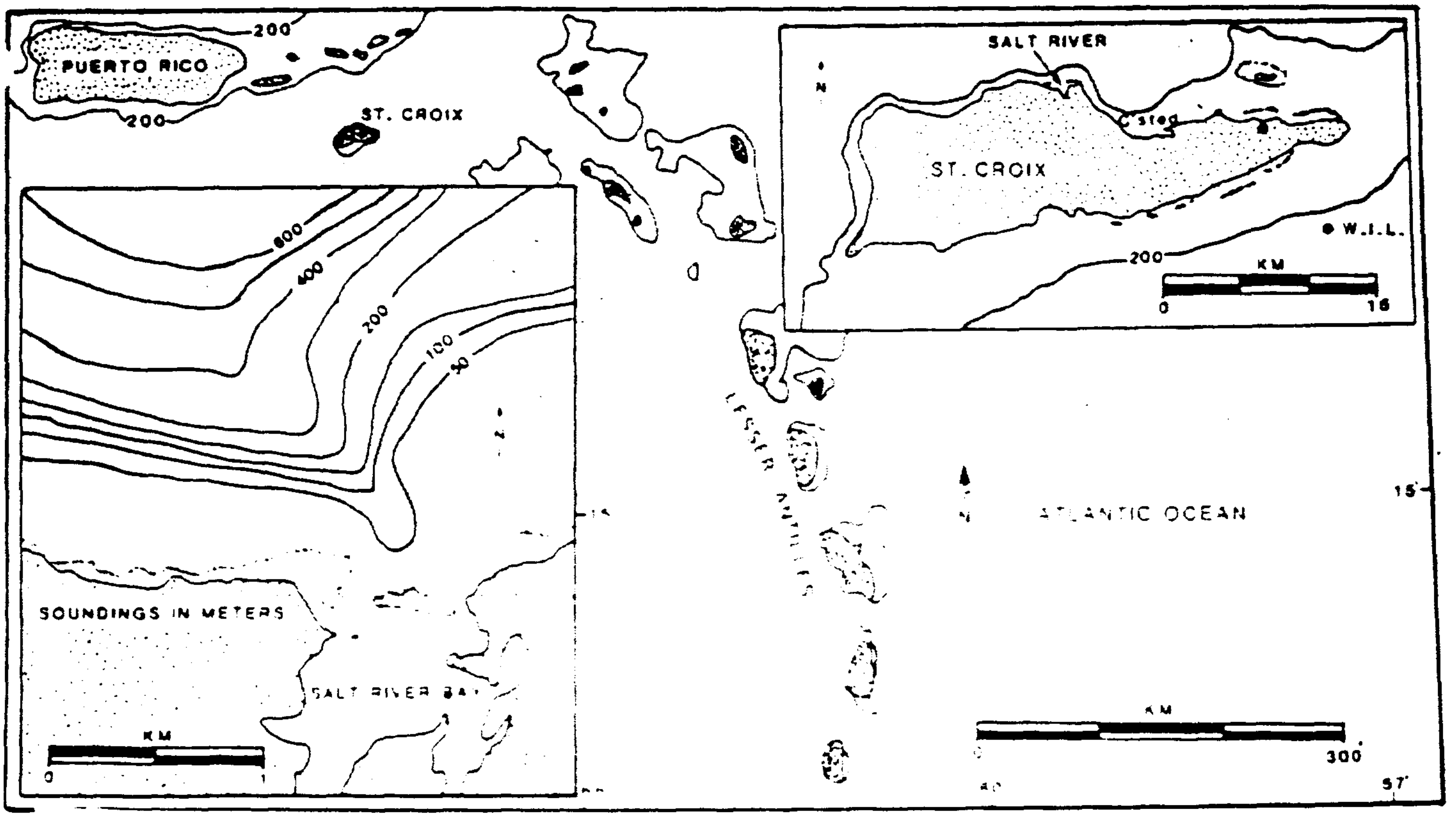


Figure 2 Map showing the location of Salt River Submarine Canyon. Cristiansted Submarine Canyon is also shown.

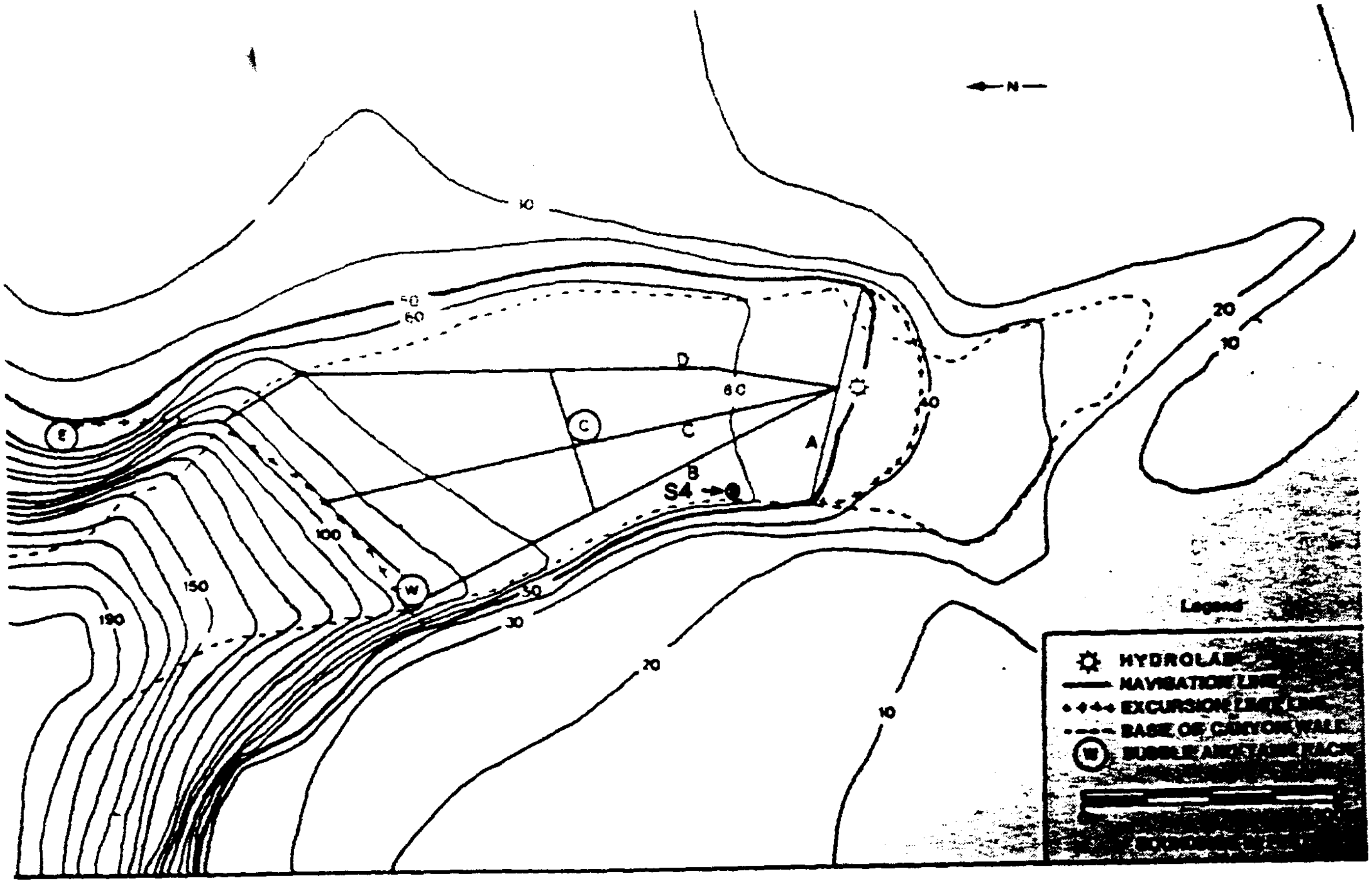


Figure 3 Topographical canyon map and navigation grid system.

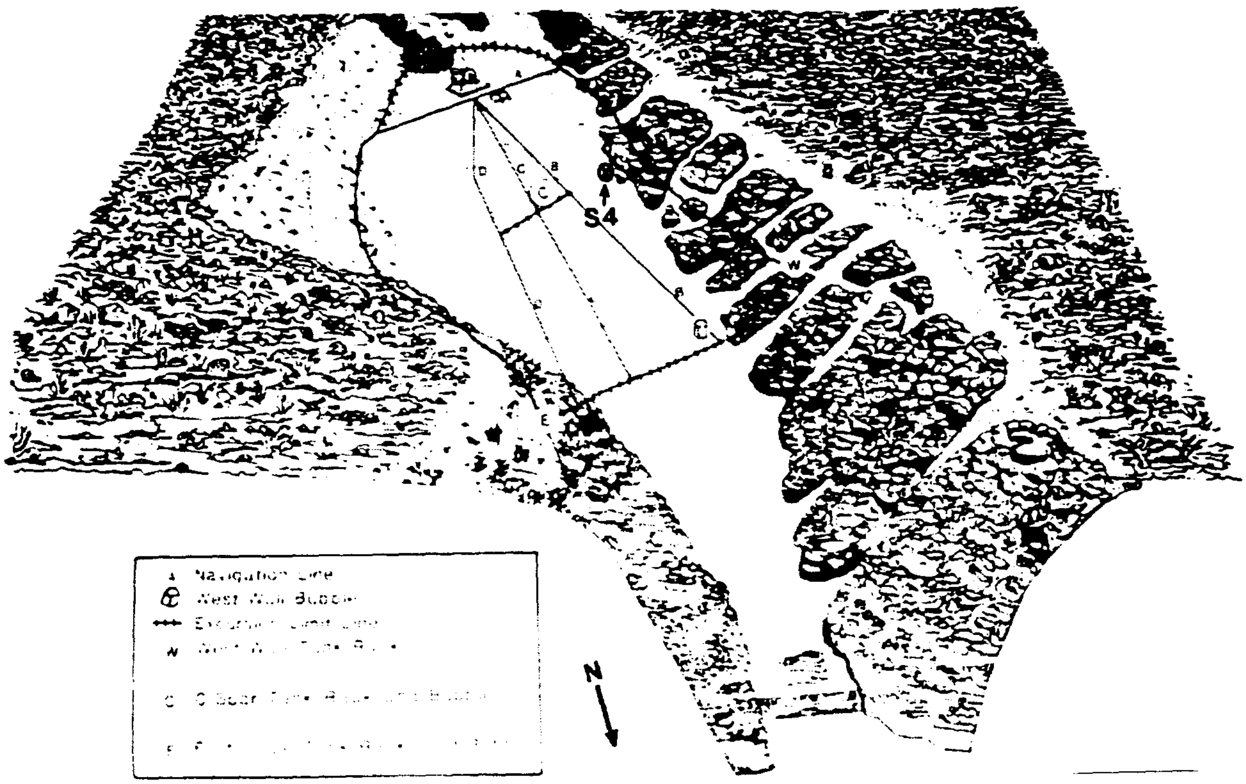


Figure 4 Artists conception of Salt River Submarine Canyon.

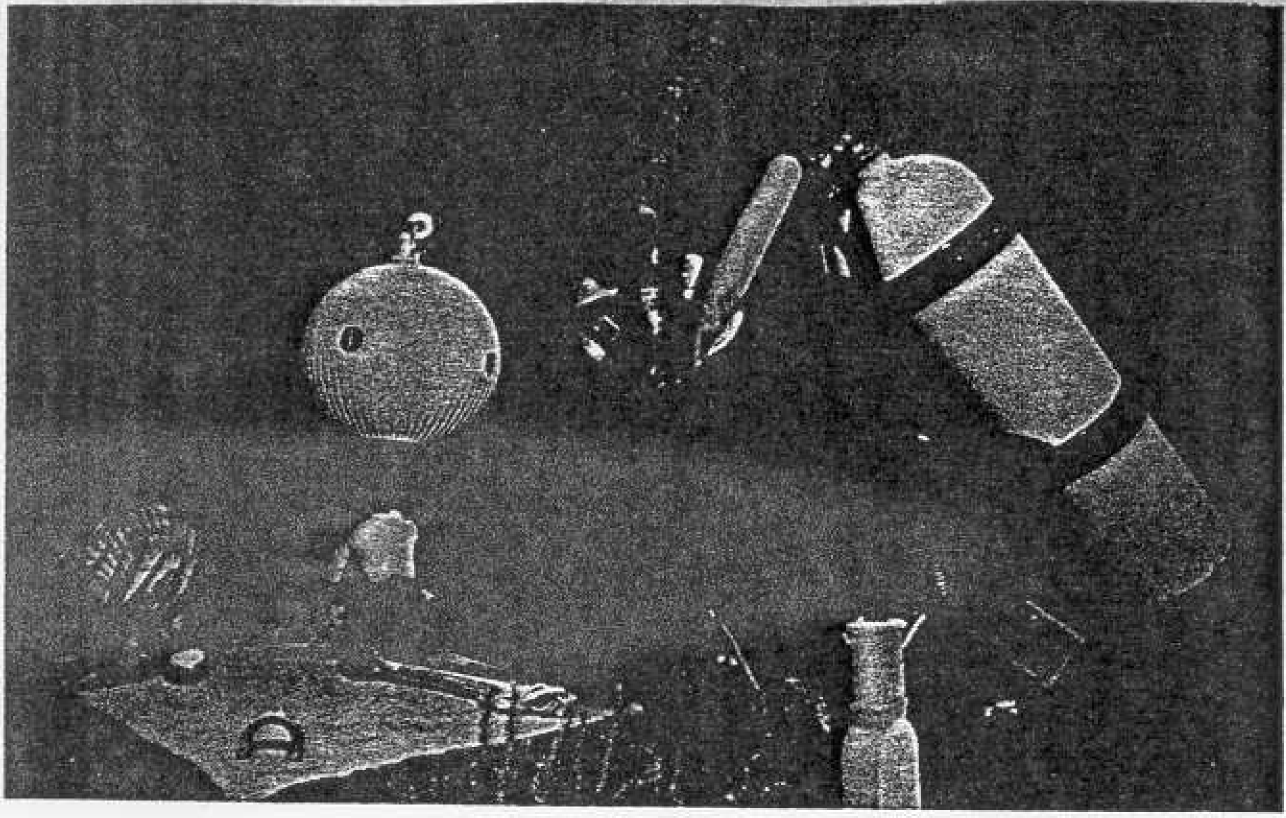


Figure 6

OBSERVATIONS DURING STORM PASSAGE

Easterly winds were strong on the morning of 17 September and increased to gale force by afternoon, at which time, the author observed from shore and from a vessel on the Salt River estuary, that the entire East Slope area of the canyon was breaking. At 2200 hours on 17 September the eye of the hurricane was approximately 40 miles south east of St. Croix and it had slowed from 15 miles per hour to eight miles per hour. The eye of the hurricane came ashore along the South shore at approximately 0230 hours, 18 September and exited the West end of St. Croix at approximately 0400 hours. The hurricane destroyed homes, tore off roofs, blew out windows, and totally crippled power and communications. During passage of HUGO sustained winds of 140 miles per hour were recorded with gusts over 200 miles per hour measured at the East end of the island, Hess Oil Refinery, and at the airport.

INSTRUMENT RETRIEVAL

On 22 September, Glenn Taylor and Steve Miller, the Science Director for the National Undersea Research Center, recovered the S4 Current Meter. The meter and baseplate were still intact. However, they had moved laterally 10 feet (three meters) on the sand bottom toward the West wall of the canyon. The current meter and baseplate were upright and still attached to the lines, although the assembly had trapped some debris (leaves, coconuts, palm fronds, sea fans, and sponges). Newly exposed substrate along the wall indicated scouring and sand transport. In the data it was noted that the starting and ending depths differed by about one meter indicating the extent to which the entire bottom in that area had dropped. Further along the canyon to the North the depth of scouring reached four meters

The data were retrieved using a car battery to power the S4 interface and a gas generator to power an IBM pc. The data set was transferred to a floppy disk and forwarded to InterOcean Systems for additional analysis.

PRESENTATION AND REVIEW OF DATA

A full analysis of the data and the geophysical implications are not the subject of this paper but will be presented by others in future publications. Highlights of selected portions of the data will be presented in various formats to show how the newer generation instruments such as the S4 or S4DW along with intelligent application software running on personal computers provides a means to collect data and produce processed results with less effort and in less time than previously possible. The S4 Current Meter began logging at 1433 hours on 16 september, 1989. The instrument continued to log data until 1041 hours on 19 September, 1989 at which time it filled memory and automatically shut down. The number of samples recorded was 37,201. Since the data was recorded in 18 minute bursts every two hours, and each burst consists of 1,080 samples, this corresponds to 34.44 burst periods. The first 18 minute burst period was recorded prior to installation on the sea floor leaving 33 complete burst periods for Directional Wave analysis.

The data was reviewed by first scanning and plotting the raw vector current speed and direction, and depth records for the entire recorded period and then plotting this same data for each six hour interval. This was done to verify the integrity of the data prior to processing for directional wave analysis.

RAW DATA PRESENTATION

Figures 6a, 6b, and 6c are graphic plots of the Current Speed/Direction and Depth data for the entire recording duration. Figure 6a is a plot of vector magnitude and direction versus sample number. Figure 6b is a plot of the North and East vector speed components versus sample number. Figure 6c is a plot of the instantaneous water depth values versus sample number.

Figures 7a through 17b are plots of expanded portions of the data shown in figures 6a through 6c. Figures 7a, 7b, and 7c cover the first three burst intervals (six hours) following the instrument deployment. Figures 8a through 15c include the buildup of the storm and the passage of the eye of the hurricane over the island. Figures 16a through 17b shows data collected for six hour period starting 12 hours after the passage of the eye of HURRICANE HUGO over St. Croix. The burst numbers are indicated with the figure numbers to assist in correlating the raw data with the processed directional wave data.

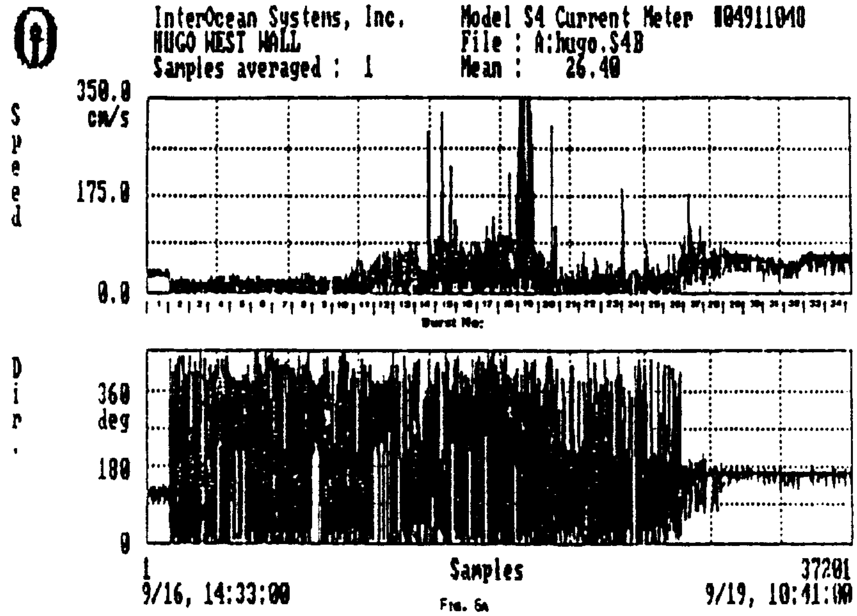


Fig. 6a

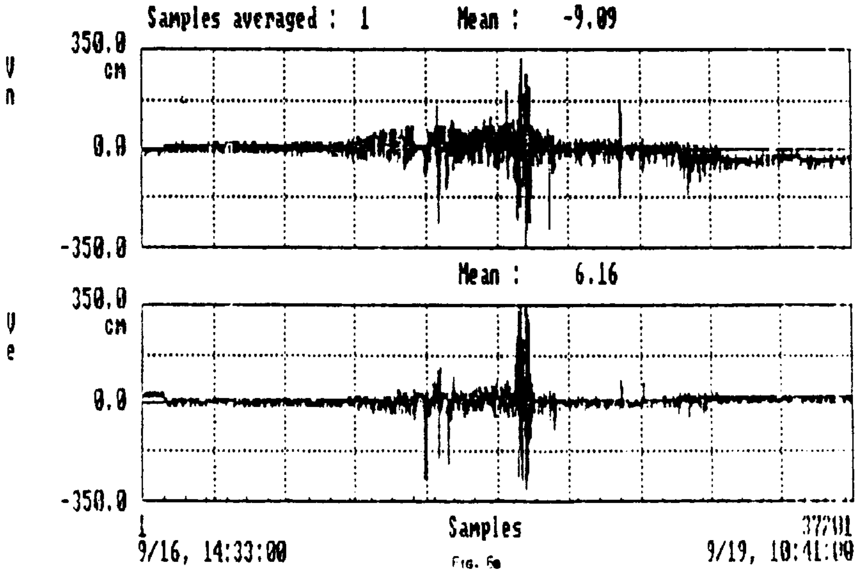


Fig. 6b

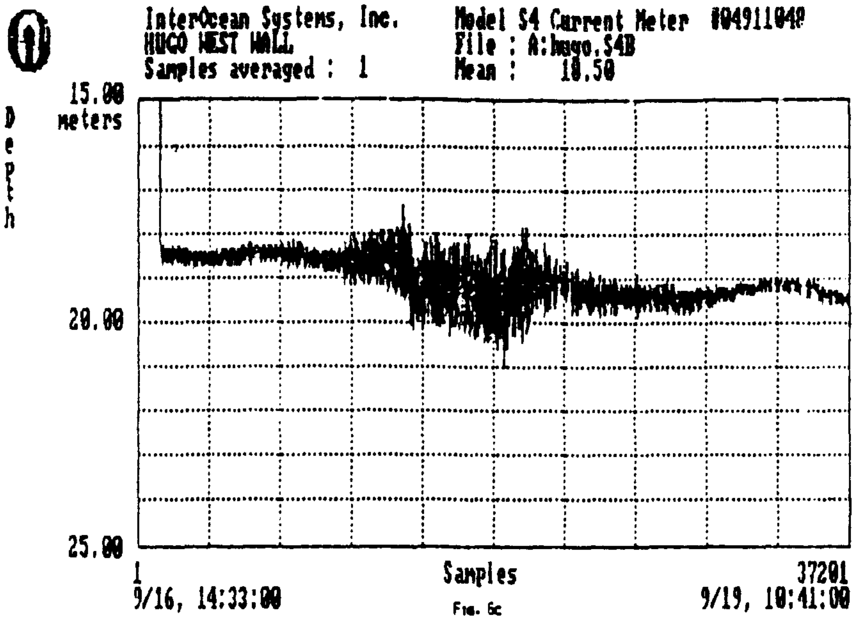


Fig. 6c

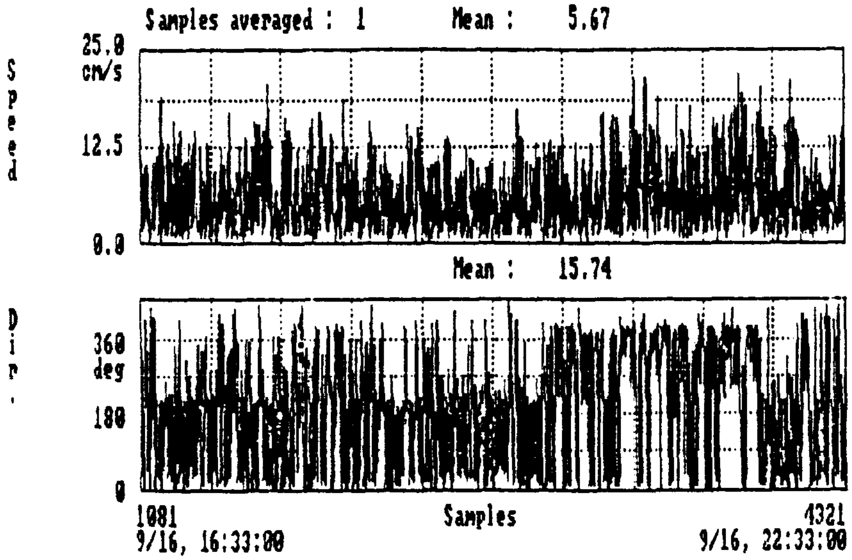


Fig. 7A Bursts 2, 3, & 4

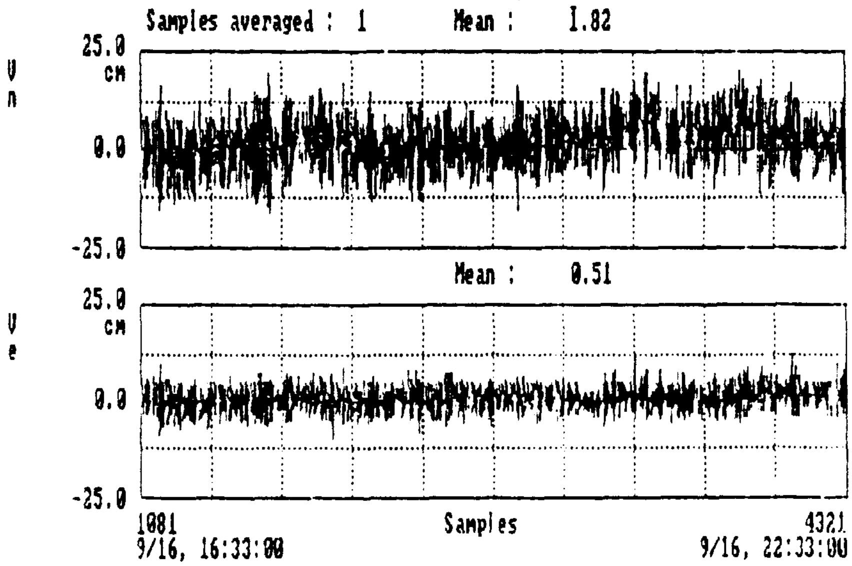


Fig. 7B Bursts 2, 3, & 4

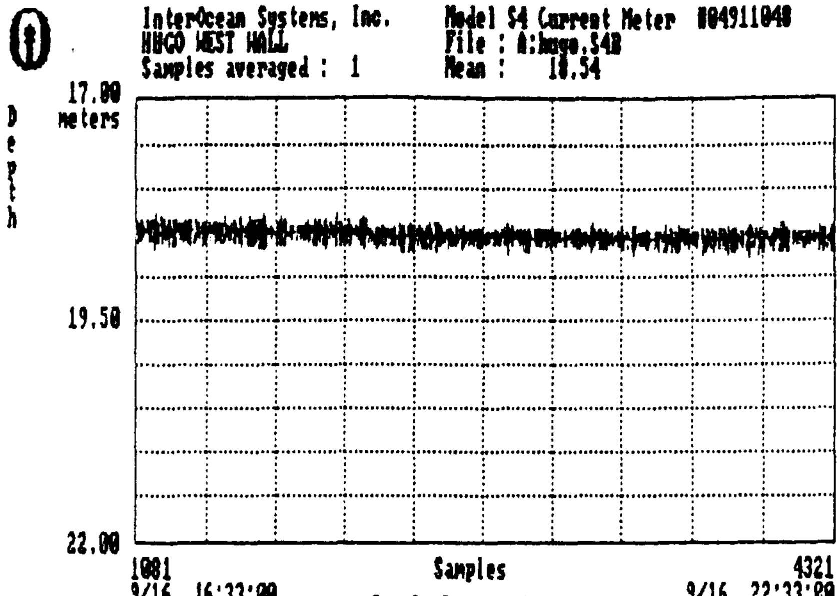


Fig. 7c, Bursts 2, 3, & 4

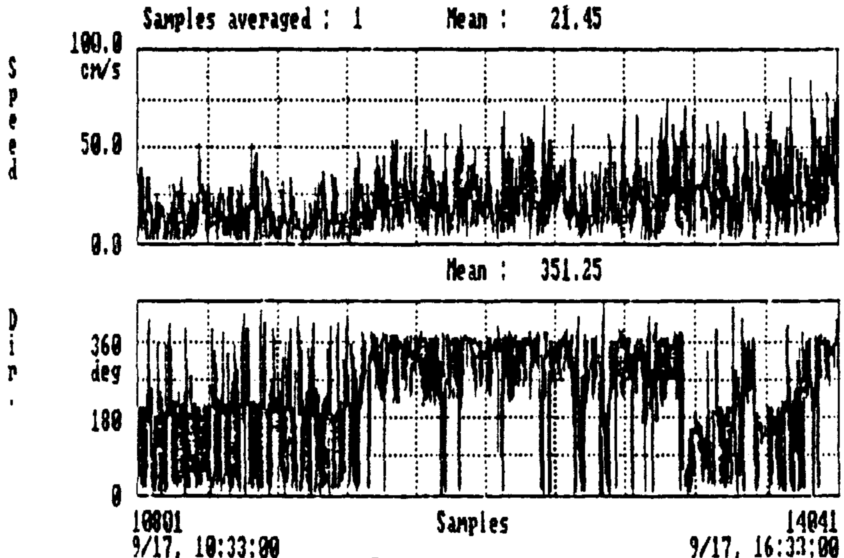


Fig. 8a Bursts 11, 12, & 13

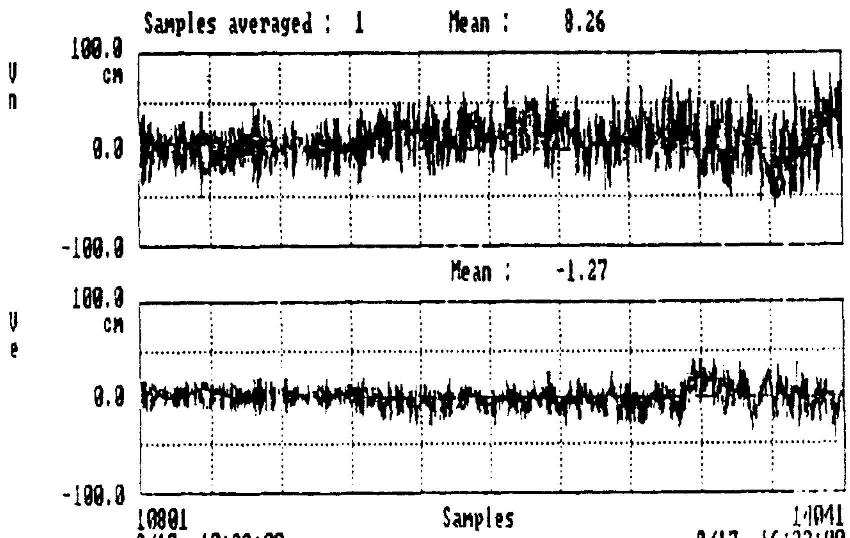


Fig. 8b Bursts 11, 12, & 13

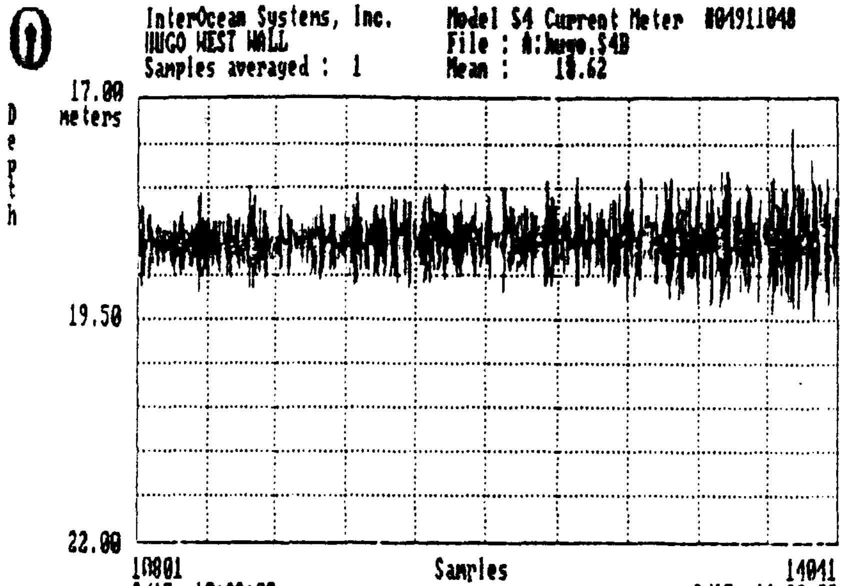


Fig. 8c Bursts 11, 12, & 13

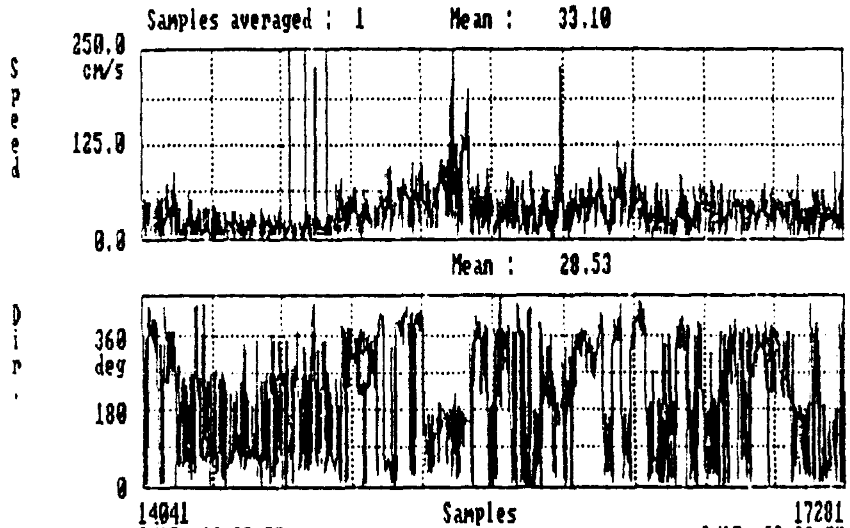


Fig. 9a Bursts 14, 15, & 16

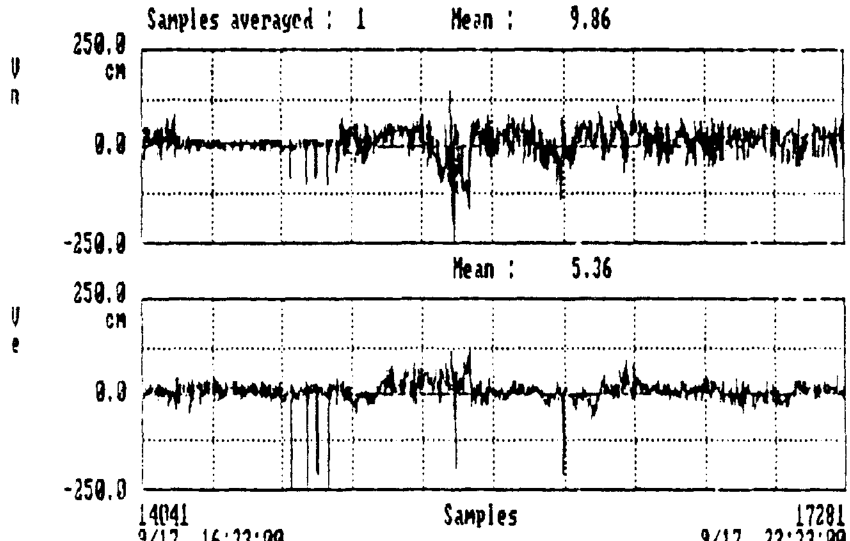


Fig. 9b Bursts 14, 15, & 16

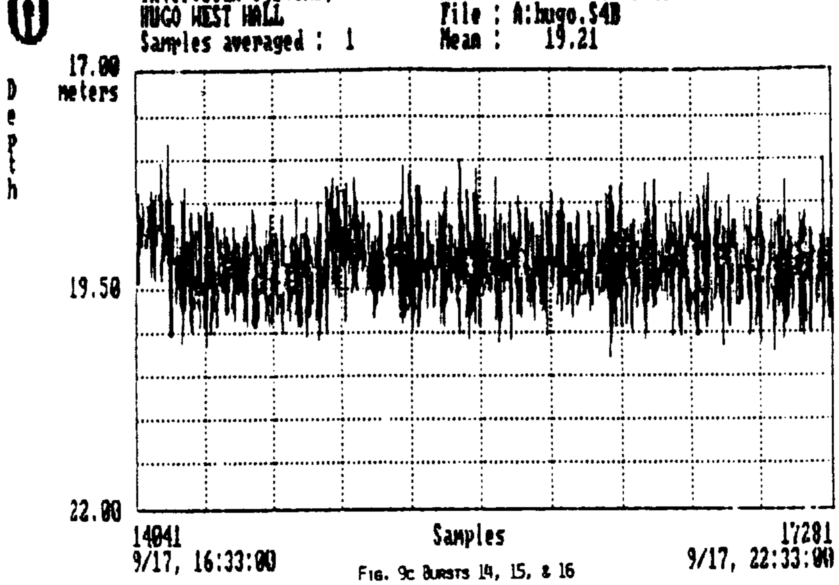


Fig. 9c Bursts 14, 15, & 16

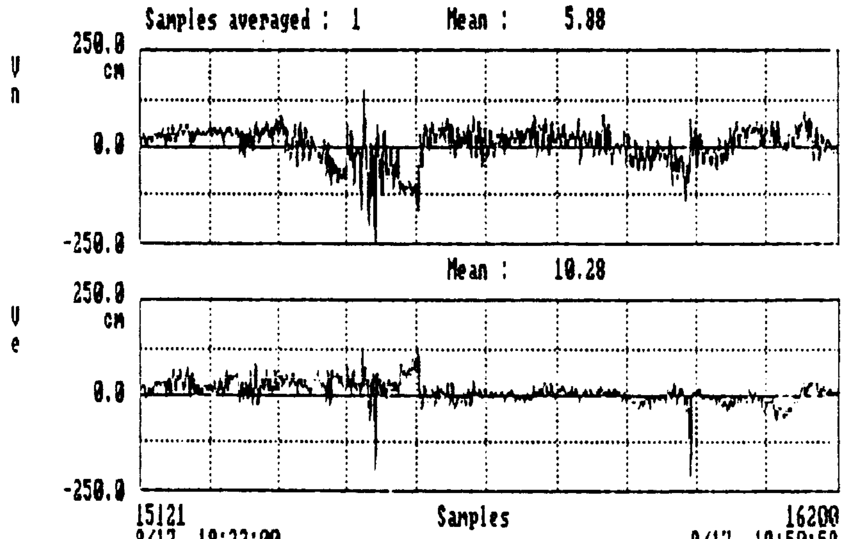


Fig. 10a Burst 15

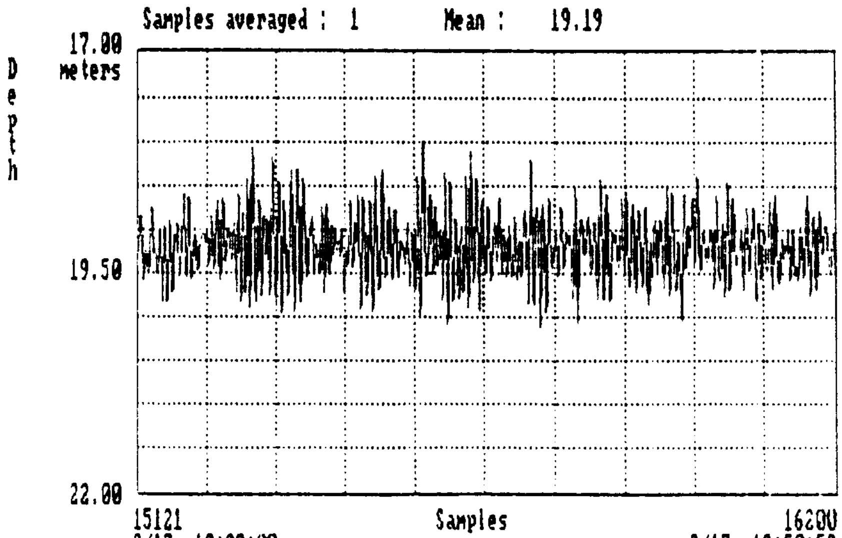


Fig. 10b Burst 15

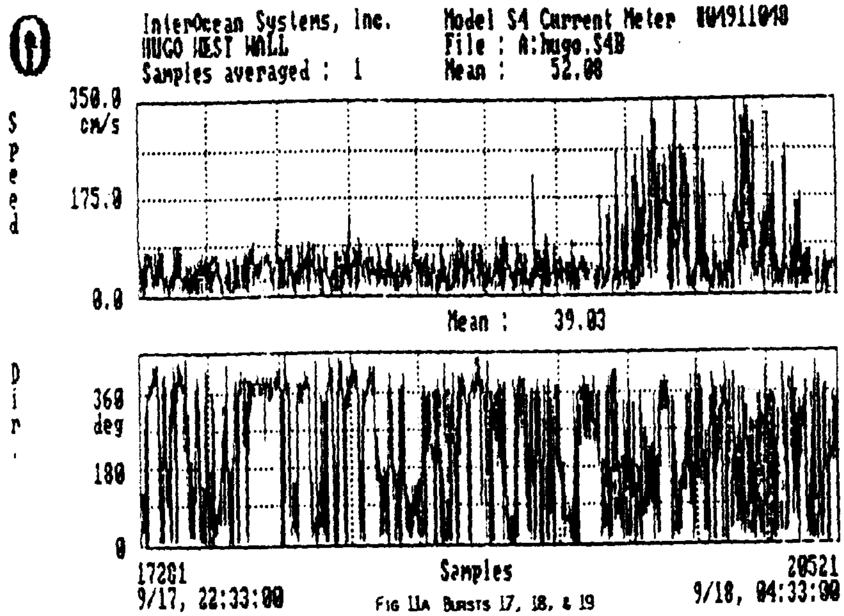


Fig 11a Bursts 17, 18, & 19

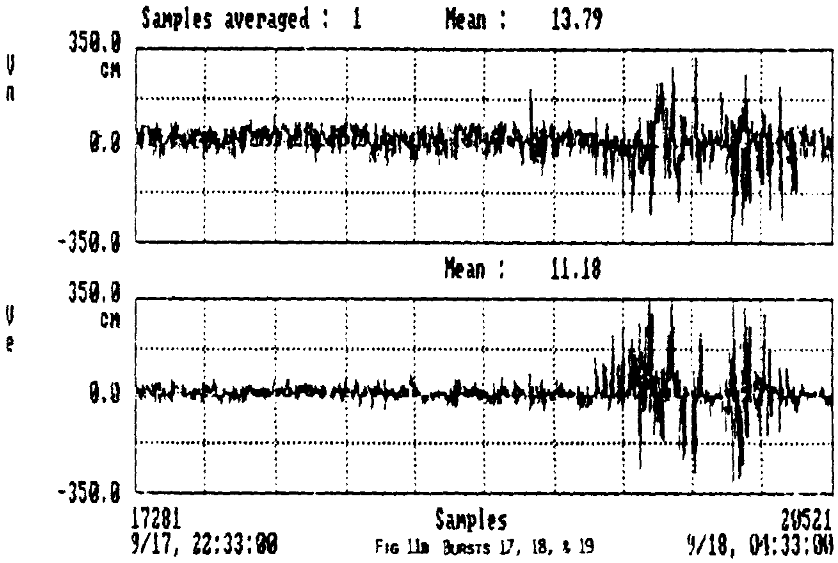


Fig 11b Bursts 17, 18, & 19

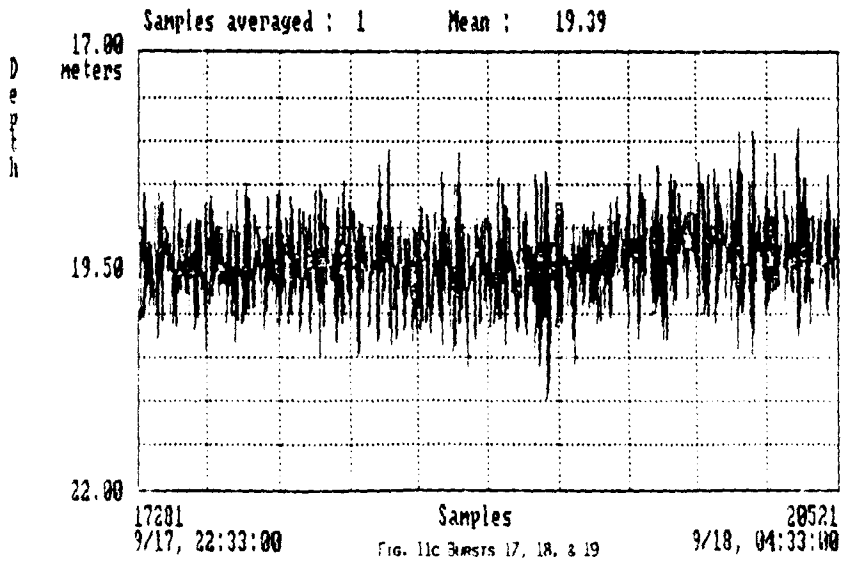


Fig. 11c Bursts 17, 18, & 19

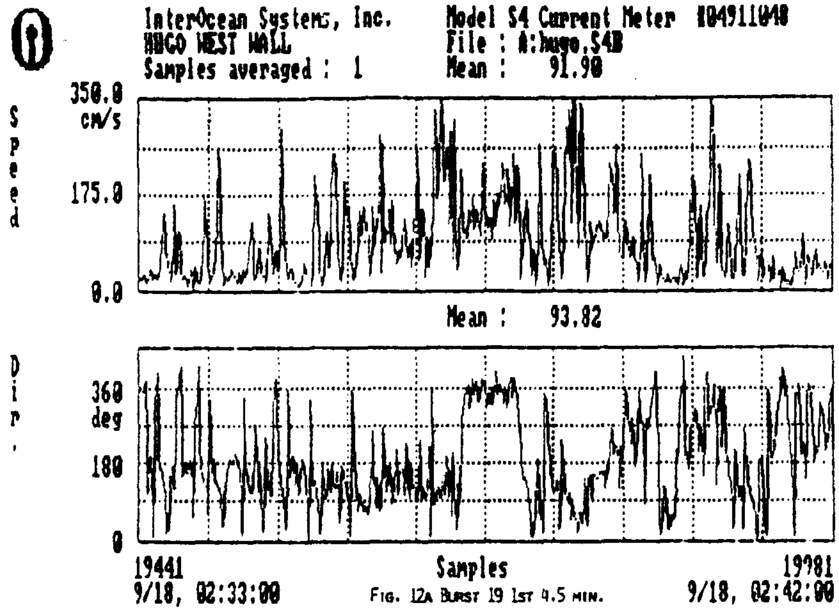


Fig. 12a Burst 19 1st 4.5 min.

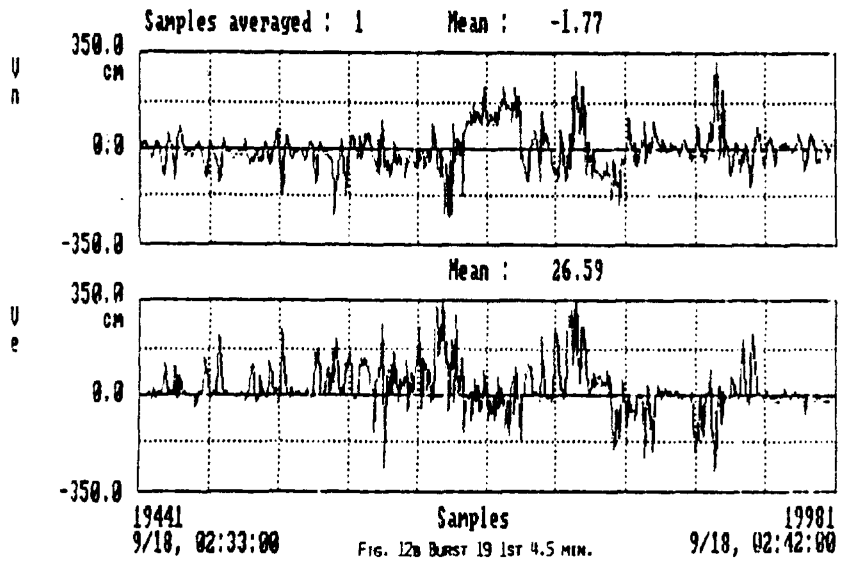


Fig. 12b Burst 19 1st 4.5 min.

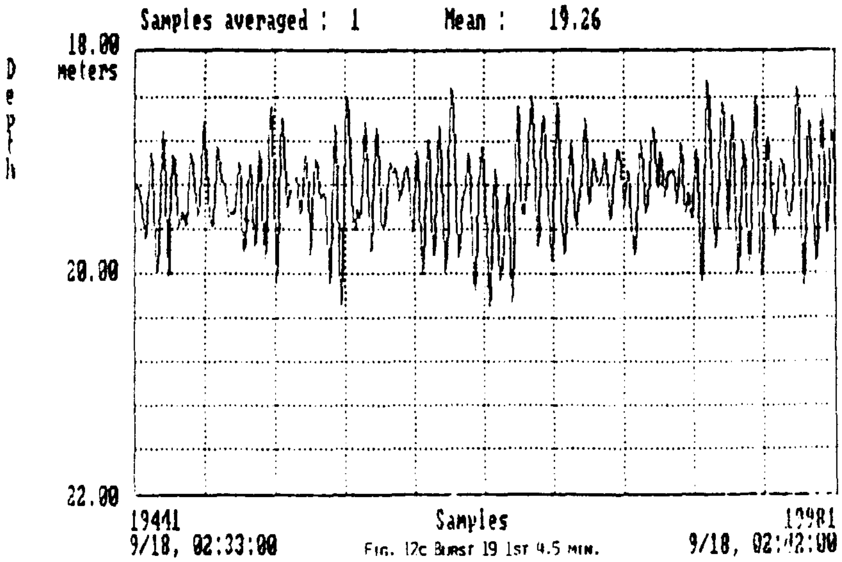


Fig. 12c Burst 19 1st 4.5 min.

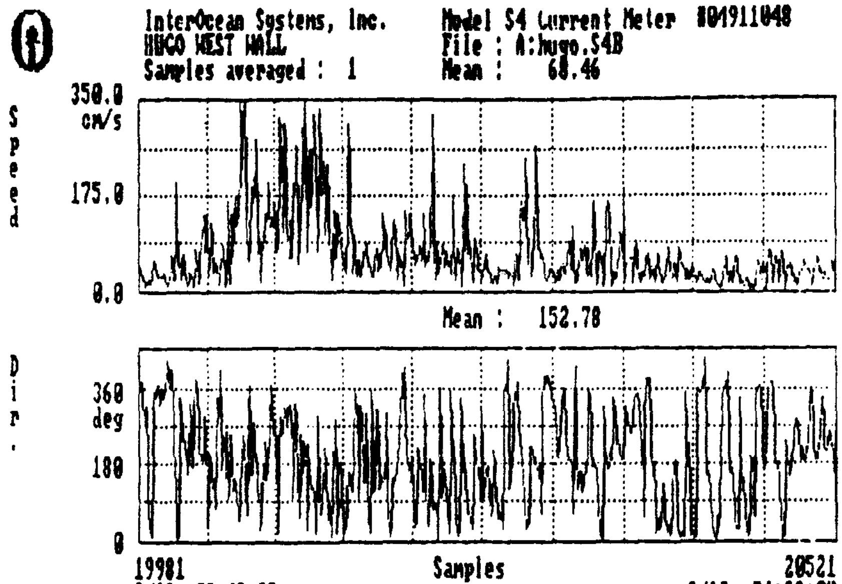


Fig. 13a Burst 19 2nd 4.5 min.

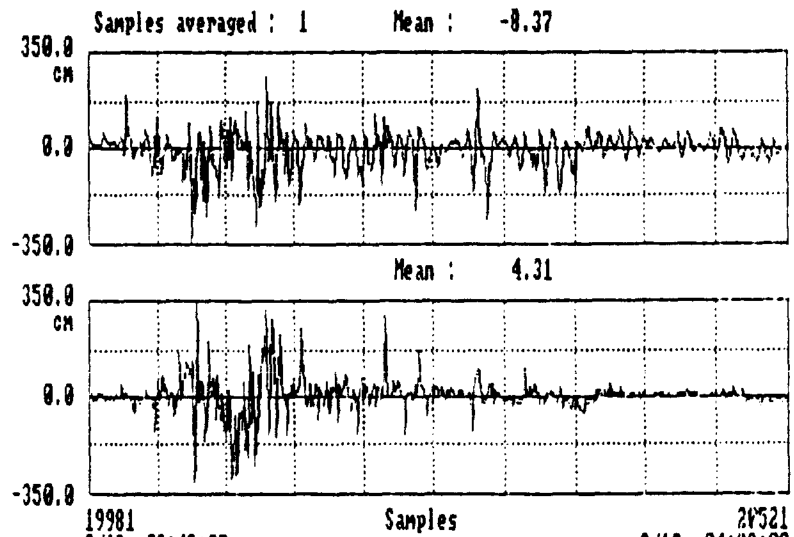


Fig. 13b Burst 19 2nd 4.5 min.

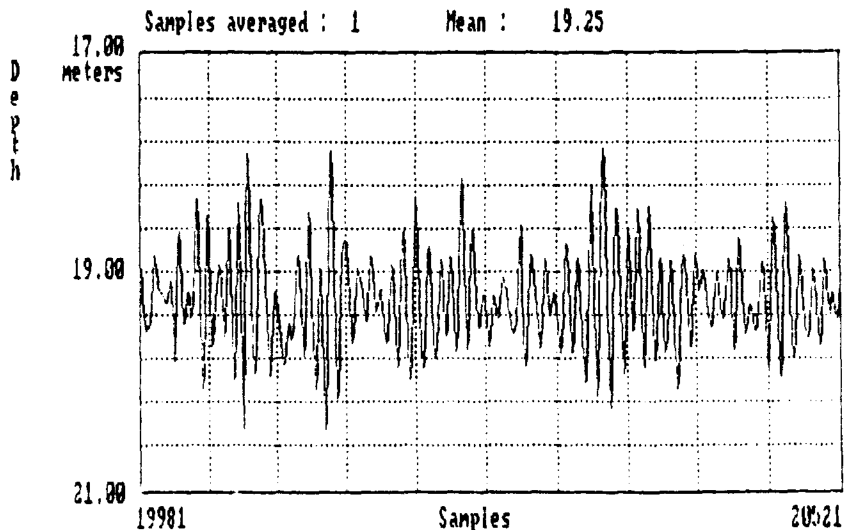


Fig. 13c Burst 19 2nd 4.5 min.

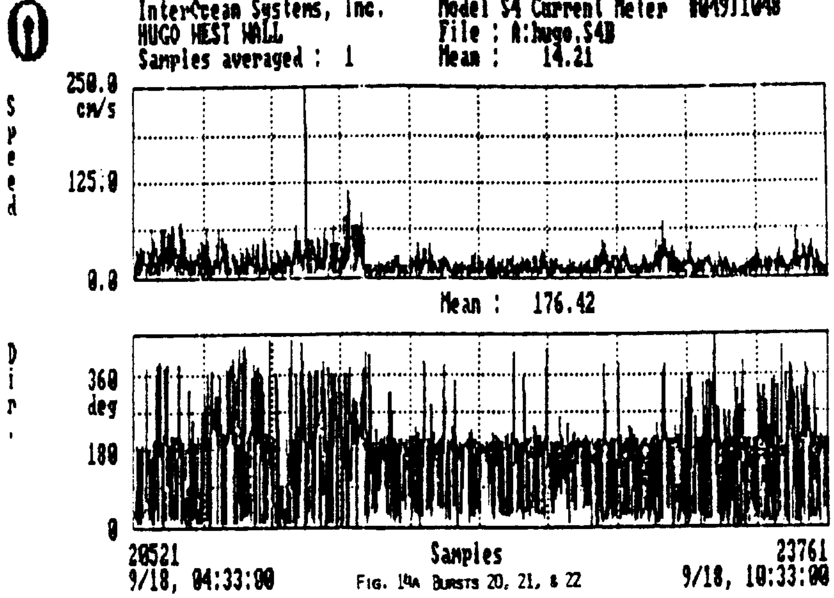


Fig. 14a Bursts 20, 21, & 22

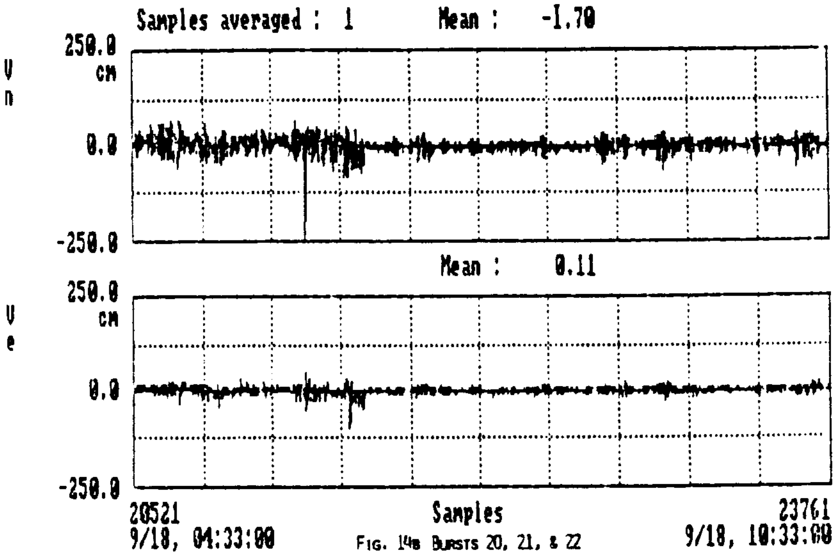


Fig. 14b Bursts 20, 21, & 22

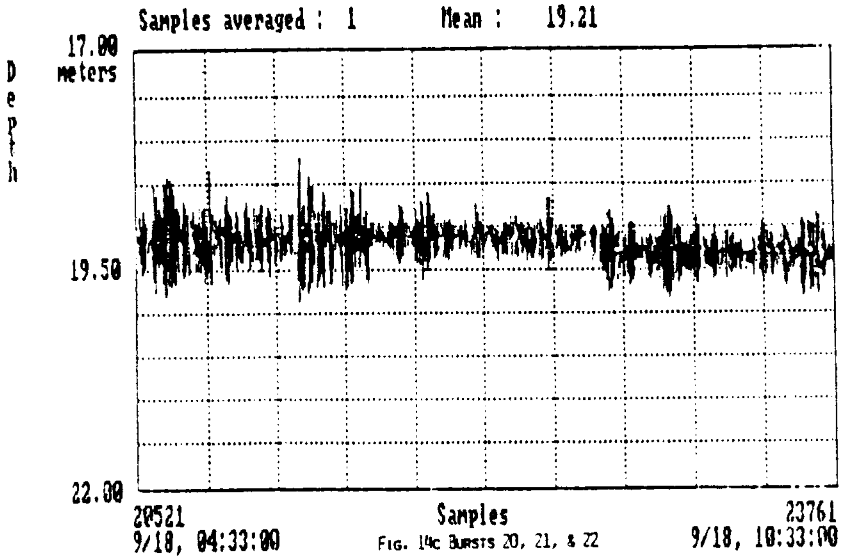


Fig. 14c Bursts 20, 21, & 22

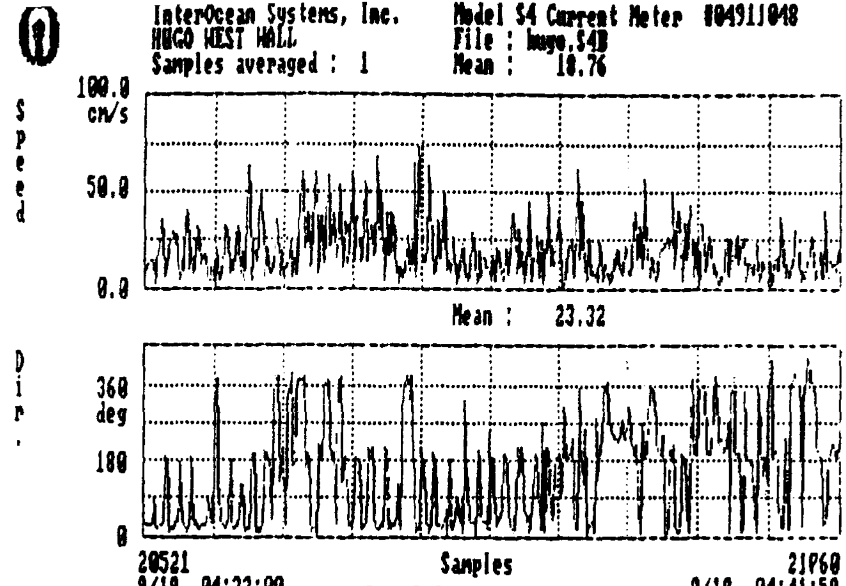


Fig. 15a Burst 20 1st 4.5 min.

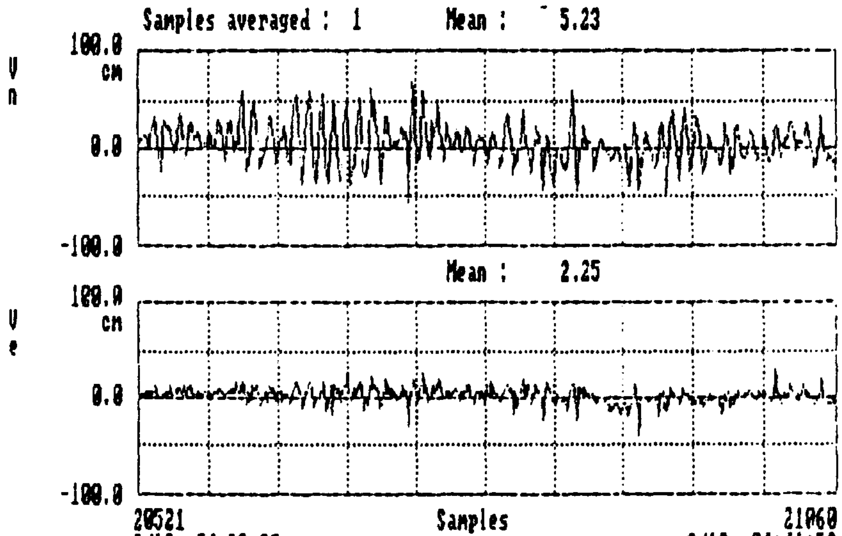


Fig. 15b Burst 20 1st 4.5 min.

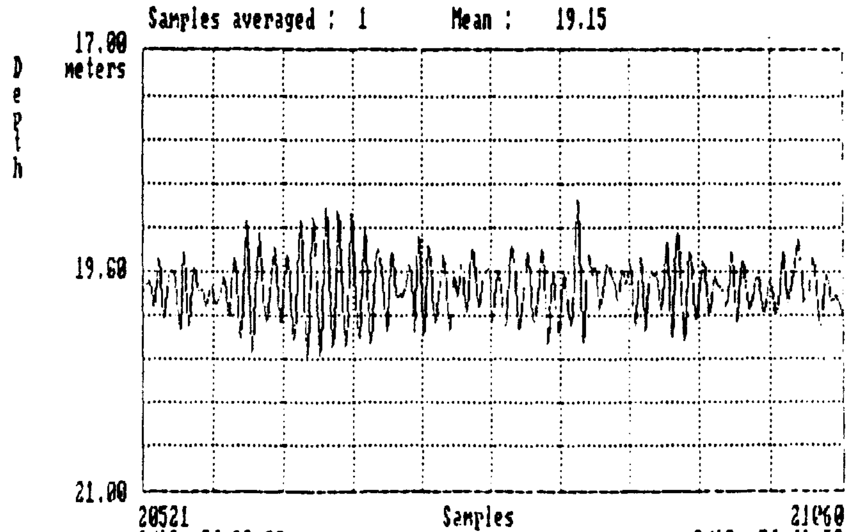


Fig. 15c Burst 20 1st 4.5 min.

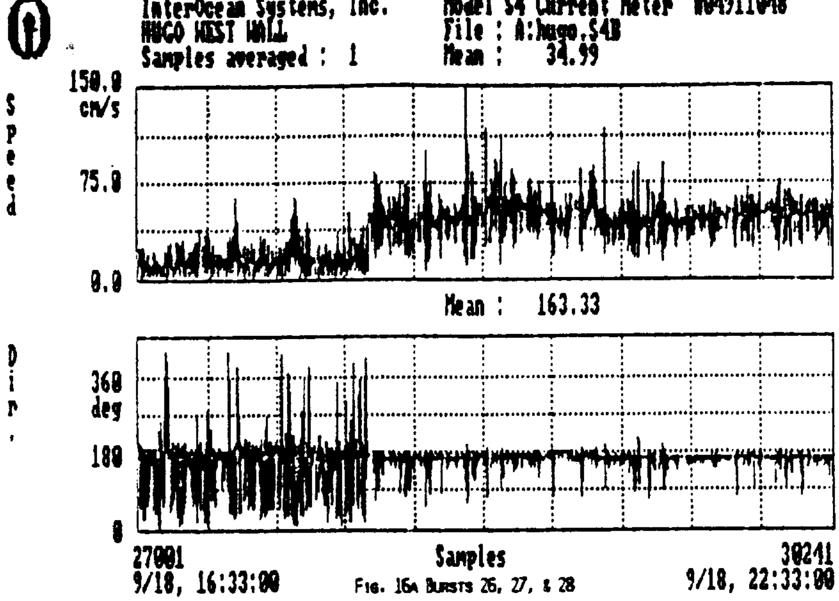


Fig. 16a Bursts 26, 27, & 28

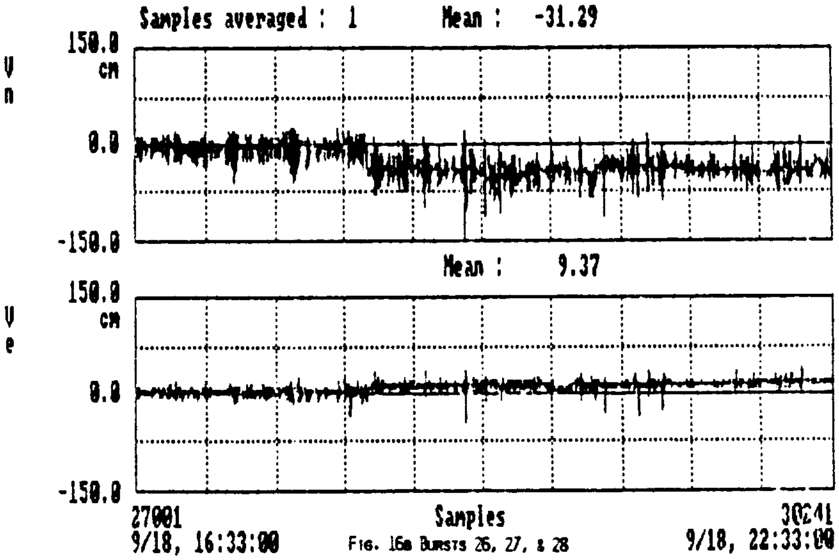


Fig. 16b Bursts 26, 27, & 28

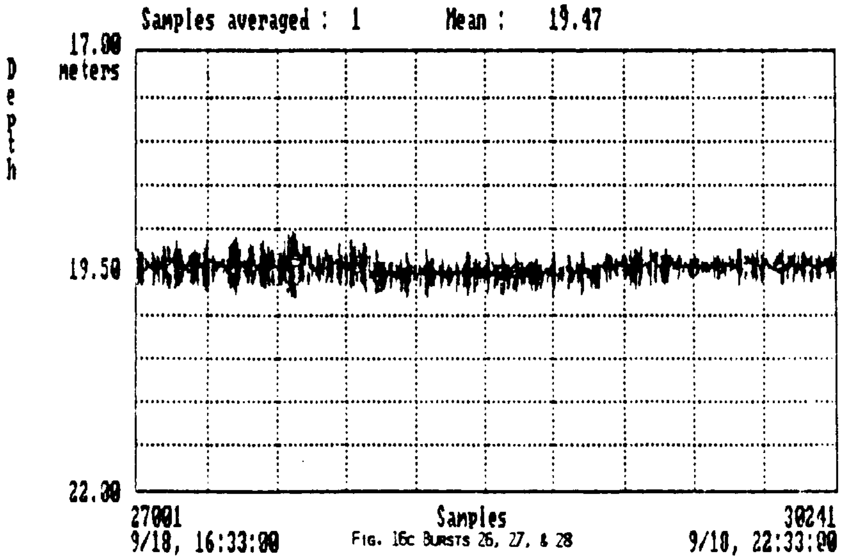


Fig. 16c Bursts 26, 27, & 28

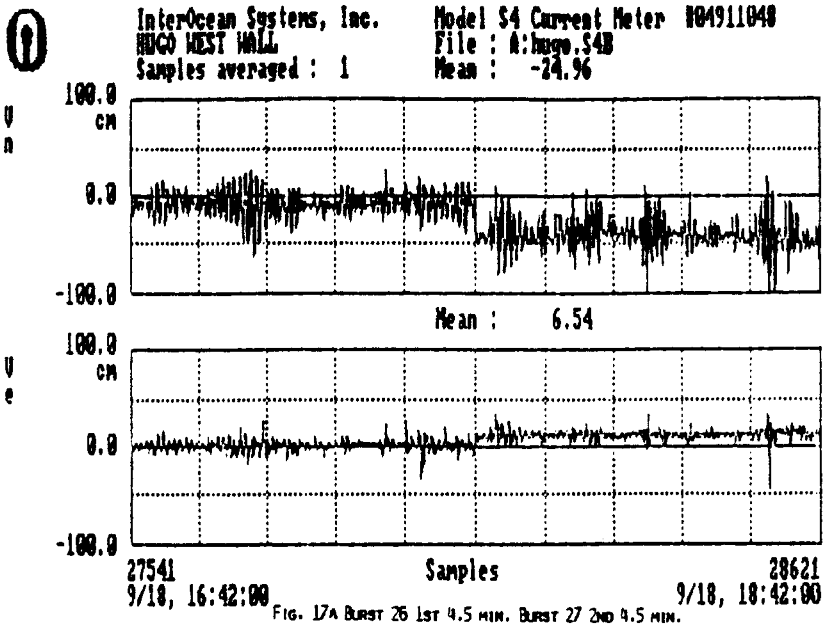


FIG. 17A BURST 26 1ST 4.5 MIN. BURST 27 2ND 4.5 MIN.

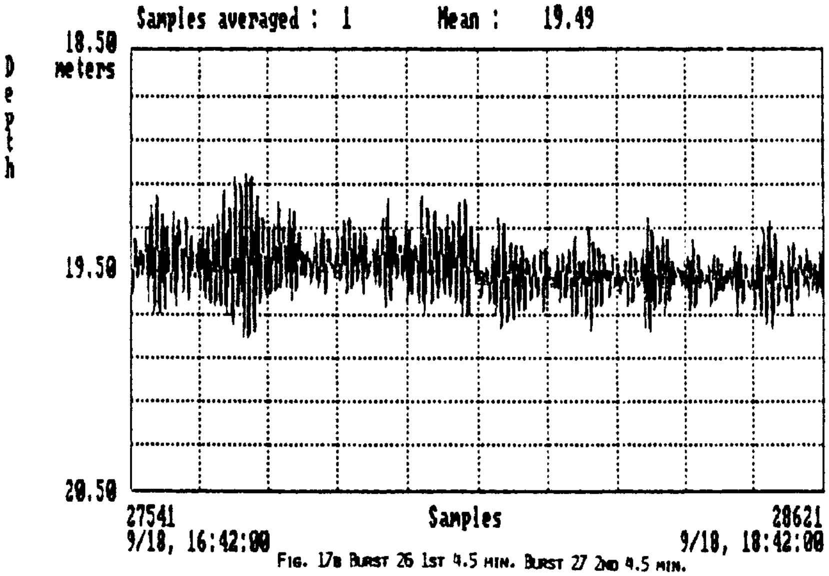


FIG. 17B BURST 26 1ST 4.5 MIN. BURST 27 2ND 4.5 MIN.

DIRECTIONAL WAVE ANALYSIS

For directional wave analysis, the same data file used in the raw data presentation above was processed using the InterOcean Systems developed "WAVE" software package. The "WAVE" program utilizes the measured wave pressure information at a point to compute the statistics of sea surface elevation η. The Fourier coefficients of sea surface elevation were obtained by applying the frequency dependent depth correction to the Fourier coefficients of the pressure time series. The correction is given by linear wave theory and is a function of wave frequency. The very large correction required for high frequency wave limits the upper frequency which can be studied (cut off frequency). At frequencies higher than this, small amounts of noise are amplified into spuriously large sea surface variations. The value of the cutoff frequency is dependent on the water depth, the distance between the sensor and the bottom, and the accuracy of the pressure sensor. The total variance σ^2_η of the sea surface displacement η are obtained by summing the variance in the frequency range up to the cutoff frequency. Thus, very high frequencies greater than the cutoff frequency are not included in the variance. A significant wave height Hs is then obtained through the formula

$$Hs = 4(\sigma^2_\eta)^{1/2} = 4\sigma_\eta$$

where σ_η is the standard deviation of surface elevation and is equal to rms value.

From the higher moments of the surface elevation spectrum estimates of Spectral Band Width (Eps or ε), Average Wave Zero Crossing Period (Tz), Average Wave Crest Period (Tc) are made.

Information about the directional properties of the waves is obtained from the phase differences observed between the surface elevation η and the two components of particle kinematics vn and ve. The program gives a mean direction $\alpha(f_i)$ over the frequency range for each burst. In the summary of the results the mean direction of the peak frequency (i.e. the direction corresponding to the band with maximum energy is reported. This is to enable the user to compare the mean wave direction between various bursts.

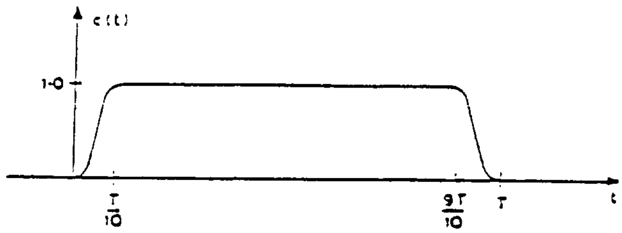
Prior to detailed analysis, each time series is scanned for erroneous data in terms of abnormal amplitudes or slew rates defined as sudden change between two successive measurements. Erroneous data points (spikes) are patched, providing that they occurred in the form of short groups.

The corruption of spectral estimates by values remote from the frequencies under consideration (side lobe leakage) due to the limited sample size can be improved by use of a cosine taper function applied to each time series as

$$x'(t) = c(t)\, cx(t)$$

The illustration below shows an example of the cosine taper function with winow factor equal to .2 (i.e. 20% of the time series is tapered). In the wave program the user is allowed to apply a window to the measured data by choosing a value for the window factor greater than 0 or not to apply window by setting the wind factor equal to 0. The user can choose the window factor parameter which ranges from 0 to 1 to determine the percentage of time series to be tapered.

The spectral estimates can be merged together to obtain smoothed estimates for the spectral density with smaller confidence intervals on the estimates. Again in the "WAVE" program the user has the choice to select the number of points to merge together. Notice that the points to merge together is a power of 2.



Cosine Taper Function for Data

The data presented in Figures 18 through 38 was processed using the following setup parameters:

Height above bottom	=	1 meter
High Frequency Cutoff	=	0.2 Hz
No. of points for FFT	=	1024
Window Factor	=	0
No. of points for smoothing	=	4

Figure 18 is a tabular summary of the wave processing results for burst numbers 2 through 34. This table lists the date and time for the start of the burst, Standard deviation (STD), Significant Height (HS), Period of spectral energy peak (TP), Average wave zero crossing period (TZ), Significant wave period (TS), Average wave crest period (TC), Direction of peak spectral energy (DIR), and Spectral band width (EPSI) for each burst period.

Figure 19 is a summary of the wave parameters Hs, Tp, eps, and DIR plotted versus burst number.

Figure 20 is a summary of the wave period estimates Tp, Tz, Ts, and Tc plotted versus burst number.

Figures 21 through 38 are individual plots for selected bursts corresponding to the raw data presented in Figures 7a through 17b. Each figure presents a time series plot of measured wave pressure (PRES), Power Spectral Density of surface elevation (Sp), Mean Wave Direction versus frequency (DIR), Root Mean Squared value of surface elevation (RMS), Mean Water Depth, Significant Wave Height (Hs), Period of the peak spectral energy (Tp), and Spectral Band Width (eps) for the selected burst period.

The data was processed using the InterOcean "WAVE" software running on a 386-based PC with a coprocessor and clock speed of 20 MHz. The time to process each burst was two seconds. The total processing time for the entire deployment record was less than five minutes exclusive of the time to print the selected graphs.

InterOcean Systems, Inc.
Wave Analysis Program

FILE: hugo.s4b

SUMMARY OF RESULTS

B#	DATE	TIME	STD	HS	TP	TZ	TS	TC	DIR	EPSI
2	09/16/89	16:33	.19	.75	7.4	6.5	6.6	6.2	19.2	.32
3	09/16/89	18:33	.20	.78	6.2	6.1	6.2	5.9	22.4	.29
4	09/16/89	20:33	.18	.71	5.7	6.2	6.2	5.9	33.8	.28
5	09/16/89	22:33	.23	.93	5.9	6.1	6.1	5.8	30.3	.28
6	09/17/89	00:33	.25	1.01	6.3	6.1	6.2	5.9	37.6	.26
7	09/17/89	02:33	.22	.87	6.6	6.2	6.3	5.9	29.3	.30
8	09/17/89	04:33	.25	.99	6.6	6.4	6.4	6.1	18.5	.28
9	09/17/89	06:33	.23	.93	7.2	6.4	6.6	6.0	23.5	.36
10	09/17/89	08:33	.28	1.11	5.6	6.4	6.5	6.0	36.3	.33
11	09/17/89	10:33	.46	1.84	7.6	6.9	7.0	6.6	26.0	.33
12	09/17/89	12:33	.52	2.10	7.4	7.0	7.1	6.6	20.6	.35
13	09/17/89	14:33	.69	2.74	8.6	7.5	7.7	6.9	26.8	.39
14	09/17/89	16:33	.80	3.20	7.2	7.4	7.8	6.8	57.7	.45
15	09/17/89	18:33	.76	3.06	8.4	7.3	7.5	6.6	16.8	.44
16	09/17/89	20:33	.83	3.32	8.6	7.4	7.6	6.7	27.7	.41
17	09/17/89	22:33	.88	3.50	5.1	6.7	6.9	6.1	37.6	.42
18	09/18/89	00:33	.88	3.51	8.9	7.3	7.6	6.4	23.0	.48
19	09/18/89	02:33	.80	3.19	8.9	7.9	8.2	6.9	5.1	.48
20	09/18/89	04:33	.48	1.91	10.0	8.0	8.3	6.9	15.0	.49
21	09/18/89	06:33	.22	.87	11.3	8.5	8.9	7.3	23.6	.52
22	09/18/89	08:33	.29	1.18	10.8	9.4	9.6	8.2	20.8	.49
23	09/18/89	10:33	.26	1.05	9.6	8.7	8.9	7.9	12.4	.42
24	09/18/89	12:33	.22	.89	8.9	8.1	8.3	7.4	6.9	.41
25	09/18/89	14:33	.26	1.02	10.0	7.8	8.0	7.2	6.7	.39
26	09/18/89	16:33	.28	1.11	8.9	7.6	7.8	7.0	12.3	.39
27	09/18/89	18:33	.22	.88	8.9	7.3	7.4	6.7	10.2	.38
28	09/18/89	20:33	.19	.77	8.9	7.1	7.2	6.6	11.3	.36
29	09/18/89	22:33	.14	.55	8.1	7.3	7.1	6.6	9.7	.34
30	09/19/89	00:33	.13	.52	7.6	7.0	7.1	6.6	16.2	.33
31	09/19/89	02:33	.13	.51	8.1	6.9	7.0	6.5	11.6	.34
32	09/19/89	04:33	.14	.58	6.5	6.6	6.7	6.3	22.9	.31
33	09/19/89	06:33	.18	.71	7.6	6.8	6.9	6.5	13.9	.32
34	09/19/89	08:33	.15	.58	6.8	6.9	7.0	6.4	8.3	.26

FIG. 18

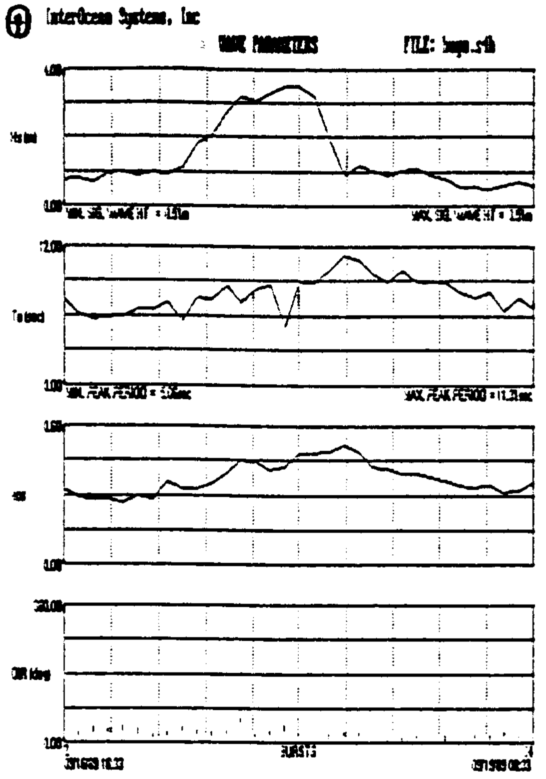


Fig. 19

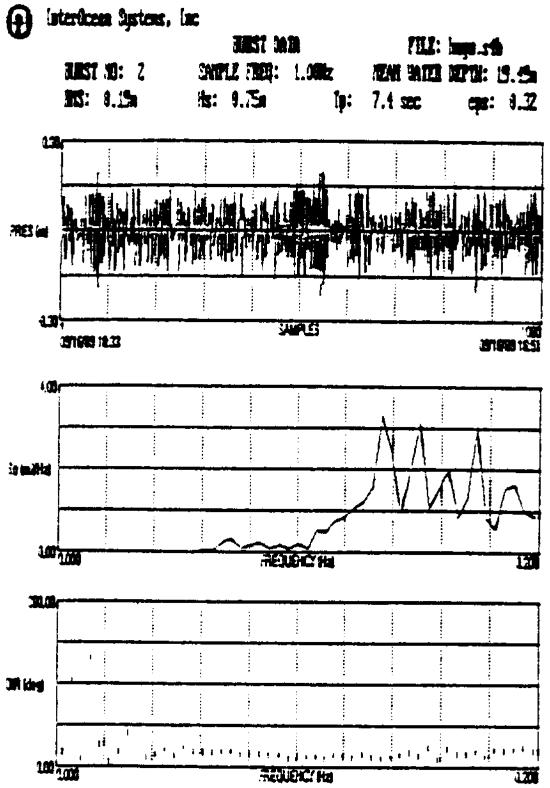


Fig. 21

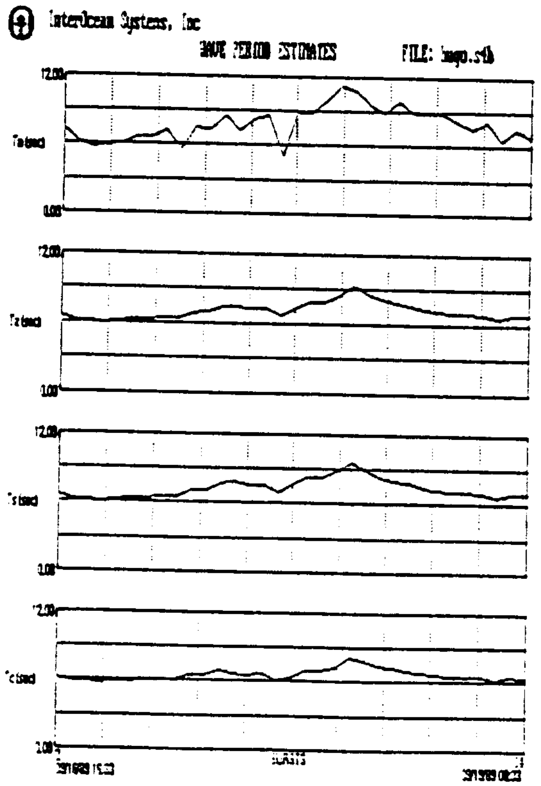


Fig. 20

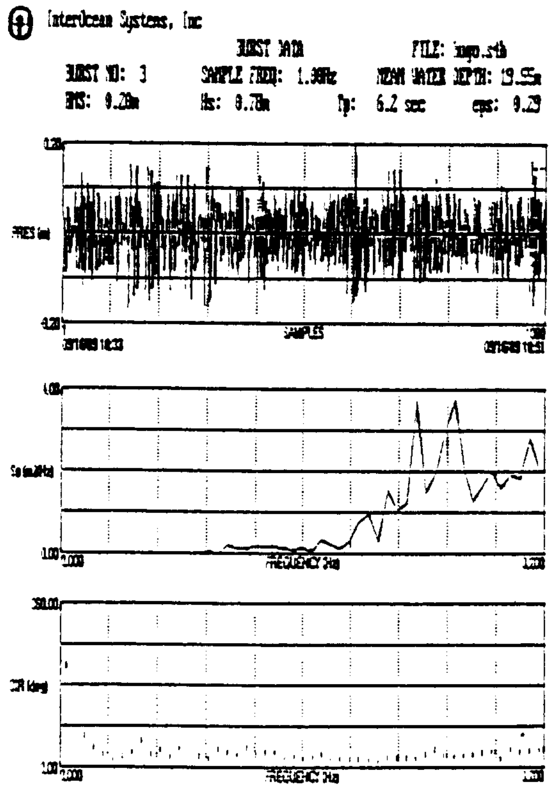


Fig. 22

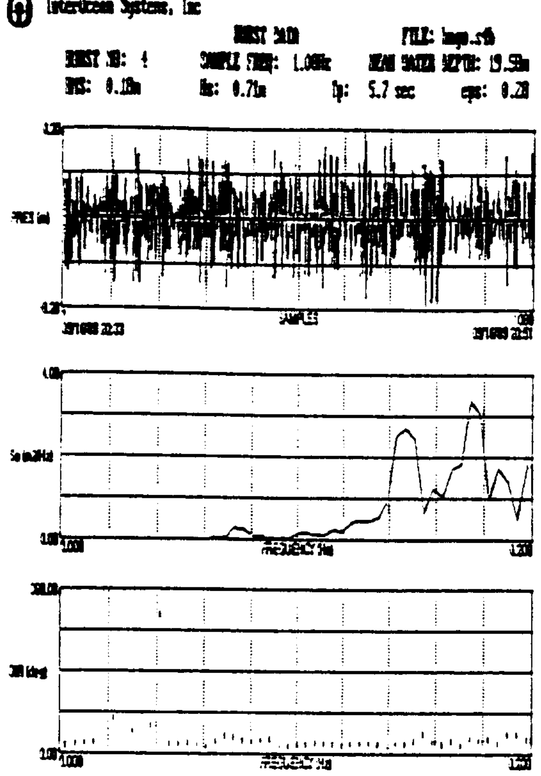


Fig. 23

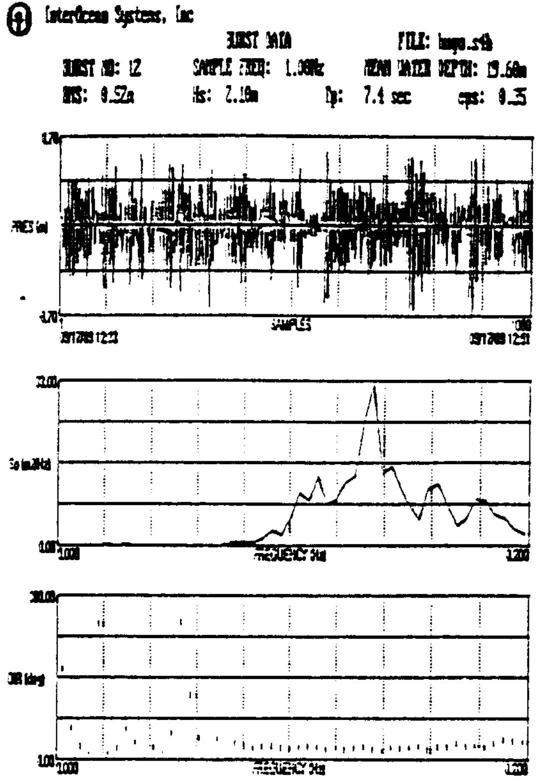


Fig. 25

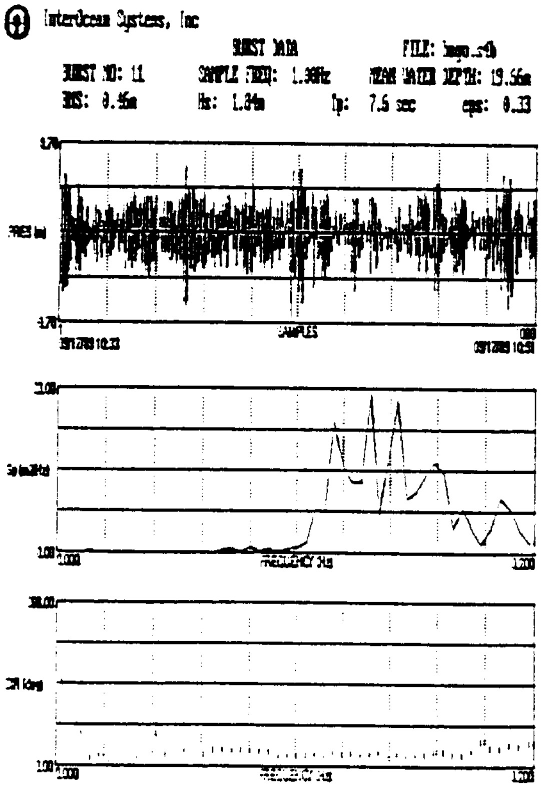


Fig. 24

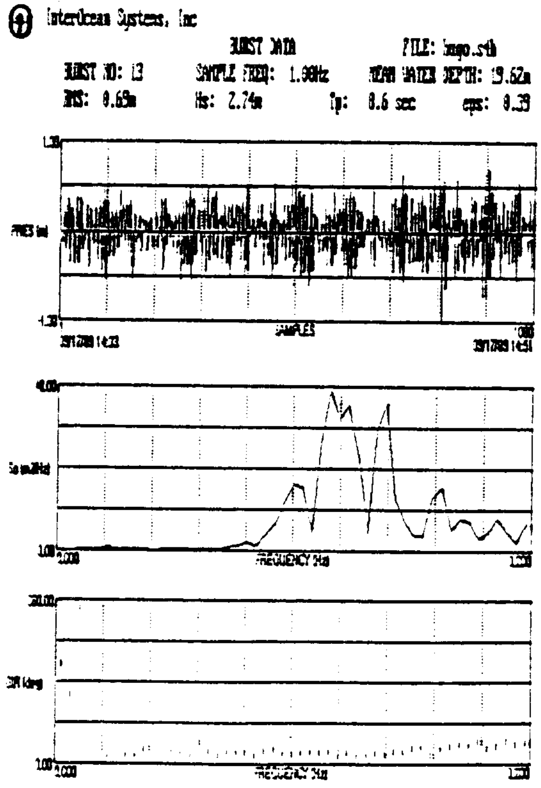


Fig. 25

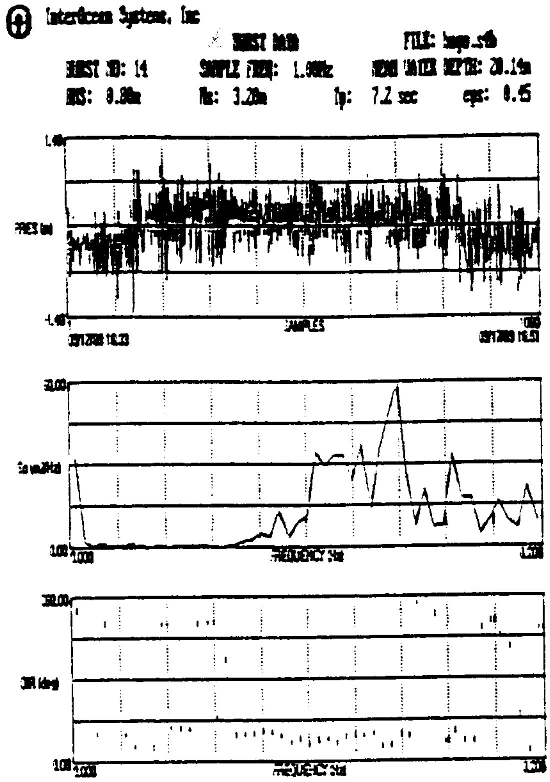


Fig. 27

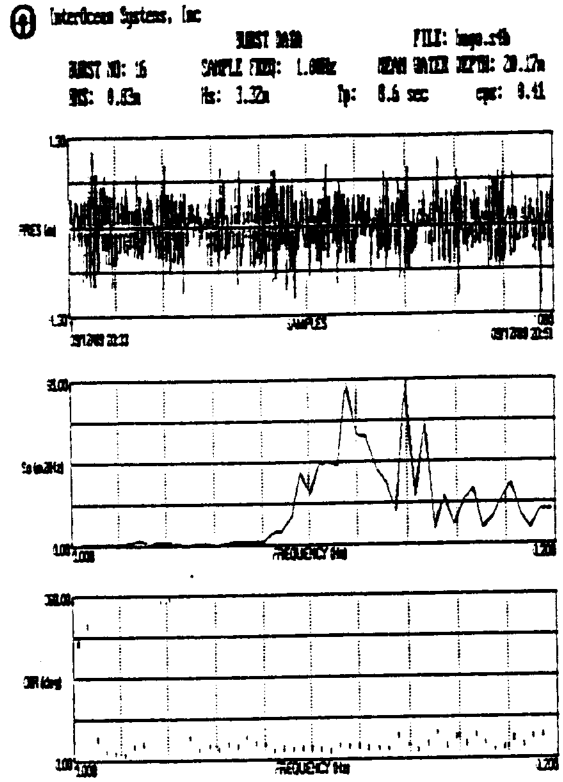


Fig. 29

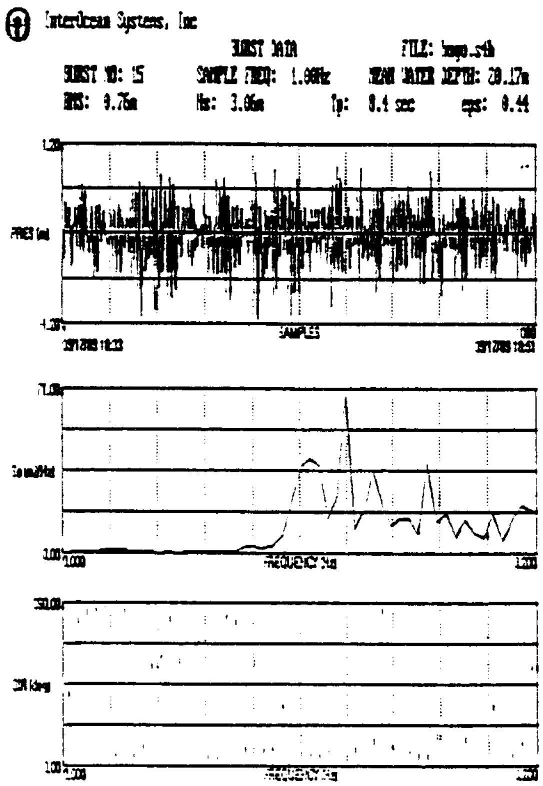


Fig. 28

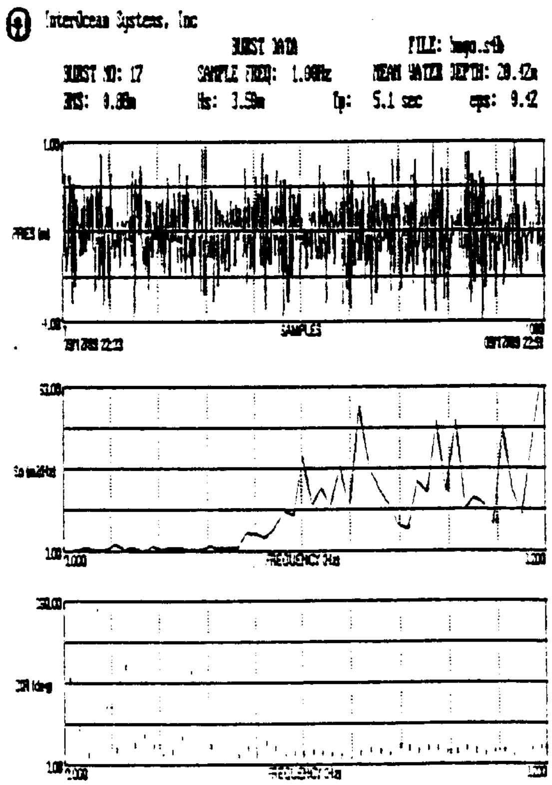


Fig. 30

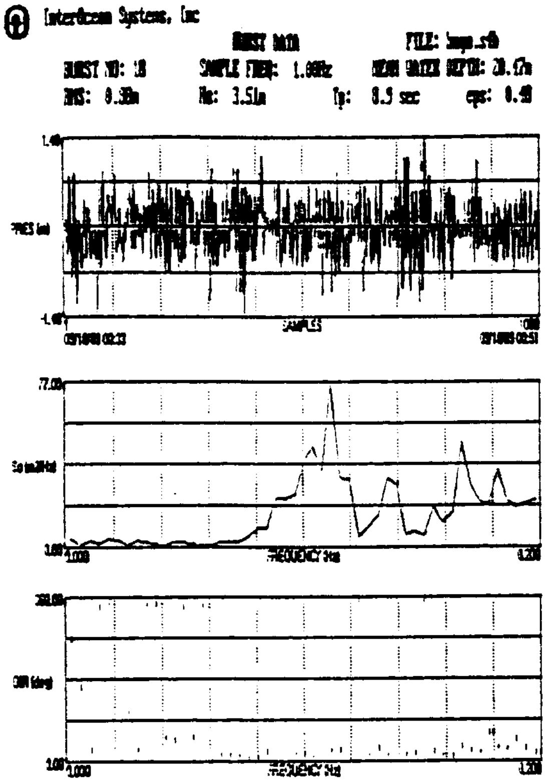


Fig. 31

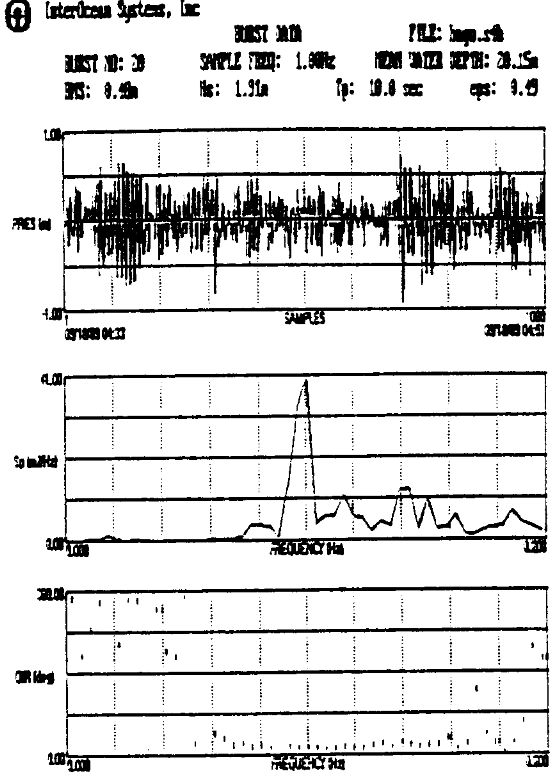


Fig. 33

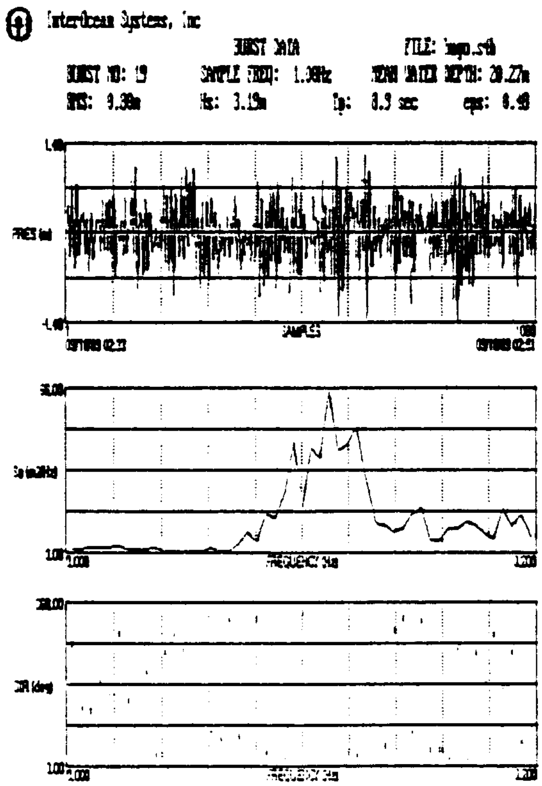


Fig. 32

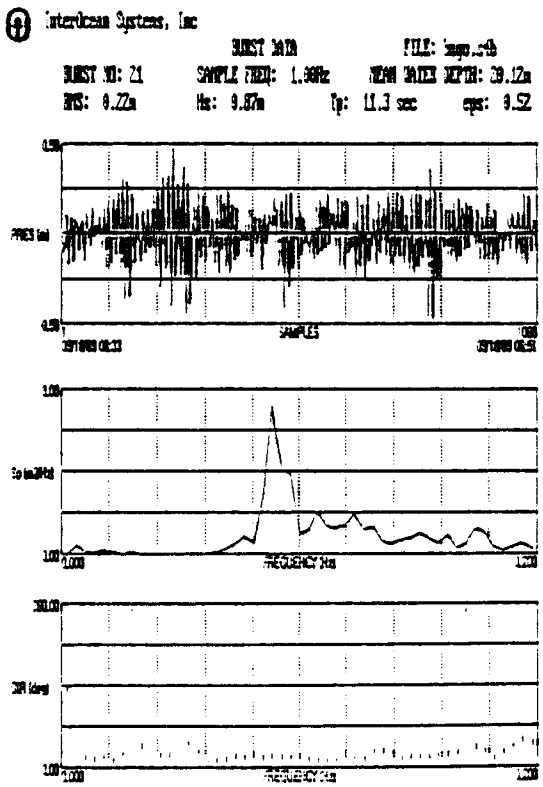


Fig. 34

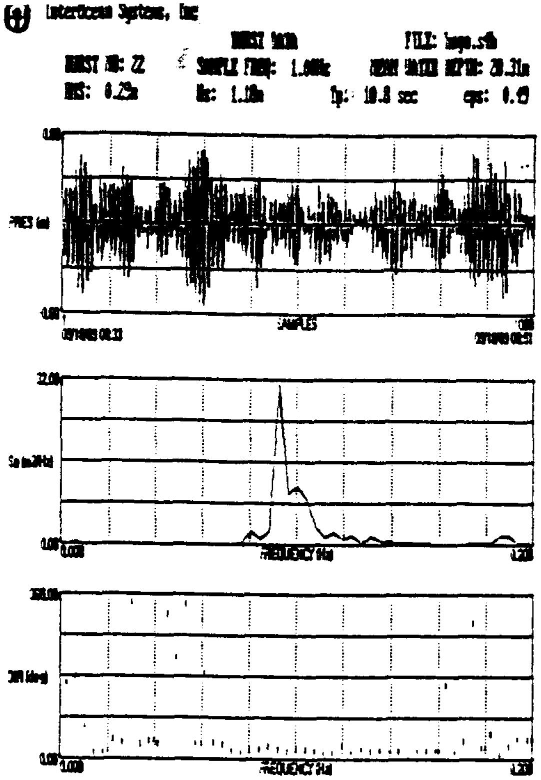


Fig. 35

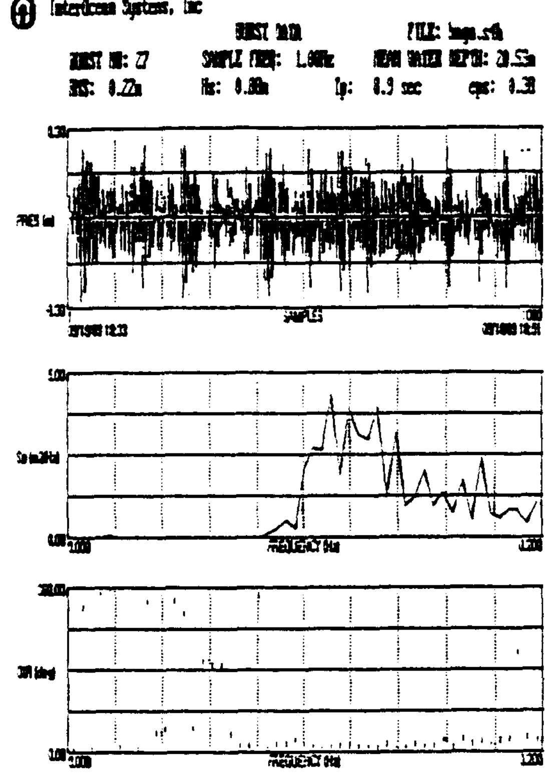


Fig. 37

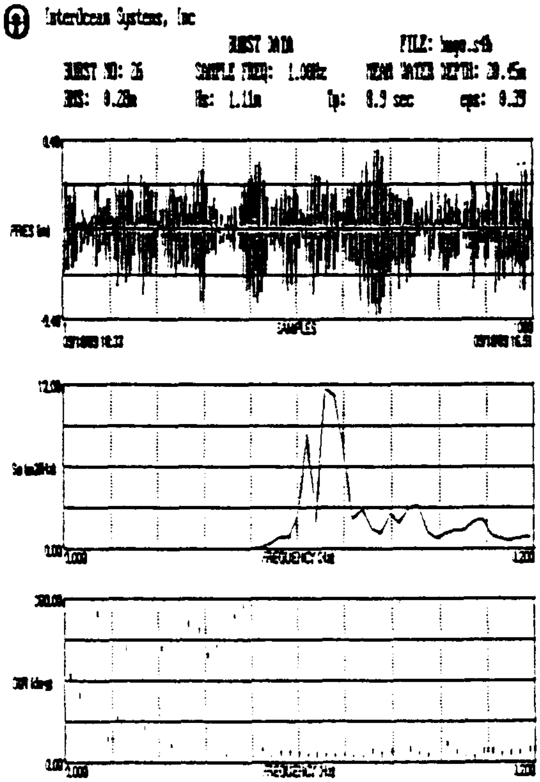


Fig. 36

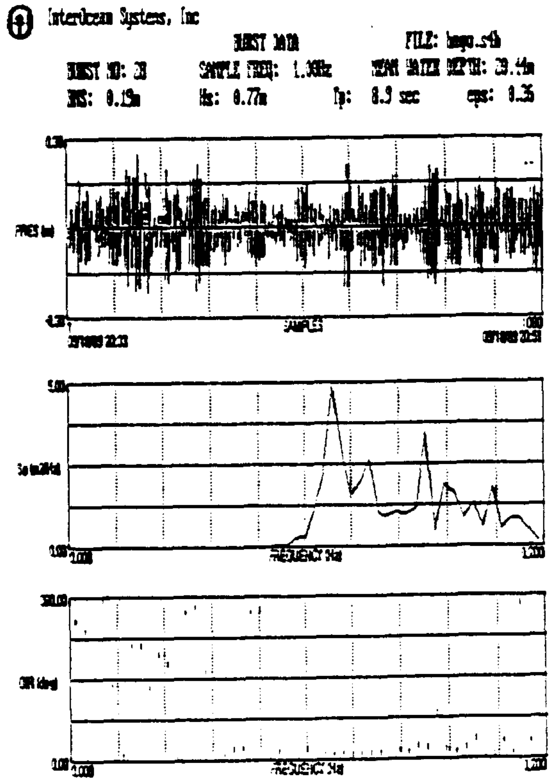


Fig. 38

CONCLUSION

A standard S4 Current Meter, outfitted with 0 to 70 meter high resolution depth option and 256K bytes of non-volatile memory, was set up and deployed with very short notice to collect data during an impending violent storm event. Although the passage of HURRICANE HUGO directly over St. Croix devasted the island, took, out all power and communications facilities, and markedly altered the topography of the submarine canyon where the S4 was moored, the instrument and mooring not only survived but successfully accomplished the task intended. The data shown herein only presents the highlight of the information which is now available to the scientists for further analysis. The combination of a new generation, rugged, easy to use instrument and off-the-shelf application software running on commonly available personal computers provides a means of collecting and processing oceanographic data in a timely and cost efficient manner previously not possible.

[1]Lawson, Lemieux, Luck, Woody. 1983 The development of a Sperical, Electromagnetic Current Meter, Oceans '83 Conference Paper No: AB 1137