FINAL REPORT

MIAMI OCEAN MONITORING SYSTEM (MOMS)
SITE 1 MONITORING STUDY

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Atlantic Oceanographic and Meteorological Laboratory
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Region 4 Water Management Division
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MIAMI MOMS SITE 1 MONITORING STUDY
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I. INTRODUCTION

This report describes the sediment monitoring program at the Miami Ocean Monitoring System (MOMS) site 1 location. This project was undertaken to asses the levels of suspended sediment present on the southeastern reef tract under the range of normally occurring oceanic and atmospheric conditions, to asses the levels of suspended sediment occurring during severe weather events and to assess levels of suspended sediment present during dredged material disposal operations. Measurements were made of suspended sediment concentration, ambient currents, the surface wave field above the site, water temperature and salinity. In addition to the direct measurements, an indirect estimate of suspended sediment concentration derived from acoustic backscatter is presented. From these direct and indirect measurements, estimates of the expected values of the concentration of suspended material at this site and estimates of the frequency of events that produce high levels of suspended sediments are given. During the times that the instruments were deployed, several severe weather events occurred. A summery of the data and observations from these events will be presented.

II. BACKGROUND

Between 1998 and 2006 several sites in the coastal area off the coast of Miami were instrumented with various types of sensors. The First Interim Report (1999) and the Second Interim Report (2001) describe the initial installations and the results from those deployments. Some conclusions from these first MOMS deployments are summarized below.

1) Wind forcing, currents and wave heights are significant factors in suspending sediments.
2) In highly bio-active coastal waters, data from optical sediment concentration sensors degrade quickly due to bio fouling.
3) Acoustical sensors are less susceptible to bio fouling than optical sensors.
4) Under certain restrictions, a linear relationship exists between the logarithm of the sediment concentration measured by the optical sensors and the logarithm of the acoustic backscatter intensity. Environmental and systematic corrections can be applied to the acoustic backscatter signal from acoustic Doppler current profilers and this data can then be used to estimate the concentration of suspended sediments. Data analysis from preliminary deployments suggests that the MOMS site 1 is a good candidate for acoustically estimating sediment concentrations. To continue the long term measurement program it was decided to concentrate efforts at the MOMS site 1 and obtain the maximum density of data at that site.

III METHODS AND PROCEDURES

MOMS Site 1 is located at 25.716 degrees North and 80.089 degrees West, in 18.9m of water. (Plate 1.) At the MOMS site 1 location, three instrument platforms were placed on the bottom. The first, a concrete base, was used to mount a Teledyne RD Instruments 1200 kHz Workhorse Acoustic Doppler Current Profiler (ADCP). This mounting placed the transducer of the ADCP approximately 59cm above the bottom. The second mounting was a tripod structure which held a 600kHz Teledyne RD Instruments ADCP with the transducer at a height of 80 cm above the bottom. The tripod was also held a YSI 6600 series environmental monitoring sonde. The YSI sondes were equipped with sensors for temperature, salinity and optical backscatter. The sondes were mounted so that the sensors were approximately 1m above the bottom. The third platform was referred to as the “Stalk”. The stalk held a custom built datalogger which recorded data from instruments mounted on the stalk. Instruments connected to the stalk datalogger were, a McVan Instruments optical backscatter sensor (OBS), a D&A Instruments OBS and a Quantum sensors Photosynthetically active radiation sensor (PAR). All of these instruments were mounted at a height of 1m off the bottom. Table 1 lists the deployments during the time period cover by this report. The deployments are grouped into four periods for convenience.

Table 1 MOMS Site 1 Deployments

Equipment	Deployment A	Deployment B	Deployment C	Deployment D
1200 kHz ADCP	9/21/01-1/12/02	4/23/02-8/30/02	6/22/05-8/19/05 8/19/05-2/28/05	3/20/06-5/16/06
600 kHz ADCP with waves capability			8/19/05-2/7/06	3/20/06-5/16/06 5/23/06-6/22/06
YSI sondees with Temperature , salinity and optical backscatter	9/21/011-1/20/01 12/17/01-3/17/01	4/23/02-6/11/02 4/24/02-6/11/02	8/19/05-9/27/05 10/12/05-1/16/06	3/20/06-5/20/06 5/20/06-6/29/06 6/29/06-9/13/06
Mc Van OBS on stalk		4/23/02-6/9/02	6/22/05-8/19/05 8/19/05-2/28/05	
OBS on stalk			6/22/05-8/19/05 8/19/05-2/28/05	
PAR on stalk			6/22/05-8/19/05 8/19/05-2/28/05	

Dissimilarities in the endurance of the instruments resulted in the some of the data sets being significantly longer than others for any given deployment. This is discussed further in the data review section.

A. Acoustic Doppler Current Profiler current measurements

The Teledyne RD Instruments Acoustic Doppler Current Profiler (ADCP) current meters estimates current velocities by measuring the Doppler shift from the return signal of a acoustic pulse transmitted from four transducers which are angled 20 deg off the vertical. These Doppler velocities are then transformed into estimates of the three dimensional water velocities in cells or bins spaced vertically above the instrument. (RD Instruments Principles of operation) At the MOMS site1 a 1200 kHz ADCP and a 600kHz ADCP were deployed (Table 1). The 600 kHz unit also provided surface waves measurements as well as current measurements. In cases where a 1200kHz ADCP was deployed simultaneously with a 600kHz ADCP, the 1200kHz data is identified with an “a” and the 600kHz data is identified with a “b”.

In preliminary ADCP deployments of the 1200 kHz ADCP, the current meters were set to a 0.5 m bin size. When a 600 kHz ADCP became available to deploy at Site 1, the bin size was set to 0.6 m on both instruments to accommodate the requirements of the 600kHz unit and so that the data from the 1200 kHz ADCP and the 600 kHz ADCP could be made to align vertically in the water column. The depth of the ADCP measurement cells changed depending on how the instrument was set up. Based on a mean water depth of 18.9m at the MOMS site 1, a set of standard analysis depths were defined and the closest ADCP bin to that depth was used. Table 2 lists the actual measurement depths that correspond to a standard analysis depth. It was identified as a priority from the preliminary deployments that the acoustic backscatter measurements be made to align as closely as possible with the measurements made by the optical sediment measurement devices. To facilitate this, the blanking distance on the 1200kHz unit was set to zero in later deployments. This placed the center of bin 1 at a distance of 1.24m above the bottom. The decision to null the blanking distance on the 1200 kHz unit was made with the understanding that current velocity data from the first bin might be biased. Only data from bins 3 and above were used in the current velocity analysis.

Table 2 ADCP Standard Analysis Depths

Analysis depth	Actual depth for MOMS 6,8a,9a	Actual depth for MOMS 8b,9b,10b	Actual depth for MOMS 5, 7
18m	18.04m	NA	18.24
16.8m	16.84	16.84	16.74
16.2m	16.24	16.24	16.24
11.4m	11.44	11.44	11.24
10.8m	10.84	10.84	10.74
3.6m	3.64	3.64	3.74
3.0m	3.04	3.04	3.24

B. Acoustic Doppler Current Profiler waves measurements.

The Teledyne RD instruments 600 kHz ADCP which was deployed as Moms 8b,9b and 10b was enhanced and able to estimate the directional wave spectrum. The times of these deployments are listed in Table 7 of the waves section. To make the wave measurement, the instrument was programmed to take 2400 samples at 2Hz. This data was then processed using the RD instruments Waves Mon software following procedures outlined in the software documentation. (RD Instruments Waves User Guide) The deployment depth and characteristics of the instrument define the minimum observable wave period. For these deployments this was 2.15 sec for non direction wave estimate and 3.35 sec for the directional wave estimate. Some wave parameters obtained from the data were. Significant wave height, defined as the average height of the highest 1/3 of the waves, the period of the principal wave and the direction from which the principal wave arrives. (RD Instruments Waves User Guide) There were many sample intervals where no valid data was reported. This appears occurs during calm conditions in which the waves would have periods shorter than the minimum observable period.

C. Acoustic Doppler Current Profiler Temperature Measurements.

The acoustic Doppler current profilers used at Moms site 1 also record temperature as part of there data record. The temperature data is not calibrated but is reasonably accurate. When compared to the available temperature data from the YSI instruments or the 600kHz ADCP, the data is in close agreement. (for the 2005-2006 data, the mean temperature from the ADCP is 0.38 deg C colder than the YSI.) The Differences in the temperature measured by the YSI sonde and the ADCP may be attributed to the fact that the ADCP temperature sensor is located 59 cm above the bottom while the YSI sensor is 1m above the bottom). The ADCP data record is the longest record available for the site and will be used for analysis. Data from the preliminary ADCP deployments (10/2/98-2/4/99 and 6/24/99-10/20/99) were not used in current velocity analysis due to differences in the deployment strategy. However; this data was included in the temperature analysis because the mounting location of the temperatures sensor remains unchanged for each deployment.

D) YSI 6600 Sonde

The YSI Incorporated model 6600 sonde is a self recording instrument that measures temperature, conductivity and turbidity via optical backscatter. Salinity is provided as a calculated data product from the instrument as well. A calibration was performed using suspended sediment solution for all of the sondes used in the MOMS deployments. This is described in appendix B. The calibration equations were then applied to the OBS data to calculate suspended sediment concentration in units of mg/l. However, it was observed that after applying the calibrations to the data, some of the calculated concentrations were reported as being less than zero. Those data values are excluded from the analysis.

E. Additional PAR and OBS sensor package.

An instrument package (the stalk) was deployed at MOMs site 1 with two optical backscatter sensors (OBS): a McVan OBS sensor # 82128 and a D&A OBS Sensor # 17880. The McVan OBS system has the advanced feature of an optical cleaning arm which wipes the sensor face before the measurement is taken. A Quantum Sensors (LI-COR LI 193SA) #2271 spherical Photosynthetically Active Radiation sensor (PAR) was also deployed on the stalk

The data from these three sensors were collected with a custom built data logger which utilized an ONSET Tattletale Model 8 data logger. The data was stored on a Persistor CF8 data recorder. The data recorders were packaged in a custom housing that also provided power to the sensors. Data was acquired for 1 minute during each sample period at a sample rate of 1 Hz and then averaged by the data logger. This average is the reported value. Similar to the YSI sondes, the OBS sensors used on the stalk system were calibrated using solutions of suspended sediments, where the sediments were collected at the MOMS site 1.

F. Wind Data

Wind data used in this report was obtained from the Fowey Rocks C-MAN Station (station FWYF1) which is owned and maintained by the National Data Buoy Center. This station is located at 25.59 N 80.10 W approximately 9.5 nautical miles south of the project location. The anemometer is located 43.9 meters above sea level. Wind speed is reported in meters per second. Wind direction is defined as the direction the wind is coming from in degrees clockwise from North. Data is averaged over an eight-minute period and reported every 10 minutes.

G. 2005 Severe Storms.

During 2005, four severe storms passed close enough to the Moms site 1 to impose clear signals on the sensors. For analysis purposes, a time period of seven days centered on the peak winds is used to compare these events. Table 3 gives the beginning and ending times used for analysis.

Table 3 Severe Storm Analysis Periods

Storm	Analysis period start	Analysis period end
Dennis	7/5/2005 19:00 UT	7/12/2005 19:00 UT
Katrina	8/22/2005 11:00 UT	8/29/2005 11:00 UT
Rita	9/17/2005 03:00 UT	9/24/2005 03:00 UT
Wilma	10/21/2005 00:00 UT	10/28/2005 00:00 UT

H. Acoustically derived suspended sediment estimates

Difficulties in obtaining long term time series of suspended material from optical sensors free from the degrading effects of bio fouling, suggested that other means for obtaining long term estimates of suspended sediments be sought. Although the ADCPs used at MOMS site 1 were not designed to deliver calibrated acoustic backscatter as a data product, methods have become available (Deines 1999) to make corrections to the backscatter data so that the data is repeatable from instrument to instrument and from deployment to deployment. These corrections involve; 1) System corrections that account for system electronics and the physical characteristics of the acoustic transducers. 2) Environmental corrections which account for ambient temperature, depth and sound absorption. 3) Corrections which account for the change in transmitted power due to the depletion of the ADCP battery with time. These procedures are detailed in the second interim report of this study and in Appendix A. Identifying the optimal data to use for calculating the relationship between the acoustic and optical data required careful consideration as the optical data exhibits large variation at low concentrations and the regression relationships derived from high turbidity events gave varying results. Data from three severe storms in 2005 were analyzed to asses the relationship between the optical backscatter data collected by the YSI sondes and the 1200 kHz acoustic backscatter data collected by the ADCP. For the time periods given in Table 3, Table 4 gives the regression parameters and the correlation coefficient (R) between the acoustic backscatter data and the log of the suspend sediment concentration measured by the YSI sondes OBS sensor.

Table 4.

STORM	SLOPE	INTERSECPT	R
KATRINA	0.9386	64.00	0.884
RITA	1.1082	81.12	0.922
WILMA	0.8958	62.81	0.952

Data from hurricanes Katrina and Wilma were chosen to develop the relationship between the suspended sediment concentration as measured by the YSI sonde OBS and the acoustic backscatter as measured by the 1200kHz ADCP because they had the most similar regression parameters when analyzed individually. Also, the optical backscatter data from the YSI sondes, which suffer from the effects of bio-fouling, was felt to be of good quality. (The analysis period for hurricane Katrina begins on 8/22/05 and the YSI sonde was installed on 8/19/05, the analysis period for hurricane Wilma begins on 10/21/05 and the YSI sonde was installed on 10/12/05) The YSI data for the period encompassing hurricane Rita showed evidence of fouling. (Figure 10) (The analysis period for hurricane Rita began on 9/17/05 and the YSI sonde was installed on 8/19/05)

To construct a relationship between the observed turbidity data reported by the YSI instruments and the corrected acoustic backscatter data collected the ADCPs, the following steps were taken.

1) Calibrations were applied to convert the YSI OBS data to units of mg/l.
2) A three point median smoothing filter was applied to the converted OBS data.
3) OBS data which had a value less than zero were excluded from the analysis.
4) Ten time the base ten logarithm was taken of the conditioned OBS data.
5) Data was limited to the 7 day period centered on the maximum winds of hurricanes Katrina (8/22/05:11:00 UT- 8/29/05:11:00 UT) and Wilma (10/21/05 00:00 UT -10/28/05 00:00UT).
6) The log YSI data was limited to those values that were greater than five and less than 25. (This corresponds to suspended sediment concentrations greater than 3.16 mg/l and less than 316 mg/l)

A linear regression was calculated between the acoustic backscatter and the conditioned logarithmic OBS turbidity data. (Figure 1.) For that calculation, the coefficient of correlation was R = 0.89, R^2= 0.788 . The standard error of this regression is 0.7857. This regression equation was then applied to the entire record of 1200kHz backscatter data to generate acoustical estimates of suspended sediment concentration for the time periods that the 1200kHz ADCP was deployed at MOMS site 1. Figure 1b shows the residuals from the regression shown in Figure 1. plotted against Sv and also a normal probability plot of the residuals. These plots suggest that the regression relationship is not biased.

In utilizing acoustic or optical backscatter to measure suspended sediment concentrations, it must be pointed out that these techniques are sensitive to changes in the particle size distribution of the scatterers. For the majority of the measurements at MOMS site 1, it is felt that the scatters are suspended out of the local sediment and that this remains fairly constant. There may be times when this is not the case. Figure 32 graphs the ratio of the 600kHz acoustic backscatter to the 1200kHz acoustic backscatter. From this graph it can be seen that the ratio of the backscatter at the two acoustic frequencies is changing during the passage of Hurricane Wilma. It would be expected that the two frequencies of acoustic backscatter have the most sensitivity to particles of a different size, and this may be a case where the particle size distribution is changing.

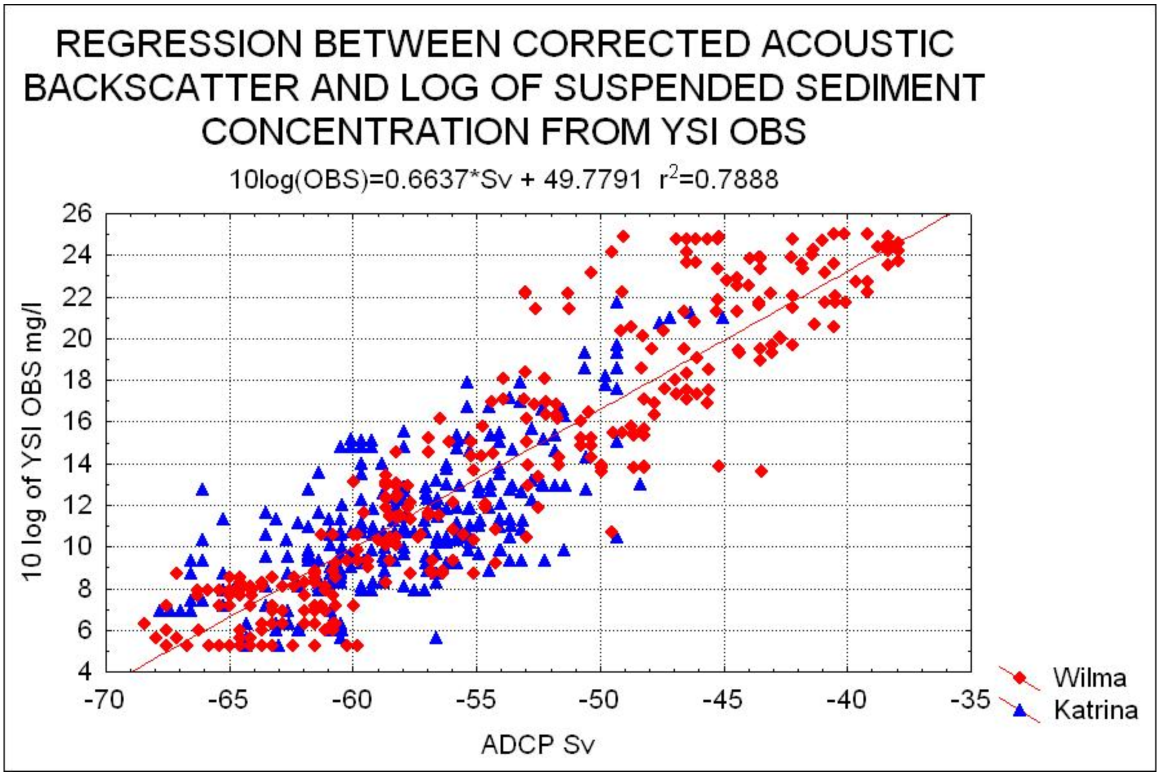

Figure 1.

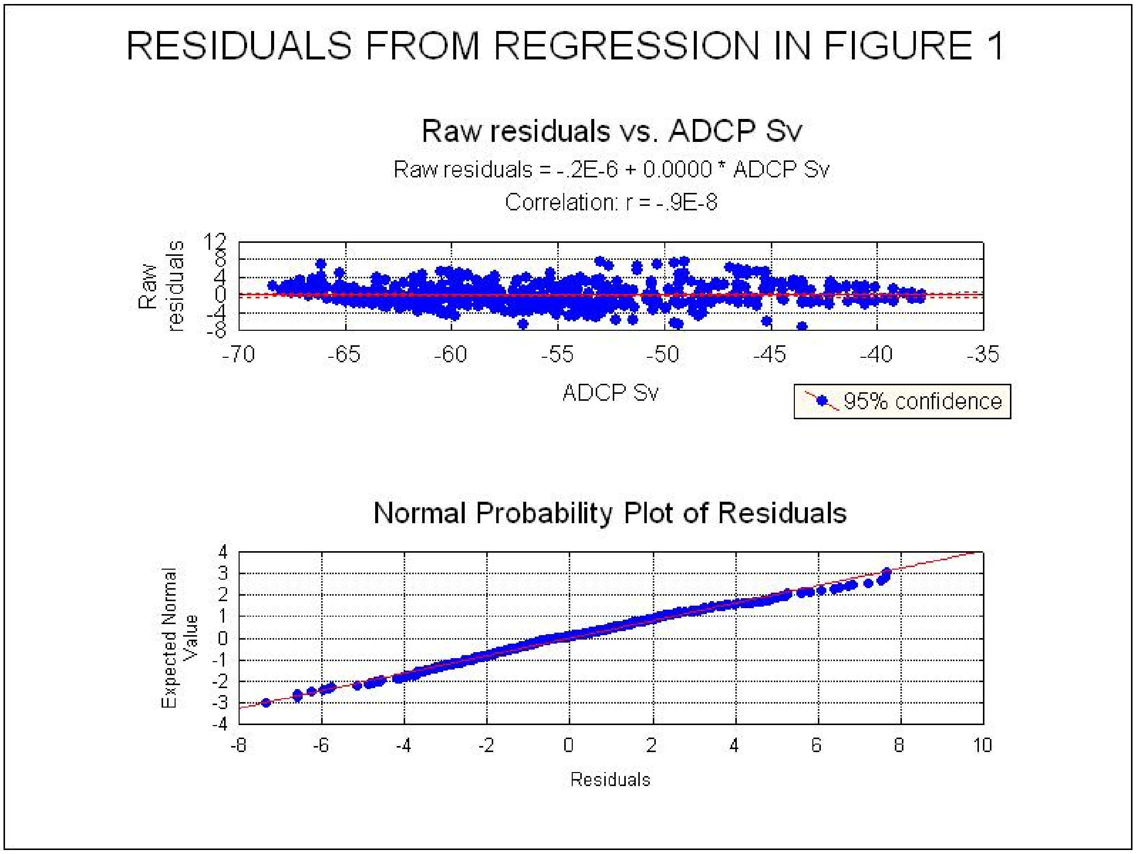

Figure 1b

IV. DATA REVIEW

The focus of the data analysis in this report is to establish the long term statistics of the suspended sediment climate at the MOMS site 1. A review of the optical instruments is presented and a review of the data derived from the ADCP deployments is presented. Emphasis is placed on the acoustically derived suspended sediment concentrations.

A. ADCP Currents.

Table 5 lists the ADCP deployments at MOMS site 1.
Note that because of the different blank size used in the MOMS 3 and MOMS 4 deployments, data from these deployments were not used in the current analysis. Those data are used in the temperature analysis and the acoustic backscatter analysis.

Table 5: MOMS Site 1 ADCP deployments

Deployment	frequency	Start time	End time	Instrument s/n	Bin size / blank size
MOMS 3	1200kHz	10/9/98	2/4/99	546	0.5/0.44
MOMS 4	1200kHz	6/24/99	10/20/99	546	0.5/0.44
MOMS 5	1200 kHz	9/21/01 15:40 UT	1/12/02 22:20	1544	0.5 / 0.0
MOMS 6a	1200 kHz	4/23/02 20:50	8/30/02	1544	0.6/ 0.0
MOMS 7	1200 kHz	8/6/04 14:30	12/12/04 19:20	1544	0.5/0.0
MOMS8a-1	1200	6/22/05 13:40	8/19/05 14:30	1544	0.6/0.0
MOMS 8a-2	1200	8/19/05 17:50	12/28/05 12:10	1544	0.6/0.0
MOMS 8b	600kHz	8/19/05 15:00	2/7/06 13:00	2153	0.6/0.87
MOMS 9a	1200 kHz	3/20/06 15:10	8/3/06	1544	0.6/0.0
MOMS 9b	600 kHz	3/20/06 15:00	5/16/06 16:20	2157	0.6/0.87
MOMS 10b	600kHz	5/23/06 17:10	6/22/06 07:30	2157	0.6/0.87

A data set was constructed using the data collected by1200kHz ADCP from deployments 5,6,7,8-1,8-2 and 9 with data collected by the 600kHz ADCP to fill the gap between12/28/05 and 2/7/06. For each data set corrections were applied for local magnetic variation. Table 6 lists the Mean, minimum and maximum velocity for the U (East-West) and V (North-South) components of the current velocity at three selected depths.

Table 6: Mean Current Velocities from ADCP Data

Depth	N obs	Mean cm/sec	Min cm/sec	Max cm/sec	
U 16.8m	105381	0.435560	-38.000	32.1000	
U 11.4m	105883	-0.042732	-58.200	34.8000	
U 3.6m	105566	0.642810	-123.200	77.4000	
V 16.8m	105883	5.699176	-60.200	97.2000	
V11.4m	105883	8.283138	-76.400	120.0000	
V3.6m	105566	8.960969	-83.700	109.8000	

The U (East-West) velocity is near zero for all three depths and the mean V(North-South) velocity is less than 10 cm/sec at all depths. Figure 4 shows the histograms of the U and V component at three representative depths.

Table 7 gives the monthly average and maximum current magnitude at 16.8m
Figure 5 graphs the monthly average of the current velocity magnitude at the 16.8m depth.

Table 7 : Mean and Maximum Current Magnitude by month

	MEAN CURRENT MAGNITUDE 16.8M cm/sec	MAXIMUM CURRENT MAGNITUDE cm/sec	N obs
JAN	12.3	54.3	6183
FEB	10.7	43.9	944
MARCH	11.6	40.1	1637
APRIL	14.1	49.5	5203
MAY	13.1	48.6	8928
JUNE	13.5	48.9	9854
JULY	15.7	53.6	13294
AUG	13.4	51.2	12566
SEPT	16.2	73.7	9976
OCT	12.9	97.8	13392
NOV	10.7	45.6	12945
DEC	12.0	50.9	10459
ALL DATA	13.3	97.8	105381

B)Waves

Table 8 lists the 600kHz ADCP deployments at MOMS site 1 that collected waves data. These three data sets were merged together and descriptive statistics were calculated (Table 9) demonstrating the mean significant wave height and the mean periods of the principal wave observed for each month. Figures 6 and 7 show the significant wave height and principal wave period grouped by month. It is important to remember that this instrument has a high frequency cut off resulting in waves with a period less than 2.15 seconds not being represented.

Table 8: ADCP waves data sets

File name	Start time	End time.	Sample interval
8b	8/19/05 14:50	2/7/06 05:50	3hr
9b	3/20/06 15:00	5/16/06 12:00	3hr
10b	5/23/06 18:00	6/22/06 07:00	1.5hr

Table 9: Wave statistics by Month

MONTH	Mean Significant wave Height (m)	Mean Wave period (sec)	N obs
JAN	.84	5.6	217
FEB	.58	4.8	38
MARCH	.6	4.7	64
APRIL	.57	5.1	180
MAY	.29	4.5	193
JUNE	.4	4.0	275
JULY			0
AUGUST	.63	4.5	66
SEPT	.62	5.8	171
OCT	.82	5.6	199
NOV	.66	4.9	211
DEC	.54	5.4	191
ALL DATA	.59	5.1	1802

C. Temperature.

Table 5 lists the times of the 1200kHz ADCP deployments at MOMS site 1.
Figure 8 shows the monthly mean, standard deviation, minimum and maximum of the temperature recorded by the 1200kHz ADCP for the all of the MOMS site 1 ADCP deployments. It is observed that colder water often occupies Site 1 after the passage of severe storms. Also observe that colder water occupies site 1 in June. This may be upwelled water from offshore or internal waves breaking on the Florida shelf. Figure 9 show the temperature record from Site 1 and also the temperature record from an ADCP deployed near the Offshore Dredged Material Disposal site located 2.2 nautical miles North-Northeast of MOMS site 1 in 73m water depth. The temperature signal from the passage of Hurricane Wilma is clearly seen in both records.

D. YSI Sondes

Table 10 list the times of the YSI sonde deployments.

Table 10. YSI SONDE DEPLOYMENTS

location	ID	File name	Start time	End time
S1	A	Moms0921	9/21/01 15:01	11/20/01 14:21
S1	B	S11217	12/17/01 20:20	3/17/02 02:30
S1	C s4	Site1s4b	4/24/02 11:41	6/11/02 14:41
S1	C tri	Site1tri	4/23/02 14:21	6/11/02 12:41
S3	D	St361402	11/1/02 00:00	11/19/02 00:20
S1	E	S18905	8/19/05 13:40	9/27/05 08:10
S1	F	S1100705	10/12/05 11:40	1/16/06
S1	G	032006	3/20/06 10:00	5/20/06 12:30
S1	H	052006 s1	5/20/06 17:40	6/29/06 20:50
S1	I	S1 062906s1	6/29/06 20:30	9/13//06 16:10

In all the deployments, biofouling caused a degradation of the data with time. Optical backscatter sensors often showed evidence of fouling after a few days. Figure 10 is a time series of temperature, OBS and salinity data from a YSI deployment which illustrates the effects of biofouling. It is observed that in some cases, the optical backscatter data appeared to remain elevated after the occurrence of a high turbidity event. The data from hurricane Rita (Figure 10.) is an example of this. The conductivity data also deteriorates with time, albeit over longer time scales than the optical sensors.

E. Data logger.

The OBS and PAR instruments attached to the data logger system were deployed 3 times at MOMS site 1. Table 11 lists times of the deployments. As in the case of the YSI instruments, biofouling degraded the quality of the data over time. Figure 11 shows the first 20 days of the raw data from the 8/19/05 deployment. Data from the Mc Van OBS sensors showed good correlation to the YSI during Hurricane Katrina (R=0.896) and also good correlation to the acoustics (R=0.885) However, good quality data was not recorded during hurricanes Rita or Wilma. Therefore; data from these sensors was not included in the acoustic suspended sediment estimation algorithm. PAR data from the datalogger appears to be of good quality and clearly shows the reduction of light caused during the passage of severe weather events.

Table 11. Dataloger/OBS PAR deployments.

Start	End	Notes
4/23/02 11:20	6/9/02 11:00	20min sample interval McVan sensor only
8/19/05 14:10	10/4/05 17:30	10 min sample interval PAR data is bad after 9/27 OBS data is bad after 9/5 McVan data is bad after 9/8
10/12/05 12:00	1/26/06 10:40	20 min sample interval OBS and McVan data appear to be bad PAR shows a decrease in level with time

F. Acoustically estimated suspended sediment concentration.

Table 5 lists the ADCP deployment at MOMS site 1. Data from all the 1200 kHz ADCP deployments were merged and corrections applied so that this data could be used to generate a long time series record of acoustically estimated suspended sediment concentrations. This record has 134241 data points representing 932 days of data. It should be noted that the deployment parameters of the ADCP (bin size and blanking size) were not always the same. In the case of MOMS 3 and MOMS 4, this would cause the measurement cell's location to be shifted 40cm higher in the water column. The value of the suspended sediment estimates from these data may be somewhat lower than data from the other deployments where the measurement is made closer to the bottom. However, this data was retained in the analysis as it significantly increased the record length. Keeping this in mind however, data from the 2005 -2006 data sets were analyzed separately to produce statistics both with and without severe weather events. (The ADCP parameters were held constant for the 2005-2006 data.) Table 11 lists some descriptive statistics for this data. Figure 12 is a histogram illustrating the distribution of the acoustically estimated suspended sediment concentration and includes all data. Figure 13 illustrates this distribution as a cumulative histogram. Table 12 gives the monthly averages, minimum, maximum and standard deviation of the data. This is shown graphically in figure 14.

Table 12. Acoustically Estimated Suspended Sediment Concentration.

	N obs	Mean (mg/l)	95th percentile	99th percentile	SD	Min	Max
All data	134241	3.158	8.586	41.597	11.000	0.079	302.633
2005-2006 data	46722	3.121	6.387	60.251	13.347	0.079	289.633
2005-2006 data no severe storms	42686	1.528	3.850	9.4032	1.660	0.079	68.721

Table 13. Monthly Statistics of Acoustically Estimated Suspended Sediments

	N obs	Min	Max	Mean	SD
Jan	6181	0.38	52.72	3.67	4.81
Feb	521	0.61	13.27	2.84	2.87
March	1637	0.34	10.11	1.13	0.98
April	5347	0.26	22.67	1.35	1.88
May	8928	0.08	124.00	2.37	6.44
June	10772	0.19	20.70	1.12	0.71
July	17856	0.31	181.27	2.61	10.95
August	17094	0.24	97.65	1.55	2.95
Sept	14306	0.37	213.54	4.94	14.47
Oct	19729	0.31	302.63	5.57	19.04
Nov	17280	0.37	216.47	4.30	12.89
Dec	14590	0.28	65.33	2.02	2.13

V. DISCUSSIONS.

This section contains the discussion of the statistics derived relating to the suspended sediment climate at MOMS site 1 and describes the conditions that existed during the passage of three hurricanes in 2005 and elevated suspended sediment events that occurred in 2006 and 2006.

A. Suspended sediment climate at MOMS site1.

From Table 12 and Figures12 and 13 it can be seen that the majority of the acoustically estimated suspended sediment values are below 10 mg/l. Also, from Table 12 it can be observed that if the severe storms are excluded from the 2005-2006 data sets, the mean and standard deviation of the suspended sediment concentration are greatly reduced. This implies that high turbidity events are likely to be associated with strong weather events. Figure 15 is a regression between the significant wave heights and acoustically estimated suspended sediments. This regression includes the data from Wilma, Katrina and Rita. The correlation coefficient is R=0.69. Figure 16 is a regression between the significant wave heights and acoustically estimated suspended sediments. This regression includes the data from 2005 and 2006 however it excludes the data from Wilma, Katrina and Rita. The correlation coefficient R=.51. This plot also suggests that a step increase in the suspended sediment levels occurs at a significant wave height of about 1.4m.
The data from 2005-2006 were analyzed excluding that data which is associated with severe storms and the correlation between the current magnitude at 16.8m depth and the acoustically estimates suspended sediments concentration is R=0.23. This suggests that currents may also account for part of the total suspended sediment concentration at MOMS site 1. The acoustically estimated suspended sediment data set from the deployments of the 1200kHz ADCP in 2005 and 2006 were examined to identify periods of elevated suspended sediment concentration. These are presented in the following two sections.

B. Description of observations during severe weather events.

During the 2005 hurricane season the MOMS site 1 area was impacted by 4 severe storms. During three of these storms (Katrina, Rita and Wilma) the MOMS site 1 was fully instrumented. Several lesser weather events also produced elevated suspended sediment concentration levels. We define these lesser events as events where acoustically estimated suspended sediment concentrations exceeded the 95% percentile level of 8.586 mg/l for a period of one hour or more. These events presented the opportunity to study the response of this area to weather events that can be expected to occur more frequently than the severe weather associated with hurricanes.

Hurricane Katrina:

Figure 17 shows the wind speed and direction during the time of hurricane Katrina passage. Prior to the onset of Hurricane Katrina the winds had been coming from the ENE at a speed of roughly 5 m/s at about 15:00 UT on 8/26/05 the winds continually shifted counter clockwise through the north reaching a SE direction at 15:00 UT 8/26/05. The maximum wind speed of 29.1 m/s occurred at 23:00 UT on 8/25/05. Figure 18 shows the significant wave height and wind speed during the time of hurricane Katrina's passage. The maximum significant wave height of 2.1m was observed at 09:00 UT on 8/26 the wave period at this observation was 8.5 sec and the principal wave direction was 139 degrees. The envelope of wave significant height observation closely followed that of the wind field. Figure 19 shows the wind speed and significant wave height with measured and acoustically estimated suspended sediment concentrations for the time of hurricane Katrina's passage. Suspended sediment concentrations began to increase at about 10:00 UT on 8/26/05. Suspended sediment concentrations remained elevated until 03:00 8/28/05. Suspended sediment concentration levels remained above pre hurricane levels for several weeks after the passage of the storm.

Table 14 reports the correlations between the wind speeds, significant wave height, ADCP backscatter (Sv) and the log of the suspended sediment concentration measured by the YSI sonde OBS sensor. (YSI OBS data was processed by applying a calibration equation to convert to units of mg/l, applying a 3 point median smoothing filter and taking 10 times the base 10 logarithm of this)

Table 14. Correlations between data measured during hurricane Katrina.

	Wind speed	Significant wave height	Log YSI OBS
ADCP backscatter	0.537	0.695	0.845
Wind speed		0.935	0.395
Hs			0.605

Hurricane Rita:

Figure 20 shows the wind speed and direction for during the time of Hurricane Rita's passage. Prior to the passage of Hurricane Rita the winds speed and direction were variable. On 9/18/05 at about 14:50 UT the wind speed began to increase and reached a maximum speed of 22.0 m/s on 9/20/05 17:30. Figure 21 shows the significant wave height and the wind speed during the passage of Hurricane Rita. The maximum significant wave height of 3.28m was recorded on 9/20 05 at 18:00. At that time the wave period was 7.1 sec and the principal wave direction was 116 degrees. The envelope of wave significant height observation closely followed that of the wind speed. Figure 22 shows the wind speed and wave height with the measured and calculated turbidities. The envelope of the turbidity measurements closely mimics that of the wind speed. The turbidity remained elevated through 9/20/05. In this example, the calculated suspended sediment concentration and the acoustically estimated suspended concentration are not in good agreement during the peak wind period. After the winds subsided, the optically measured suspended sediment concentration is elevated with respect to the acoustics. This may be an artifact caused by the degradation of the optical data due to fouling. Figure 10 shows the data from the YSI sonde during this period and it can be seen that after September 3rd 2005 the turbidity levels frequently spike to very high values.
This is one of the principal reasons that data from hurricane Rita was not included in calculating the relationship between the YSI OBS and the acoustic backscatter.
Table 15 reports the correlations between the wind speed , significant wave height, ADCP backscatter (Sv) and the log of the suspended sediment concentration measured by the YSI sonde OBS sensor. (YSI OBS turbidity data was processed by applying a calibration equation to convert to units of mg/l, applying a 3 point median smoothing filter and taking 10 times the base 10 logarithm of this)

Table 15. Correlations Between Data Measured During Hurricane Rita.

	Wind speed	Significant wave height	Log YSI OBS
ADCP backscatter	0.827	0.857	0.922
Wind speed		0.925	0.766
Hs			0.836

Hurricane Wilma:

Figure 23 shows the wind speed and direction for during the passage of Hurricane Wilma. Prior to the passage of Hurricane Wilma the winds were directed from the South East and speeds were on the order of 5-10m/s. On 10/23/05 at about 12:00 UT the wind speed began to increase and reached a maximum speed of 45.6 m/s on 10/24/05 12:40 UT. Figure 24 shows the significant wave height and the wind speed during the passage of hurricane Wilma. The maximum significant wave height of 3.23m was recorded on 10/24/05 at 12:00. At that time the wave period was 8.5 sec and the principal wave direction was 134 degrees. The envelope of wave significant height observation closely followed that of the wind speed for the peak winds of the storm. However on 10/25/05 at about 06:00 UT a series of longer period (14-15 sec) waves begin to be observed. These waves arrive from the North East and have a significant height of about 1.5m. Figure 25 shows the wind speed with the measured and calculated turbidities. The envelope of the turbidity measurements closely mimics that of the wind speed during the period of storm winds. There is a second period of high turbidity levels associated with the long period waves that arrive later. This second period of very high turbidity levels is on the same order of magnitude as the turbidity levels seen during the passage of the hurricane winds. The turbidity remained elevated for a significant period after the passage of the storm and its related waves. It is not possible to determine how long the elevated turbidity levels would have lasted because winter storm front passages in November cause additional sediment suspension events.

Table 16 reports the correlations between the wind speeds, significant wave height, ADCP backscatter (Sv) and the log of suspended sediment concentration measured by the YSI sonde OBS sensor. (YSI OBS turbidity data was processed by applying a calibration equation to convert to units of mg/l, applying a 3 point median smoothing filter and taking 10 times the base 10 logarithm of this)

Table 16. Correlations Between data measured during Hurricane Wilma

	Wind speed	Significant wave height	Log YSI OBS
ADCP backscatter	0.519	0.679	0.952
Wind speed		0.822	0.407
Hs			0.621

C. Description of observations during elevated suspended sediment events

Elevated suspended sediment event 1: Figure 26
On September 6th 2005 wind speed increased to 10 m/s and the significant wave height reached 1.1m. During the next 30 hours, two suspended sediment spikes occurred both of which exceeded the 95% threshold of 8.6 mg/l . The first was approximately 3.2 hours in duration and the second, 1.5 hours in duration.

Elevated suspended sediment event 2: Figure 27.
On October 2nd 2005 at 16:40 UT the wind speed peaked at 13.3 m/s. A concurrent wave field developed which had a maximum significant wave height of 1.7m
Almost concurrent with the build up of the wave field was an elevation in the suspended sediments which exceeded the 95% threshold for 3.8 hours.

Elevated suspended sediment event 3: Figure 28
Shortly after the passage of hurricane Wilma a wind-wave event occurred on October 29th 2005 and another lesser event occurred on November 14th 2005. In these examples, the suspended sediment concentration closely tracks the wind/wave field. For time period represented in Figure 28, the correlation between the significant wave height and the suspended sediment concentrations is R=0.83. In this example, the first period of elevated suspended sediments lasted for about 30 hours with the suspended sediment concentration advancing above and retreating below the 95% threshold several times.
A second peak occurred on November 4th. During this event the suspended sediment levels exceeded the 95% threshold for 3.2 hours.

Elevated suspended sediment event 4: Figure 29.
This is an interesting case as the elevated suspended sediment level observed on 12/6-12/7 is apparently related to an increase in the wind/wave field. However; the suspended sediment event on 12/2 seems to not be closely correlated to the wind/wave field. Figure 30 shows that during this period, cold water moved across the MOMS site 1 area and water temperature is anti-correlated with the elevated suspended sediment levels.
R= -0.53. In this example, the first period of elevated suspended sediments lasted for about 48 hours with the suspended sediment concentration advancing above and retreating below the 95% threshold several times. During the December 2nd event the suspended sediment levels exceeded the 95% threshold for 7.8 hours.

Elevated suspended sediment event 5: Figure 31.
The elevated turbidity levels observed on April 11th and 12th 2006 follow closely with the increase in wind and waves observed over this period. For time period represented in Figure 31, the correlation between the significant wave height and the suspended sediment concentrations is R=0.86 The suspended sediment concentration exhibited three peaks during which the suspended sediment concentration exceeded the 95% threshold for 8 hours,7.3 hours and 3.3 hours respectively.

D. Suspended Sediments during dredge disposal operations.

During 2005 and 2006 dredge material from the Port of Miami was disposed of at the offshore dredge disposal site. (Plate 1) The acoustically estimated suspended sediment data set was carefully inspected in an attempt to identify any increase in suspended sediment concentration concurrent with those operations. Special attention was placed at those times when disposal operations began or stopped. No evidence was found to suggest that an increase in the ambient suspended sediment concentration levels occurred during these operations.

VI. CONCLUSIONS AND SUGESTIONS.

The generation of estimates of suspended sediment concentration from the 1200kHz ADCP backscatter data does provide a significantly longer record of suspended sediment estimates that would be possible with optical instruments which were deployed.
Some suggestions for improving the acoustically estimated suspended sediment data set might be.

1) Reevaluating the data selection that is used to develop the regression relationship between the optical and the acoustical data. Data from the seven day periods centered on the peak winds from Wilma and Katrina were used but perhaps another choice of data may result in a better regression calculation.
2) Suspended sediments measured by the optical instruments at low levels are variable and regression calculations with the acoustics using only low level data does not produce a regression equation with a high correlation. Alternative filtering and conditioning techniques for the optical data may improve the regression relationship for low levels of suspended sediment.
3) An analysis of the optical data with the 1200kHz data and the 600kHz ADCP may lend some insight into shifts in the particle size distribution in the suspended sediment.
Fig 32 gives the wind speed and the ratio of the 600kHz raw backscatter data to the 1200 kHz raw backscatter data during Hurricane Wilma. From this graph it can be seen that the ratio of the 600kHz data to the 1200 kHz data evolves with the passage of the storm. This may imply that the type and or size distribution of the suspended sediments is changing. It would be very useful to have information regarding the type and size distribution of the suspended sediments During the latter MOMS deployments a Sequoia Instruments LISST 25 laser particle size counter was deployed with the instrument at MOMS site one. However the data collected was not of good quality and was not used.

APPENDIX A.

Corrections to ADCP to generate volume backscatter data.

Procedures to calibrate RD instruments ADCP backscatter data to units of Volume Scattering strength (Sv) have by described by Kent Deines. (Deines 1999) These corrections take the form of

1) System corrections that account for system electronics and the physical characteristics of the acoustic transducers
2) Environmental corrections which account for ambient temperature, depth and sound absorption.
3) Corrections which correct for the change in transmitted power due to the depletion of the ADCP battery with time.

From the Deines paper the equation that allows the ADCP backscatter data to be converted to units of scattering volume is

Eq1. $Sv=C+10Log((Tx+273.16)R^2)-L_{DBM}+P_{DBW}+2\alpha R+Kc(E-Er)$

Where Sv is the Scattering volume in decibels re $(4\pi m)^{-1}$
C is a system constant specific to the ADCP
Tx is the temperature at the transducer. (degC)
R is the slant range along the acoustic beam to the measurement point.
L_{DBW} is the 10 times the base ten logarithm of the transmitted pulse length (m)
P_{DBW} is the 10 times base ten logarithm of the transmitted power (watts)
Kc is a calibration coefficient for the ADCPs received signal strength indicator.
E is the received signal strength reported by the ADCP
Er is a reference received signal strength (system background level)
α is the absorption coefficient of water at the ADCP operating frequency.

The terms L_{DBW}, R,and C may be calculated directly from information given in the Deines paper and the deployment parameters of the ADCP. The terms Tx , P_{DBW} and E can be calculated by information given in the Denies paper and data from the deployment. The Er term is instrument specific and is determined by operating the instrument out of the water and recording the raw backscatter values. The Kc terms is derived from a bench test procedure where a signal is introduced into each of the ADCPs transducers at multiple levels and the response of the ADCP to this signal is recorded. From this procedure, the Kc parameter for each beam of the ADCP may be calculated. (Figure 2.) This procedure was performed on instrument #1544. The values of Kc that were measured for instrument #1544 were used to calculate Sv for the data from that instrument and also used for instrument #546 as we were not able to perform the calibration on instrument #546. The attenuation coefficient α is specific to the water that the ADCP is operating in and it can change with depth. However information was not available to allow the direct calculation of α. A typical value of $\alpha=0.48$ dB/m was used for all depths.

In all deployments of instrument #1544, the blanking distance was set to zero. This was done so that the acoustical sampling volume could be made as close as possible to the optical sampling volume. However, this also puts the data from the first ADCP bin in the region known as the near field (Dines 1999). At distances close to the acoustic transducer, the acoustic pulse moving away from the transducer cannot be described as a plane wave. The exact characteristics of the acoustic pressure field in the near field region is not well defined (TRDI 2008). Consequently, the calculated value of Sv for the first bin may not be correct in its absolute value. For this reason, data from the first bin of the 1200kHz ADCP is not used in comparison with data from other ADCP depth bins. Data from bin1 of the ADCP is used only to develop an empirical relationship with the optical backscatter data. Any error in the value Sv in bin 1 would, most likely, express itself as a constant. This constant would factor into the empirical relationship between Sv in bin 1 and the log of the suspended sediment concentration measured by the optical instruments and the values calculated for the acoustically estimated suspended sediment concentration estimates would not be affected.

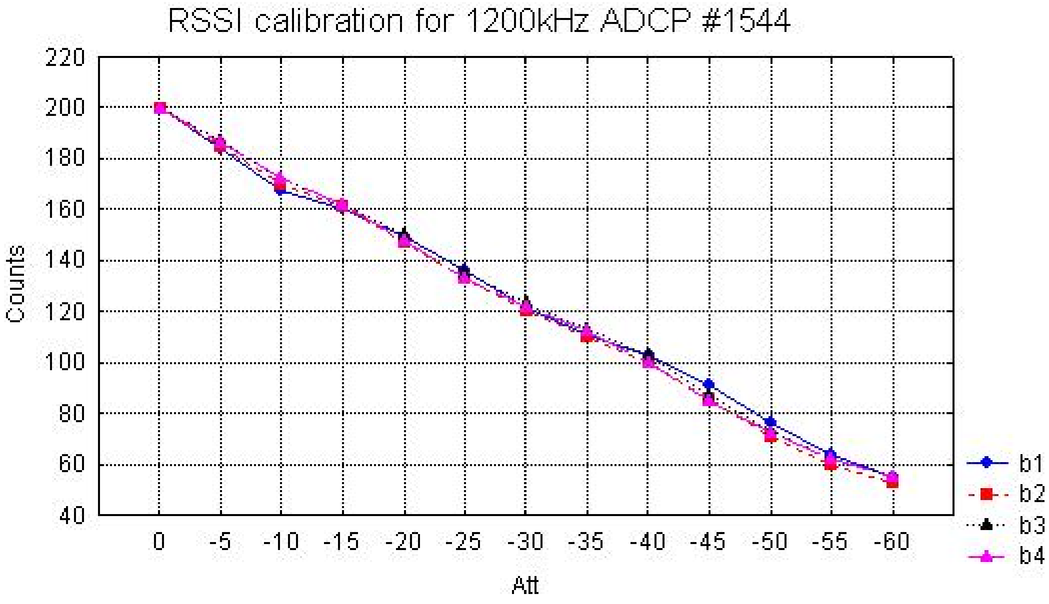

Figure 2.

APPENDIX B.

To convert the turbidity units reported by the YSI OBS into units of suspended sediment concentration, a calibration was performed using sediment collected at the MOMS site 1 for the calibration. Sediment from the deployment site was collected via diver and transported back to AOML. Sediments were freeze dried and sieved through a ≤ 63µm stainless steel sieve. All sediments > 63µm were discarded and only sediments ≤ 63µm in size were used for the turbidity calibration of the optical sensors. The following concentrations (mg/L) of sediment were used for the turbidity calibrations (0, 0.1, .5, 0.75, 1.0, 2.0, 4.0, 6.0, 10.0, 25.0, 50.0, 75.0, 100.0, 125.0, 50.0 and 250.0). A proper amount of ≤63µm sediment was weighed using a Perkin-Elmer Model AD-27 microbalance to achieve the above concentrations. Optical sensors were placed in a round black test tank with a stirring device and the appropriate amount of clean seawater (seawater collected from the Gulfstream). The optical sensors were set to record data every second. Data was collected for approximately two minutes each time new sediment was added. Before any sediment was added the optical sensors collected background data for two minutes on the clean seawater. After each two minute sampling and before the addition of new sediment to the test tank a 1-L sample of water was collected. These 1-L samples were filtered on pre-weighed 47mm 0.4µm polycarbonate filters and dried at 50^0C overnight. These filters were then weighed and new concentrations calculated. The new calculated concentrations of sediment were plotted to make the calibration curve. Upon completion of the turbidity calibration, the data was downloaded from the YSI sonde. The data were averaged over each of the two minute collection periods. These data from the optical sensors (FTU/NTU) were plotted with the calculated concentrations (mg/L) of sediment from the test tank (Figure 3). This allowed the FTU and NTU units to be converted to concentration units (mg/L).

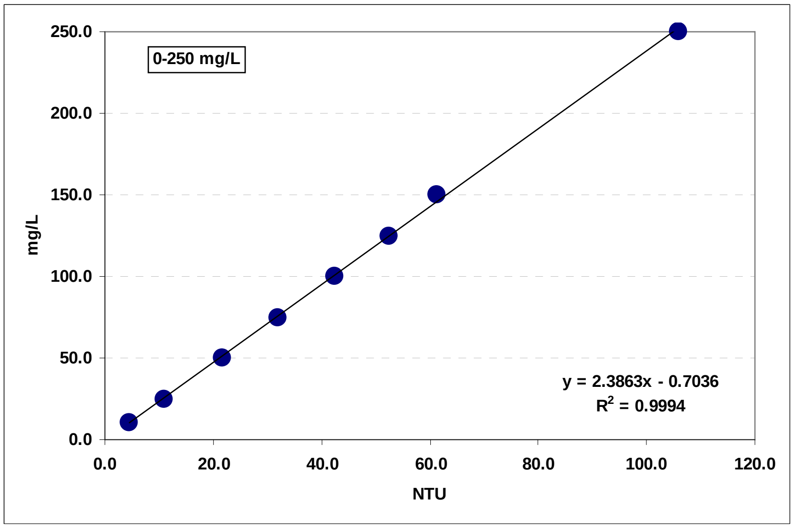

Figure 3

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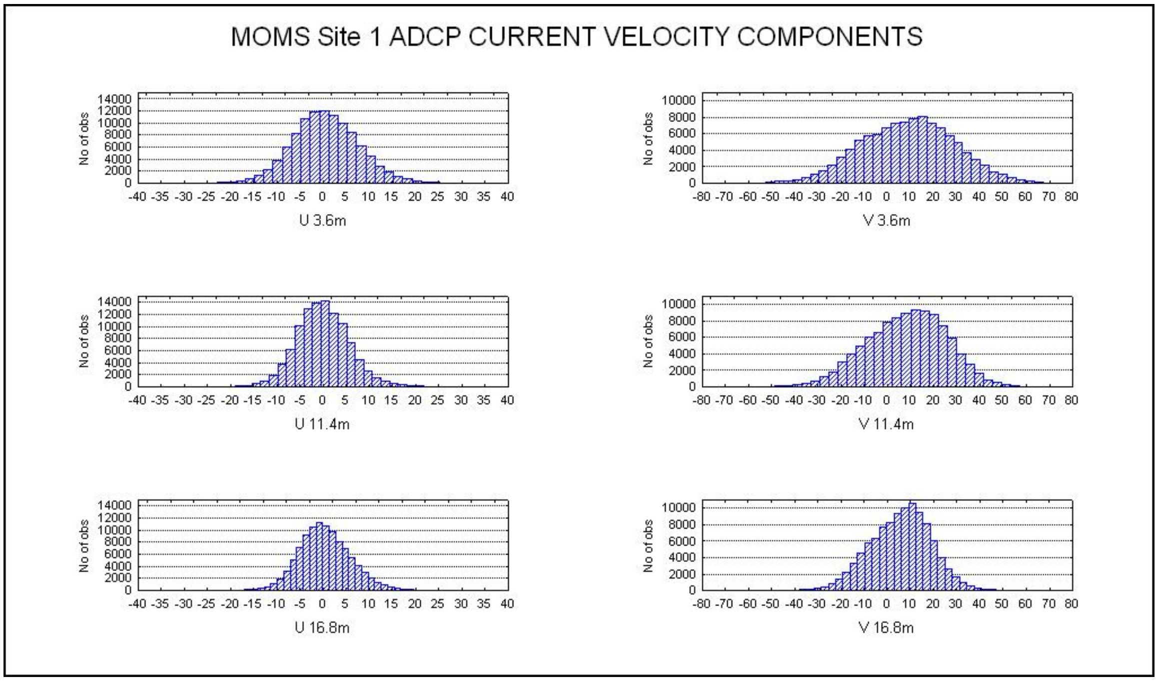

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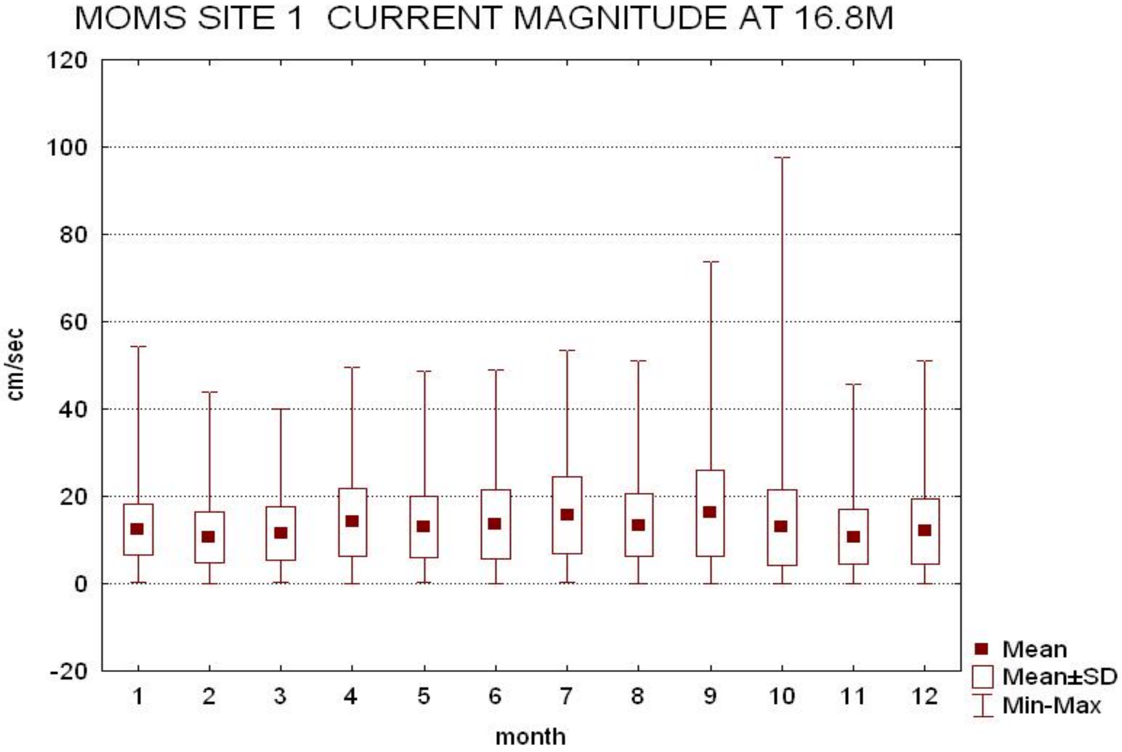

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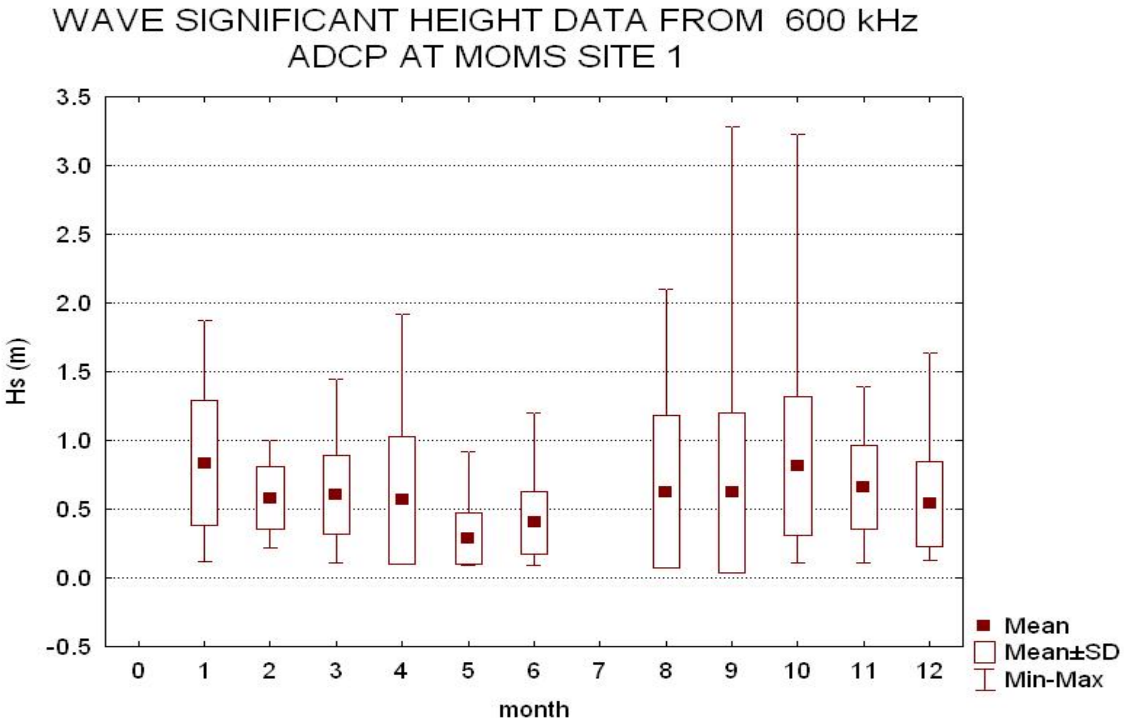

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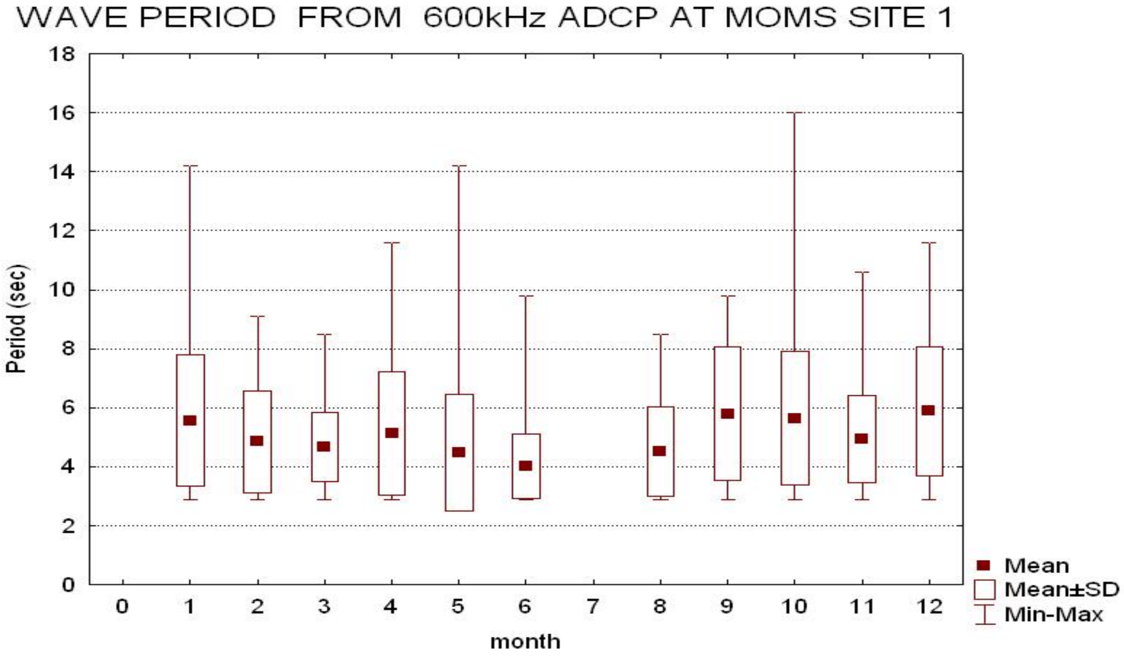

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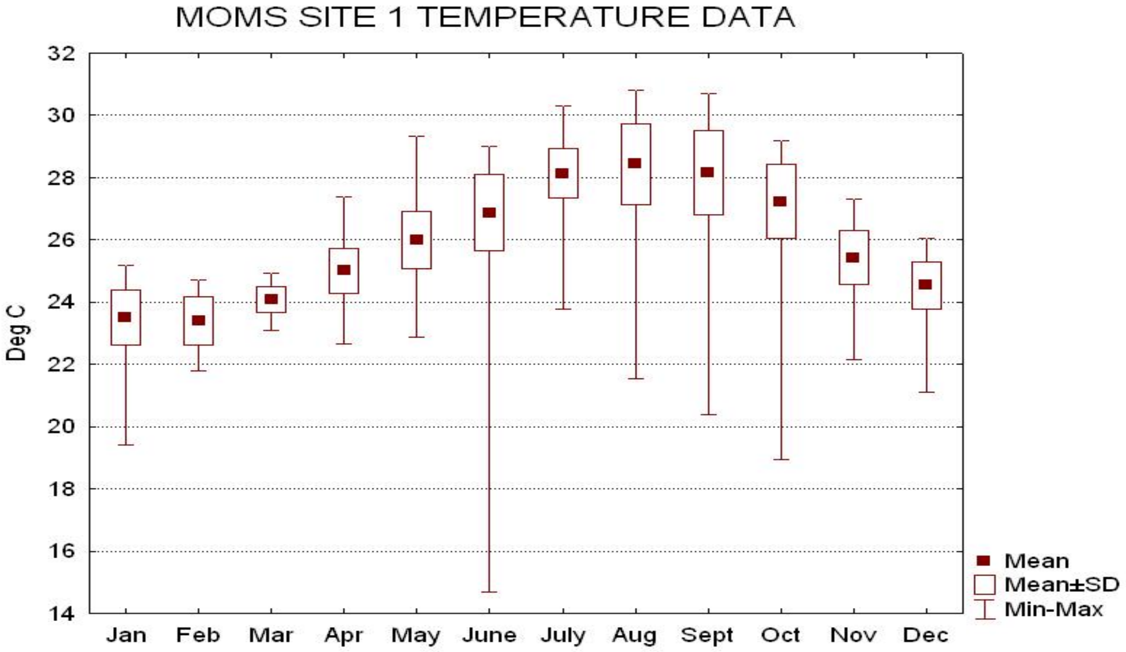

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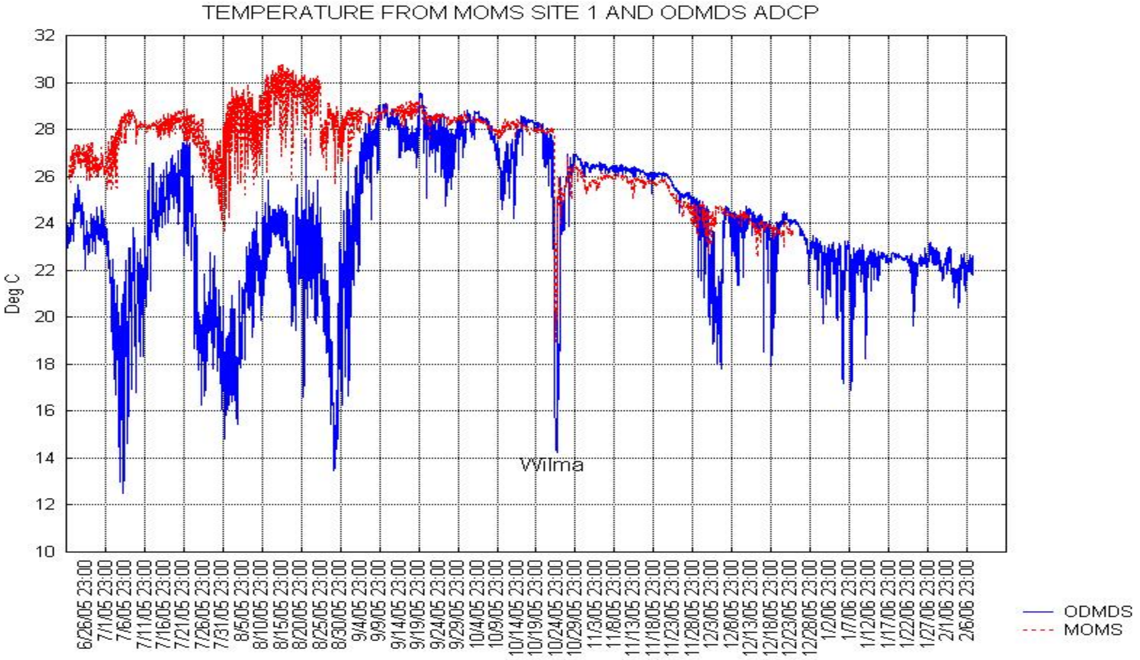

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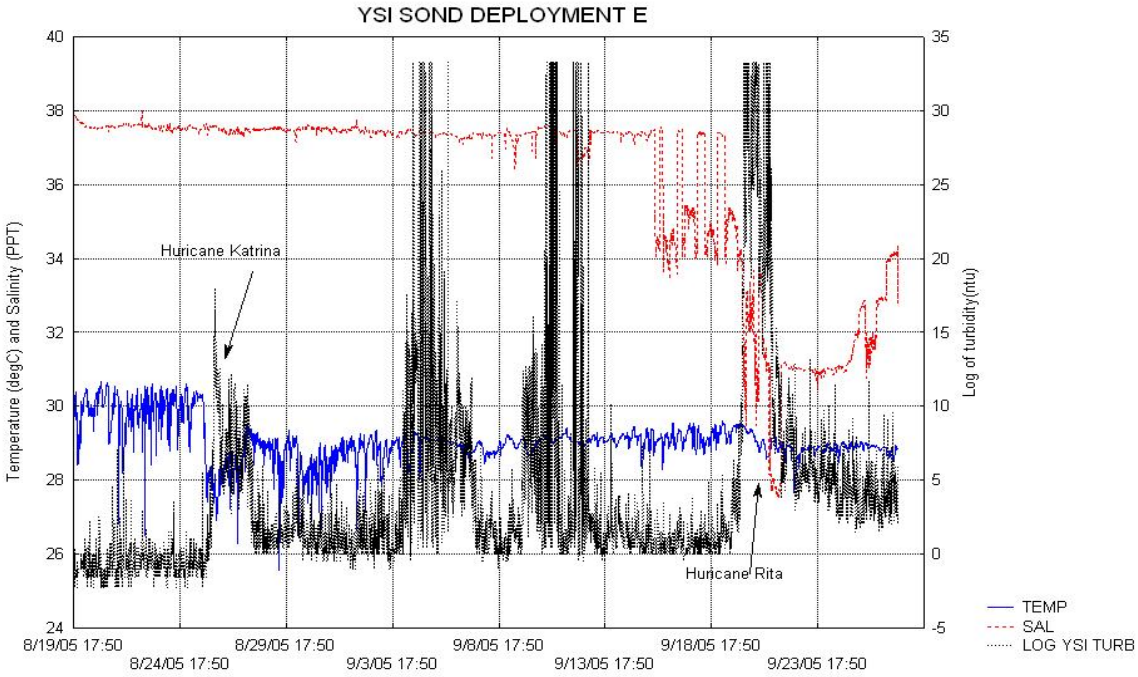

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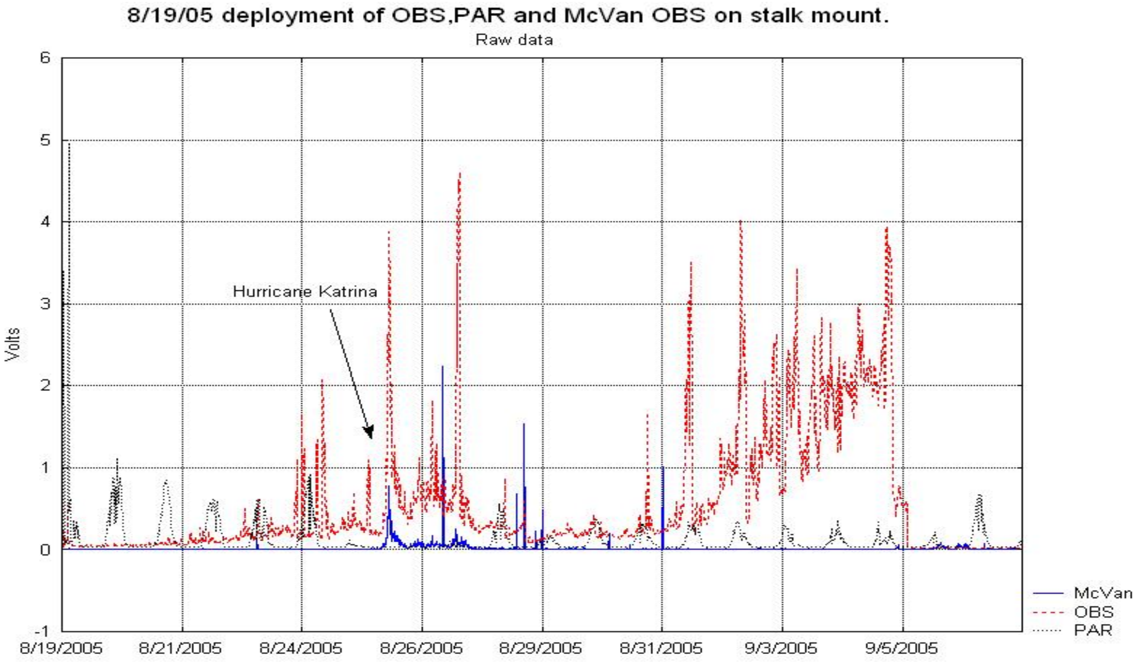

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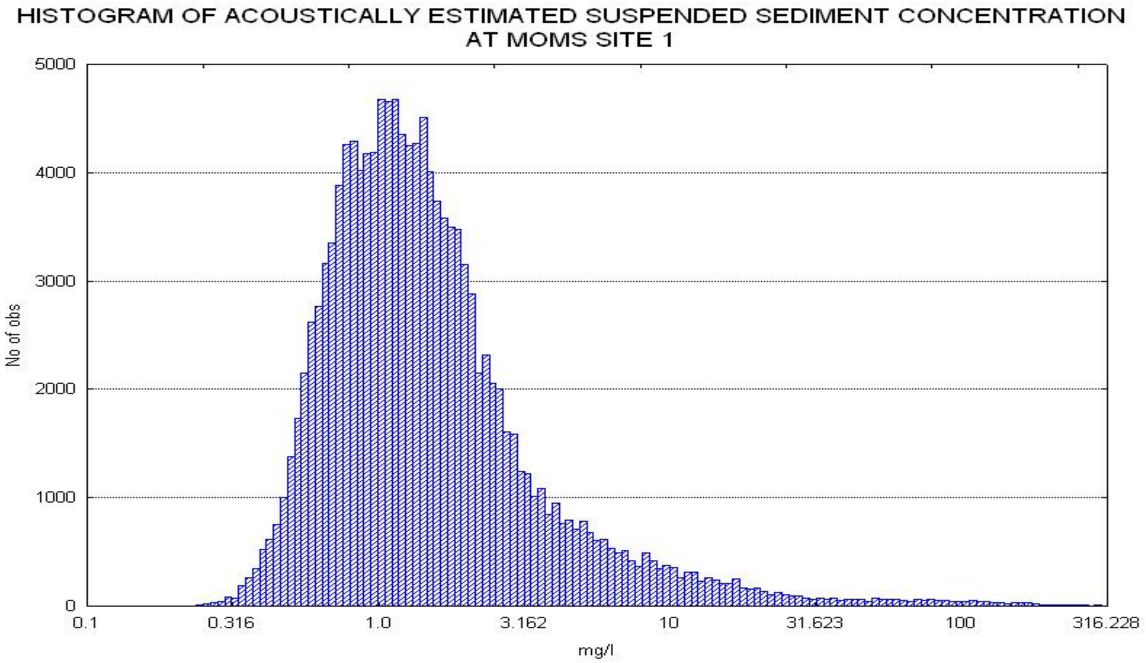

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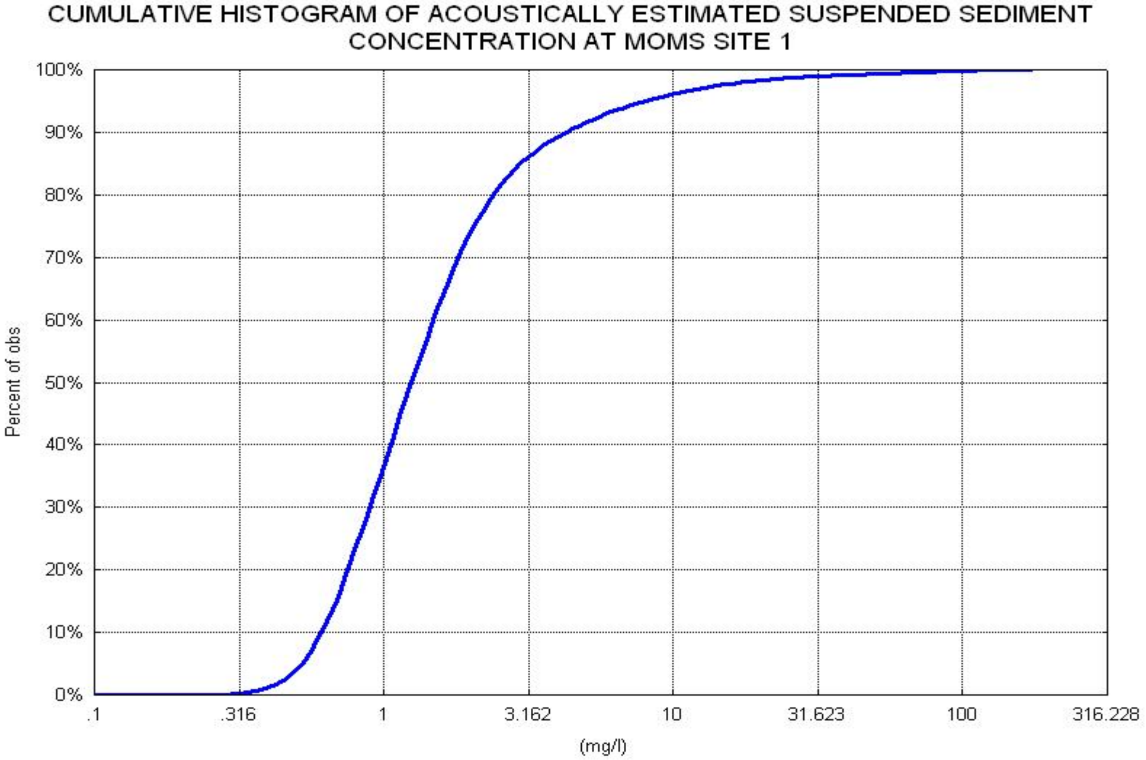

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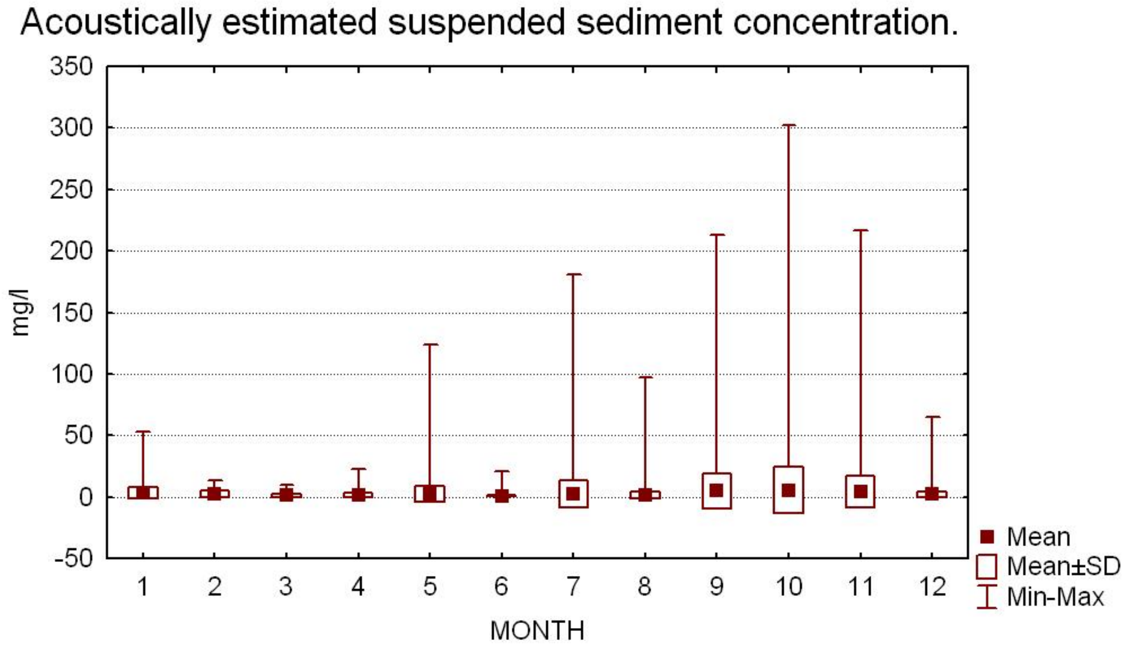

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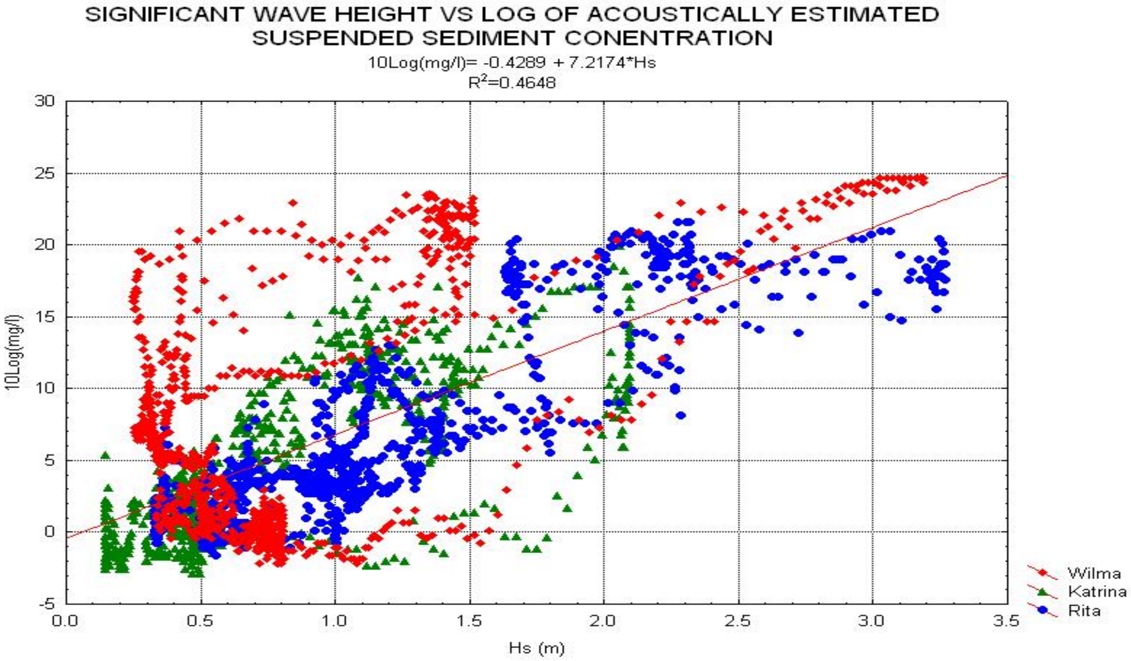

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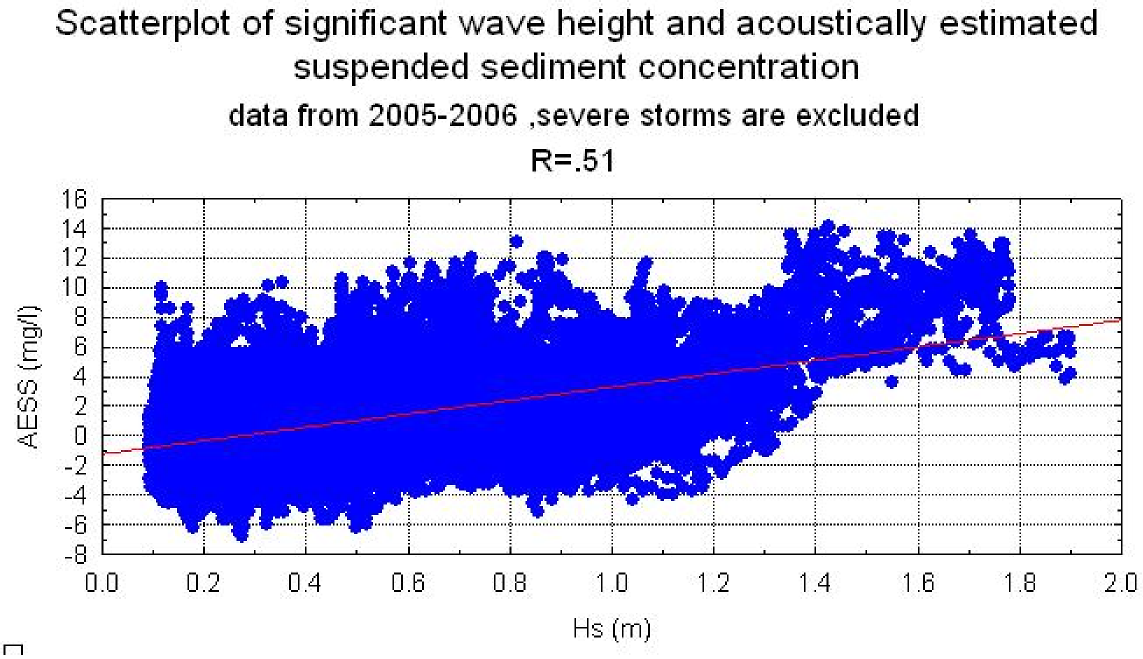

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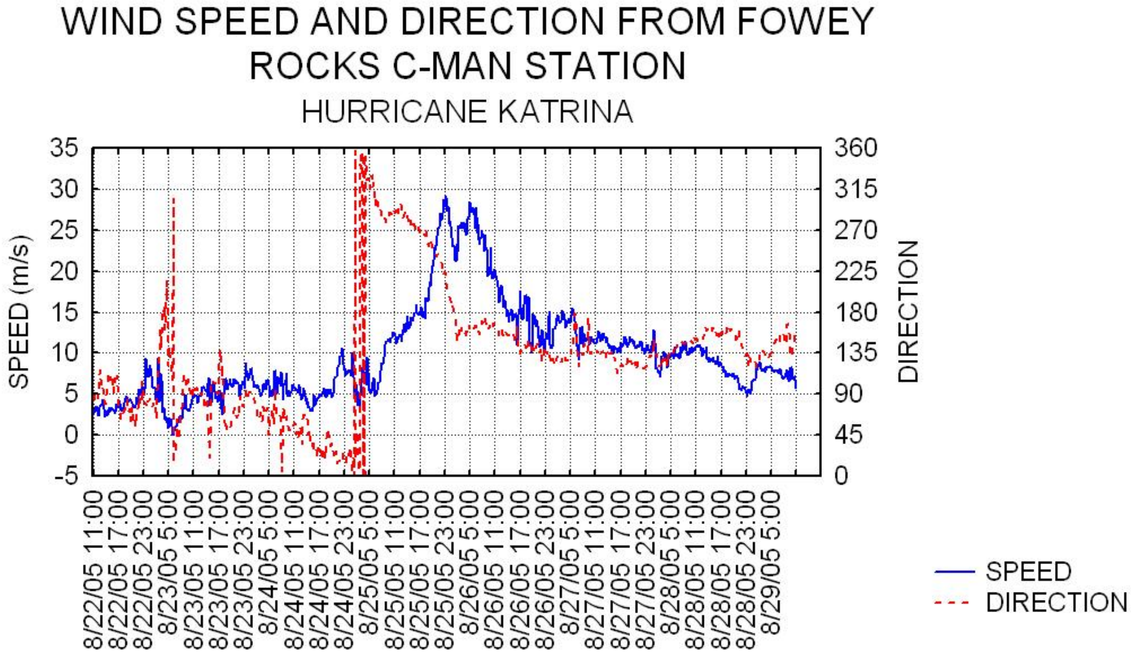

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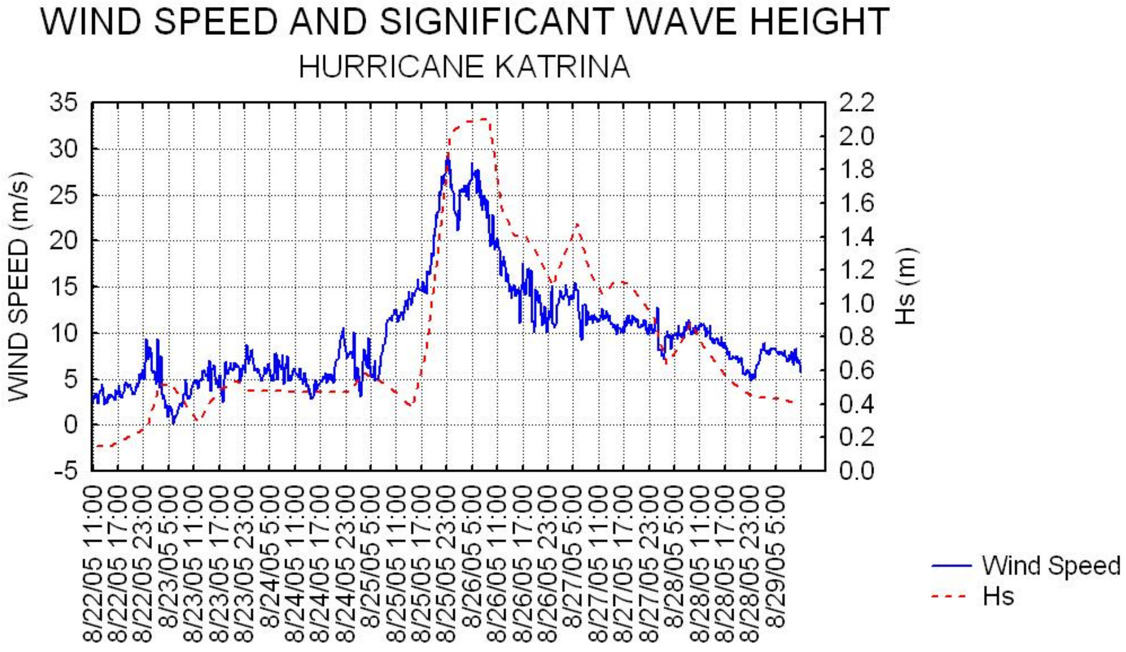

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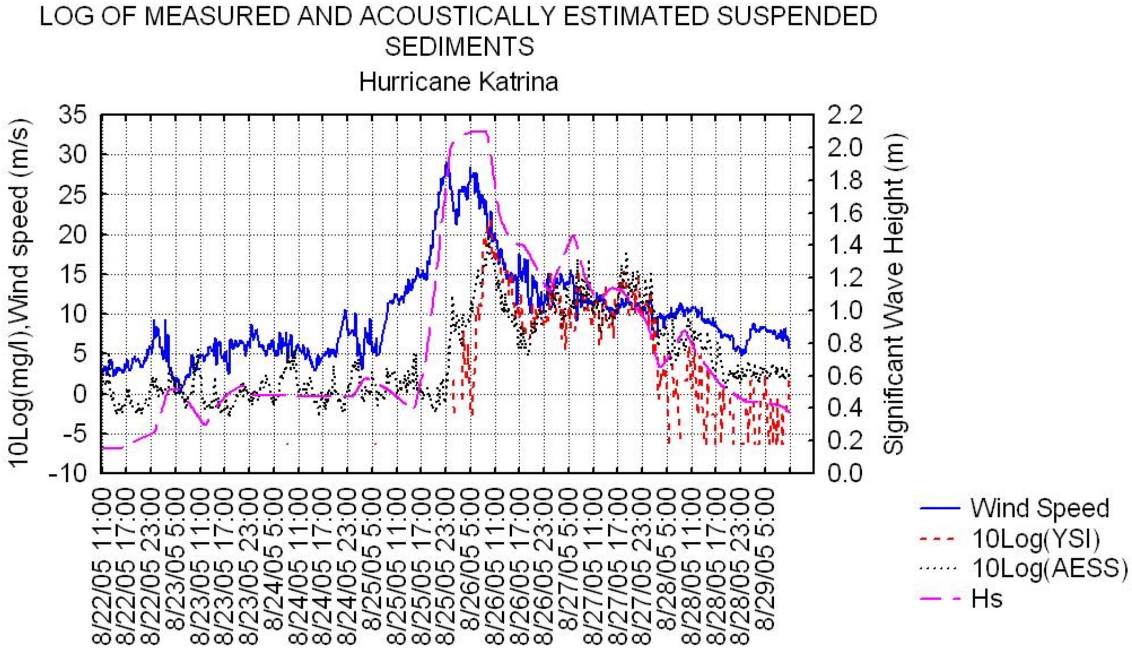

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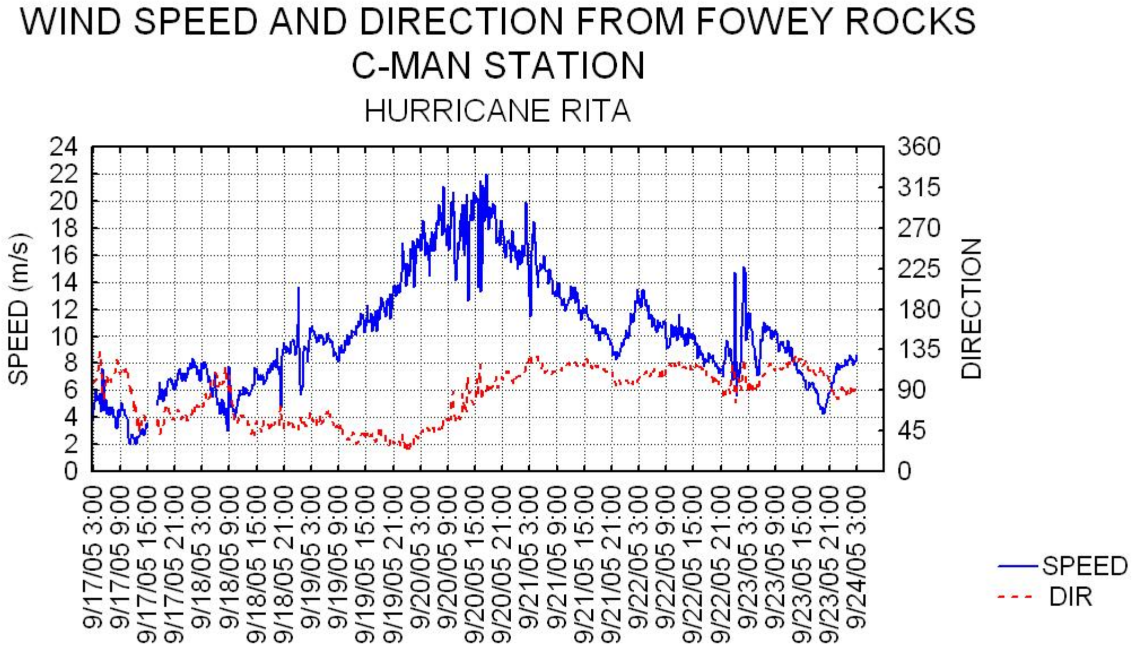

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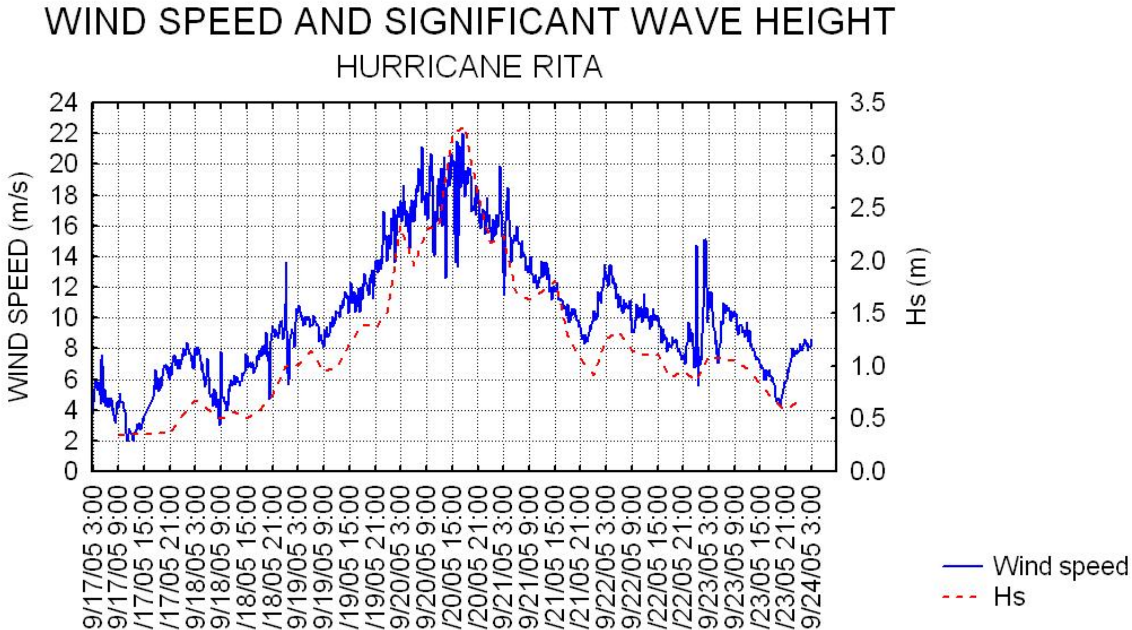

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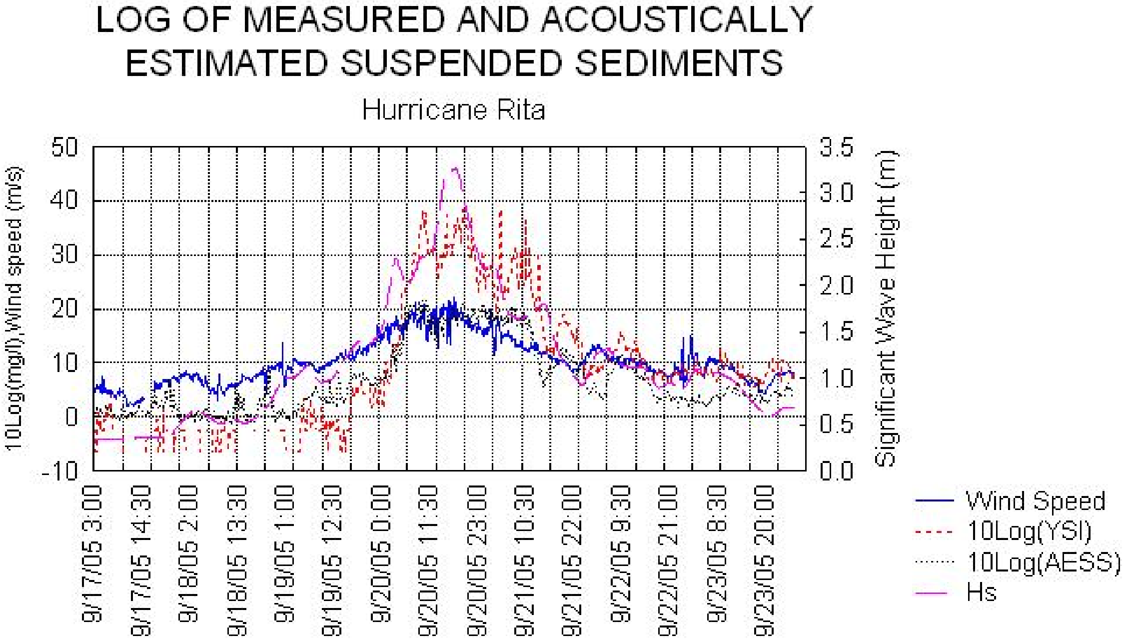

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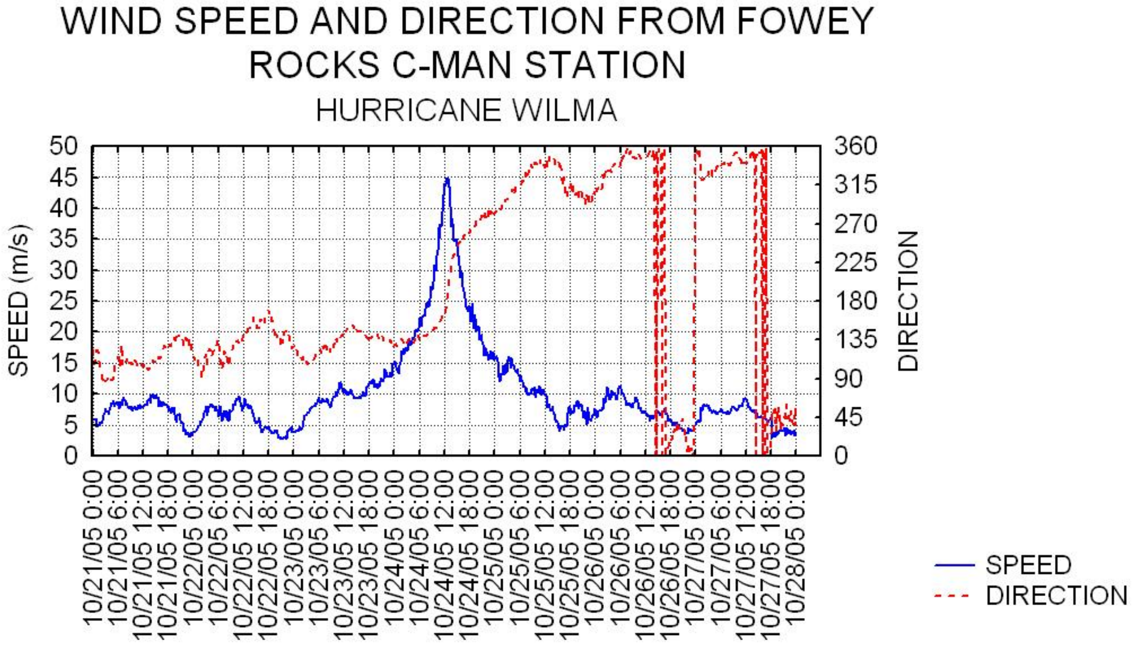

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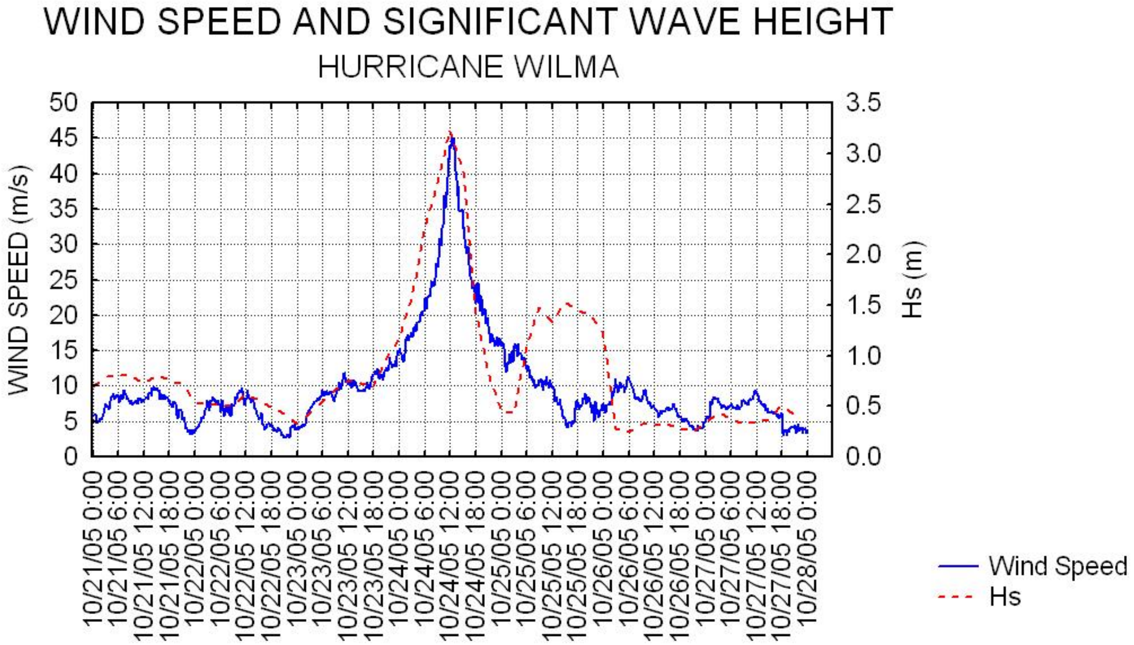

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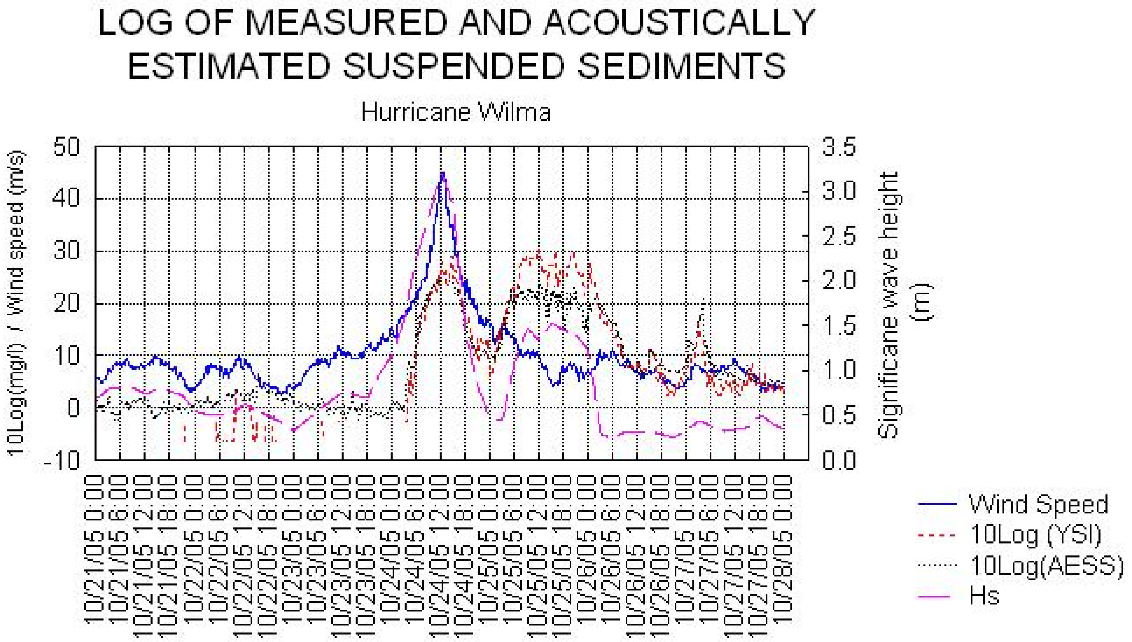

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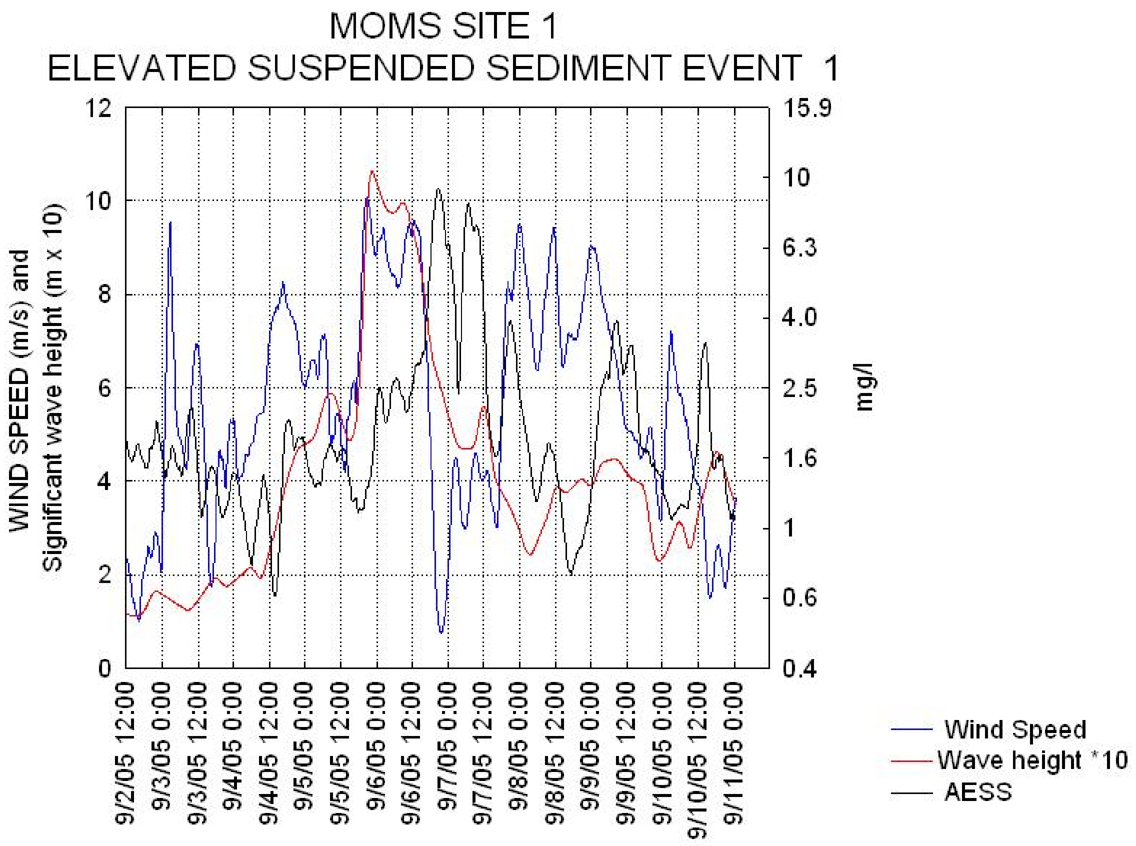

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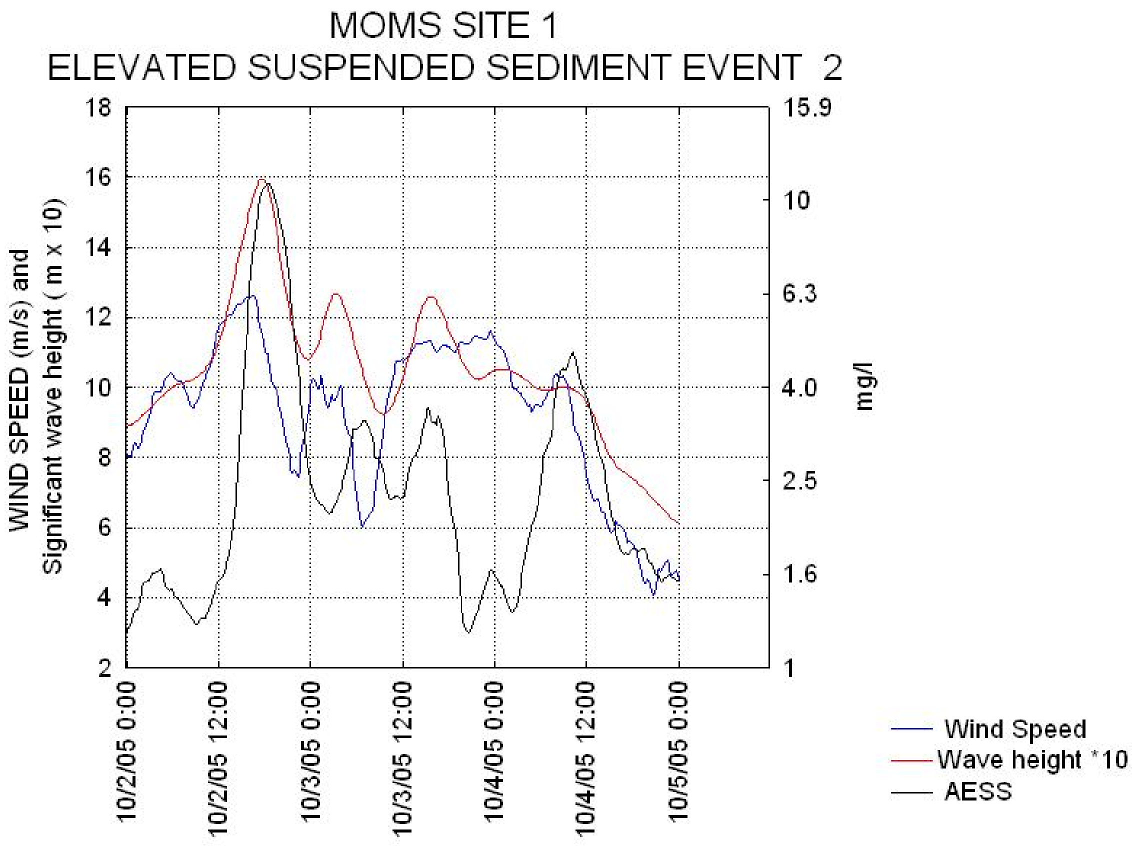

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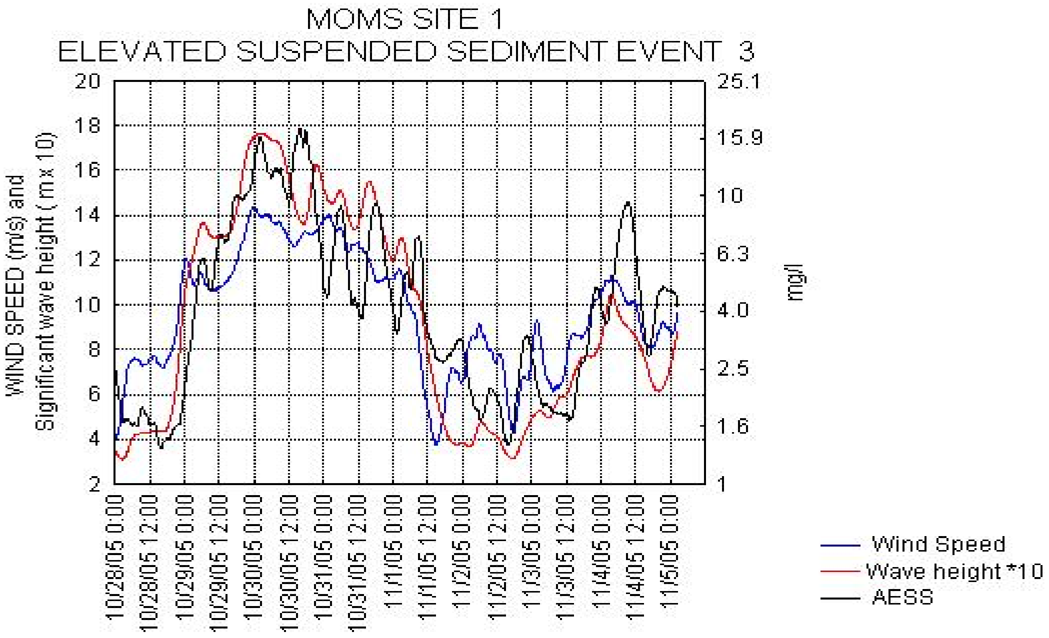

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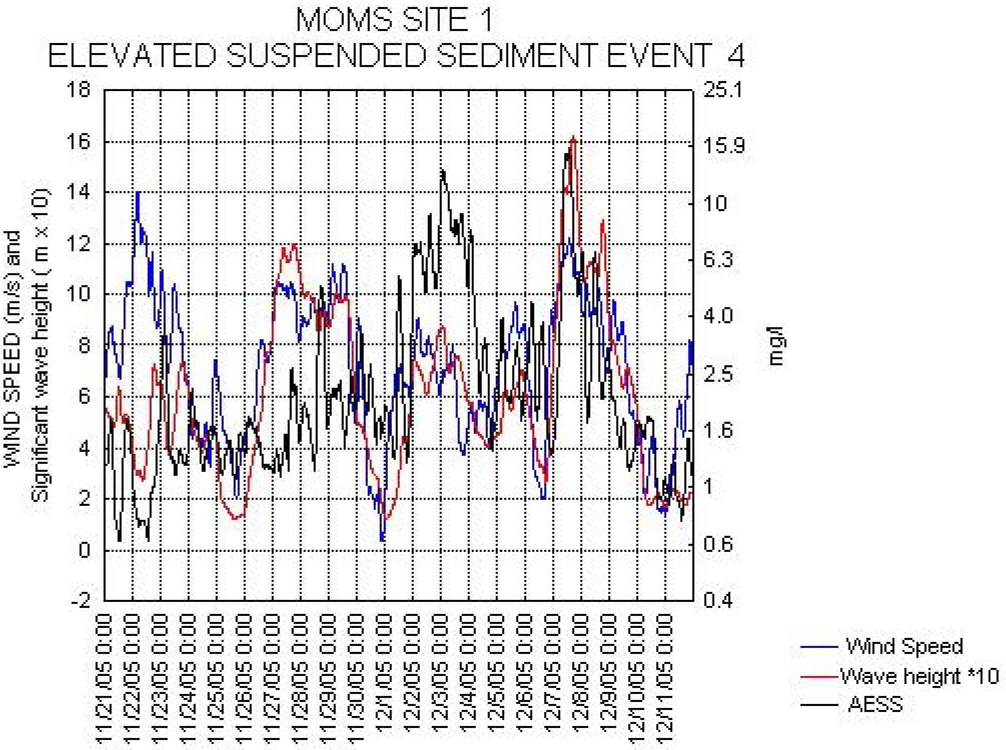

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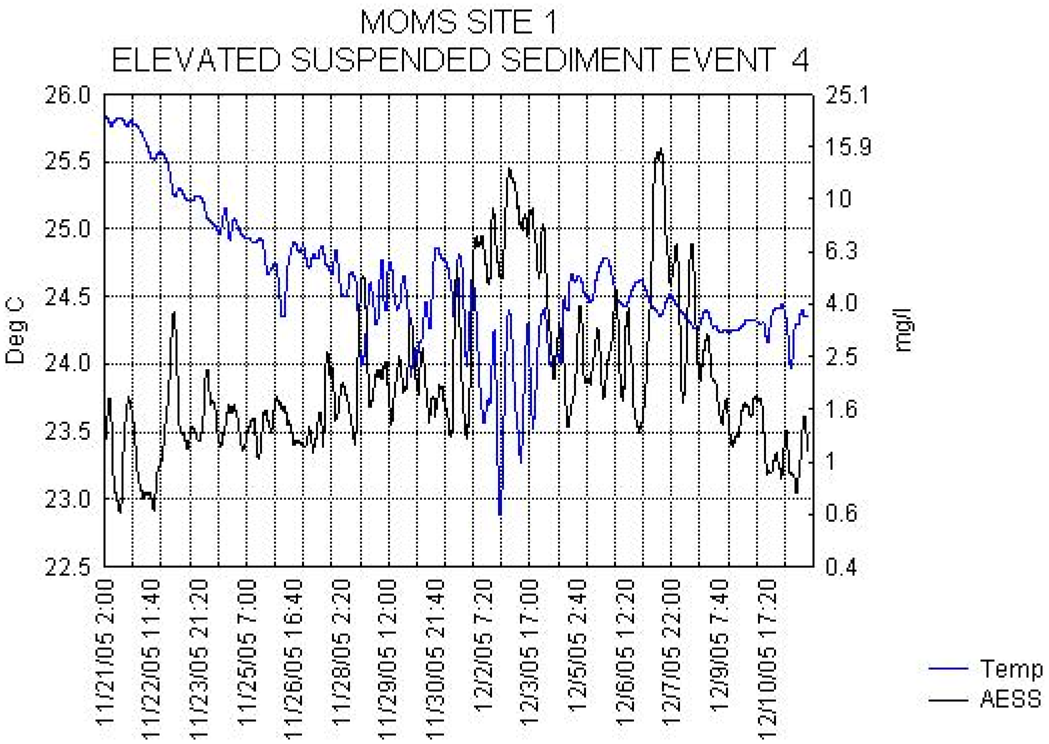

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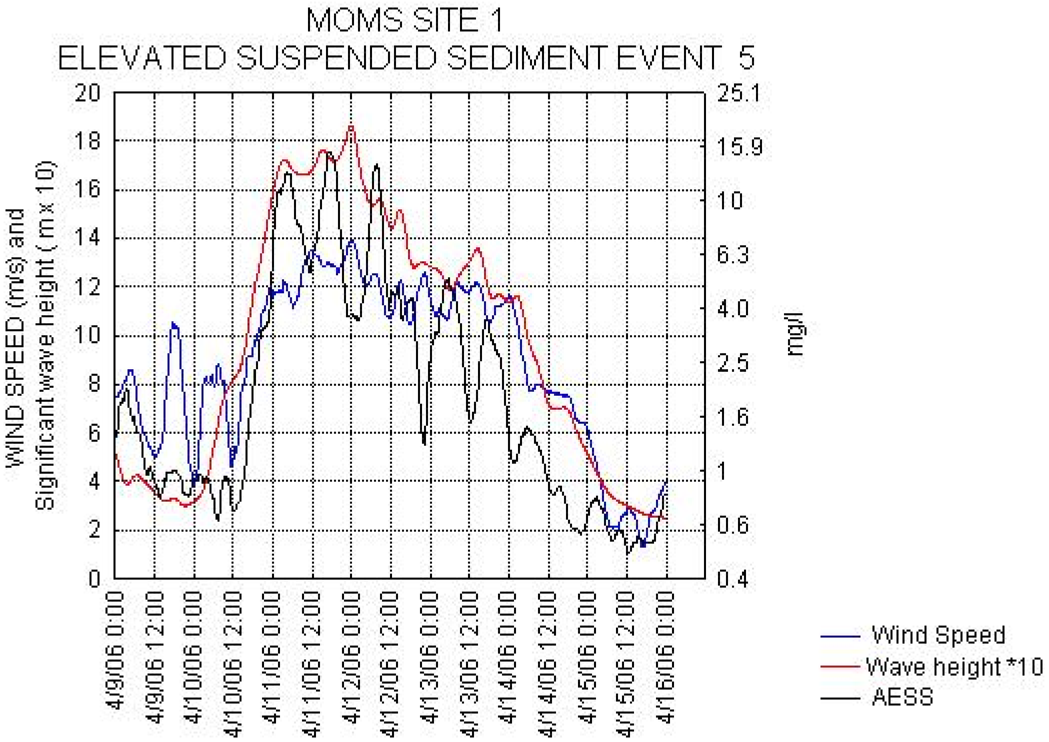

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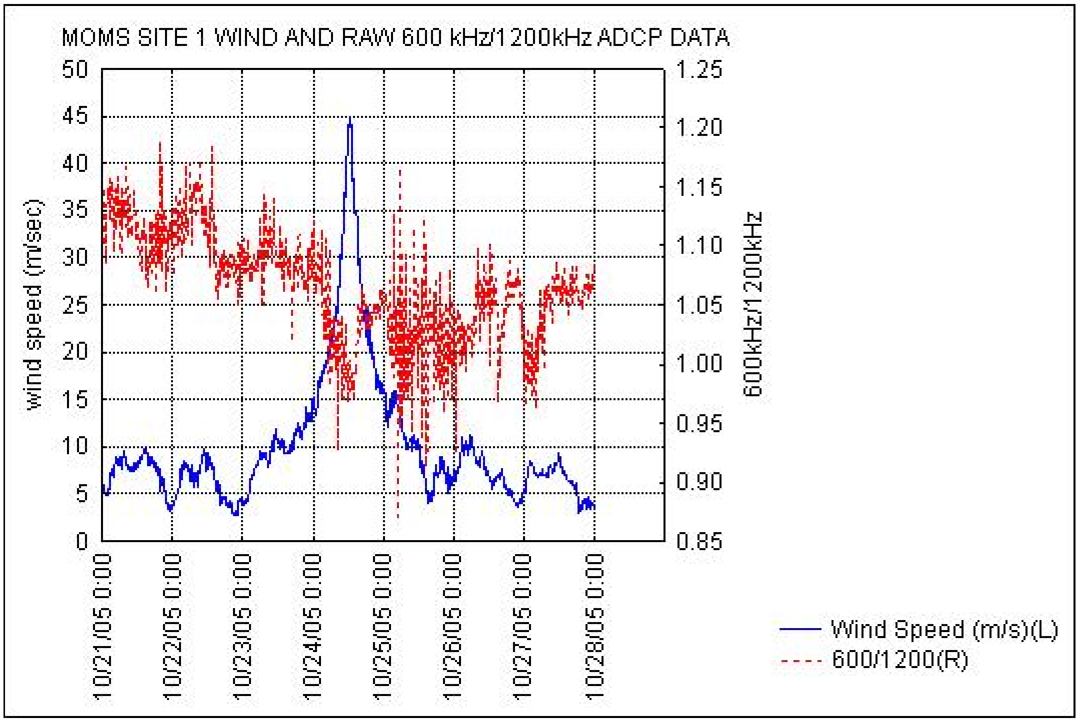
MOMS SITE 1 WIND AND RAW 600 kHz/1200kHz ADCP DATA
wind speed (m/sec)
600kHz/1200kHz
50
45
40
35
30
25
20
15
10
5
0
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
10/21/05 0:00
10/22/05 0:00
10/23/05 0:00
10/24/05 0:00
10/25/05 0:00
10/26/05 0:00
10/27/05 0:00
10/28/05 0:00
Wind Speed (m/s)(L)
600/1200(R)

Figure 32.

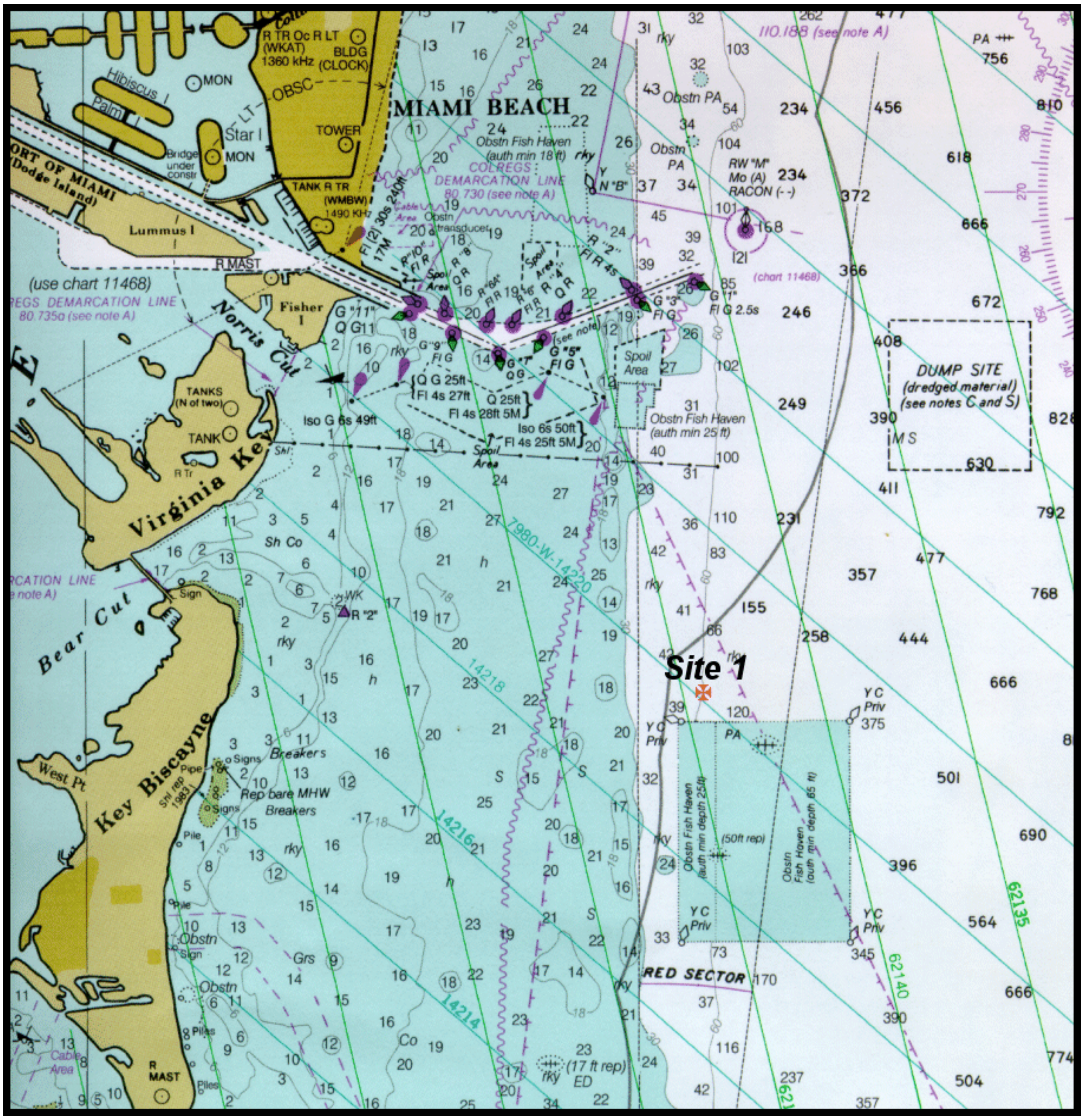
MIAMI BEACH
Site 1
PORT OF MIAMI (Dodge Island)
Lummus I
Fisher I
Norris Cut
Virginia Key
Bear Cut
Key Biscayne
West Pt
Hibiscus I
Palm I
Star I
DUMP SITE (dredged material) (see notes C and S)
COLREGS DEMARCATION LINE 80.730 (see note A)
(use chart 11468)
Obstn Fish Haven (auth min 18 ft)
Obstn Fish Haven (auth min 25 ft)
Obstn Fish Haven (auth min depth 25ft)
Obstn Fish Haven (auth min depth 65 ft)
RW "M" Mo (A) RACON (- -)
Spoil Area
RED SECTOR
Breakers
Rep bare MHW Breakers
7980-W-14220
14218
14216
14214
62135
62140
YC Priv
(chart 11468)
110.188 (see note A)

Plate 1.