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The Miami Ocean Monitoring System (MOMS) Site 1 Study

Atlantic Oceanographic and Meteorological Laboratory
Miami, Florida

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S. Jack Stamates

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UNITED STATES DEPARTMENT OF COMMERCE
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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Acronyms

ADCP	Acoustic Doppler current profiler
AOML	Atlantic Oceanographic and Meteorological Laboratory
FTU	Formazin Nephelometric Unit
MOMS	Miami Ocean Monitoring System
NTU	Nephelometric Turbidity Unit
NOAA	National Oceanic and Atmospheric Administration
OBS	Optical backscatter sensor
PAR	Photosynthetically active radiation

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Abstract

A suite of sensors was placed in 19 meters of water depth at a site offshore of Miami, Florida. These sensors made measurements of suspended sediment concentration, ambient currents, temperature, salinity, and waves. Meteorological data for the time period of the experiment were retrieved from the Fowey Rocks lighthouse station (FWYF1). The received signal strength intensity data from the acoustic Doppler current profilers deployed for this project were processed to provide data in units of volume scattering strength. These scattering strength data were then used to provide a second estimate of the suspended sediment concentrations. During the course of this experiment, several severe storms impacted the area. Suspended sediment concentration estimates are presented for average conditions and for the cases of these severe storms.

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1. Introduction

This report describes the sediment monitoring program at the Miami Ocean Monitoring System (MOMS) site 1 study location offshore of Key Biscayne, Florida in 18.9 m of water (25.716°N, 80.089°W) (**Figure 1**). The MOMS study was undertaken to assess the level of suspended sediment present on the southeastern reef tract under the range of normally-occurring oceanic and atmospheric conditions, severe weather events, and dredged material disposal operations.

Measurements were made of suspended sediment concentrations, ambient currents, the surface wave field above the site, water temperatures, and salinity. In addition to these 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 sediment are given. During periods when the instruments were deployed, several severe weather events occurred. A summary of the data and observations from these events are presented in section 5.2.

2. Background

Between 1998 and 2006, several sites in the coastal area off of Miami were instrumented with various types of sensors. A few conclusions from these first MOMS deployments are summarized as follows:

- Wind forcing, currents, and wave heights are significant factors in suspending sediments.
- In highly bioactive coastal waters, data from optical sediment concentration sensors degrade quickly due to biofouling.
- Acoustical sensors are less susceptible to biofouling than optical sensors.
- Under certain restrictions, a linear relationship exists between the logarithm of the sediment concentration measured by 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 these data can be used to estimate the concentration of suspended sediments.

Data analysis from these preliminary deployments suggested that MOMS site 1 was a good candidate location for acoustically estimating sediment concentrations. To continue this long-term measurement program, it was decided to concentrate efforts at MOMS site 1 to obtain the maximum density of data at this location.

3. Methods and Procedures

Three instrument platforms were placed on the seabed at the MOMS site 1 location. 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 59 cm above the bottom. The second mounting was a tripod structure which held a 600 kHz Teledyne RD Instruments ADCP with the transducer at a height of 80 cm above the bottom. The tripod also held a YSI Incorporated 6600 series environmental monitoring sonde. The YSI sonde was equipped with sensors for temperature, salinity, and optical backscatter. It was mounted so that the sensors were approximately 1 m above the bottom. The third platform, referred to as the "stalk," held a custom-built data logger that recorded data from instruments mounted on the stalk. Instruments connected to the stalk data logger included a McVan Instruments optical backscatter sensor (OBS), a D&A Instruments OBS sensor, and a LI-COR quantum sensor for photosynthetically active radiation (PAR). All of these instruments were mounted at a height of 1 m above the bottom.

Table 1 lists the deployments for the time periods covered by this report, grouped into four periods for convenience. 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 section 4.

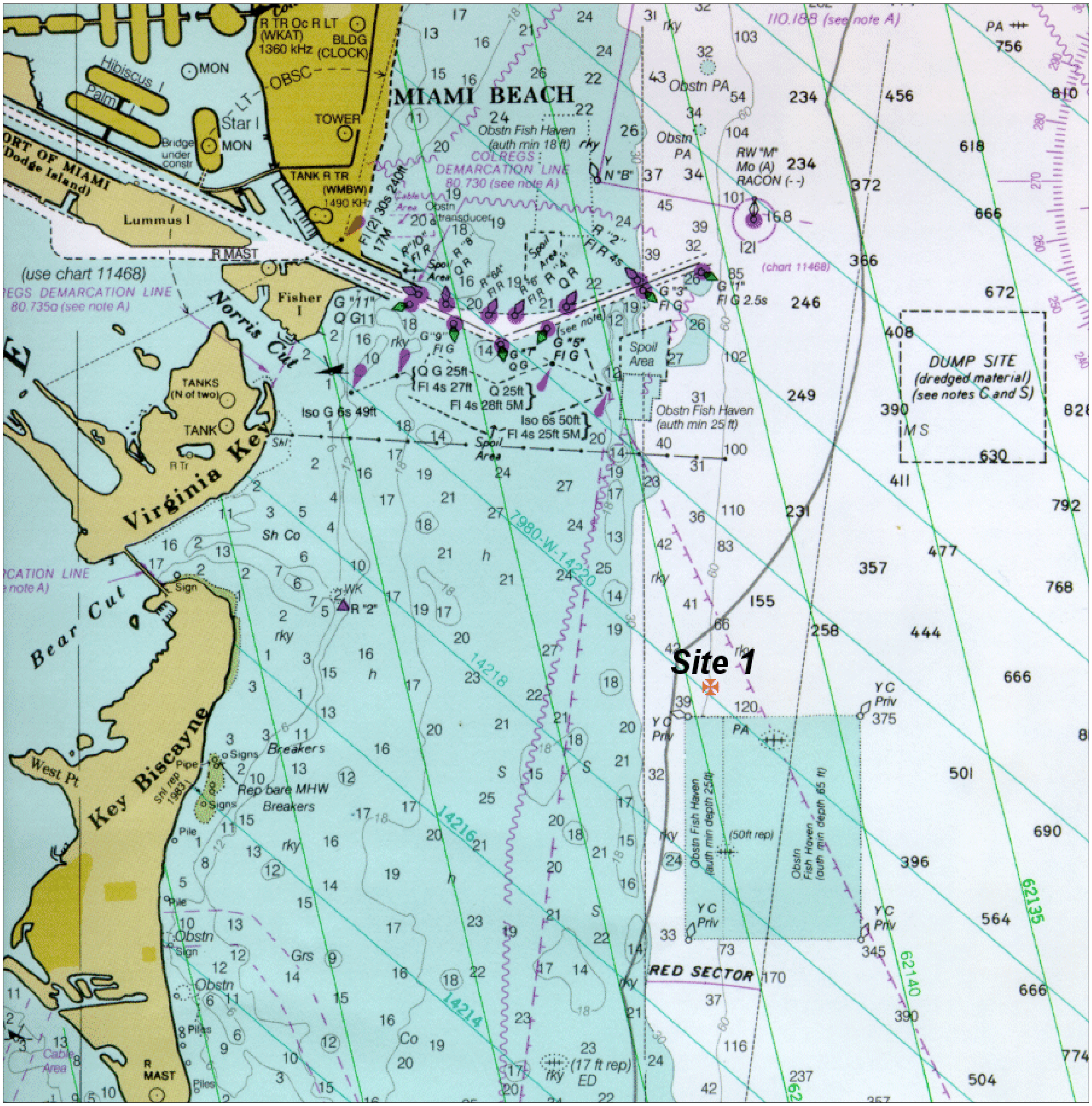

Figure 1. Map of the MOMS site 1 location.

Table 1. MOMS site 1 deployments.

Equipment	Deployment A	Deployment B	Deployment C	Deployment D
Teledyne RD Instruments 1200 kHz ADCP	09/21/01–01/12/02	04/23/02–08/30/02	06/22/05–08/19/05 08/19/05–02/28/06	03/20/06–05/16/06
Teledyne RD Instruments 600 kHz ADCP with wave capability	----------	----------	08/19/05–02/07/06	03/20/06–05/16/06 05/23/06–06/22/06
YSI sonde with temperature, salinity, and optical backscatter sensors	09/21/01–01/20/02 12/17/01–03/17/02	04/23/02–06/11/02 04/24/02–06/11/02	08/19/05–09/27/05 10/12/05–01/16/06	03/20/06–05/20/06 05/20/06–06/29/06 06/29/06–09/13/06
McVan Instruments OBS sensor on stalk	----------	04/23/02–06/09/02	06/22/05–08/19/05 08/19/05–02/28/06	----------
D&A Instruments OBS sensor on stalk	----------	----------	06/22/05–08/19/05 08/19/05–02/28/06	----------
LI-COR quantum PAR sensor on stalk	----------	----------	06/22/05–08/19/05 08/19/05–02/28/06	----------

3.1 ADCP Current Measurements

The Teledyne RD Instruments 1200 kHz and 600 kHz ADCP current profilers deployed at MOMS site 1 (**Table 1**) estimated current velocities by measuring the Doppler shift from the return signal of an acoustic pulse transmitted from four transducers which were angled 20 degrees off of vertical. These Doppler velocities were then transformed into estimates of the three-dimensional water velocity in cells or bins spaced vertically above the instrument (Teledyne RD Instruments, 2011). The 600 kHz unit also provided surface wave measurements, as well as current measurements. In cases where a 1200 kHz ADCP was deployed simultaneously with a 600 kHz ADCP, the 1200 kHz data were identified with an "a," and the 600 kHz data were 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 MOMS site 1, the bin size was set to 0.6 m on both instruments to accommodate the requirements of the 600 kHz unit and to enable data from both the 1200 and 600 kHz ADCPs to be aligned vertically in the water column. The depth of the ADCP measurement cells changed depending on how the instrument was configured. Based on a mean water depth of 18.9 m at MOMS site 1, a set of standard analysis depths was 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 1200 kHz unit was set to zero in later deployments. This placed the center of bin 1 at a distance of 1.24 m above the seabed. 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.

3.2 ADCP Wave Measurements

The Teledyne RD Instruments 600 kHz ADCP deployed at MOMS sites 8b, 9b, and 10b was enhanced to estimate the directional wave spectrum (see Table 5 for deployment dates). To make a wave measurement, the instrument was programmed to take 2400 samples at 2 Hz. These data were

Table 2. ADCP standard analysis depths.

Analysis Depth (m)	Actual Depth for MOMS Sites 6, 8a, 9a	Actual Depth for MOMS Sites 8b, 9b, 10b	Actual Depth for MOMS Sites 5, 7
18.0	18.0	NA	18.24
16.8	16.84	16.84	16.74
16.2	16.24	16.24	16.24
11.4	11.44	11.44	11.24
10.8	10.84	10.84	10.74
3.6	3.64	3.64	3.74
3.0	3.04	3.04	3.24

then processed using the RD Instruments Waves Mon software following procedures outlined in the software documentation (Teledyne RD Instruments, 2001). The deployment depth and characteristics of the instrument define the minimum observable wave period. For these deployments, this was 2.15 sec for a nondirectional wave estimate and 3.35 sec for a directional wave estimate.

Some wave parameters obtained from the data included: significant wave height, defined as the average height of the highest one-third of the waves; the period of the principal wave; and the direction from which the principal wave arrived (Teledyne RD Instruments, 2001). There were many sample intervals where no valid data were reported. This occurred during calm conditions when the waves had periods shorter than the minimum observable period.

3.3 ADCP Temperature Measurements

The ADCPs used at MOMS site 1 also recorded temperature as part of their data record. The temperature data were not calibrated but were reasonably accurate. When compared to the available temperature data from the YSI instrument or the 600 kHz ADCP, the data were in close agreement (for the 2005-2006 data, the mean temperature from the ADCP was 0.38°C colder than the YSI). The differences in the temperature measured by the YSI sonde and the ADCPs may be attributed to the fact that the ADCP temperature sensor was located 59 cm above the bottom, while the YSI temperature sensor was 1 m above the bottom. The ADCP data record is the longest record available for the site and was used for analysis. Data from the preliminary ADCP deployments (2 Oct 1998–4 Feb 1999 and 24 Jun 1999–20 Oct 1999) were not used to analyze current velocity due to differences in the deployment strategy. However, these data were included in the temperature analysis because the mounting location of the temperature sensor was unchanged for each deployment.

3.4 YSI 6600 Sonde Measurements

The YSI Incorporated model 6600 sonde is a self-recording instrument that measures temperature, conductivity, and turbidity via optical backscatter. Salinity is also provided as a calculated data product from the instrument. A calibration was performed using a suspended sediment solution for all of the sondes used in the MOMS deployments. This is described in Appendix A. 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. These data values were excluded from the analysis.

3.5 Data Logger Measurements

An instrument package (the "stalk") was deployed at MOMs site 1 with two optical backscatter sensors: a McVan OBS sensor 82128 and a D&A Instruments OBS sensor 17880. The McVan OBS system has the advanced feature of an optical cleaning arm that wipes the sensor face before the measurement is taken. A LI-COR spherical underwater quantum sensor (LI-193SA) for PAR was also deployed on the stalk.

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

3.6 Wind Measurements

Wind data used in this report were obtained from the Fowey Rocks C-MAN Station (station FWYF1), which is owned and maintained by NOAA's 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 m 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 the north. Data were averaged over an 8-minute period and reported every 10 minutes.

3.7 Severe Storms

During 2005, four severe storms passed close enough to MOMS site 1 to impose clear signals on the sensors. For analysis purposes, a time period of 7 days centered on the peak winds was used to compare these events. Table 3 provides the beginning and ending times used for analysis.

Table 3. Severe storm analysis periods.

Storm	Start of Analysis Period	End of Analysis Period
Dennis	07/05/2005 19:00 UT	07/12/2005 19:00 UT
Katrina	08/22/2005 11:00 UT	08/29/2005 11:00 UT
Rita	09/17/2005 03:00 UT	09/24/2005 03:00 UT
Wilma	10/21/2005 00:00 UT	10/28/2005 00:00 UT

3.8 Acoustically Derived Suspended Sediment Estimates

Difficulties in obtaining long term time series of suspended material from optical sensors, free from the degrading effects of biofouling, 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 became available (Deines, 1999) to make corrections to the backscatter data so that the data were repeatable from instrument to instrument and from deployment to deployment. These corrections, detailed in Appendix B, involved:

- System corrections that accounted for system electronics and the physical characteristics of the acoustic transducers.
- Environmental corrections that accounted for ambient temperature, depth, and sound absorption.
- Corrections that accounted for the change in transmitted power due to the depletion of the ADCP battery with time.

Identifying the optimal data to use for calculating the relationship between the acoustic and optical data required careful consideration, as the optical data exhibited large variations 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 assess 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 provides the regression parameters and the correlation coefficient (R) between the acoustic backscatter data and the log of the suspended sediment concentration measured by the YSI OBS sonde.

Table 4. Regression parameters from severe storms.

Storm	Slope	Intercept	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 OBS sonde and the acoustic backscatter as measured by the 1200 kHz ADCP because they had the most similar regression parameters when analyzed individually. The optical backscatter data from the YSI sonde, which suffered from the effects of biofouling, were also considered to be of good quality. The analysis period for Hurricane Katrina began on 22 Aug 2005, and the YSI sonde was installed on 19 Aug 2005. The YSI data for the period encompassing Hurricane Rita showed evidence of fouling (Figure 2). The analysis period for Hurricane Rita began on 17 Sep 2005, and the YSI sonde was installed on 19 Aug 2005. The analysis period for Hurricane Wilma began on 21 Oct 2005, and the YSI sonde was installed on 12 Oct 2005.

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

- Calibrations were applied to convert the YSI OBS data to units of mg/l.
- A three point median smoothing filter was applied to the converted OBS data.
- OBS data that had values less than zero were excluded from the analysis.
- Ten times the base ten logarithm was taken of the conditioned OBS data.
- Data were limited to the 7-day period centered on the maximum winds of Hurricanes Katrina (22 Aug 2005, 11:00 UT to 29 Aug 2005, 11:00 UT) and Wilma (21 Oct 2005, 00:00 UT to 28 Oct 2005, 00:00 UT).
- The log YSI data were limited to those values that were greater than 5 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 3**). For this calculation, the coefficient of the correlation was R = 0.89, $R^2 = 0.788$. The standard error of

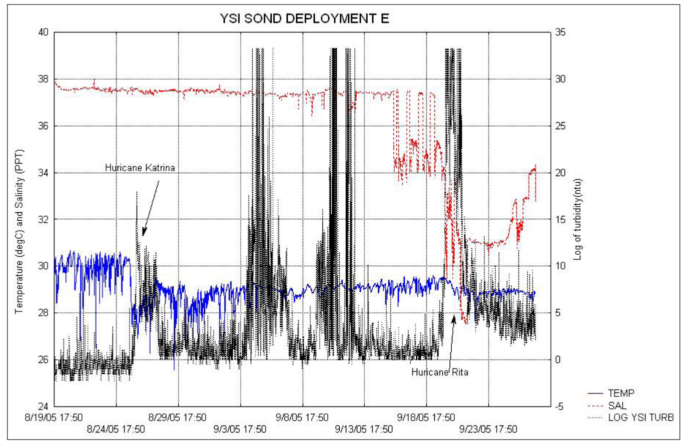

Figure 2. YSI sonde deployment showing evidence of biofouling.

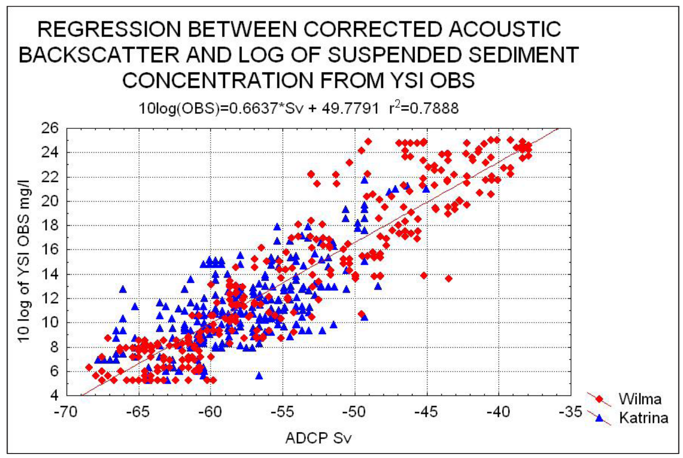

Figure 3. Linear regression between acoustic backscatter and the log of suspended sediment concentrations from the YSI OBS.

this regression was 0.7857. This regression equation was then applied to the entire record of 1200 kHz backscatter data to generate acoustical estimates of suspended sediment concentrations for the time periods when the 1200 kHz ADCP was deployed at MOMS site 1. **Figure 4** shows the residuals from the regression shown in Figure 3 plotted against Sv and also a normal probability plot of the residuals. These plots suggest that the regression relationship was not biased.

In using acoustic or optical backscatter methods 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 was determined that the scatters were suspended out of the local sediment and that this remained fairly constant. However, there may be times when this is not the case. **Figure 5** graphs the

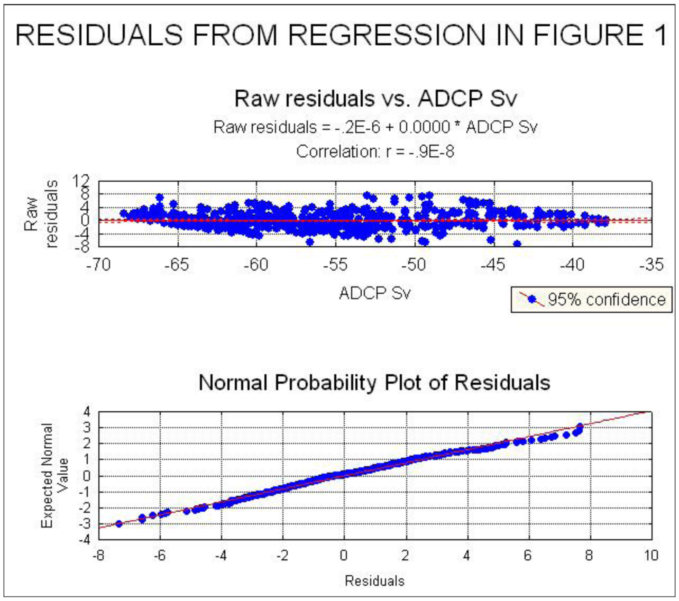

Figure 4. Regression residuals versus Sv and a normal probability plot of residuals.

ratio of the 600 kHz acoustic backscatter to the 1200 kHz acoustic backscatter. From this graph it can be observed that the ratio of the backscatter at the two acoustic frequencies was changing during the passage of Hurricane Wilma. It would be expected that the two frequencies of acoustic backscatter had the most sensitivity to particles of a different size, and this may have been a case where the particle size distribution was changing.

4. Data Review

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

4.1 ADCP Currents

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

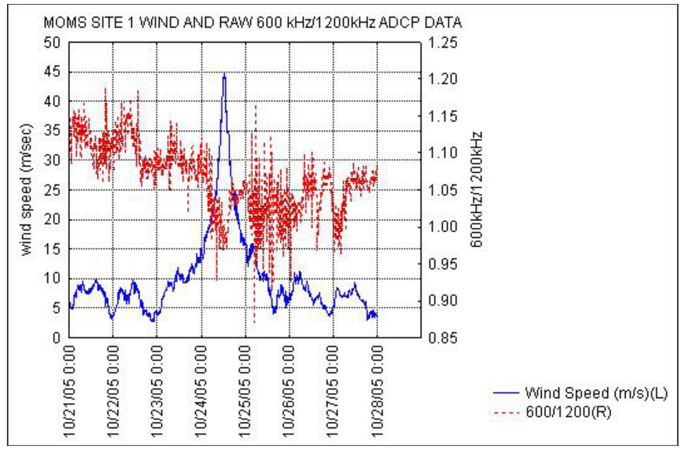

Figure 5. Wind speed and ratio of the 600 kHz and 1200 kHz raw acoustic backscatter data.

A data set was constructed using data collected by the 1200 kHz ADCP from deployments 5, 6, 7, 8-1, 8-2, and 9 with data collected by the 600 kHz ADCP to fill the gap between 28 Dec 2005 and 7 Feb 2006. Corrections were applied to each data set 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.

The U (east-west) velocity was near zero for all three depths, and the mean V (north-south) velocity was less than 10 cm/sec at all depths. **Figure 6** shows histograms of the U and V components at three representative depths. **Table 7** gives the monthly average and maximum current magnitude at 16.8 m. **Figure 7** graphs the monthly average of the current velocity magnitude at the 16.8 m depth.

4.2 ADCP Waves

Table 8 lists the 600 kHz ADCP deployments at MOMS site 1 that collected wave 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 8** and **9** 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 periods of less than 2.15 seconds not being represented.

Table 5. MOMS site 1 ADCP deployments.

Deployment	Frequency	Start Time	End Time	Instrument s/n	Bin Size / Blank Size
MOMS 3	1200 kHz	10/02/98	02/04/99	546	0.5 / 0.44
MOMS 4	1200 kHz	06/24/99	10/20/99	546	0.5 / 0.44
MOMS 5	1200 kHz	09/21/01 15:40 UT	01/12/02 22:20 UT	1544	0.5 / 0.0
MOMS 6a	1200 kHz	04/23/02 20:50 UT	08/30/02	1544	0.6 / 0.0
MOMS 7	1200 kHz	08/06/04 14:30 UT	12/12/04 19:20 UT	1544	0.5 / 0.0
MOMS8a-1	1200 kHz	06/22/05 13:40 UT	08/19/05 14:30 UT	1544	0.6 / 0.0
MOMS 8a-2	1200 kHz	08/19/05 17:50 UT	12/28/05 12:10 UT	1544	0.6 / 0.0
MOMS 8b	600 kHz	08/19/05 15:00 UT	02/07/06 13:00 UT	2153	0.6 / 0.87
MOMS 9a	1200 kHz	03/20/06 15:10 UT	08/03/06	1544	0.6 / 0.0
MOMS 9b	600 kHz	03/20/06 15:00 UT	05/16/06 16:20 UT	2157	0.6 / 0.87
MOMS 10b	600 kHz	05/23/06 17:10 UT	06/22/06 07:30 UT	2157	0.6 / 0.87

Table 6. Mean, minimum, and maximum current velocities from ADCP data.

Component	Depth (m)	Number of Observations	Mean (cm/sec)	Minimum (cm/sec)	Maximum (cm/sec)
U	3.6	105566	0.642810	-123.200	77.4000
U	11.4	105883	-0.042732	-58.200	34.8000
U	16.8	105381	0.435560	-38.000	32.1000
V	3.6	105566	8.960969	-83.700	109.8000
V	11.4	105883	8.283138	-76.400	120.0000
V	16.8	105883	5.699176	-60.200	97.2000

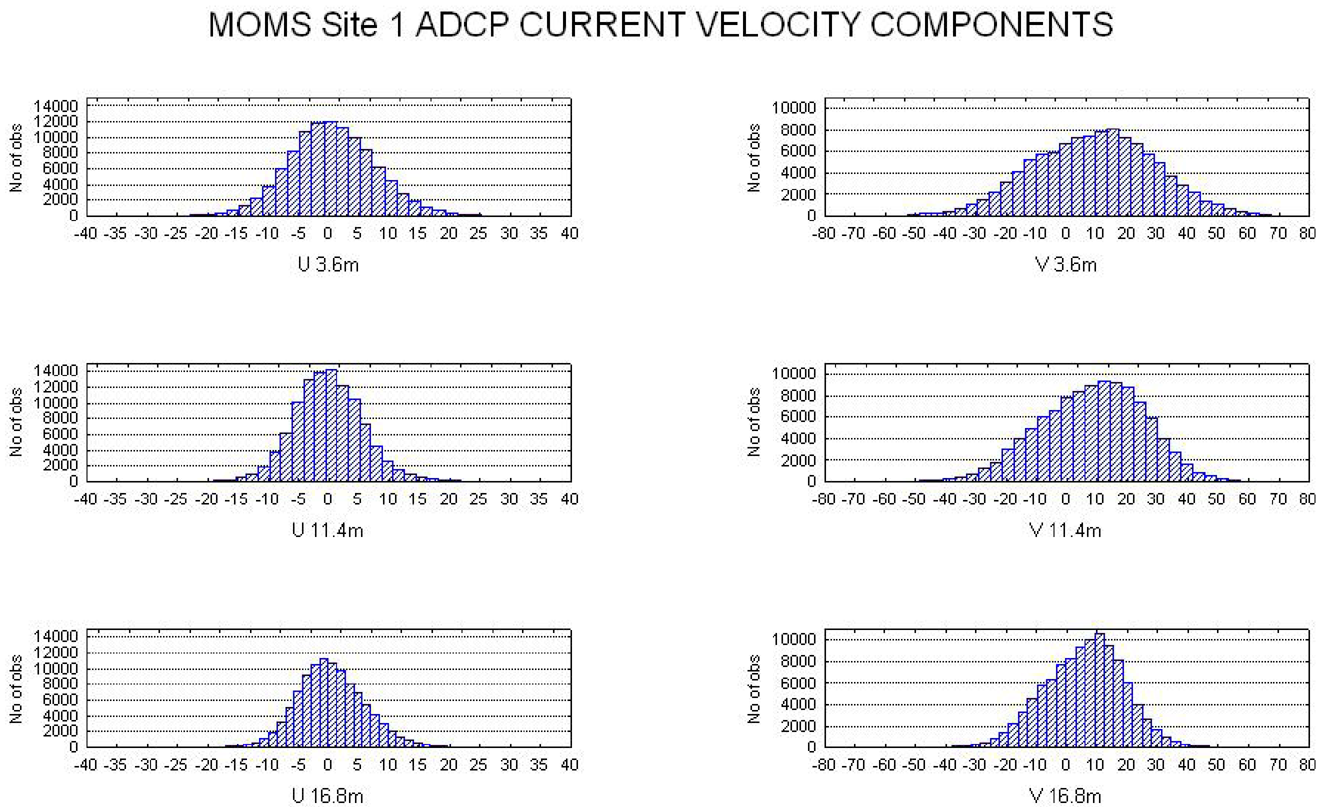

Figure 6. ADCP current velocity components (cm/sec).

Table 7. Mean and maximum current magnitude by month at 16.8 m depth.

Month	Mean Current Magnitude (cm/sec)	Maximum Current Magnitude (cm/sec)	Number of Obs
Jan	12.3	54.3	6183
Feb	10.7	43.9	944
Mar	11.6	40.1	1637
Apr	14.1	49.5	5203
May	13.1	48.6	8928
Jun	13.5	48.9	9854
Jul	15.7	53.6	13294
Aug	13.4	51.2	12566
Sep	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

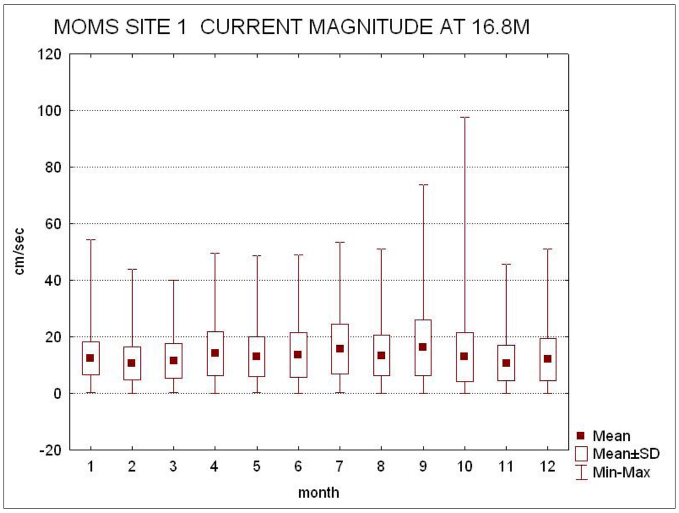

Figure 7. Monthly average of the current velocity magnitude at 16.8 m depth.

4.3 ADCP Temperature

Table 5 lists the start and end times of the 1200 kHz ADCP deployments at MOMS site 1. **Figure 10** shows the monthly mean, standard deviation, minimum, and maximum of the temperature recorded by the 1200 kHz ADCP for all of the MOMS site 1 ADCP deployments. It was observed that colder water often occupied site 1 after the passage of severe storms. It was also observed that colder water occupied site 1 in June. This may have been upwelled water from offshore or internal waves breaking on the Florida Shelf. **Figure 11** shows the temperature record from MOMS 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 at 73 m water depth. The temperature signal from the passage of Hurricane Wilma was clearly observed in both records.

Table 8. ADCP wave data sets.

File Name	Start Time	End Time	Sample Interval
8b	08/19/05 14:50	02/07/06 05:50	3 hr
9b	03/20/06 15:00	05/16/06 12:00	3 hr
10b	05/23/06 18:00	06/22/06 07:00	1.5 hr

Table 9. Wave statistics by month.

Month	Mean Significant Wave Height (m)	Mean Wave Period (sec)	Number of Obs
Jan	.84	5.6	217
Feb	.58	4.8	38
Mar	.6	4.7	64
Apr	.57	5.1	180
May	.29	4.5	193
Jun	.4	4.0	275
Jul			0
Aug	.63	4.5	66
Sep	.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

4.4 YSI Sondes

Table 10 lists the times of the YSI sonde deployments. In all of the deployments, biofouling caused a degradation of the data with time. Optical backscatter sensors often showed evidence of fouling after a few days. A time series of temperature, optical backscatter, and salinity data from a YSI deployment, which illustrates the effects of biofouling, is shown in Figure 2. It was 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 2) is an example of this. The conductivity data also deteriorated with time, albeit over longer time scales than the optical sensors.

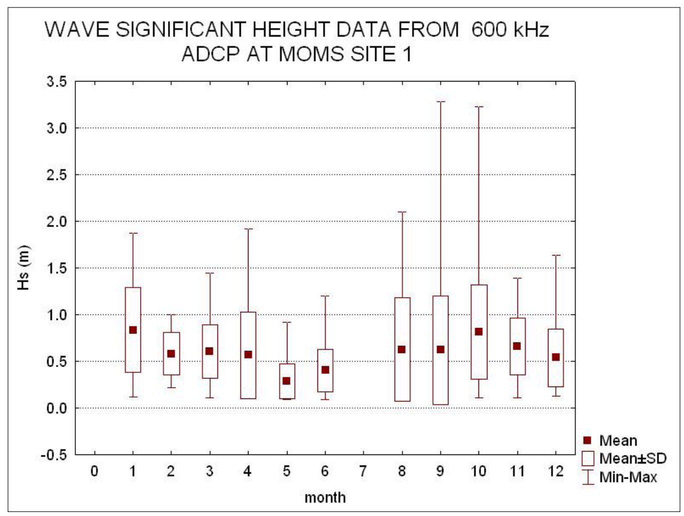

Figure 8. Significant wave height data by month for the 600 kHz ADCP at MOMS site 1.

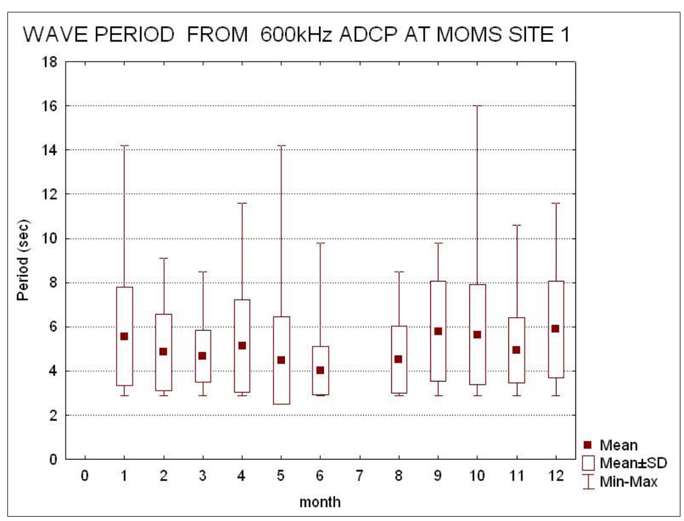

Figure 9. Principal wave period data by month for the 600 kHz ADCP at MOMS site 1.

4.5 Data Logger

The OBS and PAR instruments attached to the data logger system were deployed three times at MOMS site 1. **Table 11** lists the times of the deployments. As in the case of the YSI instruments, biofouling degraded the quality of the data over time. **Figure 12** shows the first 20 days of the raw data from the 19 Aug 2005 deployment. Data from the McVan OBS sonde showed good correlation with the YSI sensors during Hurricane Katrina (R = 0.896) and also good correlation with the acoustics (R = 0.885). However, good quality data were not recorded during hurricanes Rita or Wilma. Therefore, data from these sensors were not included in the acoustic suspended sediment estimation algorithm. PAR data from the data logger appeared to be of good quality and clearly showed the reduction of light caused during the passage of these severe weather events.

4.6 Acoustically Estimated Suspended Sediment Concentrations

Table 5 lists the ADCP deployments at MOMS site 1. Data from all of the 1200 kHz ADCP deployments were merged and corrections applied so that these data could be used to generate a long time series record of acoustically estimated suspended sediment concentrations. This record had 134,241 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 40 cm 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 was made closer to the bottom. However, these data were retained in the analysis as they 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 **(Table 12).** (The ADCP parameters were held constant for the 2005–2006 data.) **Figure 13** is a histogram illustrating the distribution of the acoustically estimated suspended sediment concentration and includes all data. **Figure 14** illustrates this distribution as a cumulative histogram. **Table 13** gives the monthly average, minimum, maximum, and standard deviation of the data. This is shown graphically in **Figure 15**.

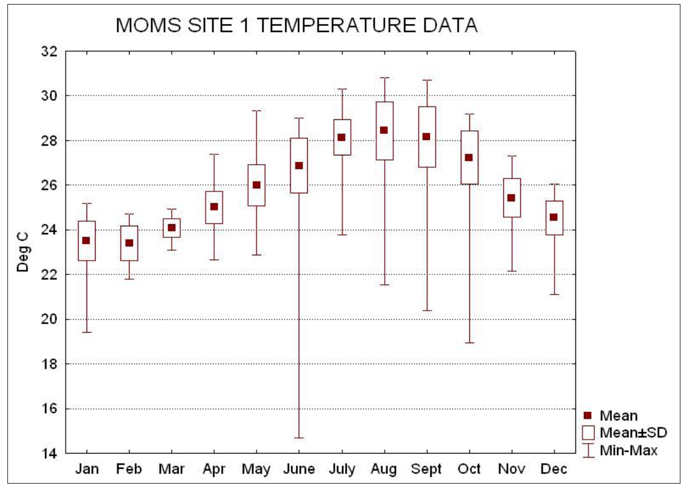

Figure 10. Temperature data recorded by the 1200 kHz ADCP at MOMS site 1 .

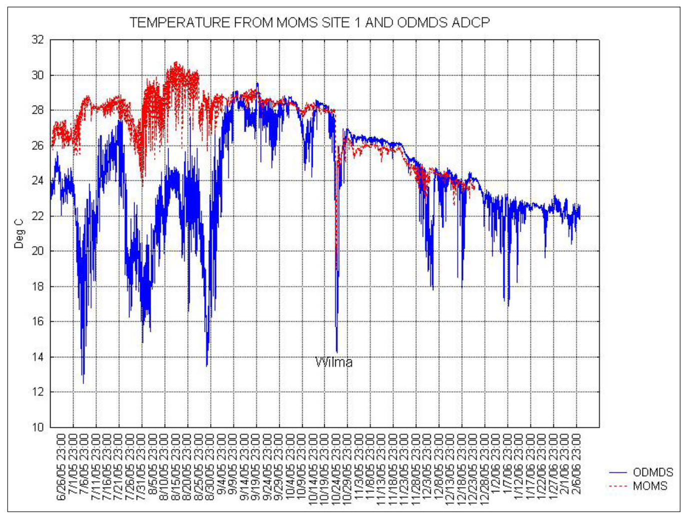

Figure 11. Temperature data recorded at MOMS site 1 and the Offshore Dredged Material Disposal Site by the 1200 kHz ADCP.

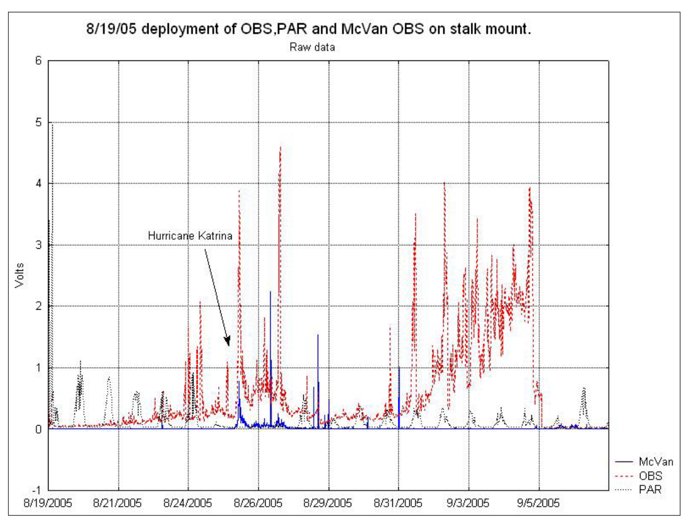

Figure 12. Data logger from the 19 Aug 2005 deployment.

Table 10. YSI sonde deployments at MOMS site 1.

Location	ID	File Name	Start Time	End Time
S1	A	Moms0921	09/21/01 15:01	11/20/01 14:21
S1	B	S11217	12/17/01 20:20	03/17/02 02:30
S1	C s4	Site1s4b	04/24/02 11:41	06/11/02 14:41
S1	C tri	Site1tri	04/23/02 14:21	06/11/02 12:41
S3	D	St361402	11/01/02 00:00	11/19/02 00:20
S1	E	S18905	08/19/05 13:40	09/27/05 08:10
S1	F	S1100705	10/12/05 11:40	01/16/06
S1	G	032006	03/20/06 10:00	05/20/06 12:30
S1	H	052006 s1	05/20/06 17:40	06/29/06 20:50
S1	I	S1 062906s1	06/29/06 20:30	09/13/06 16:10

Table 11. Data logger/OBS PAR deployments.

Start Time	End Time	Notes
04/23/02 11:20	06/09/02 11:00	20-min sample interval McVan sensor only
08/19/05 14:10	10/04/05 17:30	10-min sample interval PAR data bad after 09/27/05 OBS data bad after 09/05/05 McVan data bad after 09/08/05
10/12/05 12:00	01/26/06 10:40	20-min sample interval OBS and McVan data appear to be bad PAR shows a decrease in level with time

Table 12. Acoustically estimated suspended sediment concentrations (with and without severe weather events).

	Number of Obs	Mean (mg/l)	95th Percentile	99th Percentile	Standard Deviation	Minimum	Maximum
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

5. Discussion

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

5.1 Suspended Sediment Climate at MOMS Site 1

From Table 12 and Figures 13 and 14 it can be seen that the majority of the acoustically estimated suspended sediment values were below 10 mg/l. It can also be observed from Table 12 that if the severe storms were excluded from the 2005-2006 data sets, the mean and standard deviations of the suspended sediment concentrations would be greatly reduced. This implies that high turbidity events were likely associated with strong weather events.

Figure 16 is a regression between the significant wave height and acoustically estimated suspended sediments. This regression includes the data from hurricanes Katrina, Rita, and Wilma. The correlation coefficient is R = 0.69. **Figure 17** is a regression between the significant wave height and acoustically estimated suspended sediments. This regression includes the data from 2005 and 2006; however, it excludes the data from hurricanes Katrina, Rita, and Wilma. The correlation coefficient is R = 0.51.

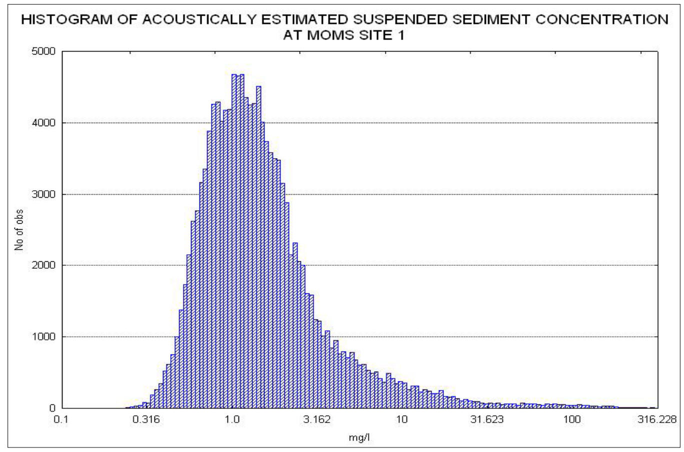

Figure 13. Histogram of acoustically estimated suspended sediment concentrations.

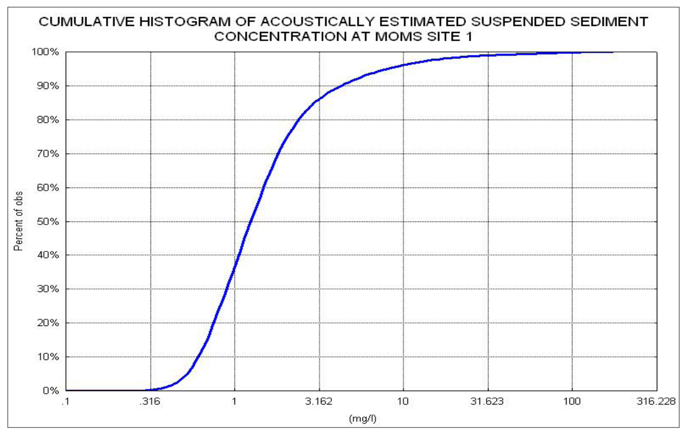

Figure 14. Cumulative histogram of acoustically estimated suspended sediment concentration data from Figure 13.

Table 13. Monthly statistics of acoustically estimated suspended sediment.

Month	Number of Obs	Minimum	Maximum	Mean	Standard Deviation
Jan	6181	0.38	52.72	3.67	4.81
Feb	521	0.61	13.27	2.84	2.87
Mar	1637	0.34	10.11	1.13	0.98
Apr	5347	0.26	22.67	1.35	1.88
May	8928	0.08	124.00	2.37	6.44
Jun	10772	0.19	20.70	1.12	0.71
Jul	17856	0.31	181.27	2.61	10.95
Aug	17094	0.24	97.65	1.55	2.95
Sep	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

This plot also suggests that a step increase in the suspended sediment levels occurred at a significant wave height of about 1.4 m.

The data from 2005-2006 were analyzed excluding data associated with the severe storms and the correlation between the current magnitude at 16.8 m depth and the acoustically estimated suspended sediment concentrations of R = 0 .23. This suggests that currents might 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 1200 kHz ADCP in 2005-2006 were examined to identify periods of elevated suspended sediment concentration. The results are presented in the following two sections.

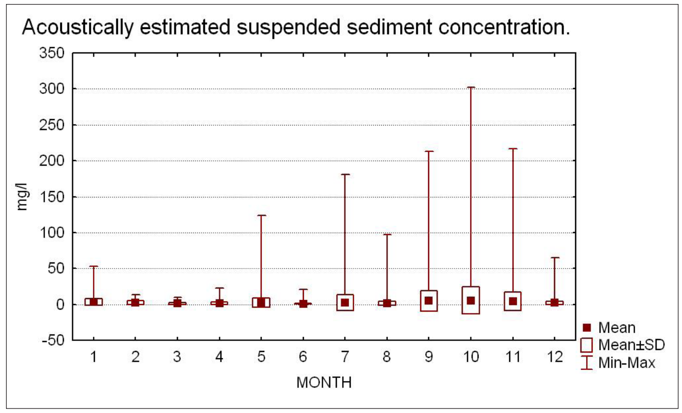

Figure 15. Acoustically estimated suspended sediment concentrations at MOMS site 1.

5.2 Observations during Severe Weather Events

During the 2005 hurricane season, the MOMS site 1 area was impacted by four severe storms. MOMS site 1 was fully instrumented during three of these storms (hurricanes Katrina, Rita and Wilma). 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 or more hours. These events presented the opportunity to study the response of this area to weather events that occur more frequently than the severe weather associated with hurricanes.

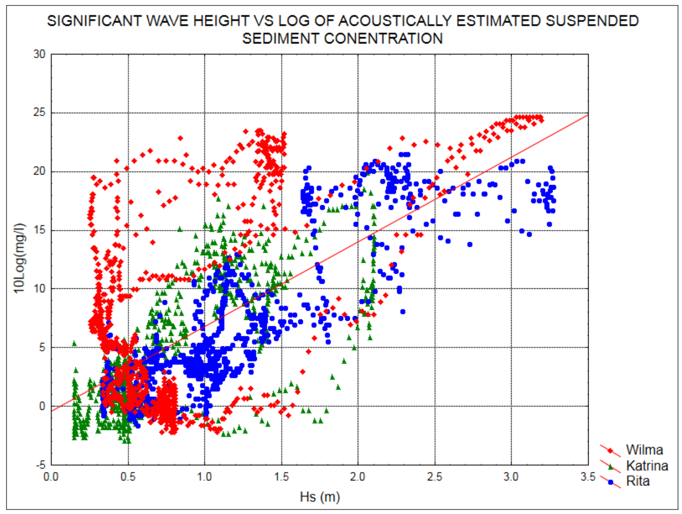

Figure 16. Significant wave height versus acoustically estimated suspended sediment.

5.2.1 Hurricane Katrina

Figure 18 shows the wind speed and direction during the time of Hurricane Katrina's passage. Prior to the onset of Hurricane Katrina, the winds were from the east-northeast at a speed of roughly 5 m/s at about 15:00 UT on 26 Aug 2005. The winds continually shifted counterclockwise through the north, reaching a southeast direction at 15:00 UT on 26 Aug 2005. The maximum wind speed of 29.1 m/s occurred at 23:00 UT on 25 Aug 2005.

Figure 19 shows the wind speed and significant wave height during the time of Hurricane Katrina's passage. The maximum significant wave height of 2.1 m was observed at 09:00 UT on 26 Aug 2005. The wave period at this

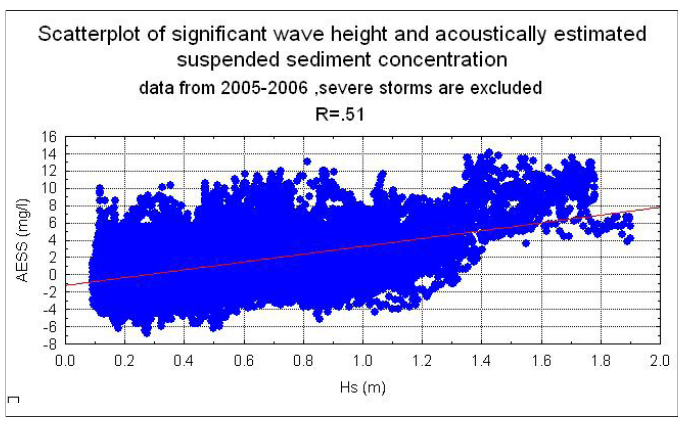

Figure 17. Significant wave height versus acoustically estimated suspended sediment with severe storms excluded.

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 20 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 26 Aug 2005 and remained elevated until 03:00 UT on 28 Aug 2005. These concentration levels remained at above pre-hurricane levels for several weeks after the passage of the storm.

Table 14 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 OBS sonde. YSI OBS data were 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.

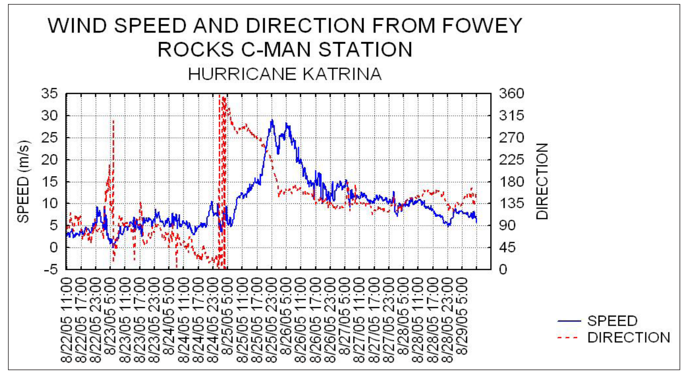

Figure 18. Wind speed and direction during Hurricane Katrina.

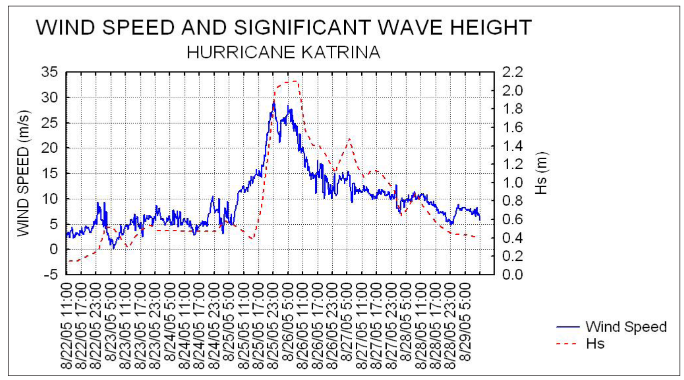

Figure 19. Wind speed and significant wave height during Hurricane Katrina.

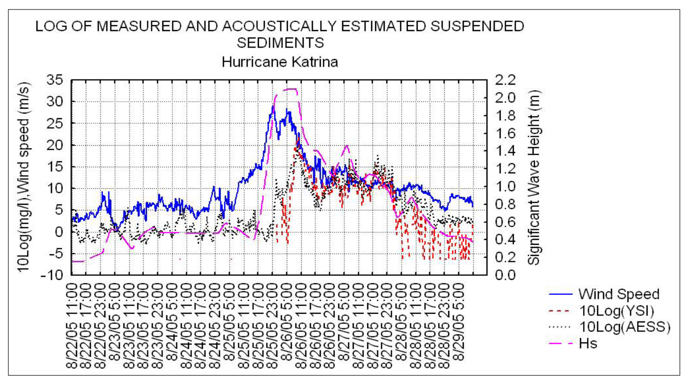

Figure 20. Measured and acoustically estimated suspended sediment during Hurricane Katrina.

5.2.2 *Hurricane Rita*

Figure 21 shows the wind speed and direction during the time of Hurricane Rita's passage. Prior to the passage of Hurricane Rita, the wind speed and direction were variable. On 18 Sept 2005 at about 14:50 UT, the wind speed began to increase and reached a maximum speed of 22.0 m/s on 20 Sept 2005 at 17:30 UT.

Figure 22 shows the wind speed and significant wave height during the passage of Hurricane Rita. The maximum significant wave height of 3.28 m was recorded on 20 Sept 2005 at 18:00 UT. 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 23 shows the wind speed and wave height with measured and calculated turbidities. The envelope of the turbidity measurements closely mimicked that of the wind speed. The turbidity remained elevated through 20 Sept 2005. In this example, the calculated suspended sediment concentration and the acoustically estimated suspended concentration were not in good agreement during the peak wind period.

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

After the winds subsided, the optically measured suspended sediment concentration was elevated with respect to the acoustics. This may be an artifact caused by the degradation of the optical data due to fouling. Figure 2 shows the data from the YSI sonde during this period. It can be observed that after 3 Sept 2005 the turbidity levels frequently spiked to very high values. This is one of the principal reasons that data from Hurricane Rita were not included in calculating the relationship between the YSI optical backscatter 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 OBS sonde. YSI OBS turbidity data were 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.

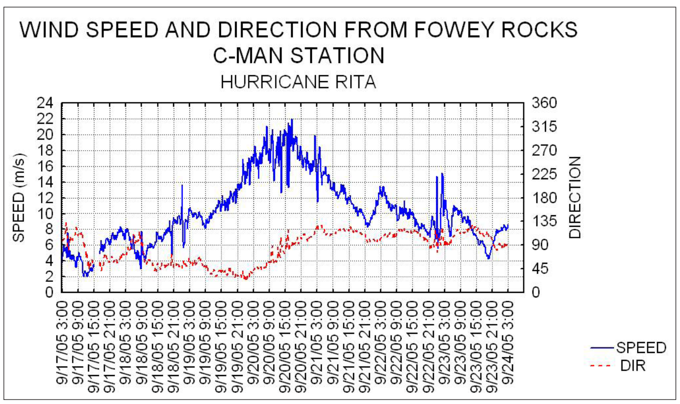

Figure 21. Wind speed and direction during Hurricane Rita.

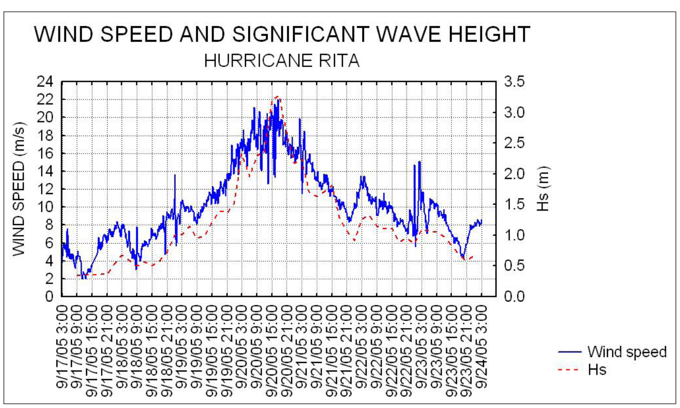

Figure 22. Wind speed and significant wave height during Hurricane Rita.

5.2.3 Hurricane Wilma

Figure 24 shows the wind speed and direction during the passage of Hurricane Wilma. Prior to the passage of Wilma, the winds were directed from the southeast, and speeds were on the order of 5-10 m/s. On 23 Oct 2005 at about 12:00 UT, the wind speed began to increase and reached a maximum speed of 45.6 m/s on 24 Oct 2005 at 12:40 UT.

Figure 25 shows the wind speed and significant wave height during the passage of Hurricane Wilma. The maximum significant wave height of 3.23 m was recorded on 24 Oct 2005 at 12:00 UT. 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 25 Oct 2005 at about 06:00 UT, a series of longer period (14-15 sec) waves began to be observed. These waves arrived from the northeast and had a significant height of about 1.5 m.

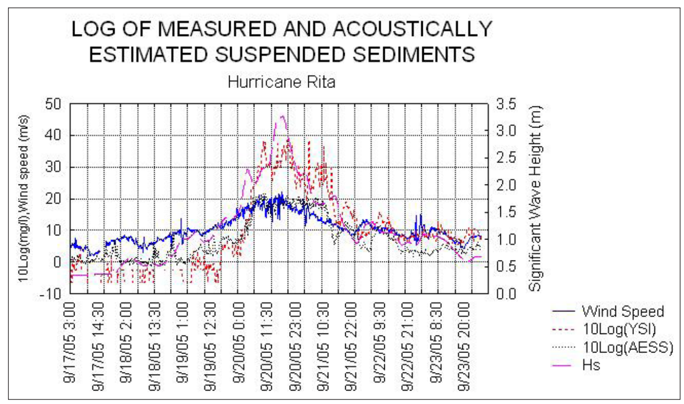

Figure 23. Measured and acoustically estimated suspended sediment during Hurricane Rita.

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

Figure 26 shows the wind speed with measured and calculated turbidities. The envelope of the turbidity measurements closely mimicked that of the wind speed during the period of storm winds. There was a second period of high turbidity associated with the long period waves that arrived later. This second period of very high turbidity was on the same order of magnitude as the turbidity levels observed during the passage of hurricane winds. The turbidity remained elevated for a significant period after the passage of Wilma 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 caused additional sediment suspension events.

Table 16 reports the correlations between the wind speed, significant wave height, ADCP backscatter (Sv), and the log of suspended sediment concentration measured by the YSI OBS sonde. YSI OBS turbidity data were 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.

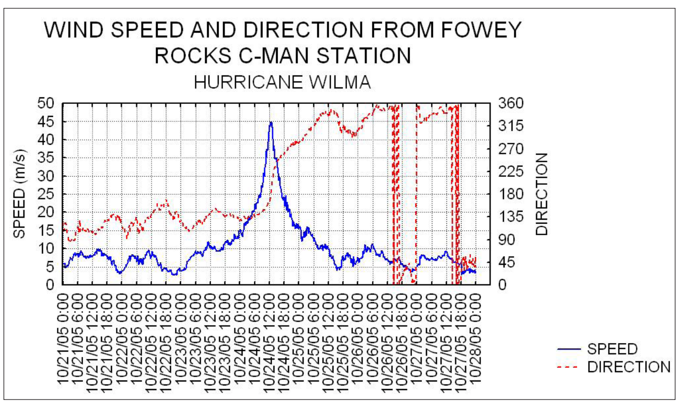

Figure 24. Wind speed and direction during Hurricane Wilma.

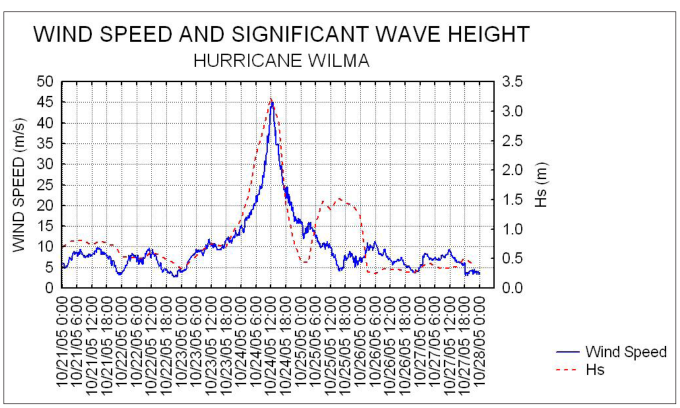

Figure 25. Wind speed and significant wave height during Hurricane Wilma.

5.3 Observations during Elevated Suspended Sediment Events

5.3.1 Elevated Suspended Sediment Event 1

On 6 Sept 2005, the wind speed increased to 10 m/s, and the significant wave height reached 1.1 m (**Figure 27**). During the next 30 hours, two suspended sediment spikes occurred, both of which exceeded the 95 percent threshold of 8.6 mg/l. The first was approximately 3.2 hours in duration, and the second was 1.5 hours in duration.

5.3.2 Elevated Suspended Sediment Event 2

On 2 Oct 2005 at 16:40 UT, the wind speed peaked at 13.3 m/s (**Figure 28**). A concurrent wave field developed that had a maximum significant wave height of 1.7 m.

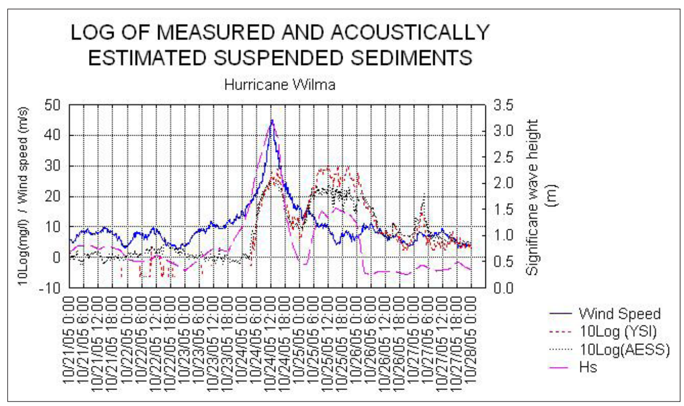

Figure 26. Measured and acoustically estimated suspended sediment during Hurricane Wilma.

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

Almost concurrent with the buildup of the wave field was an elevation in suspended sediment, which exceeded the 95 percent threshold for 3.8 hours.

5.3.3 Elevated Suspended Sediment Event 3

Shortly after the passage of Hurricane Wilma, a wind-wave event occurred on 29 Oct 2005, with another lesser event on 14 Nov 2005 (**Figure 29**). In these examples, suspended sediment concentrations closely tracked the wind-wave field. For the time period represented in Figure 29, the correlation between the significant wave height and the suspended sediment concentrations was 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 percent threshold several times. A second peak occurred on 4 Nov 2005. During this event, the suspended sediment levels exceeded the 95 percent threshold for 3.2 hours.

5.3.4 Elevated Suspended Sediment Event 4

This is an interesting case, as the elevated suspended sediment level observed on 6-7 Dec 2005 was apparently related to an increase in the wind-wave field (**Figure 30**). However, the suspended sediment event on 2 Dec 2005 seemed to not be closely correlated with the wind-wave

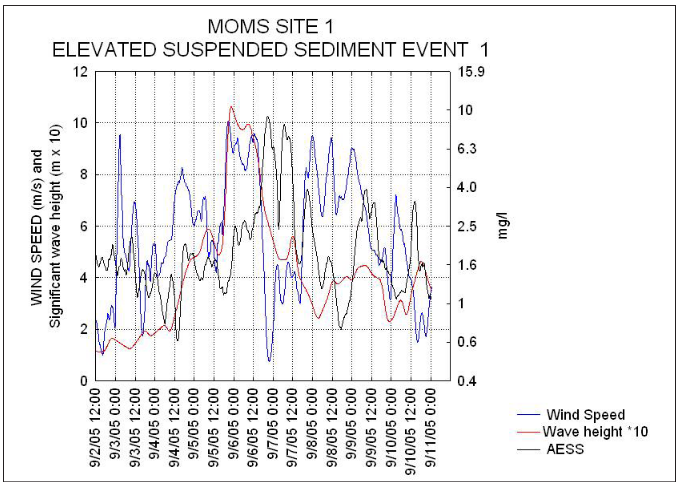

Figure 27. Wind speed, wave height, and acoustically estimated suspended sediment during elevated turbidity event 1.

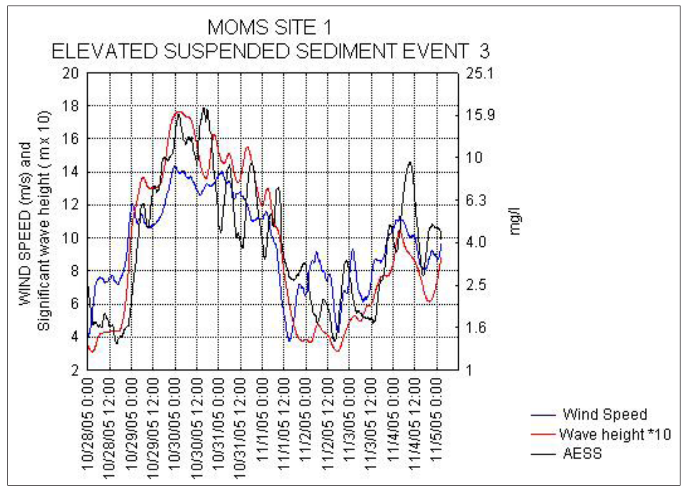

Figure 29. Wind speed, wave height, and acoustically estimated suspended sediment during elevated turbidity event 3.

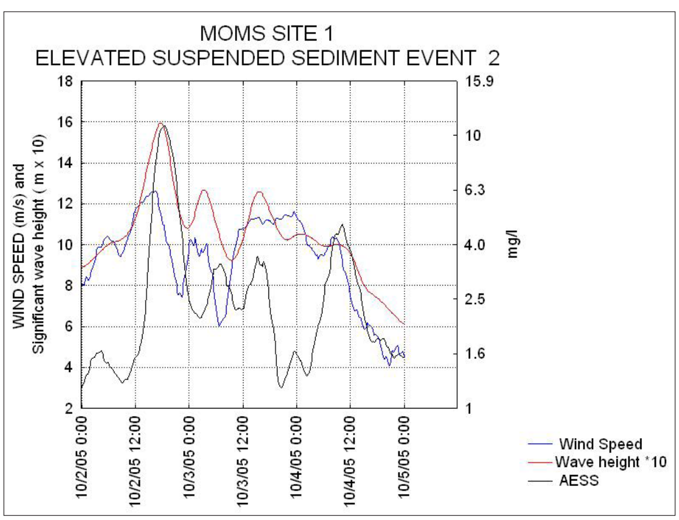

Figure 28. Wind speed, wave height, and acoustically estimated suspended sediment during elevated turbidity event 2.

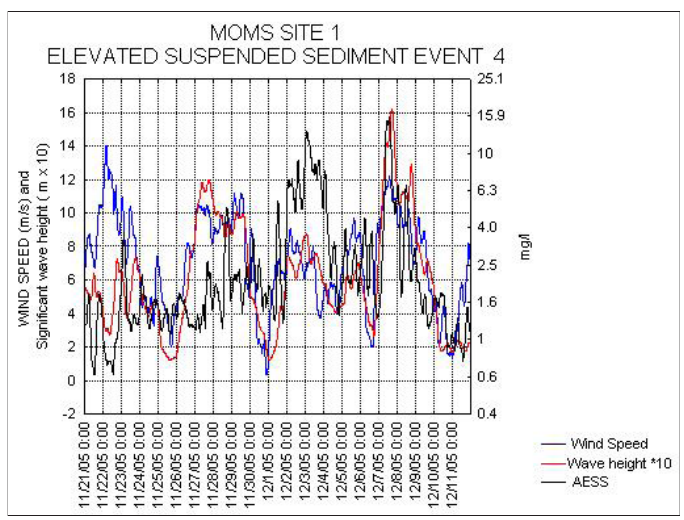

Figure 30. Wind speed, wave height, and acoustically estimated suspended sediment during elevated turbidity event 4.

field. **Figure 31** shows that during this period cold water moved across the MOMS site 1 area, and water temperature was anti-correlated with the elevated suspended sediment levels at R = -0.53. In this example, the first period of elevated suspended sediment lasted for about 48 hours, with the suspended sediment concentration advancing above and retreating below the 95 percent threshold several times. During the 2 Dec 2005 event, the suspended sediment levels exceeded the 95 percent threshold for 7.8 hours.

5.3.5 Elevated Suspended Sediment Event 5

The elevated turbidity levels observed on 11-12 Apr 2006 followed closely with an increase in wind and waves observed over this period. For the time period represented in **Figure 32**, the correlation between the significant wave height and the suspended sediment concentration was R = 0.86. The suspended sediment concentration exhibited three peaks during which it exceeded the 95 percent threshold for 8 hours, 7.3 hours, and 3.3 hours, respectively.

5.4 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 (Figure 1). The acoustically estimated suspended sediment data set was carefully inspected in an attempt to identify any increase in suspended sediment concentrations concurrent with these operations. Special attention was placed at those times when disposal operations began or ended. No evidence was found to suggest that an increase in the ambient suspended sediment concentration levels occurred during these operations.

6. Conclusions

The generation of estimates for suspended sediment concentration from the 1200 kHz ADCP backscatter data provides a significantly longer record of suspended sediment estimates than would be possible with the optical instruments that were deployed. Some suggestions for improving the acoustically estimated suspended sediment data set are as follows.

- Reevaluate the data selection that is used to develop the regression relationship between the optical and acoustical data. Data from the 7-day periods centered on the peak winds from hurricanes Katrina and Wilma were used, but perhaps another choice of data might result in a better regression calculation.
- Suspended sediments measured by the optical instruments at low levels were variable, and regression calculations with the acoustics using only low level

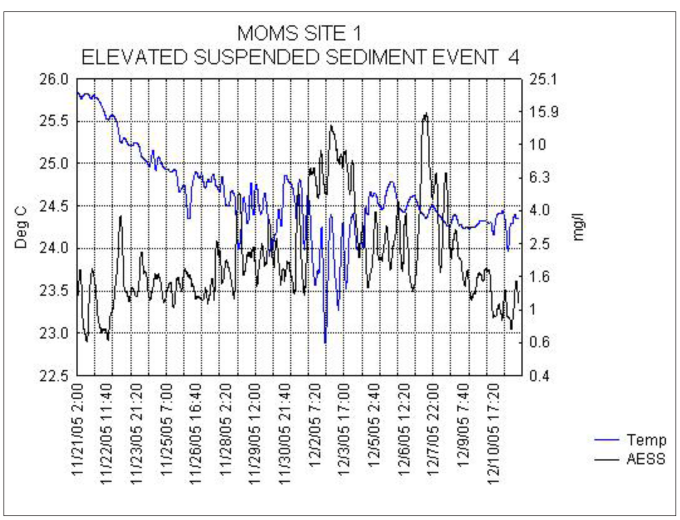

Figure 31. Temperature and acoustically estimated suspended sediment during elevated turbidity event 4.

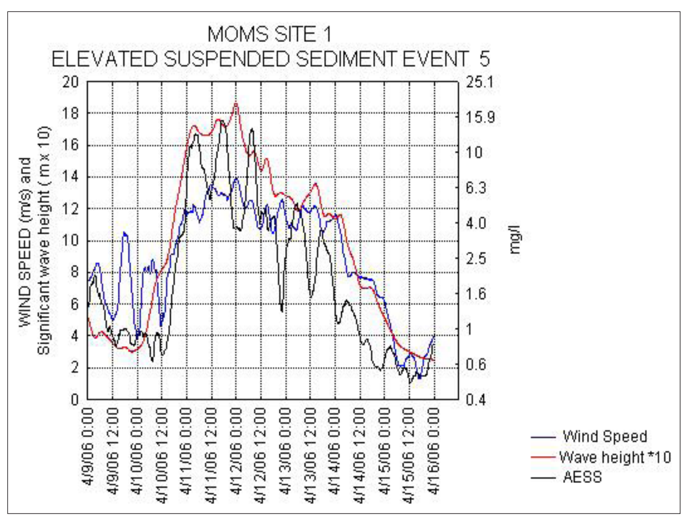

Figure 32. Wind speed, wave height, and acoustically estimated suspended sediment during elevated turbidity event 5.

data did 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.

- An analysis of the optical data with the 1200 and 600 kHz ADCPs may lend some insights into shifts in the particle size distribution of the suspended sediment.

- Figure 5 gives the wind speed and the ratio of the 600 kHz raw backscatter data to the 1200 kHz raw backscatter data during Hurricane Wilma. From this graph it can be observed that the ratio of the 600 kHz data to the 1200 kHz data evolved with the passage of the storm. This may imply that the type and/or size distribution of the suspended sediments was changing. It would be very useful to have information regarding the type and size distribution of the suspended sediments. During the later MOMS deployments, a Sequoia Instruments LISST 25 laser particle size counter was deployed with the instrument at MOMS site 1. However, the data collected were not of good quality and were not used.

7. References

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Teledyne RD Instruments, 2001: Wave user's guide. Teledyne Technologies, P/N 957-6148-00, 74 pp.

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Appendix A:

Optical Sensor Calibration

To convert the turbidity units reported by the YSI OBS sonde into units of suspended sediment concentration, a calibration was performed using sediment collected at MOMS site 1 for the calibration. Sediment from the deployment site was collected via diver and transported to AOML. The sediment was freeze dried and sieved through a ≤63 µm stainless steel sieve. All sediments >63 µm were discarded, and only sediments ≤63 µm 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, 0.5, 0.75, 1.0, 2.0, 4.0, 6.0, 10.0, 25.0, 50.0, 75.0, 100.0, 125.0, 150.0, and 250.0. A proper amount of ≤ 63 µm 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 Gulf Stream). The optical sensors were set to record data every second. Data were collected for approximately 2 minutes each time new sediment was added. Before any sediment was added, the optical sensors collected background data for 2 minutes on the clean seawater.

After each 2-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 47 mm, 0.4 µm polycarbonate filters and dried at 500°C 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 were downloaded from the YSI OBS sonde and averaged over each of the 2-minute collection periods. These data from the optical sensors (Formazin Nephelometric Unit/Nephelometric Turbidity Unit [FTU/NTU]) were plotted with the calculated concentrations (mg/L) of sediment from the test tank (**Figure A1**). This allowed the FTU and NTU units to be converted to concentration units (mg/L).

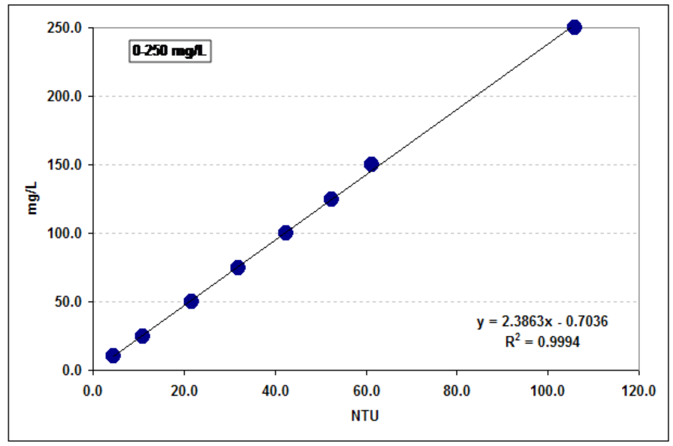

Figure A1. Plot of calculated concentration data from optical sensors.

Appendix B:

ADCP Calibration

Corrections to Generate Volume Backscatter Data

The procedures to calibrate RD Instruments ADCP backscatter data to units of volume scattering strength (Sv) are described in Deines (1999). These corrections take the form of:

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

From Deines (1999), the equation that allows the ADCP backscatter data to be converted to units of scattering volume is

$$Sv = C + 10\log_{10}((T_x + 273.16)R^2) - L_{DBM} - P_{DBW} + 2\alpha R + K_c(E - E_r)$$

where

Sv is the scattering volume in decibels re $(4\pi m)^{-1}$.

C is a system constant specific to the ADCP.

T_x is the temperature at the transducer (°C).

R is the slant range along the acoustic beam to the measurement point.

L_{DBM} is the 10 times the base 10 logarithm of the transmitted pulse length (m).

P_{DBW} is the 10 times base 10 logarithm of the transmitted power (watts).

α is the absorption coefficient of water at the ADCP operating frequency.

K_c is a calibration coefficient for the ADCPs received signal strength indicator.

E is the received signal strength reported by the ADCP.

E_r is a reference received signal strength (system background level).

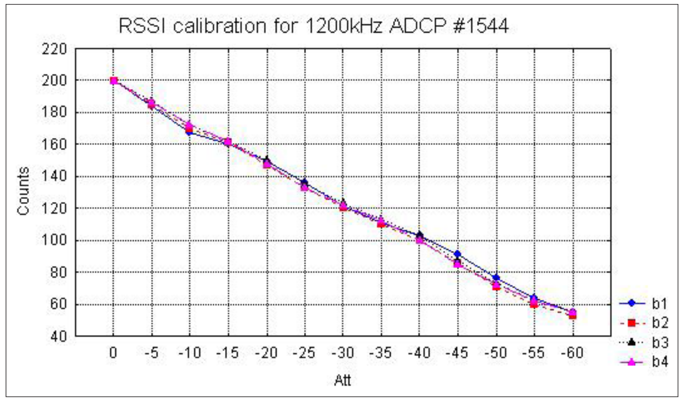

Figure B1. K_c parameter calculated for each beam of the ADCP.

The terms L_{DBM}, *R*, and *C* may be calculated directly from information given in Deines (1999) and the deployment parameters of the ADCP. The terms T_x, P_{DBW}, and *E* can be calculated by information given in Deines (1999) and data from the deployment. The E_r term is instrument specific and determined by operating the instrument out of the water and recording the raw backscatter values. The K_c term 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 K_c parameter for each beam of the ADCP may be calculated (**Figure B1**).

This procedure was performed on instrument 1544. The values of K_c 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 unable 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 α = 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 to ensure that the acoustical sampling volume could be made as close as possible to the optical sampling volume. However, this also placed the data from the first ADCP bin into the region known as the near field (Deines, 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 are not well defined (Teledyne RD Instruments, 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 1200 kHz ADCP were not used in comparison with data from other ADCP depth bins. Data from bin-1 of the ADCP were used only to develop an empirical relationship with the optical backscatter data. Any error in the value of *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. The values calculated for the acoustically estimated suspended sediment concentration estimates would not be affected.

National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
Atlantic Oceanographic and Meteorological Laboratory
4301 Rickenbacker Causeway
Miami, FL 33149
www.aoml.noaa.gov