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Inner-Shelf Bottom Boundary Layer Development and Sediment Suspension During Tropical Storm Isadore on the West Florida Shelf.

by

Justin G. Brodersen

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science
College of Marine Science
University of South Florida

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June 18, 2004

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Figure 13. Cospectra and coherence analysis conducted at 15 cm above the bed between the ABS and U velocities (a), V velocities (b), and pressure (c). Dashed line on coherence graphs represent 95% confidence levels.
Observations of the bottom boundary layer on the inner West Florida Shelf were made with a downward looking pulse coherent acoustic Doppler profiler throughout the passage of Tropical Storm Isadore during September 2002. The storm passed through the Gulf of Mexico roughly 780 km offshore of the Florida study site. Significant wave heights ranged from 0 m to 2.5 m within a span of eight days. The excellent, non-invasive, 5 cm resolution of the near bed (bottom meter) mean flows were used to estimate bed shear velocity and bottom roughness using the standard log-layer approach. A unique opportunity to examine boundary layer structure was provided by the high-resolution data. Calculated friction velocity due to currents \((u^*c)\) and apparent bottom roughness \((z_o)\) reduced considerably when velocity measurements closer to the bed were emphasized. This observation may be indicative of segmentation within the bottom boundary layer and has implications for common practices of estimating bed shear stress measurements from distances greater than a few tens of centimeters above the bed. Acoustic backscatter strength was used as a proxy for sediment suspension in the water column revealing no relationship between current parameters and sediment resuspension during the ten-day
data set. Wave effects were included following the work of Grant and Madsen and others with strong relationships between wave and wave-current parameters and the ABS as a proxy for sediment resuspension evident.
Chapter 1

Introduction

The ability to accurately model the velocity distribution and bottom shear stress under combined waves and currents is essential to the study of sediment transport (Grant and Madsen, 1979) with practical uses including pollutant transport, understanding the geologic record, and engineering applications. Considerable effort has been devoted to the development of quantitative models that can predict boundary shear stress, velocity structure, and bed roughness under conditions that typically involve combined waves and current flows over a moveable bottom (Drake et al., 1992). Water motion on the inner-continental shelf is driven by several mechanisms with the resulting fluid velocities affected by highly nonlinear friction processes in the boundary layer (Grant and Madsen, 1986). Of particular importance are properly specified contributions of wave oscillatory currents to the bed shear stress that initiates erosion (Grant and Madsen, 1986; Green et al., 1990), and the need to accurately measure and calculate temporal and spatial variation in roughness and boundary shear stress (Clark and Brink, 1985; Drake and Cacchione, 1992). The recent development of pulse to pulse coherent acoustic Doppler profilers provide an accurate method to obtain non-invasive, high-resolution, and high-frequency velocity profiles of the bottom boundary layer (Lhermite and Serafin, 1984; Zedel et al., 1996, Lacey et al. 2004).
Refining understanding of interactions and parameterization of bottom boundary flow were the primary objectives of this study. Observations of the bottom boundary layer and sediment resuspension on the inner West Florida Shelf were made with a downward looking pulse coherent acoustic Doppler profiler throughout the passage of Tropical Storm Isadore. Characteristic shear velocities and bed shear stress were obtained using Grant and Madsen’s 1986 solution. Previous studies with similar objectives were primarily limited by four to five velocity measurements within the bottom meter. With high-resolution (every 5 cm) bottom boundary layer data, detailed examination of bbl structure during the storm was conducted, investigating evidence of segmentation within the bottom boundary layer and potential implications to transport estimates. Burst mean data are then used to examine the role of wave and current interactions with sediment resuspension on the inner West Florida Shelf, followed by a review of high-frequency (2 Hz) profile data for a clear signal of sediment resuspension under individual waves and groups of waves. Discussion of each of these topics (Section 4) is followed by some conclusions regarding implications to sediment resuspension and transport estimates on the inner West Florida shelf during the storm.
Chapter 2

Methods

2.1 Study Site

The study was conducted during September 2002 on the inner West Florida Continental Shelf, approximately 10 km west off Indian Rocks Beach, Florida in 13 m water depth (Figure 1). Conditions are characteristic of the wide shelf with limited fetch. Wave and tidal energy are small (Tanner, 1960), with mean annual wave heights of 25 cm and a mean tidal range along the coast of approximately 70 cm (Gelfenbaum and Brooks, 2003). Each year tropical storms tracking offshore, and passing winter cold fronts, result in periods of elevated sea level, winds, and waves on the shelf (Hine, et al., 2003). Wave heights generally range from 0 to 3 m, with the largest waves corresponding to the passage of the winter cold fronts and tropical storms (Howd and Brodersen, 2002). Seasonal winds are the dominant process in variations of inner-shelf circulation with summer (April to September) mean shore-parallel flows from the southeast (Yang and Weisberg, 1999). Quartz sand ridges ($D_{so} = 150 \mu m$) (Section 3.1) up to 3 m thick overlying a limestone bedrock hardbottom characterize the bed (Figure 2) (Edwards, et al, 2003).
2.2 Data Collection

Data were collected as part of the Office of Naval Research Mine Burial Project on the West Florida Shelf. The objective in selecting the data analyzed in this paper was to examine the effects of a tropical storm on the bottom boundary layer and sediment resuspension at the study site. A 1.5 MHz Sontek Pulse-Coherent Acoustic Doppler

![Isadore's Path](image1)

**Figure 1:** Path of the storm. Cross-hash indicates study site location.

![Sidescan mosaic](image2)

**Figure 2:** Sidescan mosaic of the study site with instrument location indicated by cross. Quartz sand ridge with D50 = 0.15 mm. - *Image Courtesy S. Locker*
Profiler (PCADP) with Druck pressure sensor was secured to a 2.4 m aluminum quadpod deployed in 13 m water depth (Figure 3). The PCADP was oriented looking downward 1.5 m above bottom, measuring velocity in 5 cm (nominal) bins sampling at 2 Hz. The PCADP is also used to estimate significant wave height, direction and spectrally weighted wave period via the Sontek “WAVES” package (Sontek White Paper).

Acoustic backscatter recorded by the instrument is also used as a proxy for sediment resuspension in the water column. Mounted adjacent to the PCADP was a synchronous Sontek Acoustic Doppler Velocimeter (ADV), with pressure sensor, measuring velocities approximately 123 cm above bed at 4 Hz. The ADV is used to verify velocity measurements taken by the PCADP. Both instruments measure temperature. Sampling parameters for both instruments are shown in Table 1. Also mounted on the quadpod were two optical backscatter devices (OBS) at 0.5 m and 1 m, and a Sequoia Scientific

Figure 3: The Quadpod
LISST-100c laser particle analyzer (LISST) at 128 cm. Seventy-nine sediment samples were collected from the study site between August 2001 and February 2003

2.3 Data Analysis

2.3.1 The PCADP

Velocity data of poor quality, exhibiting spikes of greater than four standard deviations, were identified for both instruments by low pass filter and replaced with a linearly interpolated value. Statistical comparisons of equidistant PCADP and highly

Table 1: PCADP and ADV Sampling Parameters.

<table>
<thead>
<tr>
<th>PCADP Parameters:</th>
<th>ADV Parameters:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CellSize</td>
<td>0.048 (m)</td>
</tr>
<tr>
<td>BlankDistance</td>
<td>0.1 (m)</td>
</tr>
<tr>
<td>Ncells</td>
<td>32</td>
</tr>
<tr>
<td>AvgInterval</td>
<td>0.5 (s)</td>
</tr>
<tr>
<td>ProfileInterval</td>
<td>0.5 (s)</td>
</tr>
<tr>
<td>Pulse length</td>
<td>0.02 (m)</td>
</tr>
<tr>
<td>Max range</td>
<td>1.55 (m)</td>
</tr>
<tr>
<td>System Lag</td>
<td>2.32 (m)</td>
</tr>
<tr>
<td>System ResLag</td>
<td>0.52 (m)</td>
</tr>
<tr>
<td>MaxVertVel</td>
<td>0.74 (m/s)</td>
</tr>
<tr>
<td>MaxHorizVel</td>
<td>2.86 (m/s)</td>
</tr>
<tr>
<td>MinCorrLevel</td>
<td>30 (%)</td>
</tr>
<tr>
<td>PingInterval</td>
<td>0 (s)</td>
</tr>
<tr>
<td>BurstInterval</td>
<td>3600 (s)</td>
</tr>
<tr>
<td>ProfilesPerBurst</td>
<td>2048</td>
</tr>
</tbody>
</table>
accurate ADV velocity data were performed to confirm PCADP results. It has been demonstrated that the PCADP can be successfully used to estimate friction velocity and apparent roughness in moderately energetic inner-shelf conditions, although velocity measurements close to the transducers are frequently too noisy to produce accurate results (Lacey and Sherwood, 2004). To that end, analyzed velocity data have been selected for proximity (bottom meter) to the bed and therefore measurements within 40 to 50 cm of the transducer are disregarded. The comparisons between instruments, however, are limited by height of the single point ADV sampling volume. The comparisons are conducted at a distance from the PCADP transducer still well beyond the recommended blanking distance of Lacey and Sherwood (2004). The ADV 2 cm$^3$ sampling (nominally 27 to 29 cm below PCADP transducers) volume is located within bin 3 of the PCADP (25 to 30 cm below the PCADP transducers). Comparisons of burst mean speeds and variances between the two instruments show reasonable agreement (Figure 4).

The PCADP measures distance from each transducer to the bed at the beginning of each burst via a single pulse. The distance of the sensor off bottom was determined by taking the maximum of the three values. Hourly changes in measured scour and/or deposition of greater than 20 cm were considered false returns, thus values less than 1.3 meters are not considered and replaced by the value of the previous burst. Total water depth ($h$) is taken to be the depth measured at the pressure sensor added to the previously determined distance off bottom.

Acoustic backscatter magnitude measured by the PCADP is used as a proxy for sediment resuspension. Multiplication by 0.43 was used to convert instrument internal amplitude units (counts) to dB. Corrections for the effects of geometric spreading and
Figure 4: Comparison of PCADP to ADV mean speed (a) and variance (b). The lesser $r^2$ value on variance is expected due to the greater noise in the PCADP measurements.
absorption allowed data comparison from different portions of the profile. Spreading and absorption cause signal strength decay with increased distance from the transducers. This decay in signal strength was predicted by the following formula

\[
\Omega = -20 \log_{10} \left( \frac{\partial}{2\pi * 15} \cos \frac{2\pi * 15}{360} \right) - 2(\alpha) \left( \frac{\partial}{2\pi * 15} \cos \frac{2\pi * 15}{360} \right)
\]

(1)

where \( \Omega \) is signal decay with distance from the transducer (\( \partial \)). The first term on the right hand side represents scattering and the second, absorption. Sound absorption is represented by \( \alpha = 0.68 \text{ dB/m (for 1.5 MHz with salinity 35 ppt)} \) (Sontek White Paper). Signal strength data independent of range was then obtained by subtracting \( \Omega \) for each depth cell from the respective signal strength.

2.3.2 Estimates of Friction Velocity \((u_*c)\) and Apparent Roughness \((z_0)\)

Friction velocity due to currents \((u_*c)\) and apparent roughness \((z_0)\) are calculated by fitting a least squares curve to speed data obtained using PCADP burst mean profiles and a modified form of Von Karmen – Prandtl’s equation (the law of the wall) in which mean velocities above the wave boundary layer are logarithmically distributed with respect to depth (Drake, et al, 1992);

\[
S_{(z)} = \frac{u_{*c}}{k} \ln \left( \frac{Z}{Z_0} \right)
\]

(2)

where \( S_{(z)} \) is the burst averaged speed at height \( z \) above the bed, \( u_{*c} \) is friction velocity due to currents, \( k = 0.4 \) is the Von Karman constant, and \( z_0 \) is the hydrodynamic or apparent
bottom roughness. Over a rough bottom, flow separation around individual roughness elements cause pressure gradients resulting in generation of turbulent eddies. This creates a greater resistance felt by the current known as form drag (Grant and Madsen, 1979). An apparent roughness length ($z_0$) is determined by the $y$-intercept of the least squares fit to the velocity data. The $y$-intercept occurs at a higher elevation when waves are present. The friction velocity due to currents ($u_*$) is determined from the slope ($u_*/k$) of that regression line. Regression analysis were conducted twice, first by finding the best fit log layer result (defined below) working from the bed up into the flow, and again from a nominal height of 0.65 m and working down toward the bed. Hereafter referred to as the bed-up and top-down methods respectively. In an idealized mean flow profile the friction velocities would be identical.

The bed-up regression considers a minimum of 6 speeds nearest the bed and repeats the analysis as each additional speed bin is added to the analysis. The best-fit result is selected at the regression line with the largest percent variance explained by the regression model (the highest $r^2$ value). Similarly, the top-down profile used 4 points from 0.65 m and sequentially added bins nearer the bed. The 0.65 m top was used to prevent flow contamination from the quadpod seen at certain intervals. The minimum number of four speeds were used in the top-down analysis to increase the sample size.

For both cases the regression results chosen for further analysis also met the requirement that $r^2 > 0.95$ and the mean speed exceeded 7.5 cm/s within the flow profile (Figure 5). Error in the estimates of $u_*$ and $z_0$ are limited by the restriction on $r^2$. 
2.3.3 Non-linear Coupling of Waves and Currents

Because it is widely used, simple closed-form, analytical expressions for combined wave-current bottom boundary layer flows and associated sediment transport are obtained using the simple eddy viscosity model proposed by Grant and Madsen (1986). Input parameters used for the Grant-Madsen equations are significant wave height \(H_s\), angle of incidence between waves and currents, mean grain size, depth, \(u^*\), and \(z_0\). From these inputs a friction factor \(f_{cw}\) is calculated through an iterative process to account for relationships between waves, currents, and shear stresses. Once the friction factor is obtained a friction velocity \(u_{*cw}\) and shear stress \(\tau_{cw}\) due to the

![Figure 5: Sample burst showing bottom-up method results. Mean velocities plotted logarithmically exhibiting “law of the wall” behavior. (a), \(r^2\) values exceeding 0.95 (b), \(u_{*c}\) obtained from the slope of the regression (c), and \(z_0\) obtained from the y-intercept (d).](image)
combined effects of waves and currents are calculated. Friction velocities for waves alone \( (u_{n1}) \) and waves as effected by currents \( (u_{n2}) \) are also calculated.
Chapter 3

Results

3.1 Conditions

The data were collected 19 through 29 September 2002 during the passage of Hurricane Isadore in the Gulf of Mexico (Figure 1). The storm passed approximately 780 km offshore of the study site. The time series of site conditions during the passage of the storm are shown in Figure 6. Significant wave heights ranged from 0 to 2.5 m. The first waves with maximum period of 10 seconds began arriving on September 22. The median peak wave period during the storm was 6.8 seconds. Wave periods below four seconds were not calculated at this depth. Mean currents were tidally dominated, ranging from 0 to 20 cm/s, with a surge in mean north-south velocities and a shift in direction to the south under the peak of the storm (Figure 7). The critical shear velocity \( (u_{crit}) \) was calculated using a Shields parameter (CEM) for initiation of motion and was exceeded by the currents during the storm. At one meter above the bed mean wave velocities dominate the currents with a ratio of mean orbital velocities to currents of 2.3. Acoustic backscatter amplitude measured by the PCADP was used as a proxy for sediment resuspension in the water column (Figure 6a). Analysis of the sediment samples revealed a median grain size of 150 \( \mu \)m, which was used as grain size in the Grant and Madsen model.
Figure 6: Time series of measured conditions. (a) Acoustic backscatter magnitude. (b) Significant Wave Height. (c) Wave Period. Periods below 4 seconds were not calculated at this water depth. (d) Mean currents speeds 1 m above the bed.
3.2 Regressions Analysis

Regressions of the bottom boundary layer velocity profile conducted using the methods described in Section 2 yield different results depending upon the part of the flow profile emphasized. Of the 240 profiles analyzed, 60 met the criteria for selection using both methods, but only 57% of those selected are the same. Estimates of $u_{*c}$ and $z_0$ are substantially higher when the top-down regressions are conducted, resulting in more incidence of perceived current shear above the critical threshold for motion (Figure 8). In
fact, using the upper flow (top-down) 23% more \( u_{sc} \) calculations exceed the critical value \( (u_{scrit}) \). When analyzing the synchronous bursts, higher results were obtained for \( u_{sc} \) in 68% of bursts, and \( z_0 \) in 72% of bursts with the top-down flow. Mean value comparisons of the 34 synchronous bursts are presented in Table 2. Modeled parameter predictions of the combined effects of waves and currents \( (\tau_{cw}, u_{scw}) \), waves alone \( (u_{sw1}) \) and waves as affected by currents \( (u_{sw2}) \) produce slightly lower estimates analyzing from the top-down.

<table>
<thead>
<tr>
<th>Lower flow (bottom-up)</th>
<th>( u_{sc} ) (cm/s)</th>
<th>( \tau_{cw} ) (cm/s)</th>
<th>( u_{scw} ) (cm/s)</th>
<th>( u_{sw1} ) (cm/s)</th>
<th>( u_{sw2} ) (cm/s)</th>
<th>( z_0 ) (cm)</th>
<th>( f_{cw} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.81</td>
<td>1871</td>
<td>1.18</td>
<td>1.18</td>
<td>1.18</td>
<td>0.52</td>
<td>0.0075</td>
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</table>

<table>
<thead>
<tr>
<th>Upper flow (top-down)</th>
<th>( u_{sc} ) (cm/s)</th>
<th>( \tau_{cw} ) (cm/s)</th>
<th>( u_{scw} ) (cm/s)</th>
<th>( u_{sw1} ) (cm/s)</th>
<th>( u_{sw2} ) (cm/s)</th>
<th>( z_0 ) (cm)</th>
<th>( f_{cw} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.03</td>
<td>1764</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
<td>0.91</td>
<td>0.0060</td>
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</tr>
</tbody>
</table>

**Table 2**: The 34 synchronous bursts. Comparisons of parameter differences resulting when different parts of the boundary layer flow are emphasized.

### 3.3 Burst Averaged Data

Coupling between the flow and bed response was examined by least squares regressions between acoustic backscatter (ABS) magnitude measured by the PCADP, model outputs, and relevant measured parameters. Time series of the model results are shown in Figure 9. The ABS strength from the PCADP instrument provides a potential proxy for sediment suspension in the water column. ABS requires calibration of instrument output to known particle concentrations in order to convert the measured signal to a value of suspended sediment concentration (Wiberg et al., 1994). Calibration has also been observed to be sensitive to grain properties such as shape, angularity and
Figure 8: Estimates of $u_{*c}$ using the alternate approaches, bottom-up and top-down, showing different relationships to the critical shear velocity (a) and (b) the differences in the respective $z_0$. 
Figure 9: Time-series of modeled results throughout the storm. Shear velocity (a) and shear stress (b) from the combined effects of waves and currents. Shear velocity due to waves (c) and shear velocity due to waves as affected by currents (d). All of the above (a-d) were calculated using shear velocity due to currents regressed from the bottom-up (e). The time series of shear velocity due to currents using the top-down method is shown in (f). Dashed line represents critical shear velocity.

refractive index (Moody et al., 1987; Baker and Lavelle, 1984). Even with careful attention to such detail and complex calibration procedures, proclamations of real world observations of concentrations and volumes would be suspect, and are not attempted here. Near bed suspension is taken to represent median grain size particle suspension with no quantification of sediment volume or flux. In the recent past there have been conflicting interpretations regarding the need to include wave orbital velocities along with mean currents when estimating sediment resuspension events on the inner West Florida Shelf (Gelfenbaum and Brooks, 2003; Harrison 2003; Hafen, 2001). With this in mind,
the study focused on relative concentrations represented by signal strength and through careful analysis infers the most relevant parameters regarding sediment resuspension and transport on the inner West Florida Shelf.

ABS values from the third bin above the bed were used. This bin was selected for proximity to the bottom, while allowing enough distance above the bed to ensure that particle load was actually in suspension later in the storm. It is also in a zone of low backscatter prior to storm wave arrival when particles higher in the water column appear to be undergoing advective transport or otherwise unexplainable signal noise (e.g. fish) (Figure 6a). The selected bin provides the averaged value for 10-15 cm (nominal) above the bed.

Table 3 summarizes the results for parameters of interest. For the bottom-up flow with the given sample size, $r^2$ values between ABS and $H_s$, $u_{cm}$, $u_{sw1}$, and $u_{sw2}$ are not statistically different from one another at the 95% confidence interval. The values are statistically different from zero. Neither $r^2$ values between ABS and $u_c$, nor ABS and mean current speed are statistically different from zero. In this instance, variance in ABS magnitude is well explained by both measured wave height and modeled bed shear velocity due to combined waves and currents (Figure 10-a & b). Current shear velocities alone, however, (Figure 10-c) show no relationship to ABS. Using both segments of flow (bottom-up and top-down) parameter correlation coefficients with the ABS show no statistical difference between the two regression types and thus yield the same results at this sample size.
Table 3: Relationship of parameters of interest to the acoustic backscatter magnitude (ABS). Italicized results (right-hand side) show comparisons with parameters resulting from “top-down” analysis.

<table>
<thead>
<tr>
<th>ABS @ 15 cm to:</th>
<th>$r^2$</th>
<th>$F$</th>
<th>$p$</th>
<th>$r^2$</th>
<th>$F$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u_{scw}$</td>
<td>0.61</td>
<td>91.85</td>
<td>0.00</td>
<td>0.76</td>
<td>182.90</td>
<td>0.00</td>
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<tr>
<td>$u_{w1}$</td>
<td>0.61</td>
<td>91.85</td>
<td>0.00</td>
<td>0.76</td>
<td>182.75</td>
<td>0.00</td>
</tr>
<tr>
<td>$u_{w2}$</td>
<td>0.61</td>
<td>91.85</td>
<td>0.00</td>
<td>0.76</td>
<td>182.86</td>
<td>0.00</td>
</tr>
<tr>
<td>$\tau_{cw}$</td>
<td>0.52</td>
<td>62.75</td>
<td>0.00</td>
<td>0.69</td>
<td>130.42</td>
<td>0.00</td>
</tr>
<tr>
<td>$u_c$</td>
<td>0.00</td>
<td>0.15</td>
<td>0.70</td>
<td>0.05</td>
<td>3.37</td>
<td>0.07</td>
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<tr>
<td>$u_{10}$</td>
<td>0.02</td>
<td>1.19</td>
<td>0.28</td>
<td>0.02</td>
<td>1.4</td>
<td>0.24</td>
</tr>
<tr>
<td>$u_{100}$</td>
<td>0.07</td>
<td>4.85</td>
<td>0.03</td>
<td>0.07</td>
<td>4.3</td>
<td>0.04</td>
</tr>
<tr>
<td>$H_s$</td>
<td>0.78</td>
<td>207.97</td>
<td>0.00</td>
<td>0.82</td>
<td>268.35</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Figure 10: (a). Acoustic Backscatter magnitude at 15 cm above bed vs. significant wave height. (b). Acoustic Backscatter magnitude at 15 cm above bed vs. modeled shear velocities for combined waves and currents. (c). Shear velocity for currents alone. *Note: r values between I and II are not statistically different from one another at the given sample size. r values for $U_{scw}$ (c) are not statistically different from zero.
3.4 2 Hz Profile Data

With the strong relationship previously established between the ABS and wave action in the burst-averaged data, the instantaneous 2 Hz profile data were examined for similar variability under individual waves. Four bursts were selected at various stages of storm progression. The first burst was chosen prior to the storm under calm conditions. The second was chosen during the peak in wave period on the 22nd of September. Burst #185, the third burst selected, was at the peak of the storm with the highest wave heights and greatest ABS magnitudes. The fourth burst, similar in appearance to the first burst, is selected after storm wave height and period subsidence.

Spectral analysis of the cospectra and coherence were conducted using a 512-point ensemble FFT with a Hanning window and 50% overlap, of the 2 Hz velocity, pressure, and ABS data. The 2 Hz time-series data for burst #185 is given in Figure 11. The coherence and cospectra of the four separate bursts selected yield no significant difference in results. Burst #185 would be the most probable burst in which variability of suspension under individual waves could be seen, and therefore is discussed here in lieu of all four.

Cospectra and coherence conducted at one meter (Figure 12) and 15 cm (Figure 13) above the bed do not show a clear signal explaining variability on these time scales. While areas of coherence higher than the 95% confidence interval within the pressure (Figures 12c & 13c) spectrum may appear significant, the peaks in the spectrum here are too narrow to be confirmed as such. As a result, no relationship between variability under individual waves and resuspension events are seen during this time period on the inner West Florida Shelf.
Figure 11: 2 Hz time series of measured conditions for burst 185. (a) Acoustic backscatter magnitude. (b) Significant Wave Height. (c) Wave Period. Periods below 4 seconds were not calculated at this water depth. (d) Mean currents speeds 1 m above the bed.
Figure 12: Cospectra and coherence analysis conducted at 1 m above the bed between the ABS and U velocities (a), V velocities (b), and pressure (c). Dashed line on coherence graphs represent 95% confidence levels.

Figure 13: Cospectra and coherence analysis conducted at 15 cm above the bed between the ABS and U velocities (a), V velocities (b), and pressure (c). Dashed line on coherence graphs represent 95% confidence levels.
Chapter 4

Discussion

4.1 Quantifying the Bottom Boundary Layer

Predictive models of currents and sediment transport on continental shelves require reliable measurement and calculation of temporal and spatial variation in roughness and boundary shear stress (Clark and Brink, 1985; Drake and Cacchione, 1992). Regression analyses of the bottom boundary layer (bbl) are indicative of possible existence of segmentation in the bbl similar to that described by Chriss and Caldwell, 1982. Different methods of calculating the regressions are used to examine the high-resolution data provided by the PCADP for evidence of segmentation. Analyses have exposed differences in current shear velocity ($u^c_*$) and bottom roughness ($z_0$) results obtained from near bed velocity profiles using separate methods. Emphasizing data from the bottom of the flow profile (bottom-up) results in lower mean calculations of $u^c_*$ and $z_0$ (Table 2 and Figure 8). Alternatively, the emphasizing top-down shows a tendency to calculate higher values of $u^c_*$ and $z_0$, with 23% more of $u^c_*$ exceeding the calculated $u^*_{crit}$ at the mean grain size.

High sediment concentrations causing stratification within the bbl have been described as causality for some ‘kinks’ in boundary layers (Styles and Glenn, 2000). However, the availability of alternate interpretations of burst data prior to significant increases in entrainment appears to negate such an explanation in this instance. Thus,
data tend to support findings that local bed stress may be significantly overestimated by
the use of quadratic law or Reynolds stress techniques when data is obtained more than
a few tens of centimeters from the bed due to the possibility of segmentation in the bbl
(Chriss and Caldwell, 1982).

Previous authors have drawn attention to the need for the high resolution, high
frequency data within the bottom boundary layer that the PCADP provides (Cacchione
and Drake, 1982; Glenn and Grant, 1987; Dyer and Soulsby 1988). Results of our
regression analysis exhibit an excellent example of the importance of resolution in
understanding the bottom boundary layer.

Should segmentation be the general case on the inner West Florida Shelf, the effects
on calculating $u_\infty$ and $z_0$ from velocity profiles in the water column could cause large
discrepancies in both timing and amount of transport predicted on the shelf. According
to the data analyzed here, large scale studies, particularly those ignoring or averaging out
wave effects, without detailed information of bottom boundary velocity data may over
predict transport estimates when extrapolating shear velocities to the bed from higher
in the water column (i.e. 1 m). Furthermore, this sensitivity in calculations of $u_\infty$ help
illustrate the importance of including wave activity in large scale studies describing mass
transport on the inner West Florida Shelf as discussed in the following section.

4.2 Mean Data and Sediment Resuspension During the Storm.

Recently conflicting interpretations regarding the need to include wave orbital
velocities along with mean currents when estimating sediment resuspension events on the
inner West Florida Shelf have been put forward (Gelfenbaum and Brooks, 2003; Harrison
2003; Hafen, 2001). Evident in data analyzed here are a strong coupling of wave energy parameters and the ABS, with no apparent relationship involving current parameters alone with the ABS.

In this instance the strong relationship between ABS and wave parameters exhibit the necessity of including wave information when estimating sediment resuspension events on the inner West Florida Shelf. With ABS data showing no relationship to current parameters alone in our data set (Table 3), assumptions of sediment resuspension using current shear velocities \( u_c \) calculated from the bottom-up would be erroneous, and correct assumptions of resuspension regressing from the top-down would be coincidental. Data support the notion that waves are quite capable of entraining significant amounts of sediment on the inner shelf while offering no support to the idea that mean currents taken from a meter or more above the bed are good estimators of sediment suspension in the water column, and thus active transport. However, the simultaneous presence of waves suspending sediments and even a weak current will result in net transport (Grant and Madsen, 1979). While perhaps not always the case, in this instance waves are determined to be an integral component of resuspension on the West Florida Shelf, and wave data should be considered for increased accuracy in estimates of transport.

4.3 Sediment Resuspension Under Individual Waves and Wave Groups

Analysis of the cospectra and coherence of the high-frequency data have shown no clear signal explaining variability on these time scales on the inner West Florida Shelf. While evidence of variability under individual waves and wave groups at varying phase has been observed by other investigators, differences in sampling depth and grain size
exist at these sites (Trowbridge and Agrawal, 1995; Foster et al., 2000; Williams et al., 2002). Both Trowbridge and Agrawal, and Foster et al. were in shallower water (6 m and 2 m) with a greater wave influence and larger grain size. Data from Williams et al. are in deeper water (~20 m) with grain sizes ranging from 0.2 to 1.2 mm in size versus our mean of 0.15 mm. Hence, the resultant differences in wave energy, grain sorting, and settling velocities are hypothesized probable causes for differing results.

The absence of a clear signal under the high frequency profile data is interpreted as a lack of sediment settling between waves or wave groups. This absence of a coherent signal supports previous observations of the importance of advection of suspended sediment by currents as an important process on the continental shelf (Grant and Madsen, 1979; Grant and Madsen, 1986; Cacchione and Drake, 1982; Cacchione et al. 1994; Harris and Wiberg, 2002; among others). Similar to that described by Grant and Madsen (1986), the inner West Florida continental shelf under the storm is one in which bed stresses due to waves dominate resuspension of bed materials, but it is combined stresses due to waves and currents that are important in net transport. Thus, results in general at this location support the resuspension of sediments via wave energy and transport via the advecting currents.
Chapter 5

Summary and Conclusions

High-frequency, high-resolution PCADP data collected as part the Office of Naval Research Mine Burial Project were used to investigate the West Florida Shelf bottom boundary layer and sediment resuspension during passage of tropical storm Isadore. A unique opportunity to examine boundary layer structure and implications of methods used in estimating bed stress was provided by the high-resolution data. Calculations of $u_c$ and $z_0$ reduce considerably when velocity measurements closer to the bed are emphasized. This observation may be indicative of segmentation within the bottom boundary layer similar to previous findings and would have implications for practices of commonly estimating bed shear stress measurements from distances greater than a few tens of centimeters above the bed (Chriss and Caldwell, 1982). Subsequently modeled parameters show only a negligible difference at this time, but significant difference may occur given a larger sample size. These phenomena warrant further investigation utilizing the complete 16 month West Florida Shelf data set.

Examination of burst mean data provides evidence of a strong relationship between wave energy and sediment resuspension under storms on the inner West Florida Shelf. The strength of this relationship and the absence of any statistically significant relationship with mean currents or their calculated shear velocities and resuspension emphasize the necessity of including wave data in estimates of storm transport on the
inner West Florida Shelf. However, spectral analysis of the high-frequency profile data show no clear signal of instantaneous resuspension being related to individual waves or wave groups as noted by investigators elsewhere, indicating that current advection remains strong factor in sediment transport within this area of the inner West Florida Shelf.
References


