Vertical Length Scales of Nearshore Suspension Events

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Abstract

Most commonly, nearshore suspended sediment time series are characterized by distinct high concentration events. These events are coherent structures which should have lengths scales that are dependent on the length scale of the near bed turbulence. Possible generation mechanisms for coherent turbulent structures include bed shear, vortex shedding from bed forms, shear instabilities of oscillatory boundary layers, and surficial wave breaking. For turbulence mechanisms other than wave breaking, the characteristic length scale should be governed by the thickness of the bottom boundary layer. The objective of this investigation is to characterize the observed vertical length scales of suspended sediment plumes over the course of a single evolving storm and to compare these length scale estimates with the thickness of the displacement WBBL.

Field observations were made at Queensland Beach on the east coast of Nova Scotia in 1995. This steep planar beach faces a restricted opening, with incoming waves approaching normal to the shore and has a 1 m tidal range. The instruments were located in an intermediate water depth of 3.2 m where the median grain size was 0.02 cm. Sediment suspension was measured with a 2.25 MHz acoustic sounder looking downward and the bed geometry was measure with a rotary sonar.

Over the course of a relatively short lived storm event within a 24 hour period, the wave height ranged from .35 m to 1.4 m and the bed geometry underwent multiple transitions. During this event, the sediment suspension observations showed that while the the relatively infrequent large suspension events increase with increasing storm intensity, the mean suspension event length scale shows little variability. The suspended sediment length scales were compared with an estimate of the displacement thickness of the wave bottom boundary layer. Although the two estimates showed an order of magnitude agreement, the displacement thickness estimates increased slightly with increasing storm intensity. The rms deviation between the estimated boundary layer thickness and the mean length scale of the suspended sediment vertical excursion was 1.2 cm.

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Introduction

Nearshore suspended sediment observation time series are dominated by distinct high concentration events. Recent observations have shown these events to be spatially-discrete coherent structures (Hay and Bowen, 1994) with horizontal lengths scales ranging two orders of magnitude from 5 cm to 1 m. The length scale of the coherent plumes should be dependent on the length scale of the near bed turbulence, indicating the near bed turbulence also exhibits a coherent, spatially discrete structure. Possible generation mechanisms for these turbulent structures include bed shear, vortex shedding from bed forms, shear instabilities of the oscillatory boundary layers, and surficial wave breaking. The turbulence length scale should be governed by the wave bottom boundary layer (WBBL) thickness for these mechanisms, other than wave breaking.

The objective of this investigation is to characterize the observed vertical length scales of suspended sediment plumes over the course of a single evolving storm. Furthermore, we will compare these length scale estimates of the suspended sediment with an estimate thickness of the displacement WBBL.

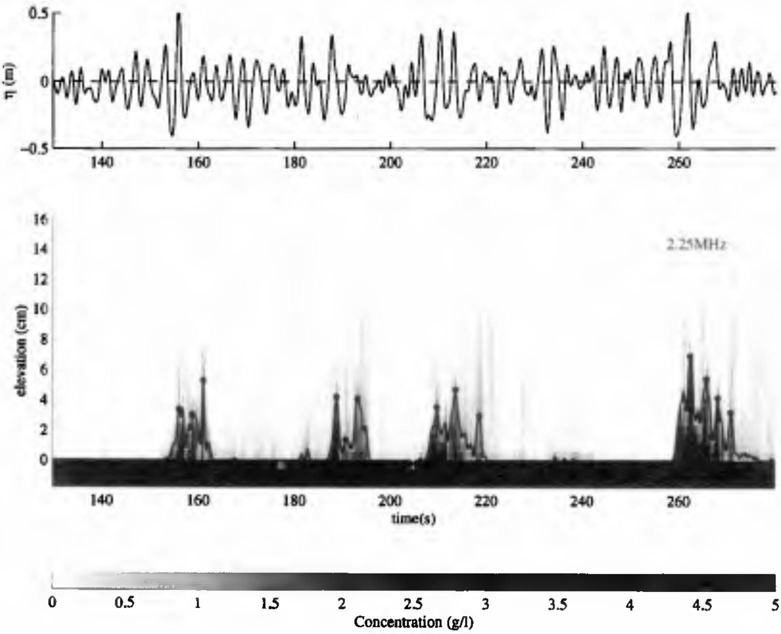

Figure 1: Sea surface elevation, η, as a function of time (top) and suspended sediment concentration, c, as a function of time and elevation (bottom). the solid black line indicates the elevation of the $1g/l$ contour line and the circles indicate the elevation of individual suspension events.

Observations

Field observations were made at Queensland Beach on the southeast coast of Nova Scotia in 1995. This steep planar beach faces a restricted opening, with incoming waves approaching normal to the shore and has a 1 m tidal range. The instruments were located 80 m offshore in an intermediate water depth of 3.2 m. The median grain size was 0.02 cm.

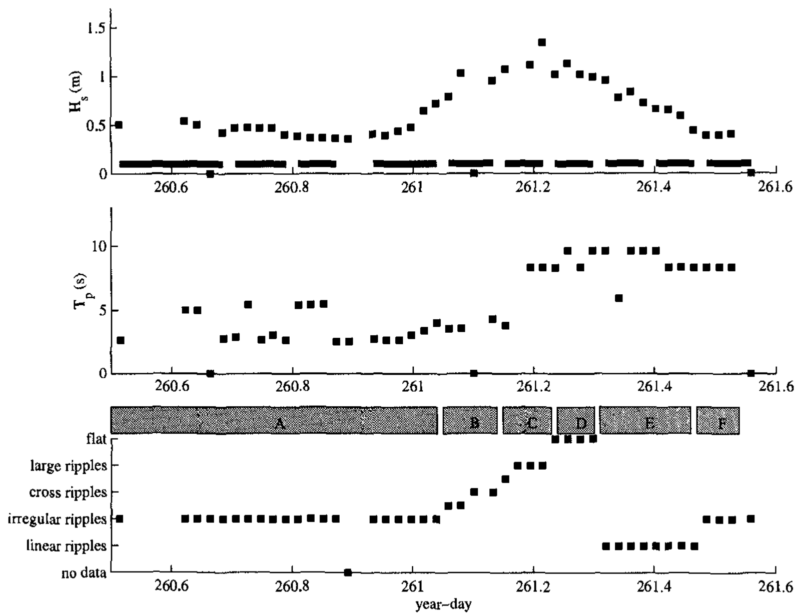

Figure 2: Significant wave height (top), H_s, peak wave period (middle),T_p, and bed form geometry (bottom) over consecutive 500 second runs during year- day 260-261.

For this investigation, sediment suspension and bed elevation were measured with an acoustic sounder operating at 2.25 MHz. The backscatter profile from the sounder spanned a vertical range of about 1 m divided into 0.6 cm range bins and was acquired at 8 Hz. Surface elevation was measured with an upward looking acoustic sounder. A sample time series of sea surface elevation and suspended sediment concentration is given in Figure 1. The concentration and sea surface elevation observations were recorded for 500 seconds every 30 minutes. Bed form geometry was determined over a 5 m radius at each 30 minute interval with a rotary sidescan and rotary pencil beam sonar.

This investigation will focus on the evolving storm during year-days 260 and 261. During the course of this storm the significant wave height, H_s, varied from .35 m to 1.4

m, and the peak wave period, T_p, varied from 2.5 s to 8.3 s. The bed varied between rippled and flat bed, Figure 2.

Results and Discussion

This section is divided into three parts. First, we determine the vertical distribution of suspension excursion. Secondly, we estimate the displacement boundary layer thickness with an empirical model. Finally, we compare the boundary layer thickness estimate with the vertical excursion length scale of the suspended sediment.

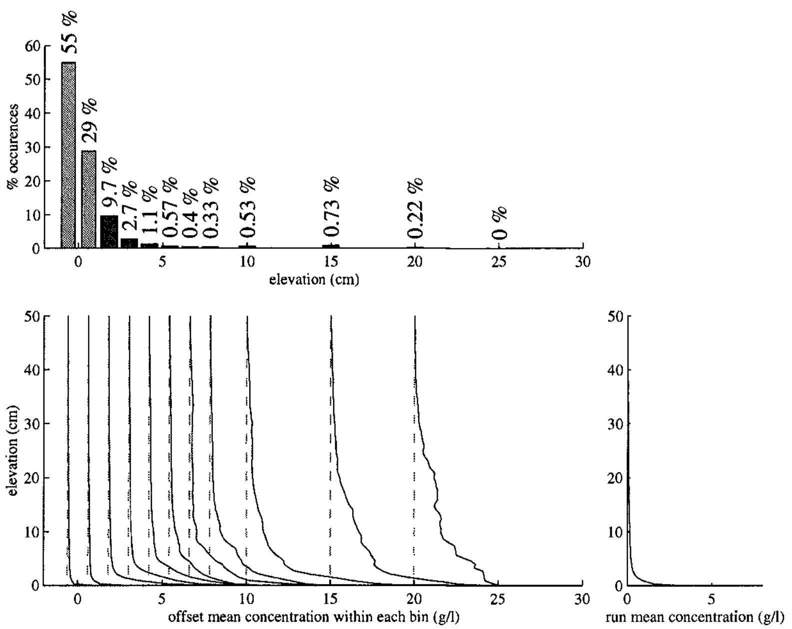

Figure 3: Histogram of the 1 g/l contour elevation of the 2.25 MHz sounder (top panel) and the offset mean profile of observations contained within each histogram bin (bottom panel). The frequency of occurence in each bin are given directly above each bar.

The upper boundary of the sediment laden water was defined with the 1 g/l elevation computed over consecutive 30 second windows, Figure 1. This example shows the 1 g/l contour elevation mostly remains on the bed and has occasional short duration excursions to elevations ranging from 2 to 7 cm. The histogram of the 1 g/l contour elevation time series for this record (Figure 3) shows that 84% of the elevations are less than 2 range bins (1.2 cm) from the bed but there are occasional occurrences where the elevation reaches 15 to 20 cm above the bed. The histogram can be used isolate the mean profile of the suspension events by conditionally sampling the observations based on the elevation of the 1 g/l contour elevation. This is accomplished by calculating the mean vertical profile

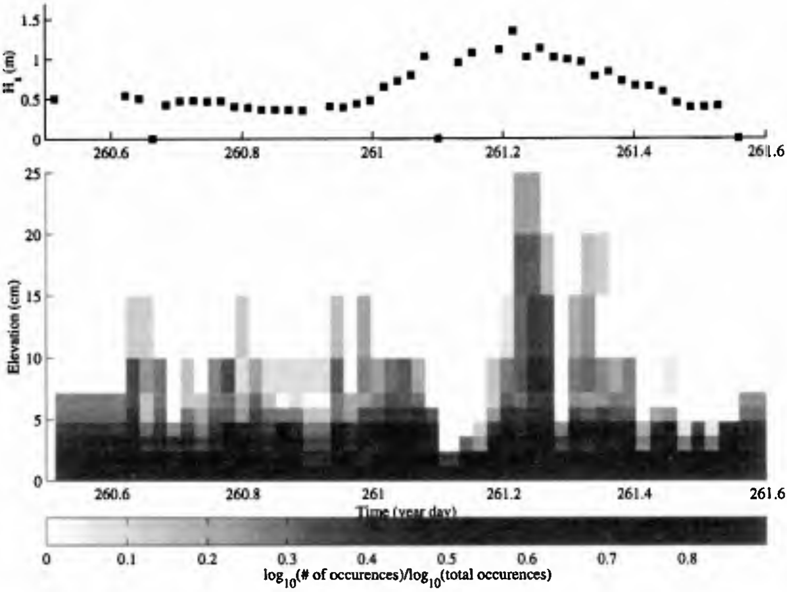

Figure 4: The significant wave height (top), and log_{10} of the fraction of events in each histogram bin. Note that an intensity corresponding to a value of 1 would indicate 100% of the events would be in the single bin and an intensity corresponding to a value of .5 indicates 50% of the events would be contained in the single histogram bin.

of the observations for the set of observations within each histogram bin. The confidence of each profile will be directly dependent on the number of samples in each histogram bin. The sample shows a significant deviation between the complete record mean profile and the mean profile within the individual bins at the higher contour elevations (see the mean profiles for the histogram bins greater than 5 cm from the bed). This sample shows the mean concentration profile of the record is strongly biased towards the large percentage of occurrences when insignificant levels of sediment are in suspension.

The histogram for each of the records over the 24 hour period are shown in Figure 4. In general, as the significant wave height increases larger suspension excursions are reached. Under the storm peak, the sediment suspension reaches elevations of at least 25 cm above the bed.

For this investigation, a displacement thickness was chosen as the characteristic length scale of the WBBL. The displacement WBBL thickness, δ, was estimated following an empirical formulation outlined in Nielsen (1992),

$$\delta_w = c_d A \tag{1}$$

where $A(=u_o/\omega)$ is the wave orbital excursion amplitude and the drag coefficient, c_d, is defined with (Swart, 1974)

$$c_d = 0.5e^{5.2r^{0.2}-6.0}. \tag{2}$$

This formulation is based on numerous laboratory experiments and relies on an accurate estimate of the bed geometry. For these observations on a restricted opening beach with normally incident waves, the excursion amplitude is dominated by onshore and offshore motions. The relative roughness, r, was assumed to be a function of the bed geometry and grain roughness (Nielsen, 1992)

$$r = \frac{\frac{8\eta_b^2}{\lambda_b} + 170(\theta_{2.5} - 0.05)^{0.5}}{A} \tag{3}$$

where η_b is the bed form amplitude, λ_b is the bed form wavelength, and $\theta_{2.5}$ is the grain roughness Shields parameter. The bed form amplitude and wave length were quantified with a rotary pencil beam sonar (Hay and Mudge, in preparation). The grain roughness shields parameter is defined with

$$\theta_{2.5} = c_{d_{2.5}}\psi \tag{4}$$

where $c_{d_{2.5}}$ is the grain roughness drag coefficient and ψ is sediment mobility number (Swart, 1974). The grain roughness drag coefficient is defined with

$$c_{d_{2.5}} = \frac{1}{2}e^{5.213(\frac{2.5d_{50}}{A})^{0.194}-5.977} \tag{5}$$

and the mobility number is defined with

$$\psi = \frac{(A\omega)^2}{(s-1)gd_{50}} \tag{6}$$

where d_{50} is the median grain size diameter, ω is the peak frequency, s is the relative sediment density, and g is gravity.

The relative roughness varies over an order of magnitude throughout the experiment, Table 1. There also exists a significant variation in the drag coefficient over the 24 hour period, Figure 5. Prior to the storm, the existing bed geometry and low excursion amplitude yields a large relative roughness. As the wave height increases and wave period decreases, the orbital excursion amplitude increases and the bed begins to plane off resulting in a significant decrease in the drag coefficient. The resulting boundary layer thickness increases by a factor of 2 as the storm intensity increases.

The mean vertical length-scale, L_z,was estimated by calculating the mean of the individual event vertical intrusion heights in each record. Individual events were identified by searching for local maxima greater than 2 range bins (1.2 cm) away from the bed of the 1 g/l contour elevation sampled at 8 Hz and smoothed with a 1/2 second boxcar win-

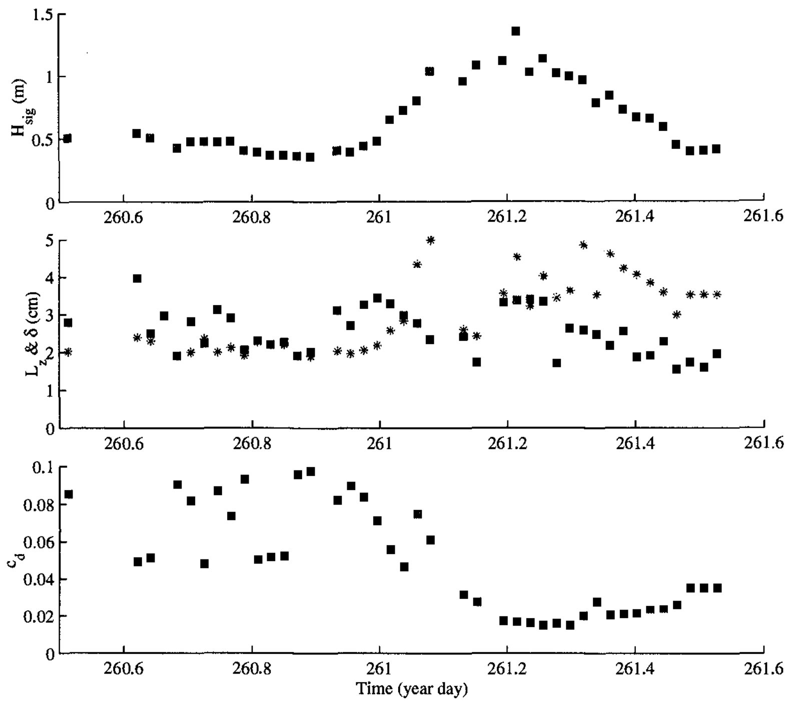

Figure 5: The significant wave height (top), mean vertical excursion length scale, L_z, (middle panel), estimated displacement WBBL thickness, δ, (middle panel), and the drag coefficient, c_d, (bottom) as a function of time.

dow. The darkened circles in Figure 1 show the time and elevation of the defined events for this example. The mean vertical intrusion height is compared with the estimated displacement WBBL thickness in Figure 5. Unlike the extreme event envelope (Figure 4), the mean vertical excursion length scale remains remarkably uniform over the period. The mean vertical length scale remains relatively uniform because the statistic is dominated by the relatively high number of small events. The rms deviation between the mean vertical length scale and estimated displacement WBBL thickness is 1.2 cm over the 24 hour record.

Summary

These results showed that while the relatively infrequent large suspension events increase with increasing storm intensity, the mean suspension event length scale shows little variability. The estimated displacement WBBL thickness increased with increasing storm intensity. The rms deviation between the estimated boundary layer thickness and the mean

	Bed Forms	η_b cm	λ_b cm	A cm	r
A	irregular	3	13	20-50	.38-.16
B	cross	2-4	50	60-80	.28-.08
C	large	3	100	90-270	.07-.03
D	flat	-	-	200-240	.02
E	linear	3	13	125-225	.07-.04
F	irregular	3	13	20-50	.1

Table 1: The bed form classification, bed form amplitude, η_b, bed form wavelength, λ_b, excursion amplitude, A, and relative roughness, r, for the duration of the storm (A-F). The six intervals are shown in the bottom panel of Figure 2.

length scale of the suspended sediment vertical excursion was 1.2 cm. Further investigations of these observations will include similar evaluations of the horizontal length-scales and temporal evolution of events. Also, vertical lengths scales as measured by 2 other sounders will be compared.

Acknowledgments

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