# Field Observations of Small Scale Sedimentation Processes

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## Abstract

*A series of field experiments have been conducted to investigate small-scale sediment dynamics near the seabed in the nearshore region. The experiments took place at the U.S. Army Corps of Engineers Field Research Facility, in Duck, North Carolina, U.S.A., where the seabed typically consists of fine to medium sized sand. An array of instrumentation was deployed at various locations across the surf zone and nearshore region between depths ranging from 1 to 5 meters. Examples of suspended sediment measurements are presented along with examples of observed bedforms. We observed that the suspension of sand tends to occur at low frequencies that correspond to the time scale of wave groups. Small wave ripples are also found to evolve over similar time scales. We explore the linkages between the suspension of sediment and the evolution of small wave ripples, and show that the size of the ripples plays a significant role in determining the amount and distribution of suspended sediment.*

## Introduction

Small-scale sedimentation processes are responsible for the movement of sediment grains in the coastal zone. We use the term "small-scale" to describe those processes affecting the sediment dynamics and hydrodynamics on spatial scales ranging from the size of the sediment grain up to approximately 1 meter. This range of spatial

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scales typically covers the thickness of the turbulent wave boundary layer, as well as small wave ripples that often are found on the seabed.

A series of field experiments have been conducted to investigate small-scale sediment dynamics near the seabed in the nearshore region. The experiments took place at the U.S. Army Corps of Engineers Field Research Facility, in Duck, North Carolina, U.S.A., where the seabed typically consists of fine to medium sized sand. An array of instrumentation was deployed at various locations across the surf zone and nearshore region between depths ranging from 1 to 5 meters. The instruments measured the local hydrodynamics using a pressure sensor and 3 axis Acoustic Doppler Velocimeter (ADV). The suspended sediment concentration was measured with a three frequency Acoustic Concentration Profiler (ACP), and the local bedforms were measured with a Multi-Transducer Array (MTA). Surficial sediment samples were also obtained at most sites, as well as water temperature, turbidity, and video images when the water wasn't too turbid. A schematic of the instrumentation is shown in Figure 1.

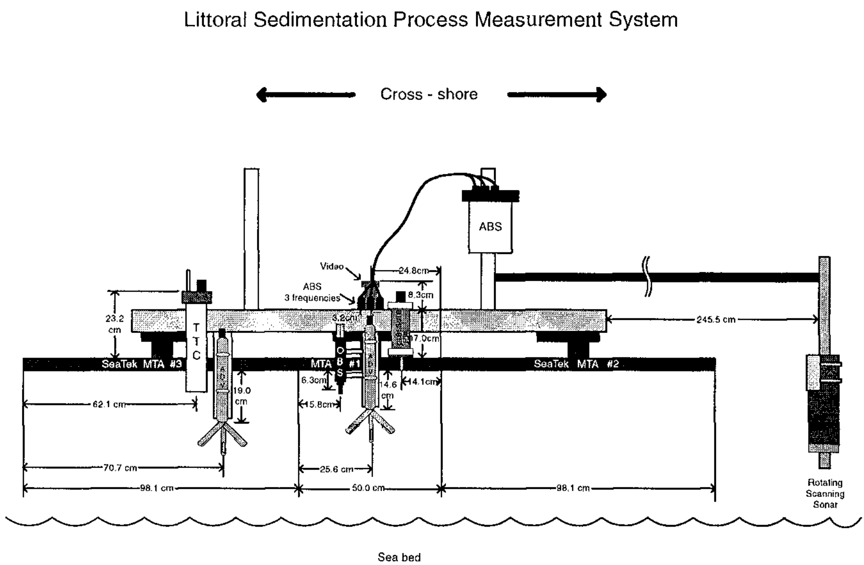


Figure 1: Instrumentation Schematic

The data were obtained over a variety of wave and current conditions, and exhibit high variability in both the suspended sediment concentration and the bedform geometry. This paper will focus on the scales of variability. In particular, we will examine the temporal variability in the concentration of suspended sediment near the seabed, and the variability in the spatial scale of the bedforms.

## Background

In steady, unidirectional flow, suspended sediment flux is calculated at a fixed depth from the product of the water velocity and the suspended sediment concentration. In the presence of waves the concentration of suspended sediment and the velocity of the water are generally not in phase, but a phase relation exists between the two quantities. This results in a component of sediment flux that depends explicitly on the time varying components of velocity and concentration. Several investigators have shown that because of this coherent transport component, significant sediment transport can occur in a direction different from that of the mean water velocity (Jaffe et al., 1985; Hanes, 1988; Vincent et al, 1991). Furthermore, this coherent transport has been shown to be frequency-dependent by using the cospectrum of measured velocities and concentrations (Hanes and Huntley, 1987). In view of the importance of this coherent transport component, accurate modeling of the transport of sediment in the presence of waves requires instantaneous time series of both water velocity and of suspended sediment concentration.

The importance of this intermittent sediment suspension on the time scale of waves has been parameterized for monochromatic waves in the surf zone by use of the Dean number (Dean, 1973).

$$D = \frac{H_b}{wT} \tag{1}$$

In eq. 1, $H_b$ is the breaking wave height, $w$ is the sediment fall velocity, and $T$ is the wave period. For low values of the Dean number, sediment movement is onshore, but at some critical value, the direction becomes offshore. Basically, the parameterization is based upon the assumption that sediment is elevated to some height at the phase corresponding to the passage of the wave crest. The quantity and direction of net sediment transport then depends on the fraction of the suspended sediment which settles before flow reversal occurs - which introduces the importance of the settling velocity of the sediment and the period of oscillation. As an instantaneous predictive model, use of the Dean number is complicated too extensively by the frequency interactions of random seas. As a conceptual model, the Dean number parameterization illustrates the 'memory' or 'history' effect of the sediment suspension process that results in the above mentioned concentration phase lag. It also illustrates some parameters important in its characterization: height of suspension, sediment fall velocity, and wave period.

## Suspended Sediment Observations

Previous research has indicated that significant variation in suspended sediment concentration occurs at frequencies below those of the incident waves, particularly at those frequencies associated with wave groups (Hanes, 1991). More recent work outside the surf zone has verified this result, showing concentration variation at wave group frequencies - even when no infragravity energy was present in the wave power spectrum.

Such a case is shown in figure 2, which shows the frequency spectrum of the concentration time series measured 1 cm above the seabed. Note in this figure the high representation at low frequencies, despite the lack of energy at these frequencies in the bottom velocity spectrum, shown in figure 3. The same study showed that these low-frequency variations in suspended sediment concentration can actually dominate the concentration spectrum (Thosteson, 1997). Moreover, the coherence between the squared magnitude of the bed velocity (chosen for the envelope or group detection properties) and the concentration is very high at these frequencies (as is apparent in figure 2), with the peak in concentration lagging slightly behind the peak in the envelope time series. These results are interpreted, as in the Dean number parameterization, to be a consequence of the history effect of sediment suspension, but on a much longer time scale. Interestingly, it is not difficult to conceptualize additional mechanisms that vary substantially on the time-scales of wave groups and that could contribute to this history effect of sediment suspension. Such mechanisms include variation in turbulence intensity, fluidization and consolidation of sand beds (which could enhance the erosion potential of the bed), bedform geometry, boundary layer stability, etc.

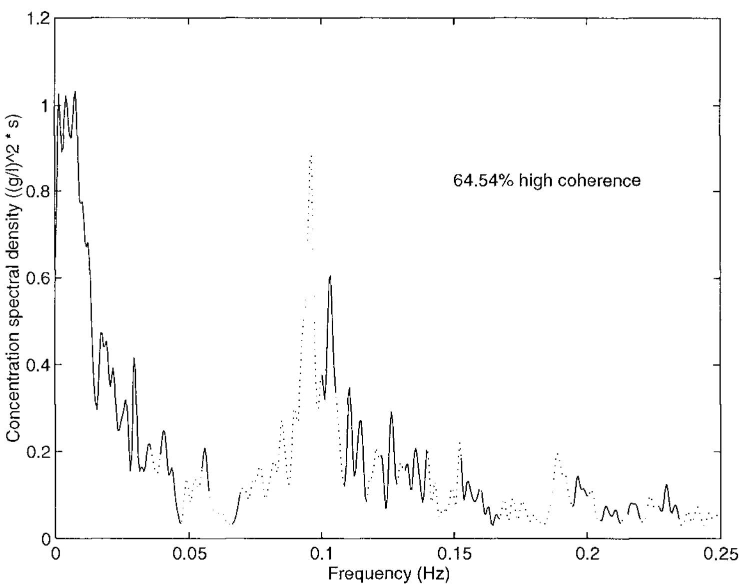


Figure 2: Frequency spectrum of concentration time series measured 1 cm above the bed. Solid line indicates coherence with square of bottom velocity magnitude > 0.60.

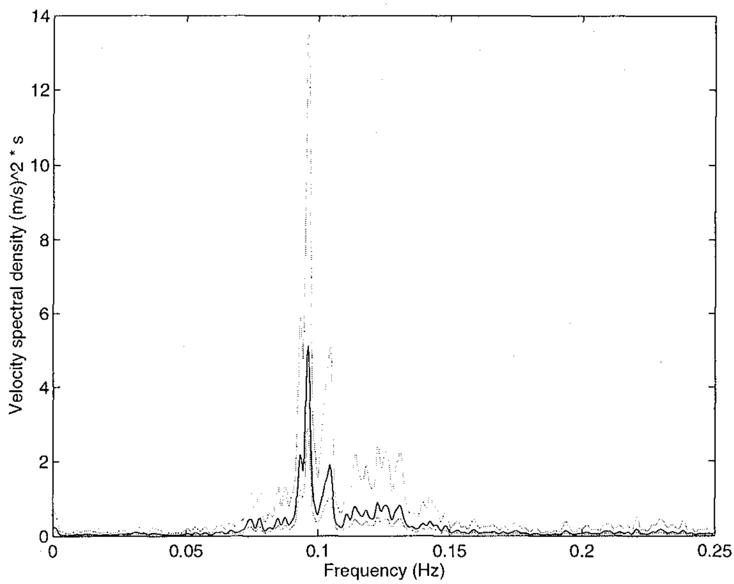


Figure 3: Frequency spectrum of bottom velocity with 80% confidence limits.

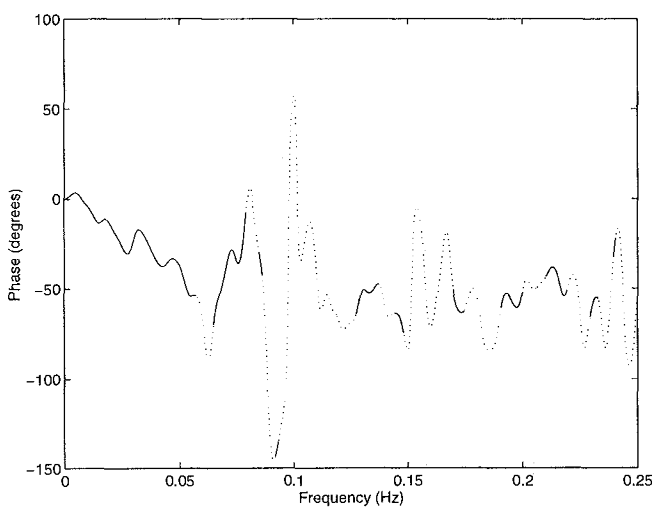


Figure 4: Phase of transfer function between near bed concentration and square of bottom velocity (envelope).

Figure 4 shows the phase of the transfer function between near bed concentration and the square of the bottom velocity (the envelope at low frequencies in absence of infragravity motion). As seen from examination of figure 4, the low-frequency phase of the transfer function could be well approximated by a linear fit. This is significant, because a linear phase response in the frequency domain corresponds to a constant time lag in the time domain.

Bedform Observations

Bedforms consisted mainly of two different types. Wave formed ripples were measured with heights up to 2 cm and lengths from 10 to 15 cm. Mega-ripples, with heights of 5 to 10 cm and lengths of 75 to 150 cm were also measured. Each of these bedform types sometimes occurred alone, and other times both types were superimposed. For example, Figure 5 illustrates the bedforms when both types were present. The center section of the MTA has higher resolution, and is blown up in the lower plot to show the smaller scale bedforms. The lines in this figure represent a sequence of scans (bedform measurement) separated in time by 1 minute; the lines have been displaced vertically by 1 mm in order to better see them. These measurements were obtained outside the surf zone in a depth of 3.9 m with a surficial sand size $D_{50} = .19$ mm, under conditions with $H_{mo} = 0.50$ m, $T_p = 10.7$ sec.

Interestingly, under very similar conditions, but closer to the breaker zone, the smaller scale ripples were not present, as seen in Figure 6. These mega-ripples were observed in a depth of 1.6 m, just outside the surf, with a surficial sand size $D_{50}$=.19 mm, under conditions with $H_{mo} = 0.53$ m, $T_p =$ 9.8 sec. It would appear that the threshold for sheet flow has probably been exceeded in this case.

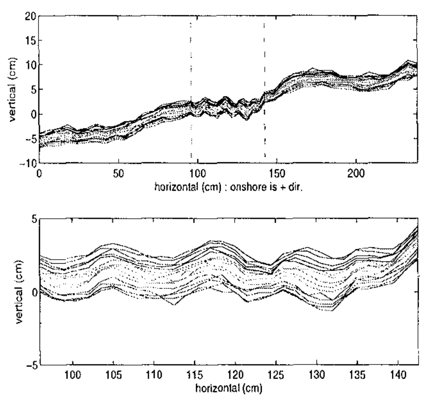


Figure 5: Small and mega-ripples

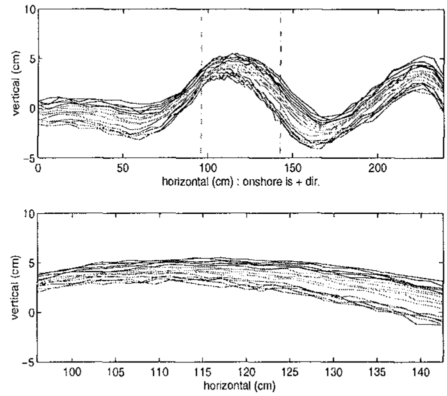


Figure 6: Only mega-ripples

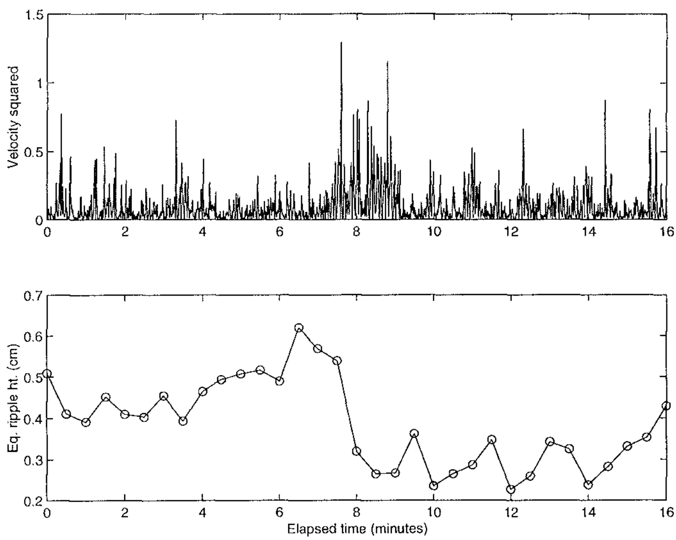


Figure 7: Effect of wave groups on equivalent ripple height

Bedform-suspended sediment interactions

For examination of the temporal variability of the bedforms, the equivalent ripple height is utilized. The equivalent ripple height is defined as the height of a sinusoidal bedform with the same standard deviation as measured by the linear array. The lower plot in Figure 7 shows the variation of the equivalent ripple height for 16 minutes during a run with a significant wave height of 0.55 meters and 9 second waves. In the upper plot of Figure 7 is the velocity magnitude squared, again used to make the passing wave groups apparent. It is interesting to note the decrease in equivalent ripple height each time a group passes, particularly the large group occurring within the 7 to 9 minute range of the plot.

Shown in Figure 8 is the time series of concentration profiles collected during the same 16 minutes presented in Figure 7. The darkest areas in the plot represent the highest concentrations, while the lighter areas show the lowest concentrations. The concentration is seen to increase with passing groups, as discussed previously, but the most dramatic concentration event occurs at nearly the same instant as the reduction in ripple height.

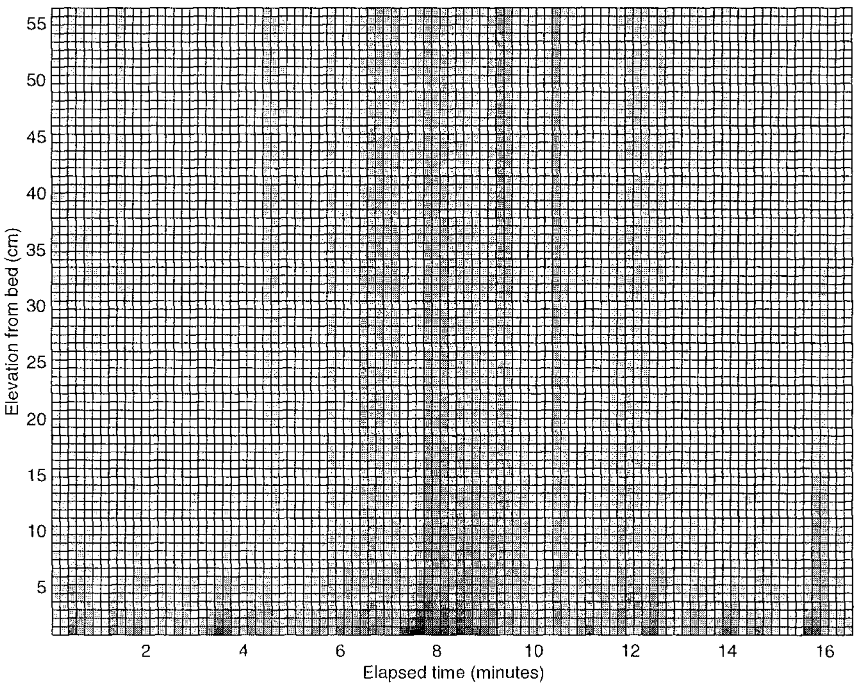

Figure 8: Time series of concentration profiles

## Summary

Suspended sediment concentration has been shown to vary most significantly on the temporal scale of wave groups. Bedforms of various spatial scales and geometries are seen to be similarly dynamic, often reduced in amplitude or wiped clean during wave group passage. In addition, the variability of suspended sediment concentration and bedform geometry are seen to be linked to one another. Continuing and future research of these processes with increasingly more advanced instrumentation, improved methods of data analysis, and measurements higher in resolution will improve our understanding of these processes and their roles in the process of sediment transport.

## Acknowledgements

The authors wish to acknowledge the generous support of the Coastal Sciences Program of the Office of Naval research and would also like to express their appreciation to those at the Field Research Facility in Duck, North Carolina for use of the facilities.

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