

Toward a 3rd Generation Sediment Dynamics Sensing System

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LONG-TERM GOALS

The central goal of this research is a deeper understanding of the dynamic adjustment of mobile sandy sediments to the variable fluid forcing the nearshore zone and inner continental shelf at small (1-cm to 10-m) and intermediate (10-m to 100-m) horizontal scales. The effort is motivated by the dual need to develop more realistic models of fluid-sediment interactions in these environments, and for suitable measurement techniques to make the observations necessary to adequately test the models.

OBJECTIVES

The objective of the proposed project is to advance the state-of-the-art of acoustic remote sensing systems for sediment and fluid dynamics studies in the wave-current bottom boundary layer. The particular focus of this project is the remote (and routine) measurement of bottom stress in energetic combined flows above mobile beds.

APPROACH

The approach involves:

- development of a new multi-frequency, several-mm vertical resolution, pulse-coherent Doppler profiler; and
- laboratory experiments in a particle-laden turbulent wall jet comparing turbulence-resolving measurements made with the new Doppler profiler to those made by Particle Imaging Velocimetry (PIV), for both hydrodynamically smooth and rough walls.

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WORK COMPLETED

Based upon our modeling studies, the principal design considerations for the new system were finalized including the optimal frequency range, and a full set of transducers have been ordered from the manufacturer. After a several-month search for data acquisition and control (DAQ) cards suitable for the project, and discussions with the various manufacturers, the primary DAQ boards were purchased, and programming these DAQ boards has begun.

Len Zedel has continued to develop and refine his model simulating the effects of scatterer advection and turbulent reconfiguration on the phase noise in coherent Doppler systems. We are using the results from the model computations to investigate the statistical properties of the scattered returns and, importantly, to develop and test our ambiguity resolution scheme.

Programming consultant Robert Craig has begun coding the data acquisition system. Electronics consultant Wesley Paul has completed the basic design of the signal conditioning circuitry, and Electronics Technologist Walter Judge has begun its implementation.

We have continued to prepare the acoustics laboratory at Dalhousie for the experiments with the new system. The suspended sediment jet apparatus has been modified to accommodate the PIV system, including in particular the periscope assembly (for ducting the laser beam through the air-water interface into the tank), which has been returned after modification by the manufacturer and set up in the tank with its Nitrogen-gas purge. M.Sc. student Stephanie Moore joined the group in September, and will be carrying out experiments on sound scattering from turbulent suspensions as part her thesis work. Stephanie will be using the new system for her research.

RESULTS

We have been continuing to work with the results obtained in field experiments with the original coherent Doppler profiler (CDP), developed in collaboration with SonTek Inc. These results are highly relevant to the present project, partly because they help lay the foundation for the scientific questions which the new system will address, and partly by guiding the design process.

Former postdoctoral fellow Qingping Zou, now a Lecturer at the University of Plymouth (UK), has been working with CDP data from an experiment carried out at Queensland Beach, Nova Scotia. The focus of this work has been on the vertical structure of the velocity field under waves propagating up a sloping beach. Owing in part to the unique nature of the data set (there have been very few such measurements made in the field), Dr. Zou's work has led to several publications dealing with different aspects of the vertical structure of wave motions over a sloping bed, and to an ongoing collaboration on this topic with colleague Dr. Tony Bowen. These vertical structure publications include the turbulent wave bottom boundary layer (Zou and Hay, 2003); the interior flow outside the wave boundary layer (Zou et al., 2003), and a recently submitted paper on the vertical structure of the wave shear stress (Zou et al, 2005).

Former M.Sc. student John Newgard, now a research assistant at the University of Western Australia, and I have nearly completed a manuscript based on his thesis, which carried on from the Carolyn Smyth's doctoral study of bottom boundary layer turbulence and wave friction factors during the SandyDuck97 field experiment. While Carolyn focused mainly on different rippled bed states, John's

research has specifically addressed the higher energy conditions during which the bed was predominantly flat and sheet flow was likely. A central result from John's work, the wave friction factor, is shown in Figure 1, together with Carolyn's earlier estimates. Also shown in the Figure are the predictions from the different semi-empirical models summarized by Tolman (1994), both for mobile and fixed-grain beds. The data points have been plotted with two values of the parameter Λ , which is related to the fraction of turbulent kinetic energy under the gravity wave peak. The two values, 1.3 and 1.7, are based on two different slopes in for the inertial subrange plotted in log-log form: the $-5/3$ value for the standard Kolmogorov cascade in isotropic turbulence, and the ≈ -1 value obtained by Smyth and Hay (2003) very close to the bed, and attributed by them to anisotropy in the turbulence field close to the bottom boundary.

The results in Figure 1 are encouraging. The data points follow the general trends indicated by the semi-empirical formulae: higher values of f_w for Shields parameters θ less than ≈ 0.8 , when ripples were present, a broad minimum at intermediate values of θ , and then a trend toward higher friction factors as the Shields parameter increases beyond unity and the grain-grain interactions associated with sheet flow become an increasingly important component of the vertical momentum flux. The absolute magnitudes of the f_w estimates are within the range of the predicted values.

IMPACT/APPLICATIONS

The significance of this project resides in the fact that bottom stress over mobile beds is not well-constrained for the range of combined wave-current forcing conditions encountered in nearshore and continental shelf environments. Consequently, neither wave height decay across the shelf, nor wave-forced circulation in the nearshore and inner shelf, nor nearshore morphology change can be predicted by existing models with a high degree of confidence. New sensor systems, capable of fully resolving the vertical structure within and above the wave boundary layer, are needed to fill this knowledge gap.

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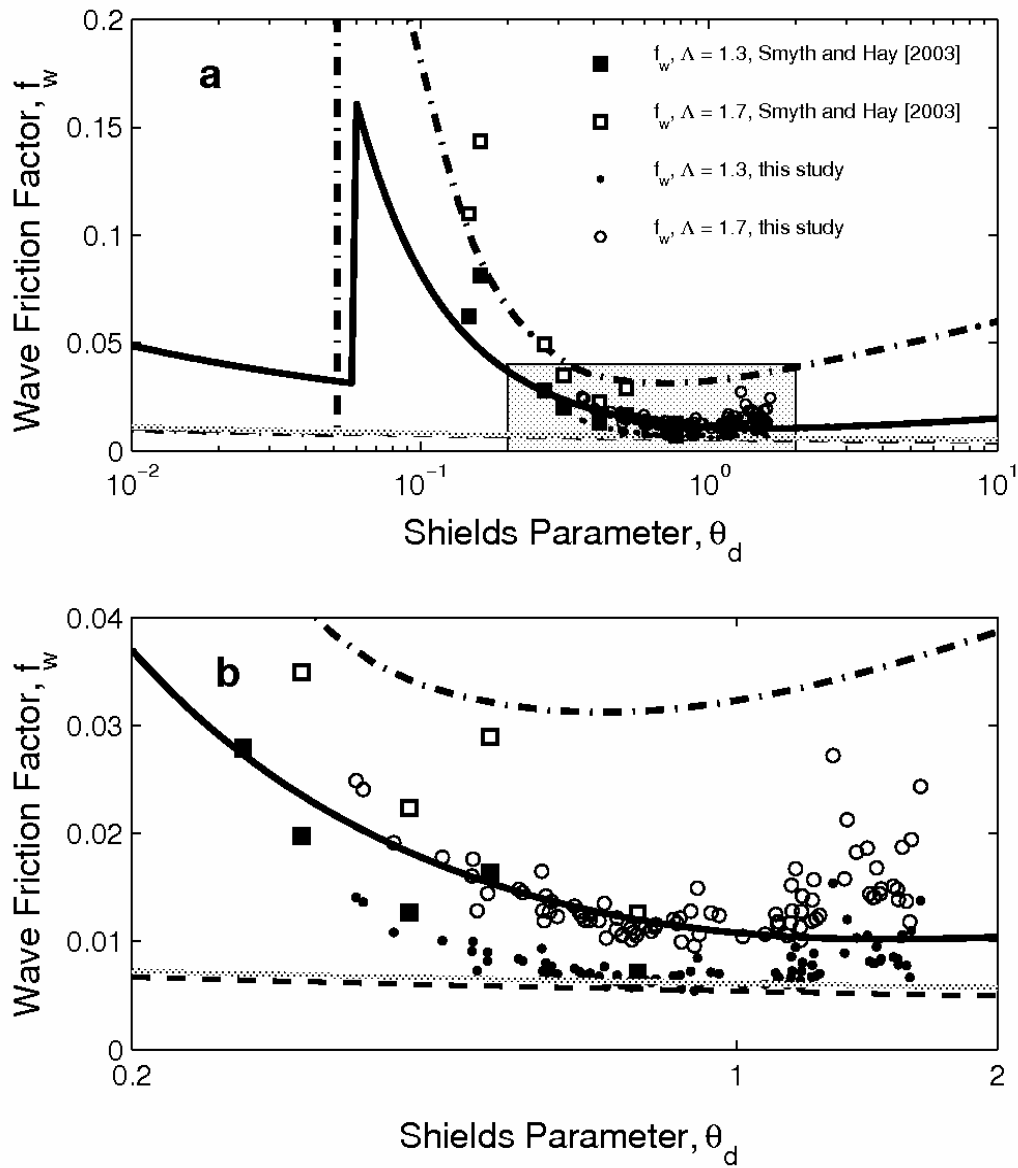


Figure 1. Wave friction factors estimated from vertical turbulence intensity measurements in the wave bottom boundary layer above rippled and non-rippled sand beds. The data points are from Newgard and Hay (in prep) indicated by “this study”, and from Smyth and Hay (2003). The curves are: Tolman (1994, solid); Grant and Madsen(1982, dash-dot); flat bed, sand grain roughness (dashed); flat bed, fixed grains (Swart, 1974, grey).