Acoustical Studies of Sediment Dynamics in the Surf Zone: SandyDuck'97

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LONG-TERM GOALS

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

OBJECTIVES

The primary objectives of this project are: (1) to study the role of bedforms of different characteristic spatial pattern and scale in the local sediment flux and momentum balances, and (2) to investigate bedform genesis, growth, migration, and decay in relation to the fluid forcing conditions and predicted sediment transport rates. Of particular interest are the relationships between sediment fluxes, bedform properties, and asymmetries in the fluid motions. A key initial objective was to obtain a comprehensive set of measurements of bed adjustment through time, as a function of cross-shore position, and over a period of several months. This data set was obtained in SandyDuck, and is providing a basis for determining cross-shore differences in response synoptically, and for differences in the response trajectories through time and between forcing events, over a suitably wide range of conditions.

APPROACH

The approach for the SandyDuck97 experiment involved an array of state-of-the-art underwater acoustic sensors for high-resolution measurements of fluid velocity and sediment concentration profiles through the wave-current boundary layer, as well as of the seabed topography over horizontal scales up to 10m The array comprised 5 instrumented frames deployed along a cross-shore line and along an alongshore line with 50-100 spacing between adjacent frames. Rotary fan and pencil-beam imaging sonars were mounted on each frame. Coherent Doppler Profiler (CDP) systems, augmented by Sontek ADV-O point velocimeters, were mounted on two of the frames. Ancillary sensors on each frame included pressure and temperature sensors, and electromagnetic flowmeters, and 2-axis tilt sensors.

The CDP system (Zedel and Hay, 1999) was developed collaboratively with Dr. Len Zedel (Memorial University), with funds from ONR. The rotary sonar system operates in master/slave mode, with custom electronics developed at Dalhousie prior to SandyDuck, in order that data from a number (up to

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8) different heads may be acquired simultaneously. The data acquisition and control system is PC- and PC-104-based, with multiple surface and underwater data acquisition and control nodes operating time-synchronously in a multi-tasking UNIX-like environment on a combination ethernet/ ARCnet network. Technical support for the system is provided by Wes Paul (electronics and acoustics technologist) and Dr. Robert Craig (data acquisition and control software). The em flowmeters and pressure/temperature measurements in SandyDuck were made by colleague Dr. Tony Bowen (Dalhousie University), as part of a separately-funded collaborative research project. David Hazen (electronics engineer) and Walter Judge (electronics technologist) provided additional technical support.

The data volume collected with these systems can be large, and the processing requirements significant. A reasonably powerful acoustic data processing capability has developed incrementally over the last 2-3 year. The system currently comprises 6 Unix workstations and about 200 Gbytes of disk space. Research Assistant Todd Mudge is responsible for the operation of the system, in addition to assisting with the data analysis.

Postdoctoral fellow Dr. Qingping Zou is participating in the analysis of the CDP data, and carrying out theoretical analyses of the hydrodynamics. Dr. Diane Foster (Ohio State University) is collaborating with us on bottom boundary layer dynamics. Doctoral student Carolyn Smyth is playing a leading role is the analysis of the CDP data. Doctoral student Phil MacAulay is using acoustic images of the space-time structure of suspension for his thesis. Dr. J. C. Doering and his students are working with the ADV data. Other collaborations include Dr. Rebecca Beavers (University of North Carolina) and Dr. Peter Howd (University of South Florida), on sediment fabric, and Dr. Tom Lippmann (Ohio State University) on processes related to wave breaking.

WORK COMPLETED

During SandyDuck approximately 250 GBytes of high-quality acoustic data were acquired continuously over a 77-day period from late August to early November. These data have been fully quality controlled, and the data products needed for inter-relating the measurements obtained with the different sensors have been generated. The data set is formed the basis of Rachel Speller's Honours B.Sc. thesis, completed last term, and Carolyn Smyth's doctoral thesis,which will be submitted in the next several months. Several manuscripts are in preparation, some based upon these thesis projects, others based upon work by other members of the group, including Daniel Petrie (megaripple characterization and migration) and Todd Mudge (cross-ripple characterization and migration).

RESULTS

A major focus of the past year has been the setting up of a data base of bedform types and characteristic scales, based upon the rotary pencil- and fan-beam sonar imagery. Figure 1 shows a summary of bedform type and physical roughness as a function of the incident wave forcing amplitude and cross shore position, for the full period of the experiment.

The data are from 4 instrument frames (designated A, B, C and D) deployed in a cross shore linear array with roughly 50 m spacing between elements, with frame A innermost. Bedform types, identified visually in the fanbeam imagery, are shown in Figure 1a for frame C superimposed upon the incident wave orbital velocity amplitude. The bedform types shown are: irregular ripples, cross ripples, linear transition ripples, and flat bed. These types do not represent the full range of types observed (lunate megaripples, for example, are omitted), in order not to complicate the Figure. The time series demonstrates the tendency for these bedform types to occur repeatably: that is, to occur in order of increasing wave forcing in the sequence irregular-cross-linear transition-flat during storm growth, and in the reverse sequence during storm decay, and within reasonably well-defined and for the most part distinct ranges of the wave orbital velocity. There are exceptions, some of which may be due to the longshore current which is not considered here. On the whole, however, the pattern is quite consistent and similar to earlier, less extensive observations (Hay and Wilson, 1994; Crawford and Hay, 2000).

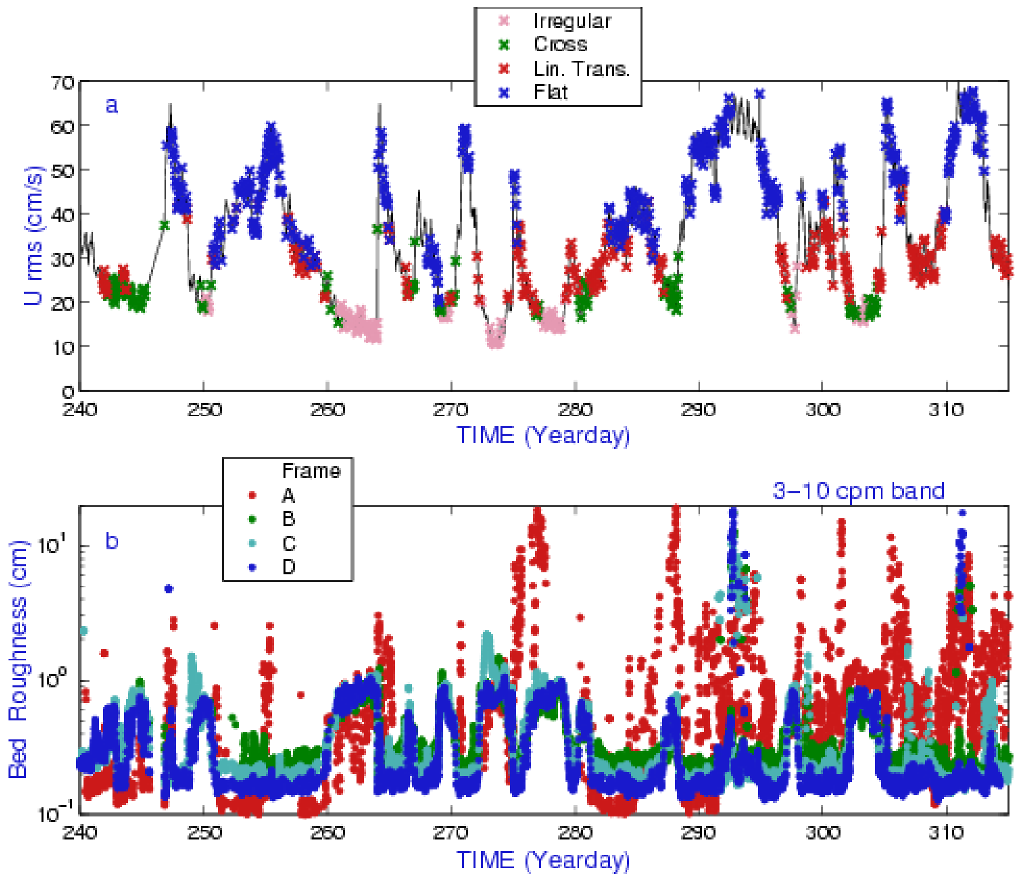

Figure 1: Time of bedform type and physical roughness during SandyDuck97. (a) Root-mean square wave orbital velocity (solid line) and bedform type (colored x's) at instrument frame C. (b) Physical roughness in the 3-10 cpm band as a function of cross shore position (from frame A closest to shore to frame D, farthest).

Figure 1b shows the rms bed elevations in the 3-10cpm reciprocal spatial wavelength band, determined from cross shore bed profiles extracted from rotary pencilbeam sonars, at 4 cross shore positions. The three outermost locations (B, C and D) are remarkably coherent, and exhibit physically reasonable tendencies for decreased roughness during storm events (consistent with the occurrence of linear transition ripples and flat bed identified in the fanbeam imagery, Figure 1a), and for roughness to decrease on average with increasing distance offshore. There are significant exceptions such as on Yeardays 293-294 and 311 when atypically large roughnesses were observed at frames C and D. The physical roughness at the innermost location, frame A, is clearly very different from the others, often exhibiting the lowest roughness of the 4 locations during periods of weaker forcing (in contrast with the tendency for roughness among the other locations to decrease offshore), and at other times exhibiting the highest roughness values both during periods of relatively intense and weak forcing.

The general conclusion to be drawn from the results in Figure 1 is that there is a gratifying correspondence between the fluid forcing amplitude in the incident wave band during successive storm events, and changes in local bed state identified through the rotary fanbeam imagery, and spatially coherent cross shore changes in the physical roughness of the bed determined from the rotary pencil beam bed elevation profiles. The fact that there are also exceptions to this general picture which are temporally coherent (and thus unlike random noise) is also interesting.

IMPACT

In the SandyDuck'97 experiment, we demonstrated that it is possible to make long-term observations of nearshore fluid-sediment interactions with sophisticated measurement systems on a continuous basis at a number of cross-shore locations. The data set is of high quality and, because of the combination of coherent Doppler profilers, 3-dimensional seabed imaging systems, and the 3-month's duration, it is also unusually comprehensive. In addition, the successful performance of the acoustic remote sensing array throughout SandyDuck for a wide range of surf zone conditions opens up a variety of new possibilities for these kinds of instruments in future nearshore dynamics experiments.

During the next several years, we anticipate that comparisons of the SandyDuck data with model predictions will yield significant insights into mobile bed dynamics in the nearshore zone, and improved parameterizations for use in nearshore sediment- and hydro-dynamic models. The results presented here underscore the importance of linkages between the small-scale sediment dynamic response and nonlinearities in the fluid motions.

TRANSITIONS

Numbers of groups world-wide are making use of our advances in the use of acoustics for the sediment transport studies, in particular the introduction of rotary imaging sonars for bedform measurements (see Hay and Wilson, 1994).

RELATED PROJECTS

A significant benefit to this project was provided by a grant from the Natural Sciences and Engineering Research Council (NSERC) of Canada to Dr. Alex Hay (Principal Investigator), and Co-Investigators: Dr. Tony Bowen (Dalhousie University), Dr. J. C. Doering (University of Manitoba) and Dr. Len Zedel (Memorial University of Newfoundland), which covered most of our field costs during the SandyDuck'97 experiment.

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