Sand Ripple Dynamics on the Inner Shelf

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LONG-TERM GOALS

To explain the genesis, dynamics, morphology, and evolution of bedforms found in sandy inner-shelf environments, with emphasis on those bedforms that affect the penetration of sound into the seabed.

OBJECTIVES

We seek to improve our understanding of the relationships between hydrodynamics and sediment motion near the seabed, as well as develop models for nearshore sediment transport derived from our understanding of the relevant physical processes. This requires coupling between hydrodynamic forcing, bedform response and feedback, bedload sediment transport response, and the suspended sediment response.

APPROACH

We use a combination of field observations, laboratory experiments, and numerical modeling to determine the relationships between ripple morphology, wave and current conditions, and sediment characteristics.

WORK COMPLETED

Laboratory experiments studying ripples formed under combined waves and currents were conducted in the large flume in Tsukuba, Japan, in January 2005. We developed an oscillating plate system and installed it in the flume in Japan to produce non-collinear currents and oscillating flows. The four-meter width of the flume allowed us to create combined wave-current flows on the same scale as those that produce bedforms in the natural environment. A manuscript analyzing the results has been completed and submitted to a peer-reviewed journal.

Two field surveys were completed as part of the SAX04/Ripples DRI experiment near Fort Walton Beach, Florida in the fall of 2004. The goal of our component of the field experiment was to document

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the spatial distribution of bedforms and sediment size. Observations were collected in a square region between 5 and 20 meters depth surrounding the SAX04 experiment site, and also along a cross-shore transect extending to approximately 50 meters depth. These data have been analyzed, and a technical data report is in USGS internal review.

RESULTS

***Laboratory experiment* --** (PIs: Rubin and Lacy)

The laboratory experiments comprised twenty runs of approximately 40 minute duration with varying wave-current conditions. Current velocities ranged from 0 to 26 cm/s, maximum oscillatory velocities ranged from 16 to 40 cm/s, oscillation period was 8 or 12 s, and the angle between waves and currents was 45°, 60°, or 90°. Median sediment grain diameter was 0.27 mm. An instrumented frame mounted on the oscillating tray held two acoustic Doppler velocimeters (ADV) to measure tray motions and current velocities at 6 and 16 cm above the bed, two imaging sonars to monitor bedform evolution, and an Acoustic Backscatter Senor (ABS) to measure profiles of suspended sediment concentration (Figure 1). After each run the bed test-section was photographed and bedform height and wavelength were measured manually. The bedforms varied from linear ripples to strongly three-dimensional structures.

Data analysis in FY06 focused on developing methods for extracting ripple wavelength and crest orientations from the sonar images using 2D Fourier transforms (FFTs), and applying them to the flume data. Based on the sonar results as well as observations during the experiments we have prepared a manuscript describing bedform categories, ripple dimensions, orientation, and evolution produced by combined wave-current flows which has been submitted to JGR-Oceans.

The response of the ripple wavelength to wave energy in the experiments is generally consistent with published predictors of wave ripples. In addition, wavelength decreased with increasing current strength. Three-dimensionality, based on the circular variance of the crest orientations from the FFTs, increased with wave orbital diameter d_o and with ratio of current to wave energy.

Maximum gross bedform normal transport (Rubin and Hunter, 1987) and wave directions are equally good predictors of crest orientation for this data, and are much better predictors than the directions of current or maximum wave-current bed shear stress (Figure 2). The distribution of crest orientations was determined from averaged FFT results from the two sonars to minimize bias due to beam direction. A dominant orientation was determined for each peak in the distribution.

Experimental runs started from a flat bed. Ripple wavelength computed from the sonar data evolved as an exponential function of number of wave periods after an initial period (5-10 minutes) of no detectable growth. This no-growth period may correspond to initial development of rolling-grain ripples. The typical time for evolution to 90% of the final wave number was approximately 120 wave periods.

The ABS data show that time-averaged SSC increases due to increased bed roughness as ripples evolve (Figure 3). Using these data, we plan to investigate variation in suspended sediment concentration (SSC) and suspended sediment flux with bedform evolution. The position of the SSC profiles relative to evolving bedform troughs and crests can be determined from the sonar images of bedforms, and will be used to investigate the spatial variability in near-bed SSC created by the bedforms.

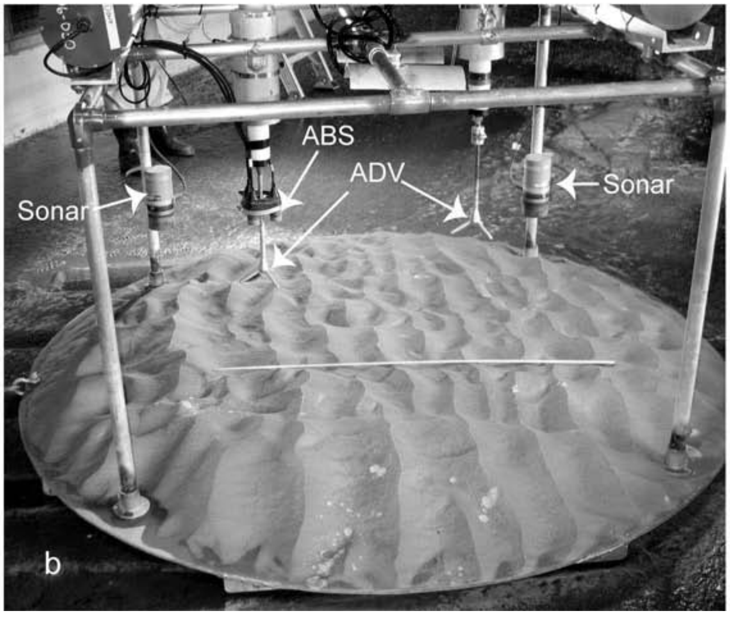
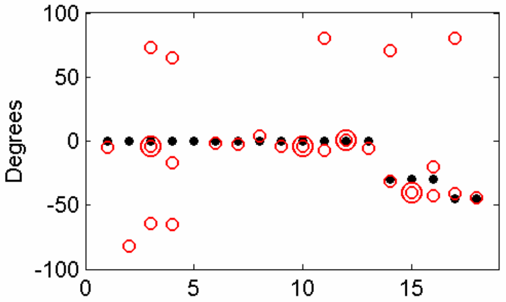
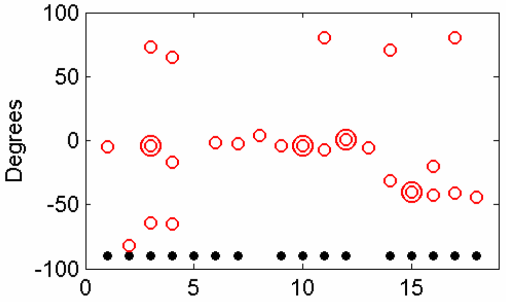


Figure 1: Photographs of experimental setup: a) flume with oscillating plate, b) oscillating plate showing position of instrumentation, at the end of a run with oscillation excursion of 60 cm and current of 12 cm/s.

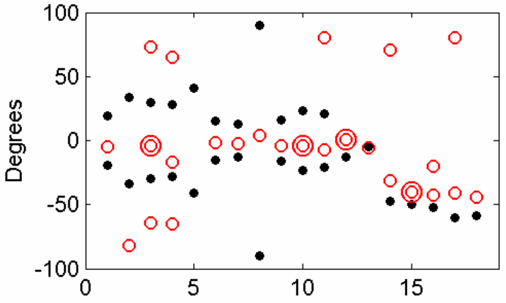
a) Waves



b) Current



c) Max. inst. τ_b



d) MGBNT

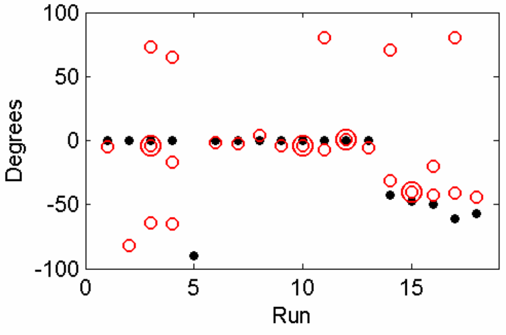


Figure 2. Predicted (black filled circles) vs. sonar-derived dominant crest orientations (red open circles) for 18 runs (no sonar data for run 5 (62-1)). Double red circles indicate largest of multiple peaks for a given run. Predictions based on direction of a) waves, b) current, c) maximum instantaneous bed shear stress, and d) maximum gross bed-normal transport.

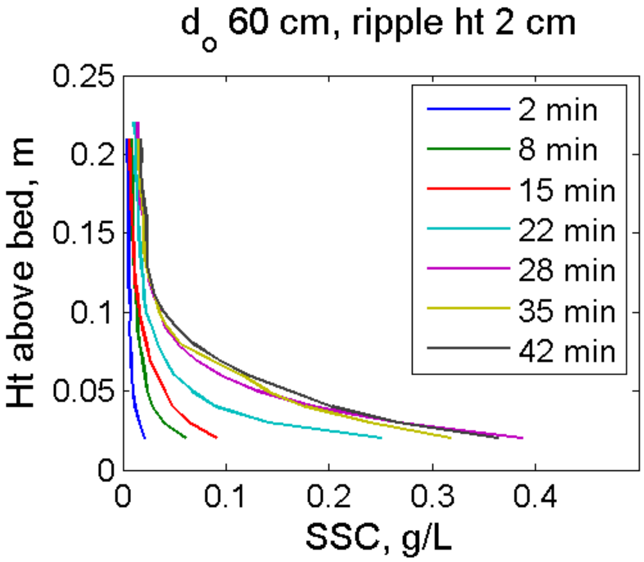


Figure 3: Three-minute averaged suspended sediment concentration measured by the ABS during a run with d_o of 60 cm, current speed of 6 cm/s, and wave-current angle of 90º. Bed was flat initially; final ripples height was 2 cm.

In FY06 J. Lacy met twice with Oliver Fringer and YiJu Chou of Stanford University to explain our experimental results and discuss their modeling approach. We also provided data to Brett Webb and Don Slinn at the University of Florida.

J. Lacy presented results from the flume experiments at the AGU Ocean Sciences Meeting (Honolulu, HI) and in the Environmental Fluid Mechanics and Hydrology Seminar Series at Stanford University in February 2006.

Field observations (SAX04) -- PI: Hanes

A tripod supporting a combination of acoustical and optical instruments powered and controlled through a single cable using network communication protocols was designed and built in collaboration with Monterey Bay Aquarium Research Institute (MBARI) to obtain hydrodynamic and seabed measurements (Fig. 4). Figure 5 shows the bed sediment camera system used to characterize the surficial sediment. Figure 6 illustrates a typical scanning sonar image from which ripple wavelength and orientation are determined.

The tripod was deployed from the *R/V Pelican* at 49 and 63 distinct locations for Cruises I (September 25-28, 2004) and II (November 7-10, 2004), respectively. Sea bed conditions during the field campaign were heavily influenced by Hurricane Ivan, which passed through the region approximately one week prior to our first cruise. The inner shelf exhibited patches of fine sediments and highly variable ripple morphology. The mid-shelf contained primarily two-dimensional large wave ripples that were probably formed in medium to coarse sand and shell during Hurricane Ivan. The presence of similar ripples on the mid-shelf during the two cruises suggests that bedform decay in this region is slow due to the low incidence of significant hydrodynamic forcing at these depths. In contrast, the evolution of ripples on the inner shelf between the two cruises indicates that typical storm conditions are sufficient to reorganize the seabed in shallow water. Figure 7 summarizes the data set of ripple lengths and orientations.

Bed sediment grain size varied significantly in space. Figure 8 shows examples of two end members of surficial sediment size, ranging from fine mud to coarse, broken shell and coral. Overall, grain size increased with distance offshore (or depth) (Figure 9). This observed tendency is opposite to the typical situation of sediment grain size decreasing with distance from shore. We anticipate that the spatial variation in sediment size and type has a significant influence on ripple morphology.

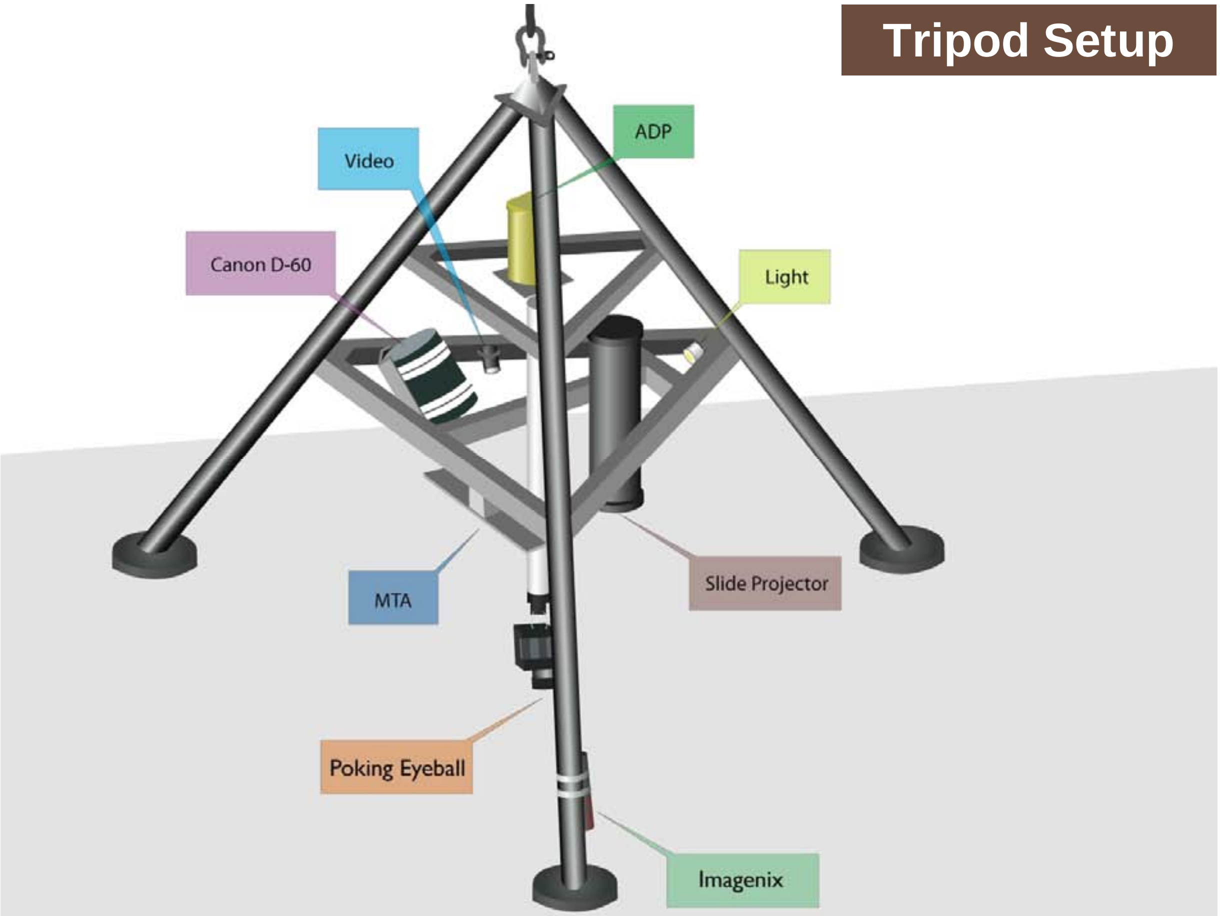
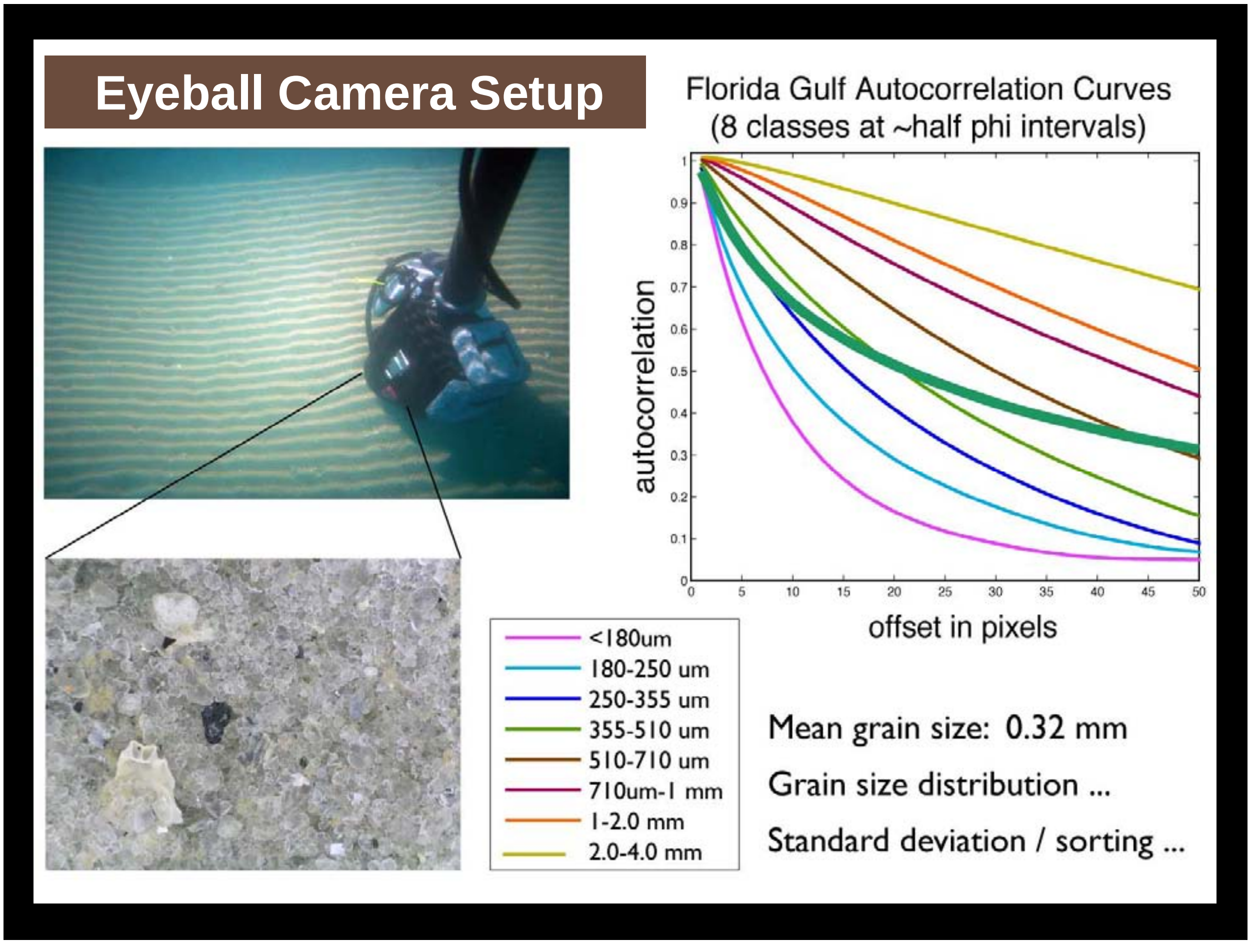


Figure 4: Schematic of tripod and instrumentation used to characterize the small-scale morphology and sediment characteristics of the seabed.



Eyeball Camera Setup

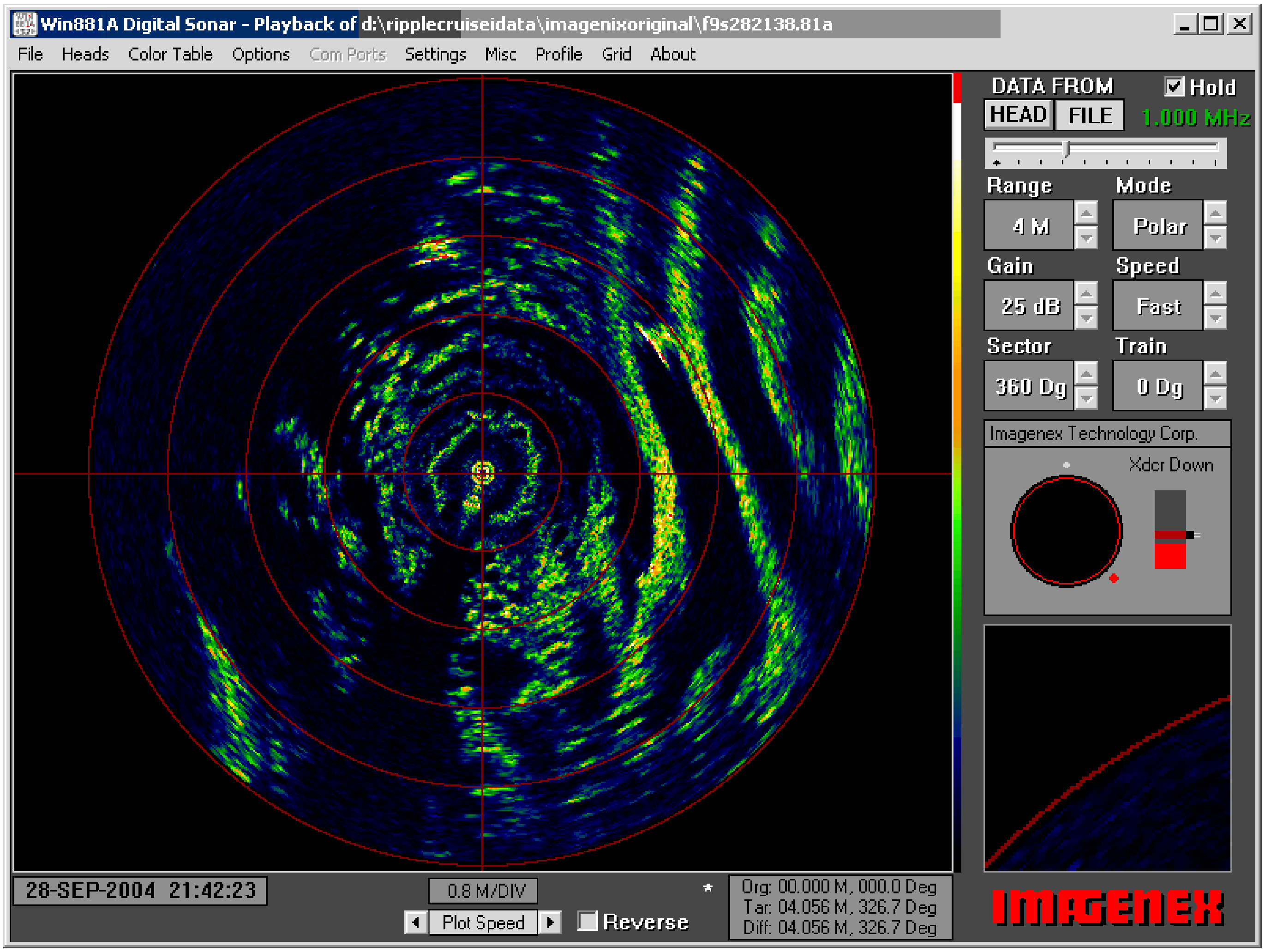
Florida Gulf Autocorrelation Curves
(8 classes at ~half phi intervals)

Mean grain size: 0.32 mm

Grain size distribution ...

Standard deviation / sorting ...

Figure 5: The bed sediment camera obtains a high resolution digital image of the seabed sediment and uses a correlation analysis technique to estimate the mean sediment grain size.



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1.000 MHz
Range: 4 M
Mode: Polar
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Speed: Fast
Sector: 360 Dg
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Xdcr Down
28-SEP-2004 21:42:23
0.8 M/DIV
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Org: 00.000 M, 000.0 Deg
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Figure 6: Rotating scanning sonar image of the seabed from approximately 40 m depth off Fort Walton Beach, FL after the passage of Hurricane Ivan in September, 2004.

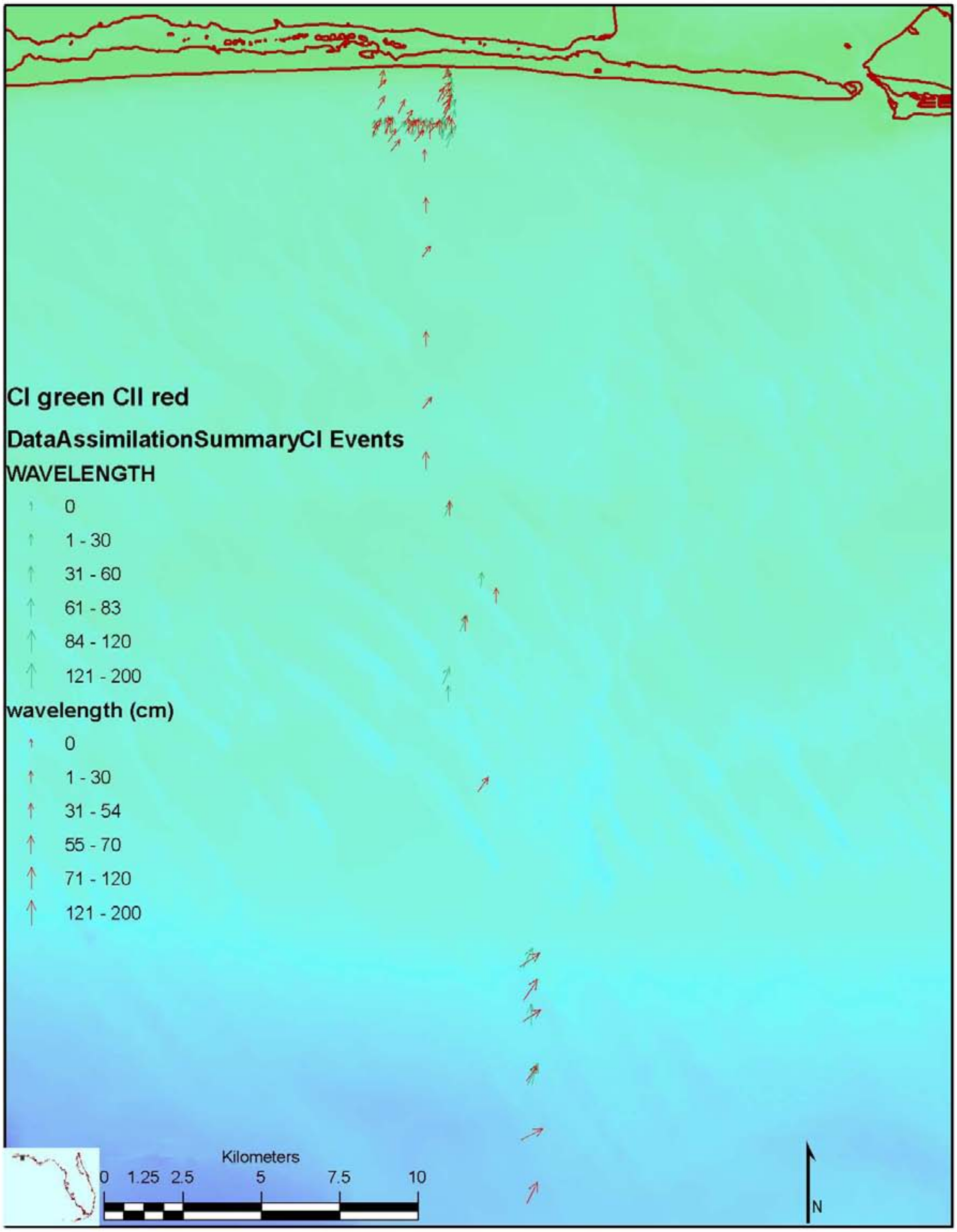

Figure 7: Summary of ripple wavelength and orientation across the continental shelf following hurricane Ivan. Cruise I: September 25-28; Cruise II: November 7-10, 2004.

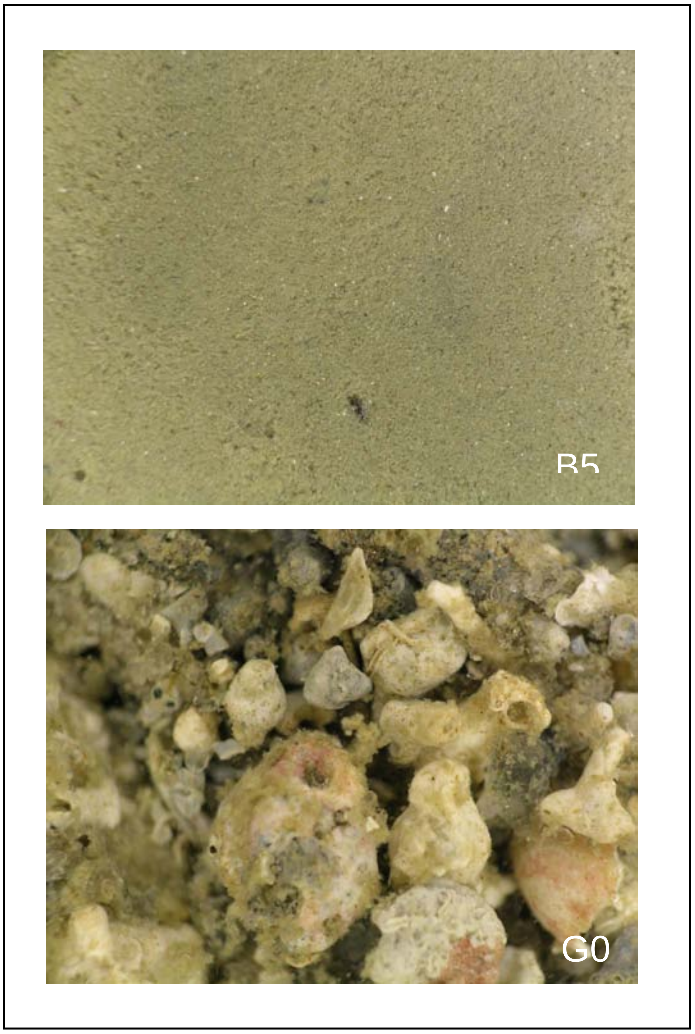

Figure 8: Examples of the variability in bed sediment grain size observed during the SAX04 experiment (same camera and settings).

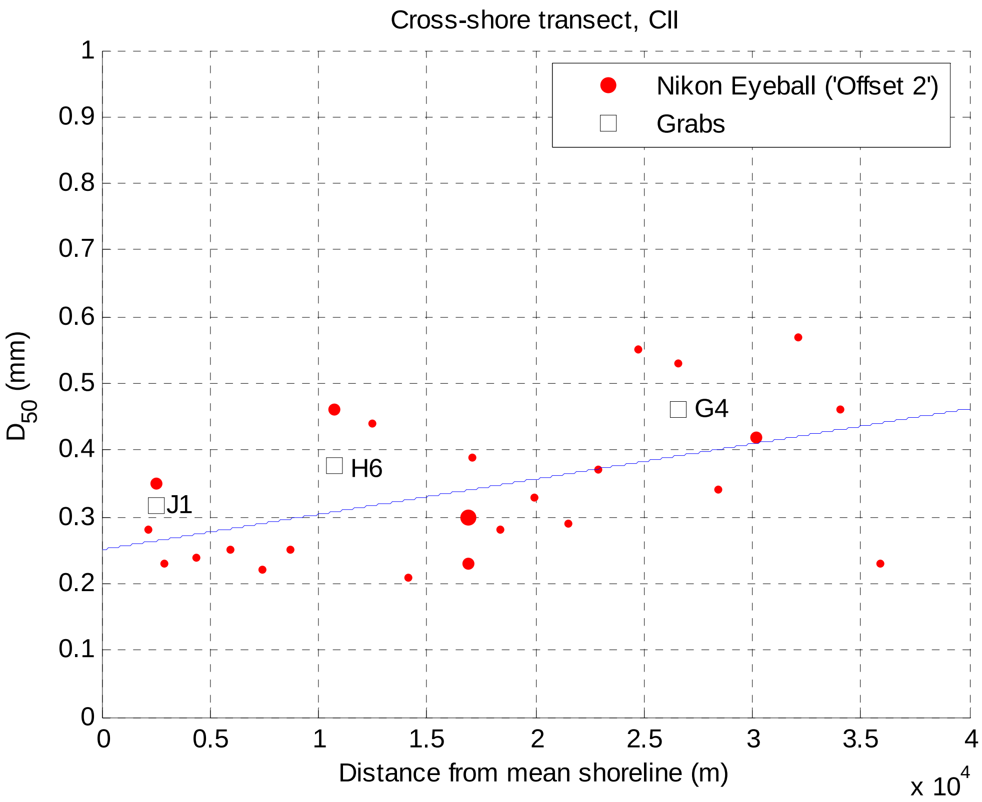

Figure 9: Surficial sediment size observed in the SAX04 experiment exhibit a general coarsening with distance offshore (and depth). Data are from Cruise II. The size of the red dot indicates the quality of the image used to estimate grain size, with larger dots corresponding to higher quality.

IMPACT/APPLICATION

The flume experiments are the second laboratory investigation to be conducted of ripples formed by non-collinear waves and currents, and the first such experiments that at are at full scale (i.e. realistic wave periods and wave excursions), and that document ripple evolution. The results provide an important contribution to understanding the types, dimensions, and orientation of ripples produced by combined flows, and to the development of empirical models relating ripple morphology to hydrodynamic conditions and grain size. In addition, the flume experiments provide calibration data for the development of process-based numerical models of ripple evolution, which are needed to advance understanding of the physical processes governing ripple evolution and morphology.

The field observations have significant and far-reaching implications. First, the observation of large wave ripples across the shelf following Hurricane Ivan suggests that major storms mobilize sediment across the entire continental shelf, therefore providing the potential to redistribute sediment both horizontally and vertically, and to evolve the submerged shelf morphology over century and longer time scales. Second, the observation of coarsening grain size offshore raises important questions regarding the origin of these shelf sediments and their subsequent history. This finding also has practical importance in terms of offshore mineral resources.

RELATED PROJECTS

This project is closely related to the USGS project entitled: Coastal Evolution: Process-based, Multi-scale Modeling. In this project our work on bedforms under waves and currents will be extended to a high energy region in the San Francisco Bight, where large waves interact with strong tidal currents and ample sediment to produce an extremely wide range of bedform morphologies and dynamics.

Work described in this report involves active collaboration with the following research groups: Slinn, Hsu, Fringer, Traykovski, Wiberg, Ikeda, and Delft Hydraulics.

REFERENCES

Rubin, D.M., and R.E. Hunter, 1987. Bedform alignment in directionally-varying flows. *Science*, 237, 276-278.

PUBLICATIONS

Lacy, J. R., Rubin, D. M., Ikeda, H., Mokudai, K., and D. M. Hanes. Bedforms created by simulated waves and currents in a large flume. Submitted to Journal of Geophysical Research – Oceans.