Measuring the Spatial Distribution of Ripples Using a REMUS AUV

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LONG-TERM GOALS

The long term goal is to develop and apply new technology to make better measurements of the spatial distribution of bedforms during both energetic conditions with ripples that are in equilibrium with forcing and during quiescent conditions where ripples are a product of previous storms.

OBJECTIVES

The specific objectives of this program are

1) to develop the capability in an autonomous underwater vehicle to measure bedform amplitude with resolution of 1 cm in the vertical and several cm in the horizontal direction;

2) to apply this technology in the Ripples DRI program to resolve the along- and across-shelf variations of bedform amplitude and wavelength across the West Florida S helf during varying wave-forcing conditions;

3) to make surveys in the strongly forced inner shelf region near the Martha's Vineyard Coastal Observatory to examine short-term changes in bedforms due to changes in wave forcing and to test the ability of the system to measure topography during energetic conditions.

APPROACH

Observations: This project is part of the Ripples DRI, in which the spatial and temporal variations of the seabed are being examined in a field site on the West Florida shelf. We are using the autonomous underwater vehicle (AUV) REMUS (Figure 1) to make better measurements of the spatial distribution of ripples, both during active conditions as the ripples are modified during energetic sea-states, and during quiescent conditions when the ripples are a product of previous energetic events. The AUV was equipped with a sidescan sonar to measure ripple geometry and a pencil-beam sonar to measure ripple

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14. ABSTRACT
The long term goal is to develop and apply new technology to make better measurements of the spatial distribution of bedforms during both energetic conditions with ripples that are in equilibrium with forcing and during quiescent conditions where ripples are a product of previous storms.

15. SUBJECT TERMS

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height. We also deployed a bottom tripod (Figure 1) with a pencil beam sonar to measure ripple height, a rotary fan beam sonar to image ripple topography, and a ADV to measure wave and current hydrodynamic forcing. Repeat surveys at varying water depths complement the high-resolution measurements at the tripod site, documenting the broader spatial scales of variation of bedform structure.

Modeling: Since equilibrium ripple models are not well suited to predict the geometry of ripples left behind after storms we have been developing a temporal ripple model that accounts for the finite time scales in which ripples adjust to changing forcing conditions. The model is based on a first order differential equation for each ripple spectral component. The solution approaches the equilibrium ripple with inverse exponential time dependence. The time constant in the exponential is defined by the ratio of ripple cross-sectional area to flux rate, thus larger ripples adjust more slowly than small ripples for the same flux rate. At zero flux rates (i.e. stresses below the critical threshold for initiation of motion) the time scale becomes infinitely long and the ripples stop adjusting.

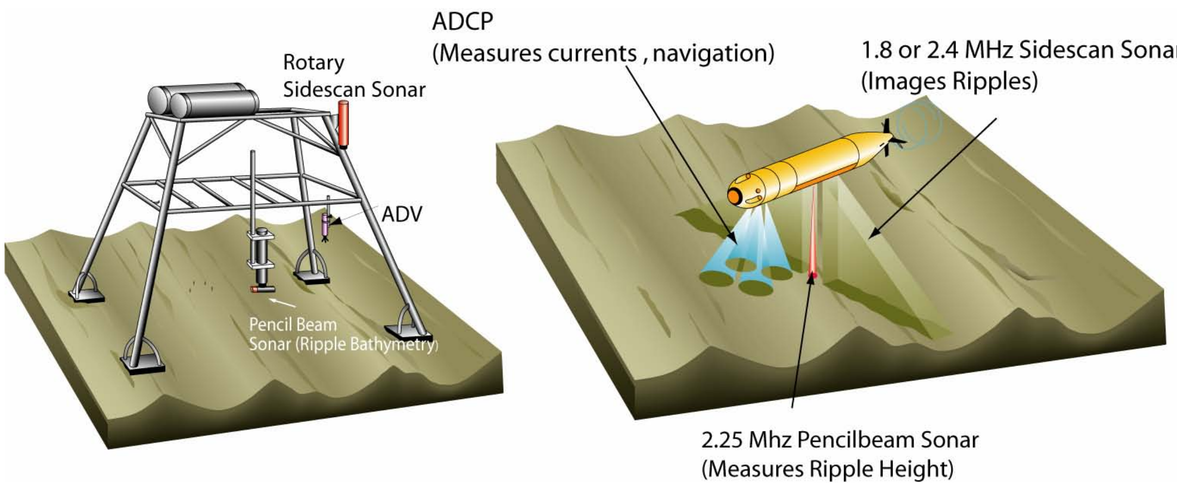

Figure 1. Left: A bottom mounted instrument frame to measure the temporal evolution of ripple parameters at a single location as part of the RipplesDRI experiment off of Fort Walton Beach Florida. Instruments on the frame measures ripple geometry and hydrodynamic forcing. Right: An REMUS AUV was used to measure the spatial distribution of bedforms during two cruises at the Florida site, and at the Martha's Vineyard Coastal Observatory. The AUV had a sidescan sonar that imaged ripple topography and a pencil beam echo sounder that measured ripple height.

WORK COMPLETED

Two survey cruises on the West Florida Shelf were conducted during September 25 –28 and November 7- 9, 2005. These cruises combined a tripod that was lowered from ship at each station to measure grain size and ripple properties (deployed by D. Hanes and USGS co-workers) with our AUV surveys. We were fortunate that our initial survey cruise on the West Florida Shelf occurred ten days after hurricane Ivan. This allowed measurement of ripples on the entire shelf left behind from this major Hurricane. In addition to the measurements on the West Florida Shelf, we also performed measurements near the Martha's Vineyard Coastal Observatory to obtain more data on the near shore region, which has not been previously sampled.

Processing of the sidescan data is almost completed and significant progress has been made on the altimeter data that measured ripple height. For the sidescan data set Matlab tools were developed to read the MarineSonics sidescan data and plot the data in a geo-referenced coordinate system using the AUV navigation data. It was found that commercial applications were not suitable for our purpose, as they did not offer sufficient flexibility to account for vehicle motion on a wave time scale. The sidescan data was processed with 2-d FFTs to measure ripple wavelength and direction. The area of mud in the sidescan imagery due Ivan was quantified by manually tracing the outline of the mud patches (Figure 2 and 5).

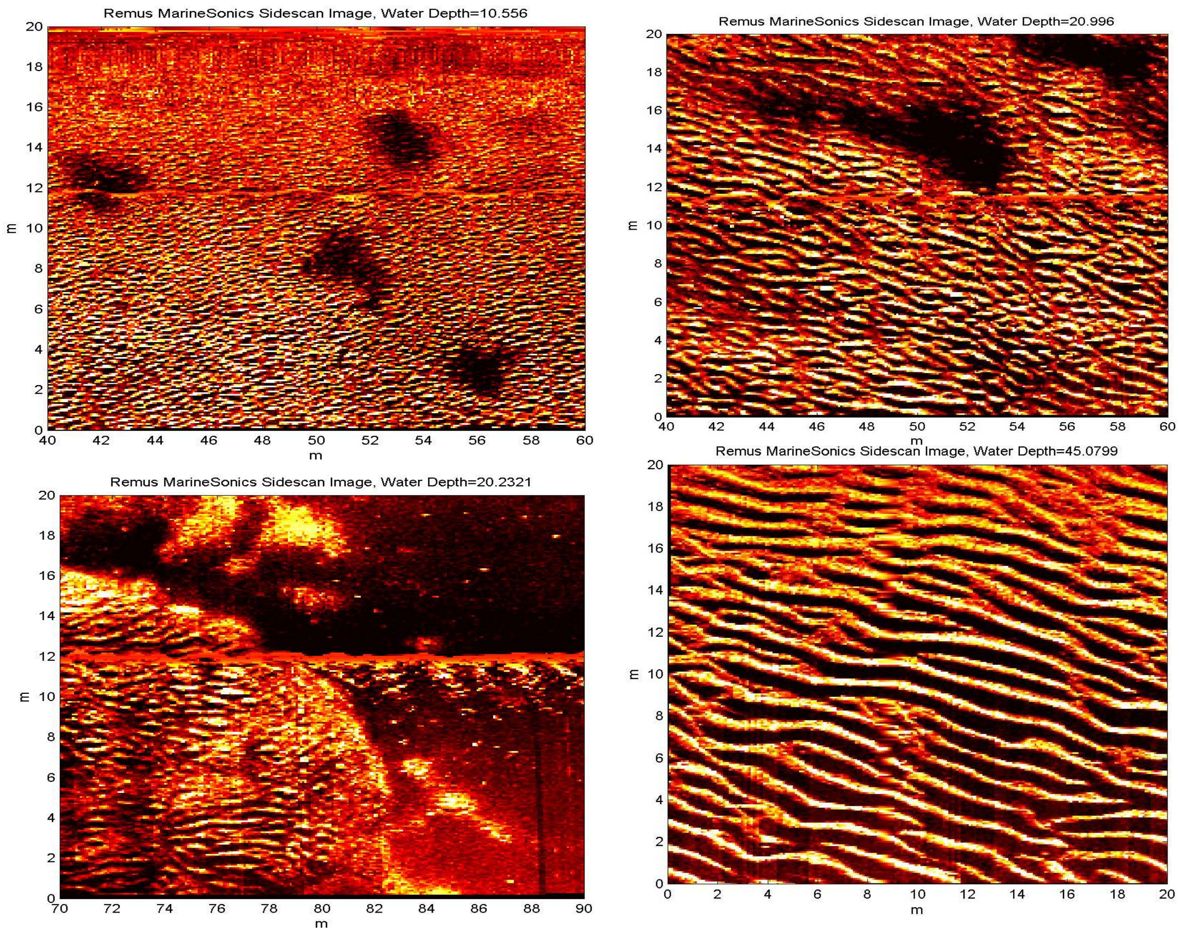

Figure 2. REMUS Sidescan results: a. In water depth of 10 m 25 cm wavelength anorbital ripples were present along with 2-4 m mud patches. b. In 20 m water depth 50 cm wavelength ripples were observed along with larger (4 -8 m) mud patches. c. Mud - rippled sand transitions were observed at the swales associated with the ridge and swale topography on the West Florida Shelf. d. In 45 m water depth the ripples had largest observed wavelengths of 1 to 1.3 m.

The model for the temporal evolution of ripples was developed and tested using data from previous ripple observations. A data set from LEO-15 (Traykovski et al, 1999) and a data set from MVCO (Traykovski et al, 2004) collected as part of the mine burial program were used to validate the model and tune the single adjustable coefficient (a multiplier for the time scale). Using these data sets the model was also compared to a simpler model, which sets the time scale at 0 when ripples are active (i.e ripples are in exact equilibrium with forcing) and infinity when the stress is below the Shield criteria for initiation of motion. The model with the variable time scale defined by the ratio of cross-sectional area to flux rate was found to be better in several regards, most noticeably in the prediction of bimodal spectra, which are often observed in the data at the beginning and end of energetic wave events.

RESULTS

The West Florida shelf REMUS sidescan surveys revealed a wide variety of bedform dimensions in depths of 5 to 45 m that appear to depend strongly on grain size. In the nearshore region (5 to 15 m water depth) the ripples are anorbital ripples in relatively fine sand (Figure 2a). Although this sediment is often in motion, the ripples have a consistent wave length of 25 cm (Figure 3), as expected for anorbital ripples that do not change wavelength in response to changing forcing during moderate conditions. The tripod data also confirmed the presence of anorbital ripples during moderate forcing conditions on the 10 m isobath. Under more energetic conditions cross-ripples appeared at the tripod site.

In water deeper than 15 m the grain size become significantly coarser and the ripples are orbital scale ripples. One of the most interesting results of the survey work was that the ripples have longer wavelengths in deeper water (Figure 3). These ripples are the result of hurricane Ivan as the one subsequent wave event was not energetic enough to mobilize coarse sediment in water depths of 15 m or more. In 15 to 20 m water depth the ripples left by Ivan had wavelengths of 50 to 80 cm. The wavelengths increased to 100 to 130 cm in 45 m water depth. These ripples were not produced at the peak of the wave energy during hurricane Ivan, as during the peak the wave orbital diameter was greater than 4 m at the 50m isobath and increased shoreward. Orbital scale ripples typically have wavelengths that scale as 0.6 to 0.75 of the wave orbital diameter (Wiberg and Harris, 1994).

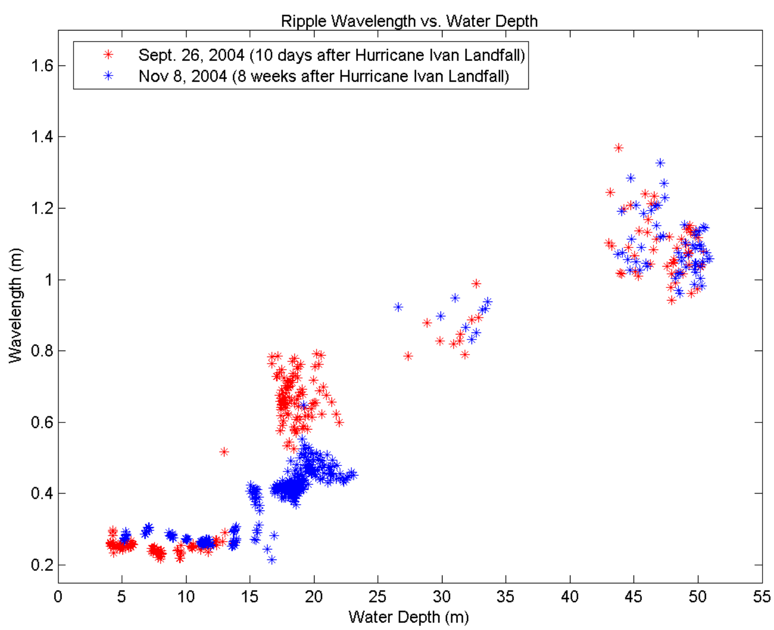

Figure 3. Ripple wavelength vs. water depth 10 days and 8 weeks after Ivan landfall. The ripple increase in wavelength from 25 cm in the nearshore (5 to 15 m water depth) to 115 cm in 50 m water depth near the shelf break.

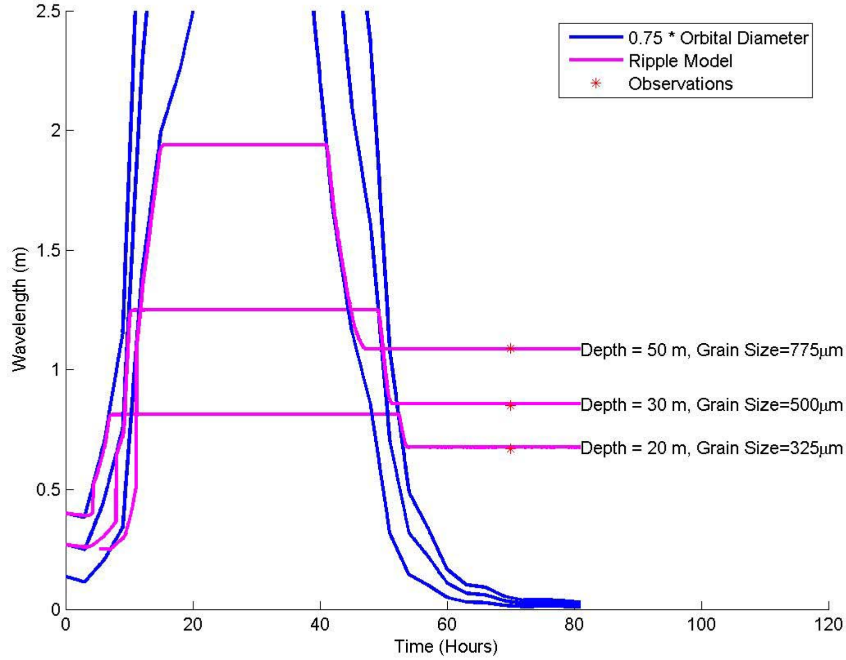

Figure 4. A time dependent model for ripple geometry shows ripples were not created at the peak of Ivan. Rather they were formed during the waning stages of the storm and require offshore grain size coarsening in order to match the observed wavelengths.

In order to examine the potential sources of the increase in wavelength with increasing water depth the temporal ripple model was run in water depths of 20, 30 and 50 m. The wave forcing was calculated from a pressure gauge located on the 87 m isobath was transformed shoreward using conservation of energy and linear wave theory. With a constant grain size at all depths the model predicted a slight increase in wavelength in deeper water due to the longer wave orbital diameter at the time when the bottom stress became insufficient to move sediment. However, the increase in wavelength predicted with a constant across shelf grain size was much smaller than the observed variations in wavelength. If the grains size in the model is increased from 325 μm in 15 to 20 m to 775 μm in 50 m water depth the modeled wavelengths can match the observations (Figure 4). Initial analysis of the measured grain size distribution do show an offshore coarsening that is roughly consistent with this; however, further grains size analysis work is required to determine if the ripple model predictions of grain size are accurate.

The effect of wave dissipation was also examined by reducing the wave height shoreward and it was found that this would increase the preserved wavelengths in shallow water (opposite of what is seen in the data) as a decreased wave height in shallower water caused the stress to drop below the critical stress sooner in the storm, when the wave periods were longer, and thus larger wave orbital diameters were present. Future work in collaboration with T. Herbers will examine wave dissipation using a spectral approach to see if gives different results from the simple approach.

The analysis of the mud patches present in the sidescan imagery (Figure 5) showed the patches covered less of the seafloor area 8 weeks after Ivan than in the initial survey 10 days after the storm. The patches were also located in deeper water and closer to the swales in the ridge and swale topography during the second survey (Figure 2c). This could be due to combination of offshore transport of the mud and burial of the mud patches by mobile sand in the nearshore.

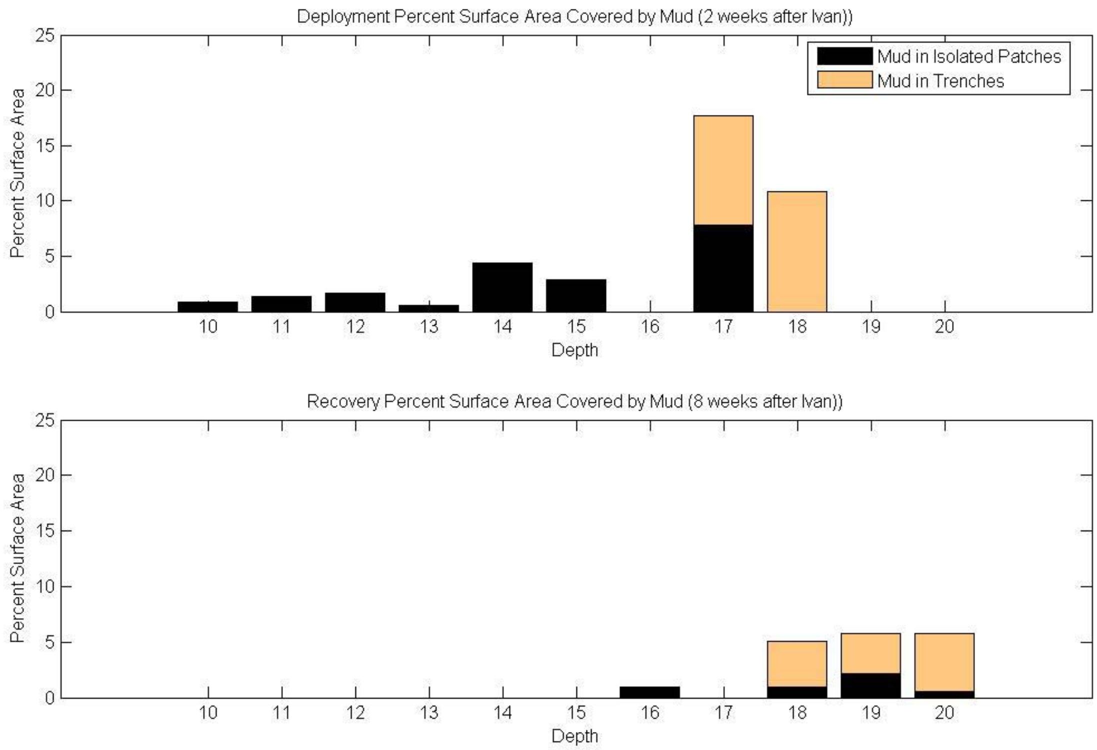

Figure 5. Analysis of mud patches visible in REMUS Sidescan data shows the patches were located in deeper water and closer to the swales in the ridge and swale topography during the second survey

IMPACT/APPLICATIONS

The capability of Remus to quantify variations in bedform geometry has implications both for research and for naval operations. The system provides unprecedented combination of high resolution and large spatial coverage of seabed conditions that can be related to seabed mobility, potential for mine burial and ability to acoustically detect mines. The temporal ripple model provides a useful tool for examining and predicting ripples that are not in equilibrium with forcing.

RELATED PROJECTS

This project is closely related to other RipplesDRI projects such as D. Hanes' efforts to map ripple geometry in relation to grain size on the Florida Shelf. It also has relations to the mine burial prediction program in that variability in grain size and bedforms has first order implications regarding the predictability of mine burial. The modeling work was dependent on previous ripple geometry time series data sets, some of which were obtained under ONR funding.

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