Dynamics of Ripples on the Sandy Inner Shelf off Martha's Vineyard: Surveys, Field Measurements, and Models

Christopher R. Sherwood
U.S. Geological Survey, Woods Hole Science Center
384 Woods Hole Road
Woods Hole, MA 02543-1598
Phone: (508) 457-2269 Fax: (508) 457-2310 Email: csherwood@usgs.gov

Richard P. Signell
U.S. Geological Survey, Woods Hole Science Center
384 Woods Hole Road
Woods Hole, MA 02543-1598
Phone: (508) 457-2229 Fax: (508) 457-2310 Email: rsignell@usgs.gov

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LONG-TERM GOALS

The long-term goal of our research is to improve fundamental understanding and numerical representation of coastal sediment-transport processes. We participated in EuroSTRATAFORM project, where our goal has been to improve quantitative models describing the relationships among meteorological and oceanographic forcing, freshwater influx, particle resuspension, and transport and accumulation of sediment in the coastal ocean. We helped obtain data for the Optics Acoustics and Stress In Situ (OASIS) project with many of the same goals and additional focus on the interaction between bed and suspended sediments and the influence of fine sediments on optical properties in the water column. We are funded through the U. S. Geological Survey (USGS) Coastal and Marine Geology Program to help a National Oceanographic Partnership Program (NOPP)-funded partnership develop a community sediment-transport modeling system (CSTMS). Quantitative understanding of sedimentary processes is important to the Navy because they define environmental conditions in coastal regions, including current speeds, turbulence, water-column turbidity, and bottom acoustic properties. They are also of great interest to geologists and coastal resource managers.

OBJECTIVES

Our objectives are to support the Office of Naval Research (ONR) Ripples Directed-Research Initiative (DRI) studies at MVCO with data collection and modeling. We have three tasks, all related to the ongoing NOPP CSTMS funded by ONR and to the OASIS project, and closely aligned with long-term USGS science objectives. They are as follows.

- Mapping: Conduct a high-resolution bathymetric survey and make a gridded bathymetric chart for use as initial conditions in wave and circulation models for the Ripples DRI study area.

- Tripod measurements: Measure ripple morphology and evolution, along with wave-orbital motions, currents, bottom stress, suspended-sediment concentrations, and sediment fluxes during the Ripples DRI experiment.

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14. ABSTRACT
The long-term goal of our research is to improve fundamental understanding and numerical representation of coastal sediment-transport processes. We participated in EuroSTRATAFORM project, where our goal has been to improve quantitative models describing the relationships among meteorological and oceanographic forcing, freshwater influx, particle resuspension, and transport and accumulation of sediment in the coastal ocean. We helped obtain data for the Optics Acoustics and Stress In Situ (OASIS) project with many of the same goals and additional focus on the interaction between bed and suspended sediments and the influence of fine sediments on optical properties in the water column. We are funded through the U. S. Geological Survey (USGS) Coastal and Marine Geology Program to help a National Oceanographic Partnership Program (NOPP)-funded partnership develop a community sediment-transport modeling system (CSTMS). Quantitative understanding of sedimentary processes is important to the Navy because they define environmental conditions in coastal regions, including current speeds, turbulence, water-column turbidity, and bottom acoustic properties. They are also of great interest to geologists and coastal resource managers.

15. SUBJECT TERMS

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- Modeling: Implement a regional wave, circulation, and sediment-transport model for the Ripples DRI and OASIS study areas using code developed in the NOPP CSTMS.

APPROACH

Task 1. Mapping – We conducted a high-resolution bathymetric survey of the Ripples DRI experiment site south of Martha's Vineyard in August 2007 using USGS survey instrumentation from a vessel of opportunity leased by WHOI.

Task 2. Tripod Measurements – We deployed a pair of autonomous tripods to measure ripple morphology, waves, currents, bottom stress, suspended-sediment concentrations, and temperature at a site on the inner shelf. The exact location of the site was chosen after discussions with researchers from both ONR-funded experiments, the Ripples DRI and the OASIS project (Traykovski, Hay, Herbers, Boss, Hill, and Milligan). We have mapped ripple morphology on both sides of the boundary and measured changes in bottom stress, near-bottom turbulence, apparent roughness, and suspended sediment as the observed boundary-layer properties change with alternating tidal flow, advecting to our sensors properties acquired over either coarse sand or fine sand.

Task 3. Modeling – We are developing a regional circulation, wave, sediment-transport, and morphology model using the Regional Ocean Modeling System (ROMS) with the wave model SWAN, as developed under the NOPP-funded CSTMS. The model incorporates a coarse outer domain for the U.S. East Coast developed by Ruoying He at North Carolina State University, and nests down to a regional (1-km) grid with a domain similar to the CBLAST model developed by Wilkin (2006) and to three finer inner domains centered on the MVCO region, with grid sizes of 200, 40, and 8 m. The objectives of the modeling studies are to critically evaluate the performance of a regional wave, circulation, and sediment-transport model with measurements made at several inner shelf locations occupied as part of the Ripples DRI, OASIS, and ongoing MVCO data collection, and to provide a regional sediment-transport context for to help interpret the point measurements.

WORK COMPLETED

Mapping – The USGS conducted nearshore geophysical mapping off the south coast of Martha's Vineyard, in the vicinity of the Martha's Vineyard Coastal Observatory (MVCO) in August 2007. Jane F. Denny was the chief scientist for the five-member survey team. The survey was conducted from the *M/V Megan Miller* August 9-14, 2007. The study area covers 35 km^2 from about 0.2 km to 5-km offshore, and ranges in depth from ~ 5 to 20 meters. The following high-resolution systems were used to map the surficial sediment distribution, depth and sub-surface geology: dual-frequency 100/500 KHz sidescan-sonar system, 234-KHz interferometric sonar, and 500 Hz -12 KHz chirp sub-bottom profiler. The sub-bottom system was surface towed and configured with a differential global positioning system (DGPS) to acquire tow-fish position, yielding 1 – 2 meter horizontal accuracy. Real-time kinematic (RTK) positioning was acquired for the interferometric and sidescan-sonar systems, yielding better than 10-cm horizontal accuracy.

A USGS Open-File Report that describes the survey and releases all of the data to the public should be published this calendar year (Denny et al., in press).

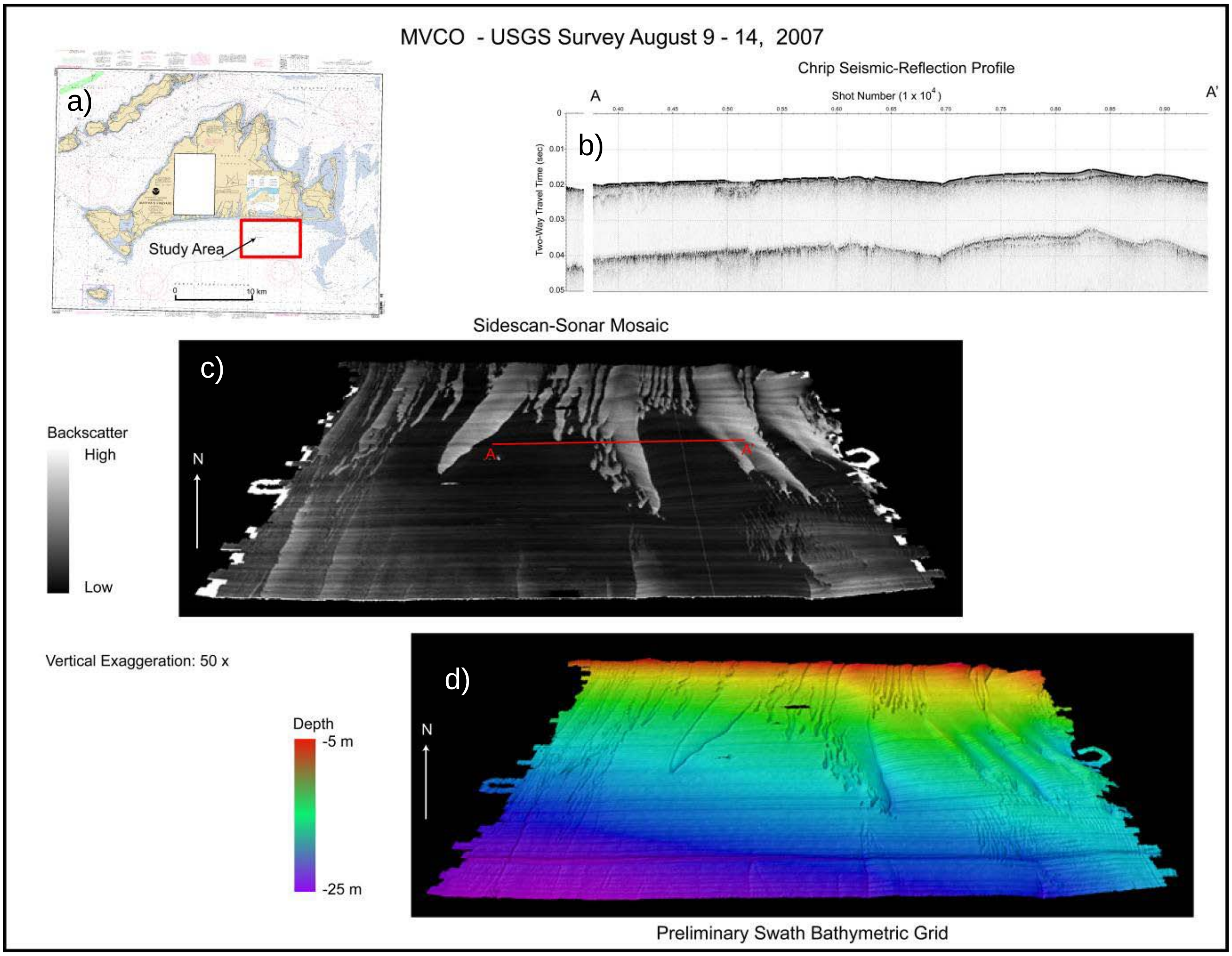

Figure 1. Results of the bathymetric and geophysical survey conducted August 9-14, 2007. a) Location of the survey at the Ripples DRI study area near MVCO, south of Martha's Vineyard; b) high-resolution sub-bottom profile along west-east track (A to A' in panel c) showing buried channels and accumulation of fine sand; c) backscatter from side-scan sonar draped on bathymetry; and e) shaded, illuminated bathymetric map from survey.

Tripods – Two instrumented tripods were deployed near the MVCO 12-m node from the *R/V Connecticut* on August 27, 2007 and recovered on October 29, 2007. The tripods were deployed at two sites approximately 40 m apart, both on the boundary between fine sand and coarse sand. Prior to deployment, the sites were surveyed by divers and short hand-cores were taken for grain-size analysis. The southernmost tripod was designed to measure flow parameters, and supports several pressure sensors, three acoustic-Doppler velocimeters mounted ~0.4 mab, a downward-looking pulse-coherent acoustic Doppler profiler, an upward-looking acoustic Doppler profiler with wave-measurement capabilities, a three-frequency acoustic backscatterance sensor, two conductivity-temperature sensors, and several optical backscatterance sensors and transmissometers. The second (northern) tripod was designed to measure suspended particle size and to obtain sonar images of ripples and bottom topography (Fig. 2). That tripod had a LISST laser in-situ particle size device, a dual-axis pencil-beam

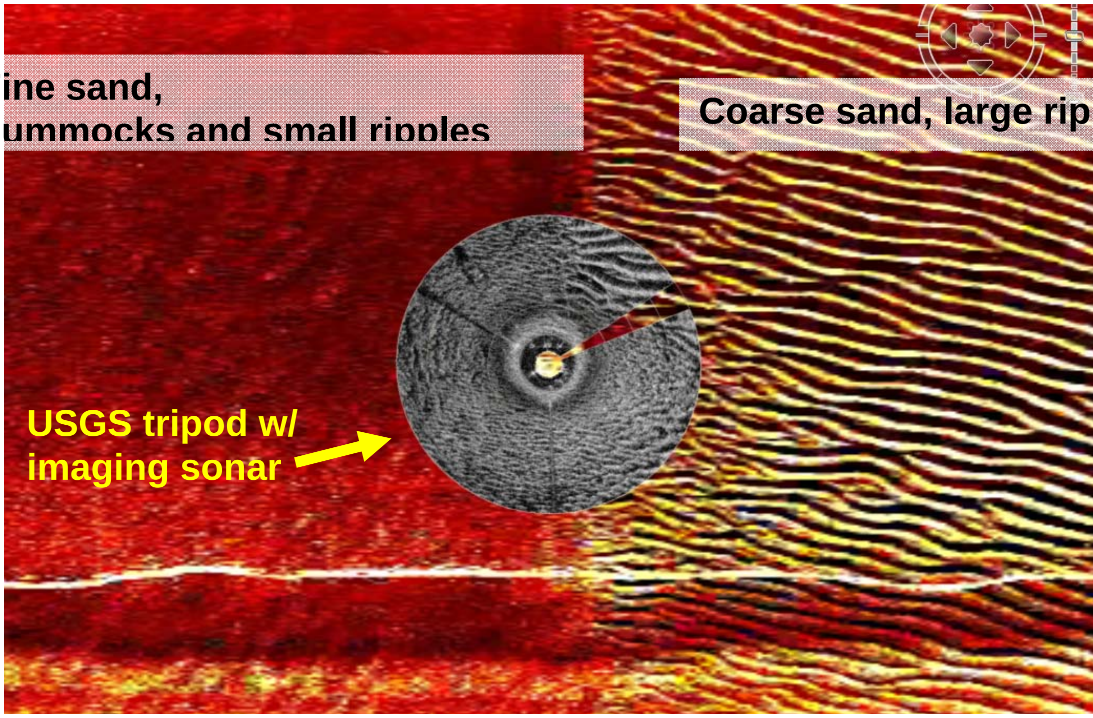

Figure 2. Side-scan sonar image of USGS particle tripod (brown and white, courtesy P. Traykovski, WHOI) overlain with rotating sonar image taken at same time from USGS tripod at the northern 12-m sites, Sept. 13, 2007.

sonar for bathymetric mapping, a fan-beam imaging sonar, a camera for imaging the bottom, and an upward-looking acoustic Doppler profiler.

Modeling – We are developing a multiply nested modeling system to investigate the influences of bottom roughness and topography associated with small-scale bathymetric features on waves and circulation. The outermost model domain (developed by collaborator Ruoying He at North Carolina State University) encompasses the entire U.S. East Coast with a grid size of ~5 km. This outer domain is needed to incorporate the effect of large-scale weather and circulation patterns on water elevations, temperatures, salinities, and ocean waves at the boundary of our regional model. The regional model covers the same domain used by John Wilkin (Rutgers University) in his CBLAST model, but uses the new 1 arc-second digital bathymetric grid that we constructed for the region using a variety of sources, including the our August 2007 survey (see http://coast-enviro.er.usgs.gov/models/grids/).

The high-resolution domains (beginning with the 200-m grid) use the two-way coupled wave and hydrodynamics model developed by Warner et al. (2008a, 2008b) under the NOPP CSTMS project and the USGS Carolinas Coastal Change Processes Project. This model incorporates the effects of wave-induced stresses on circulation and the influence of currents on wave propagation, and will allow us to accurately force ripple models and evaluate effects of topography and bottom roughness on circulation.

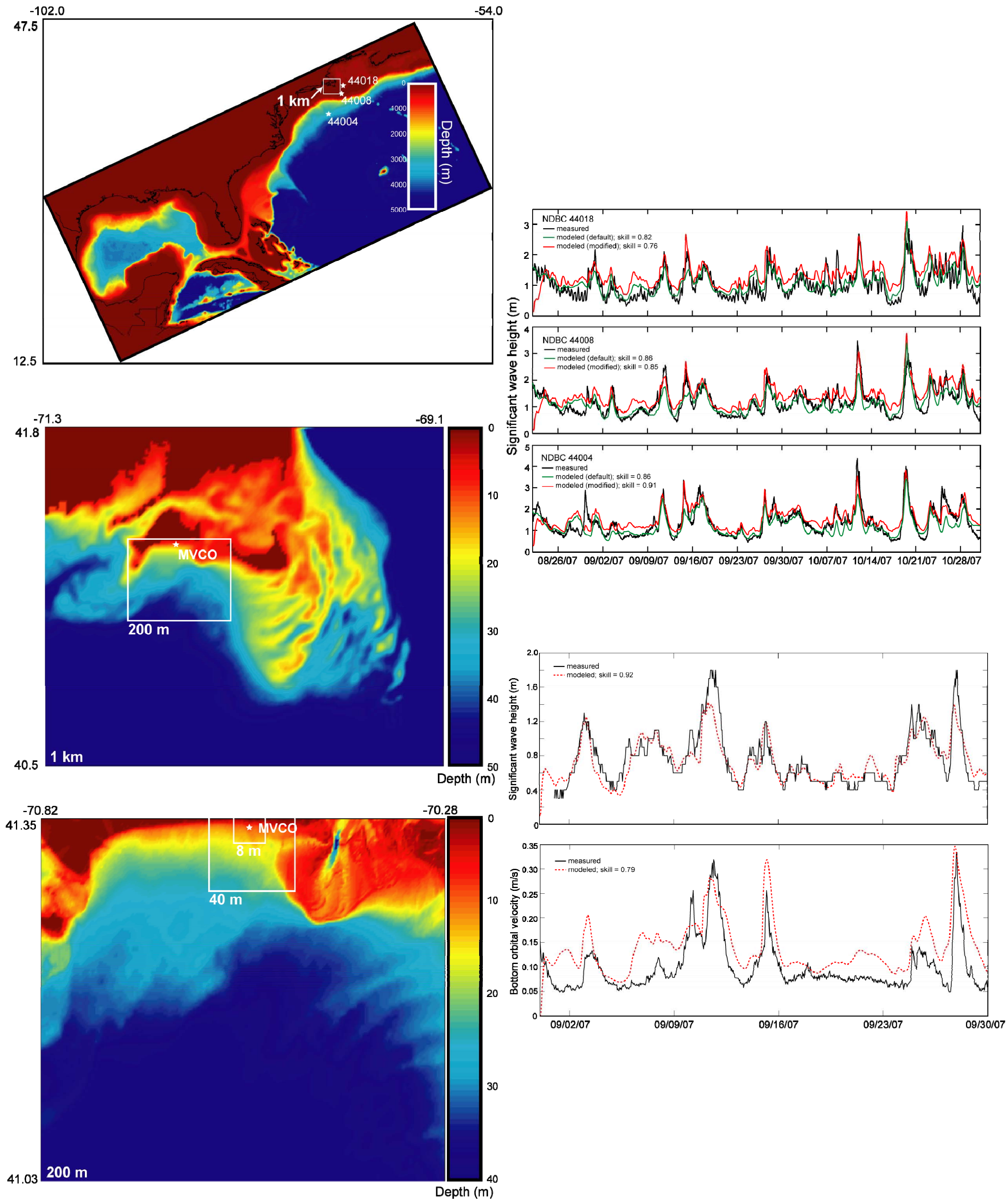

Figure 3. Model domains and model-data comparisons. Left panels show U.S. East Coast domain with 5-km grid (top), regional CBLAST domain with 1-km grid (middle) and high-resolution domains (200-m, 40-m, and 8-m grids) near the Martha's Vineyard Coastal Observatory (MVCO; lower panel). Right-hand panels show model-data comparisons for wave height with NODC buoys (top panels) and height and near-bottom wave-orbital velocity at MVCO (bottom panels).

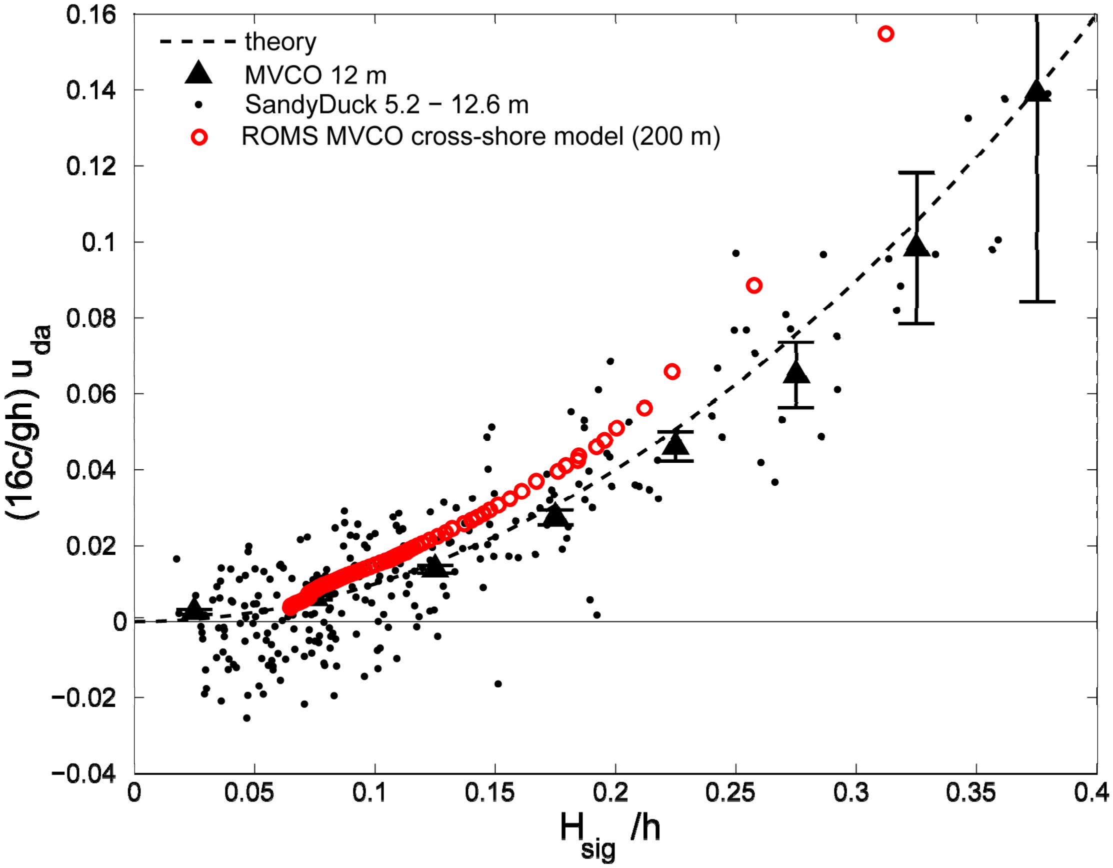

Figure 4. Plot of normalized depth-mean flow u_{da} as a function of wave height normalized by the water depth (H_{sig}/h). The dashed line is the theoretical prediction based on the Stokes transport, the data is from measurements at MVCO and Duck, NC (courtesy S. J. Lentz, WHOI; see Lentz et al., in press) and the model results are from our application of the CSTMS coupled wave-current model (Warner et al., 2008a,b) for an idealized case at MVCO.

RESULTS

The valuable results obtained in FY2007 were high-resolution bathymetric datasets. Comparison of this survey with previous surveys indicates that the fields of fine and coarse sand have not moved substantially since the first detailed surveys were performed despite well-documented sediment-transport events. Instead, the patches have undergone slight modifications and subtle shifts at the boundaries. The importance of this result is that it means grain-size variations can produce relatively stable, self-perpetuating bottom features that can retain important characteristics (elevation, ripple morphology, hydrodynamic roughness) for many years, even in energetic inner shelf environments.

In FY2008, we recovered the tripods and processed the data. A nearly complete two-month data set was obtained from all instruments, including the scanning sonar and the two-axis pencil-beam sonar. We have begun to integrate flow measurements with information on bottom topography and bedforms. Bottom boundary layer observations were obtained for flow over both coarse regions with large ripples and fine region with small ripples under a variety of wave conditions. Preliminary evaluation of this data indicates that ripple dynamics are particularly complicated at the migrating margin between the two bottom types, and that hydrodynamic roughness in flow parallel to ripple crests may be influenced more by waves than bottom geometry.

Preliminary model results have been obtained and indicate that the model exhibits significant skill at reproducing incident waves at MVCO (Fig. 3). Results of idealized model runs (Fig. 4) demonstrate that the coupled wave-current model with nearshore (3D radiation-stress forcing; Warner et al., 2008a,b) reproduces the Stokes transport determined by theory, and observed in data (Lentz et al., in press). This is a key component of forcing for circulation in the nearshore.

IMPACT/APPLICATIONS

The bathymetric and geophysical data collected last summer are being used in wave and circulation models and will, in the future, be used to evaluate temporal changes in the sorted grain-size features found on the inner shelf. The near-bottom measurements and ripple characteristics recorded by the bottom tripods are being used to validate models for waves, currents, sediment transport, and bottom morphology. Stress estimates from the flow tripod and optical data from the LISST instrument at the particle tripod have been provided to collaborators in the OASIS project. Flow properties recorded at the

RELATED PROJECTS

These studies are part of the Ripples DRI and closely related to the OASIS studies and the NOPP Community Sediment Transport Modeling Project (http://www.cstms.org/).

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