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Multi-Scale (cm to km) Hydrodynamic and Morphologic Interactions in Tidal Inlets, Dynamics of Sandwaves with Combined Wave - Current Forcing and Mine Burial Processes, and Instrumentation for Measuring Nearshore Morphologic Change and Hydrodynamic Forcing

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LONG-TERM GOALS

Our long terms goals are to understand sediment transport processes, the relevant physical forcing processes and the resulting morpholic evolution of river mouths and tidal inlets and shoals. Specific goals include understading bedform characteristics (ripple to sandwave and sandbar scale) in relation to wave- and cuurent-forced mean and turbulent flow.

OBJECTIVES

1. Quantify morphological change associated with storms and tidal forcing, and quantify the physical mechanisms causing the change (i.e., the specific wave-current-bathymetry interactions leading to divergence of sediment transport).
2. Measure the currents, sediment-transport processes and bedform evolution in the bottom boundary layer in the energetic ebb-tidal shoals, where nonlinear interactions between waves and tidal currents are critically important to the sediment transport and the morphological response to changing forcing conditions.
3. Develop instrumentation to make essential measurements for objectives 1 and 2. This includes a surface running REMUS-100 with a carrier phase GPS antenna that will remain exposed, and a multi-beam system for bathymetric surveys. Our Dopplers profilers are also in the process of being upgraded to bistatic convergent beam sampling for better resolution of near bed turbulence.

APPROACH

In order to measure the processes responsible for inlet morphologic change we plan to conduct repeat bathymetric and hydrographic surveys along with in-situ time series measurements of water velocity (waves and currents), sediment transport (both suspended load and bedload via bedforms migration) and bed elevation. In 2011 we focued on combined aerial photography and shipboard Bathymetry and ADCP surveys of the Wasque Shoals region off the South East corner of Martha’s Vineyard (Figure

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1), along with continued instrument development in preperation for work at New River Inlet and Wasque Shoals in 2011.

Bathymetric Surveys
In order to produce accurate and repeatable maps of morphologic change at scales ranging from ripples to channel and shoal migration, we plan to use a REMUS-100 with cm accuracy phase carrier resolving differential GPS and sidescan and multibeam sonar system as described in our DURIP proposal ("Instrumentation for Measuring Nearshore Morphologic Change and Hydrodynamic Forcing", Figure 2). The GPS antenna will be mounted on a surface-piercing mast so the accurate positioning data will be available at all times under calm conditions. The vertical reference provided by the GPS is essential, because neither pressure nor water surface elevation is a suitable reference for measuring bedforms under swell. The multibeam will provide digital elevation with a swath width roughly twice the water depth (2×h), and the side-scan with a swath width 10×h will allow measurement of small scale bedform morphology and overlapping tracks for larger scale bathymetry (Figure 2). The REMUS surveys will be complimented by standard shipboard ADCP, Bathymetry surveys with the same GPS system for a highly constrained vertical reference frame.

Aerial Surveys
Aerial Photographic surveys were conducted from aircraft of opportunity available for charter in the Cape Cod and Martha's Vineyard area. Variable altitudes and camera angles were used to image the shoals on different spatial scales and sun angle illumination.

WORK COMPLETED

Aerial Photographs
Aerial Photos from May 5, 2009, Aug 26, 2011 and Sept. 17, 2011 were examined to compare changes over long times scales, presumably dominated by tidal forcing vs. change due to Hurricane Irene which passed south of the region in between the two 2011 surveys on Aug. 28, 2011. The photos were georectified using features on land such as roads and buildings that are unchanged from georectified orthophotos available from USGS and bathymetric features mapped in the bathymetry surveys (Figure 3). The images were also processed using techniques we have developed for rotary sidescan analysis to identify the locations of the crests of the sandwaves (Figure 4).

ADCP & Bathymetric Surveys
Bathymetry and ADCP surveys were conducted close to each of the 2011 aerial photo survey, both to aid in registering the locations of the shoals in the photos to geographic coordinates, and to establish changes in the depth of the shoals. The ADCP survey was focused on mapping tidal rectification processes over the shoals. During the second survey, we deployed two Nortek Aquadopp current profilers in locations where we expect the largest tidal asymmetries.

Instrument Development
The REMUS-100 with the surface piercing antenna prototype has been constructed and is the process of having the control loop adjusted for stability and maneuverability with the added mass and drag of the antenna and keel (Figure 2). The same GPS that will be used for the REMUS-100 was used in the shipboard bathymetry surveys to understand its performance characteristics.

RESULTS

The bathymetry surveys revealed the sandwaves of the crest have wavelengths of 60 to 100 m and heights of 2 to 3 m. The crests have depth of 1 to 2 m and troughs are 4 to 5 m deep (Figure 3). The surveys conducted before and after the passage of Hurricane Irene revealed there was very little change to the locations of the crests of the bedforms during this major storm. Almost all the crests fell in the same location as before the storm with only minor migration of some of the bifurcations in the along crest direction. At Block Island Buoy located in 50 m water depth, 60 km to the west of the shoals, but exposed to similar southerly swell significant wave height exceeded 20 ft for 12 hrs. and peaked at 30 ft. The ADCP at the 12 m depth MVCO node recorded 17 ft waves before it went offline at the peak of the storm. In the period from May 2009 to August 2011, the morphology of the shoals changed dramatically. In 2009 there were three distinct sandwave fields, while in 2011 there was one main sandwave field in a triangular region with one corner located at Skiffs Island, and a less distinct region in between the main field and the Martha's Vineyard. This preliminary result suggests that tidal processes over longer time scales may be more effective in controlling shoal morphology than a single large wave event.

To ADCP survey revealed tidal flow with maximum velocities of 1.0 to 1.3 m/s on the shoals. Stronger currents in excess of 1.4 m/s were present tin the Muskaget channel to the East of the shoals. Largest tidal asymmetries were found on the south facing coast Martha's Vineyard, near the corner where tides were high flood dominated (to the west) due to separation of the southward direct ebb flow. The flows on the east-facing coast near the corner were ebb dominated due to separation of the eastward flood currents. On the south and east-facing edge of the triangular bedform field there were tidal asymmetries is direction with less noticeable variations in magnitude. The south-facing edge had more SSW directed ebb flows and ENE directed flood flow, while the eastern edge had S directed ebb flows and weaker NE directed flood flow. In addition to mapping the flows the highly accurate GPS allowed measurement of sea-surface elevation gradients forcing the flows. Highly spatially averaged analysis shows elevation gradients of 20 to 30 cm over 1 km. This is consistent with a quadratic drag coefficient of C_d=0.004 with 1.2 m/s flows based on the dynamic balance: $g\, d\eta/dx = C_d U^2$. Future analyses will examine if the spatial averaging can be reduced to examine the role of individual sandwaves in frictional drag.

IMPACT/APPLICATIONS

The developement of these new technologies wil have significant implications for ability to understand coastal sediment dynamics and morphologic evelution. The abilty of the REMUS system to map large scale morphologic chnage and smaller scale bedforms over a large area should provide unique insights into coastal morphodynamics. The result of little change to the shoals during a major storm was suprising and future work onthis will impove our understanding of storm vs. tidal morphodynamic changes.

RELATED PROJECTS

Three grant numbers are included in this report as N00014-10-10768 (Instrumentation for Measuring Nearshore Morphologic Change and Hydrodynamic Forcing) is a DURIP to develop equipment for the scienece projects: N00014-10-10376 (Multi-Scale (cm to km) Hydrodynamic and Morphologic

Interactions in Tidal Inlets) and N00014-11-10291 (Dynamics of Sandwaves with Combined Wave - Current Forcing and Mine Burial Processes), which are highly related.

This project is also closely related to several other proposed ONR efforts including an OASIS project with John Trowbridge to measure wave boundary layer stresses in support of optical measurments of particle dynamics (Environemental Optics), and integrating the pcADPs on Geyer's MAST (Physical Oceanography). The DURIP funding was also used to develop equipment for those projects

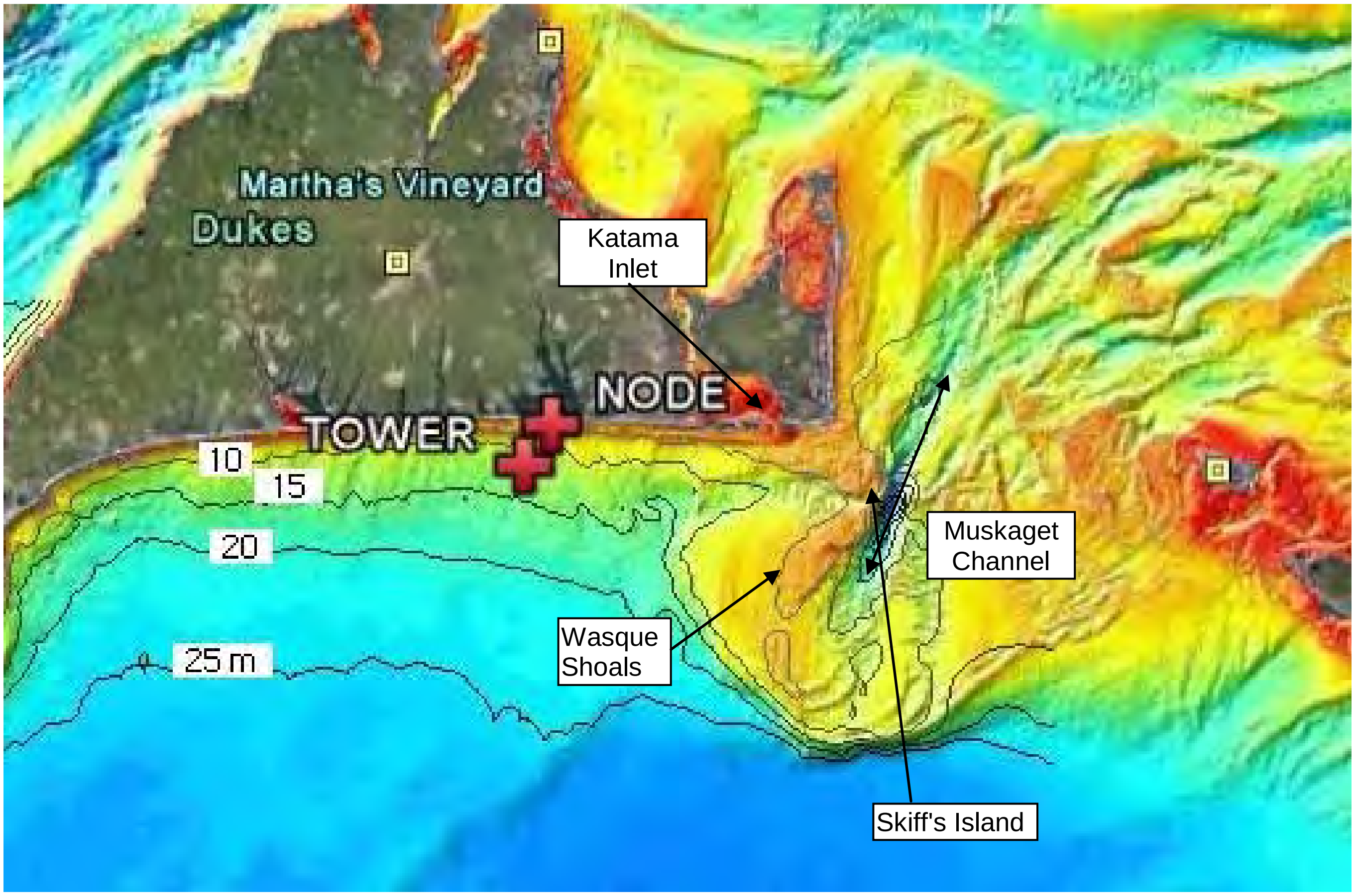

Figure 1 Bathymetry Of Martha's Vineyard-Nantucket Sounds and Wasque Shoals from USGS. The flight path of an aerial survey conducted in September 2010 is superimposed.

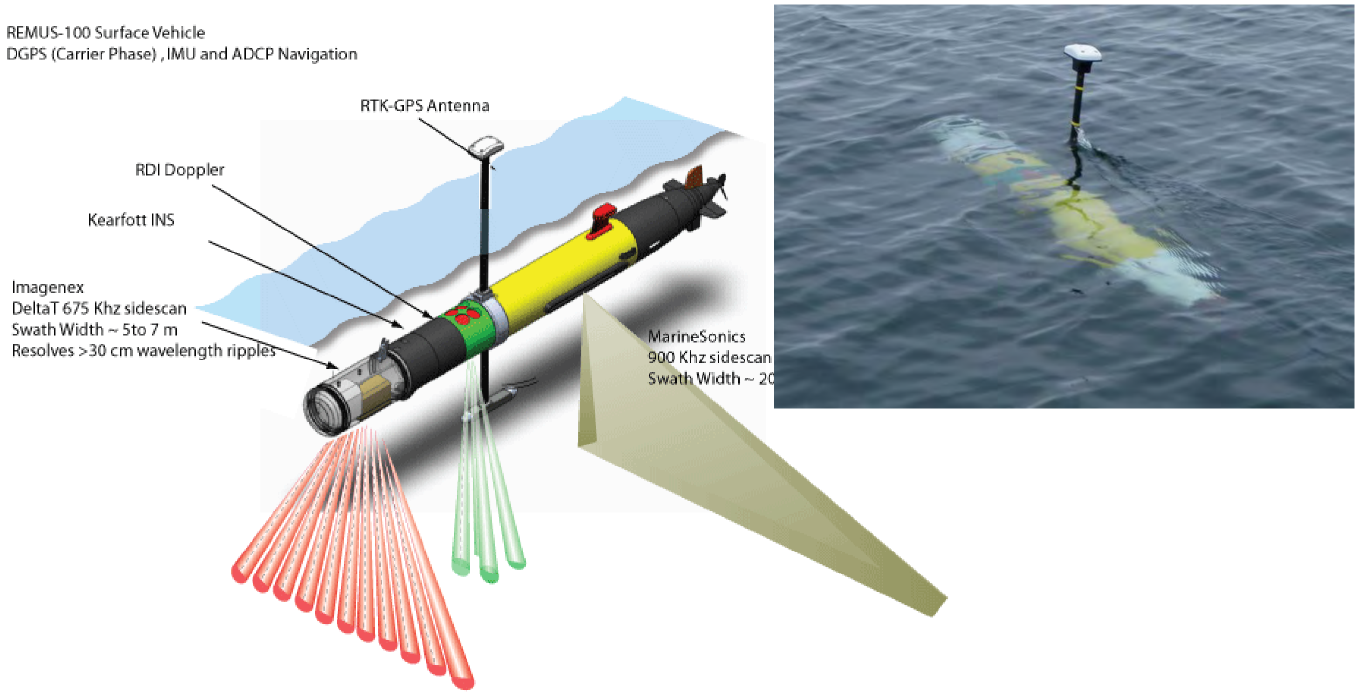

Figure 2. Schematic Of the REMUS-100 Nearshore mapping vehicle with GPS antenna, Imagenex Delta-T Multibeam, MarineSonics Sidescan sonar and Kearfott / RDI Inertial Navigation System (INS).

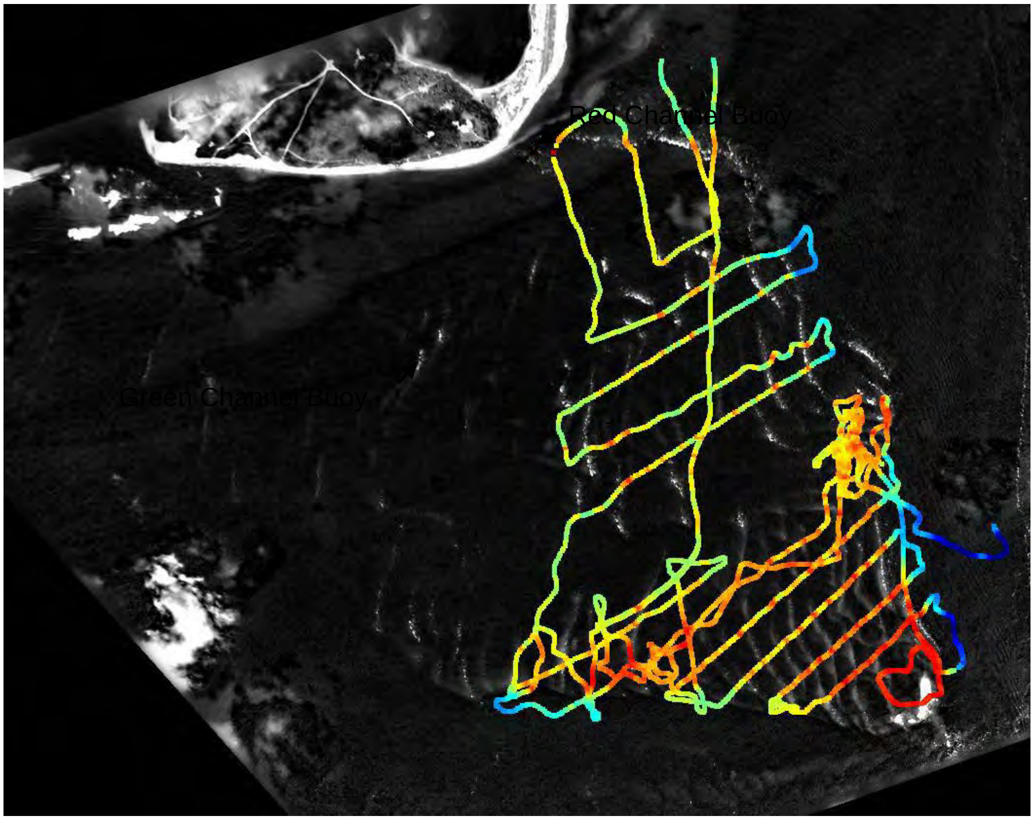

Figure 3. Post Irene bathymetric survey data overlaid on a georectified aerial photo after Hurricane Irene. On the shoals there are 100 to 200 m wavelength sandwaves with depths on the crest of 1 to 2 m and depths in the troughs with of 3 to 5 m.

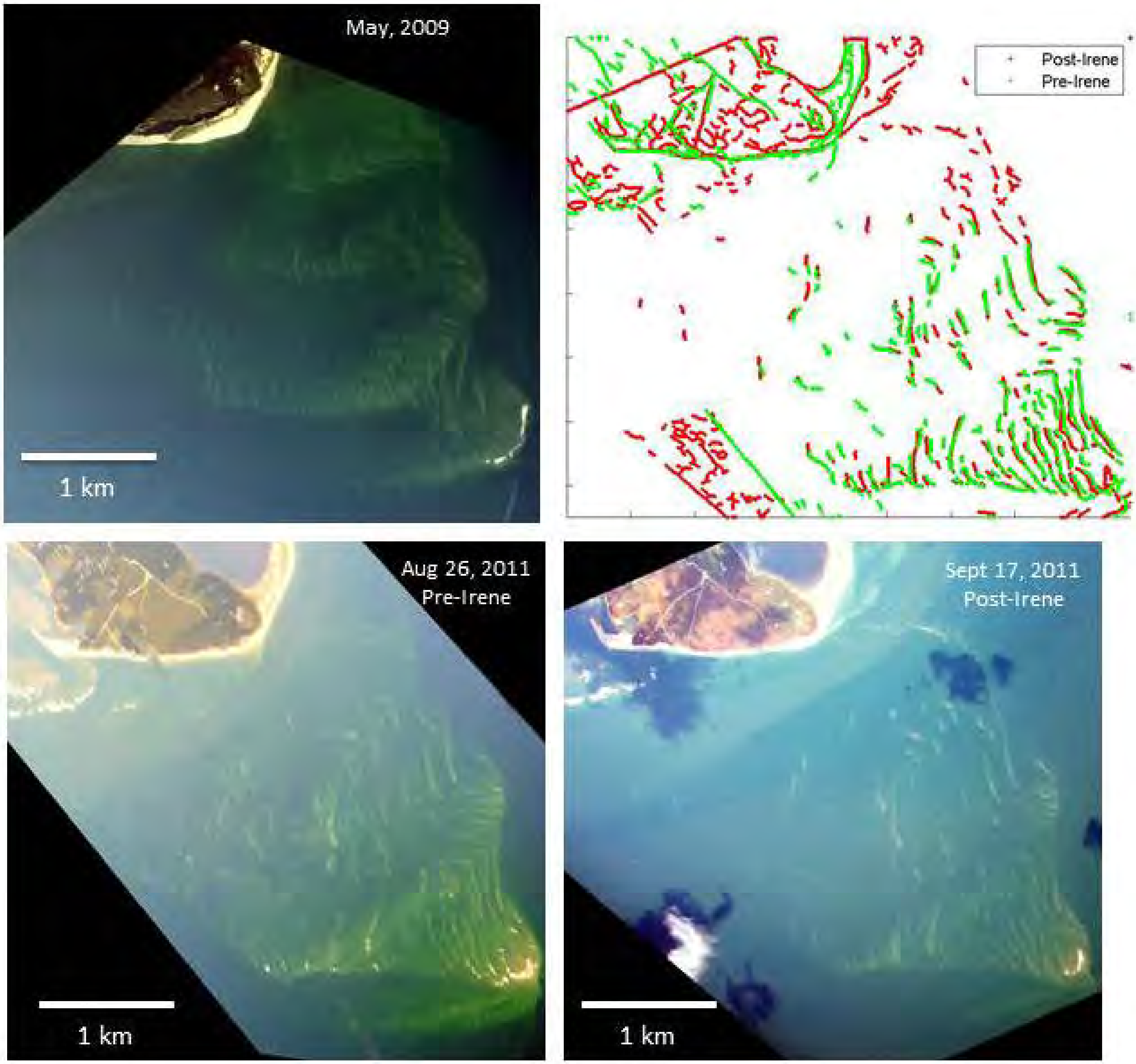

Figure 4. Georectified aerial photos taken on May 5, 2009, Aug 26, 2011 (Before Hurricane Irene) and Sept. 17, 2011 (After Hurricane Irene). The sequence of photos revealed there was very little change to the locations of the crests of the bedforms during this major storm and suggests that tidal processes over longer time scales may be more effective in controlling shoal morphology than a single large wave event.

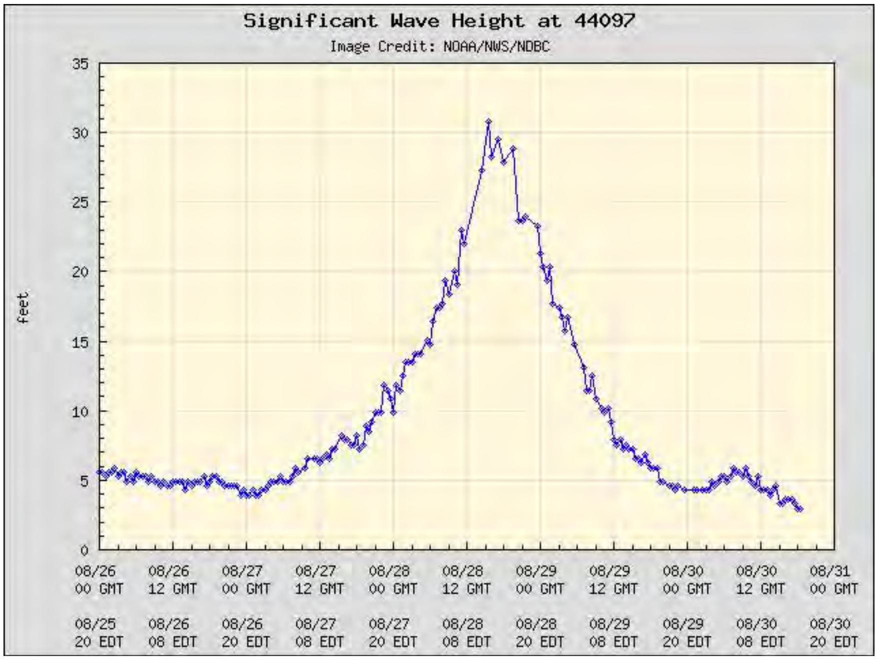

Figure 5. Significant Wave Heights from NOAA Buoy 44097 offshore of Block Island in 50m water depth during Hurricane Irene

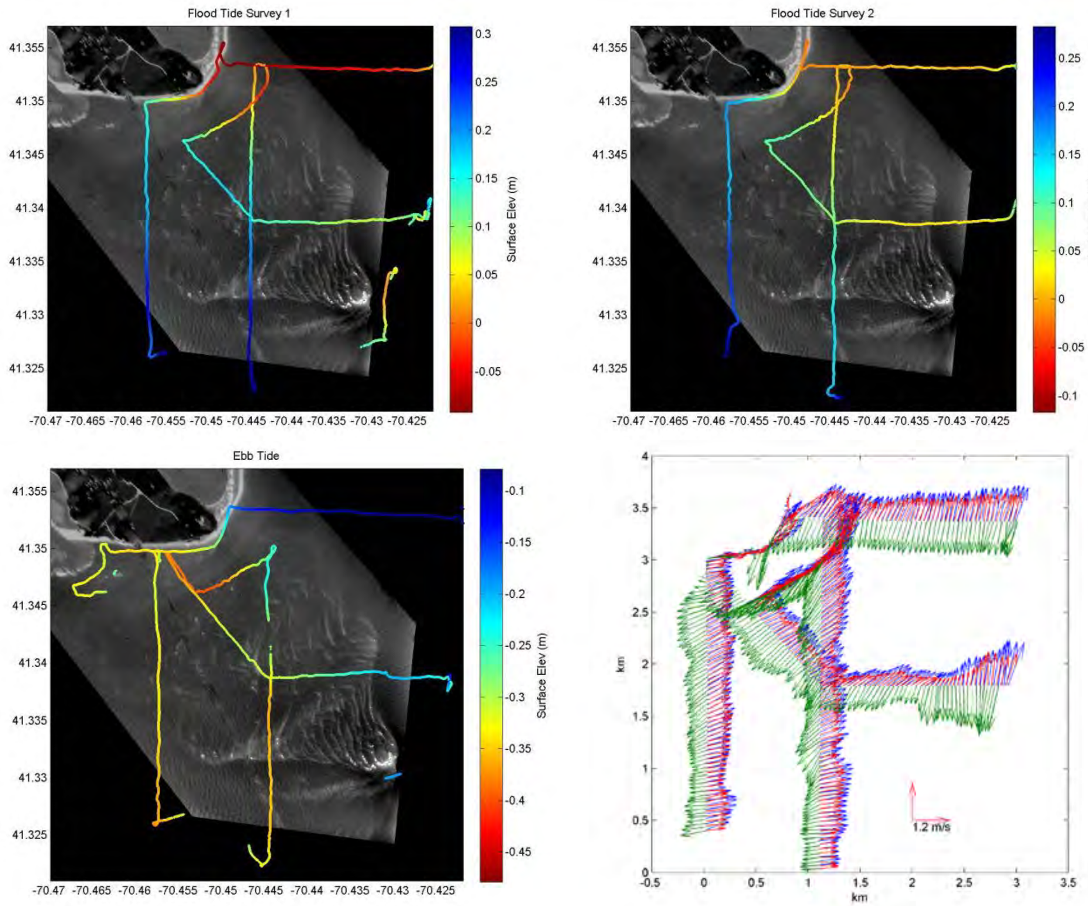

Figure 6. ADCP Tidal velocity and Surface Elevation Survey Data. Ebb tidal flow are shown as green arrows and flood tidal flows are shown as red and blue arrows (from two consecutive 1 hr surveys near maximum flood tide).