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Hurricane Sandy Storm Surge Measured by Satellite Altimetry

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Hurricane Sandy made landfall on the East Coast of the United States around midnight UTC on October 30, 2012. What made this hurricane so devastating was the storm surge, which pushed water levels one to three meters above normal along the New Jersey and New York coasts. The radar altimeter on the HaiYang ("Ocean" in Chinese) 2A (HY-2A) satellite measured the size and offshore structure of the surge at its peak, across Long Island's south shore. Significant wave heights measured by the altimeter reached almost 8 m near shore, and the combined effect of storm surge and high surf led to severe coastal inundation. The analysis presented here documents the largest storm surge signal to be captured by satellite altimetry to date, nearly 1.5 m, with validation provided by the nearby tide gauge at Montauk, NY.

Figure 1 shows the ground track of HY-2A pass-79 and the Montauk tide gauge location overlaid on a GOES-13 satellite image acquired just after Hurricane Sandy's landfall. The HY-2A altimeter passed over Long Island within 55 km of the Montauk gauge. The altimetric sea level profile in Figure 2a (bold dots) was measured at the time of maximum storm surge. The height profile shows a nearly linear increase in the surge signal across the continental shelf, reaching a maximum of 1.44 m. The time series from the Montauk tide gauge (Figure 2b) shows somewhat higher surge levels, which reach a maximum of 1.79 m at 22:12 UTC on October 29. At this time, the absolute tidal heights, relative to mean sea level, and the surge heights (measured vs. predicted) are nearly identical because the predicted tide height is near zero. The altimetric signal corresponds to 80% of the tide gauge signal. This discrepancy could be due to amplification of the surge signal at the Montauk gauge, which is located on the north side of Long Island within Long Island Sound, while the altimetry signal is measured on the south side of Long Island, facing the open ocean.

Sea surface height profiles in Figure 2a are computed as the difference of orbital altitude minus radar range, relative to a model mean sea surface (CLS10; Schaeffer et al., 2010). Geophysical and media corrections for tropospheric and ionospheric path delays, sea state bias, and solid Earth tides are applied. Ocean tide, load tide, and inverse barometer corrections are *not* removed because those physical effects contribute to the absolute height or "total water level envelope" observed at the shoreline. A 50 km Gaussian low pass filter is applied to the

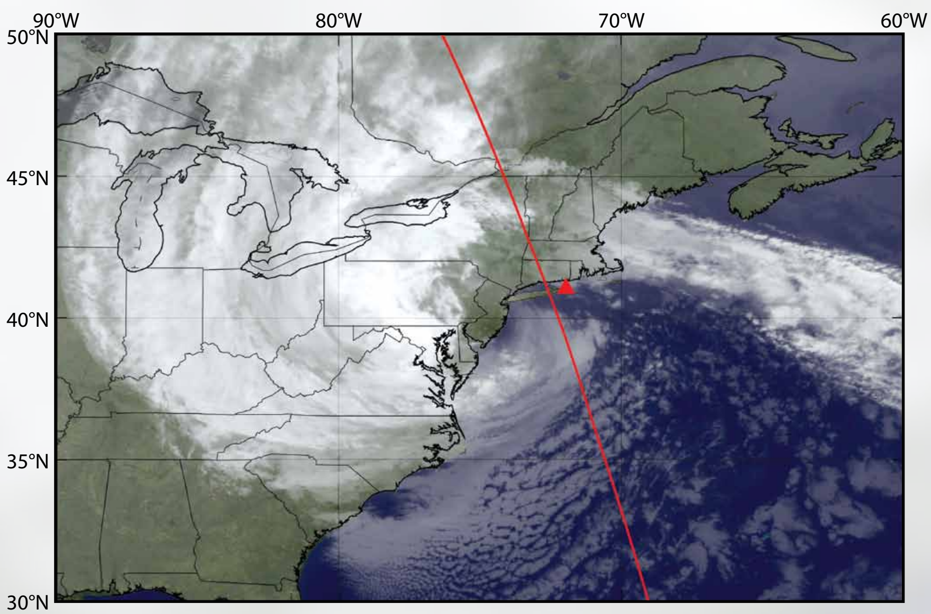

Figure 1. Infrared GOES-13 image from October 30, 2012, 01:15 UTC, showing Hurricane Sandy just after landfall. This major storm covers a large portion of the northeastern United States. The ground track of pass-79 of the HY-2A satellite is plotted in red. The red triangle shows the location of the Montauk tide gauge. China's National Satellite Ocean Application Service launched the HY-2A satellite on August 17, 2011, the first of a four-satellite series designed for operation between 2011 and 2019. HY-2A has a 14-day exact-repeat cycle. The Montauk gauge is part of an array of coastal tide gauges located around the United States that routinely provide water level data every six minutes. The gauges are managed by the National Oceanic and Atmospheric Administration's National Ocean Service.

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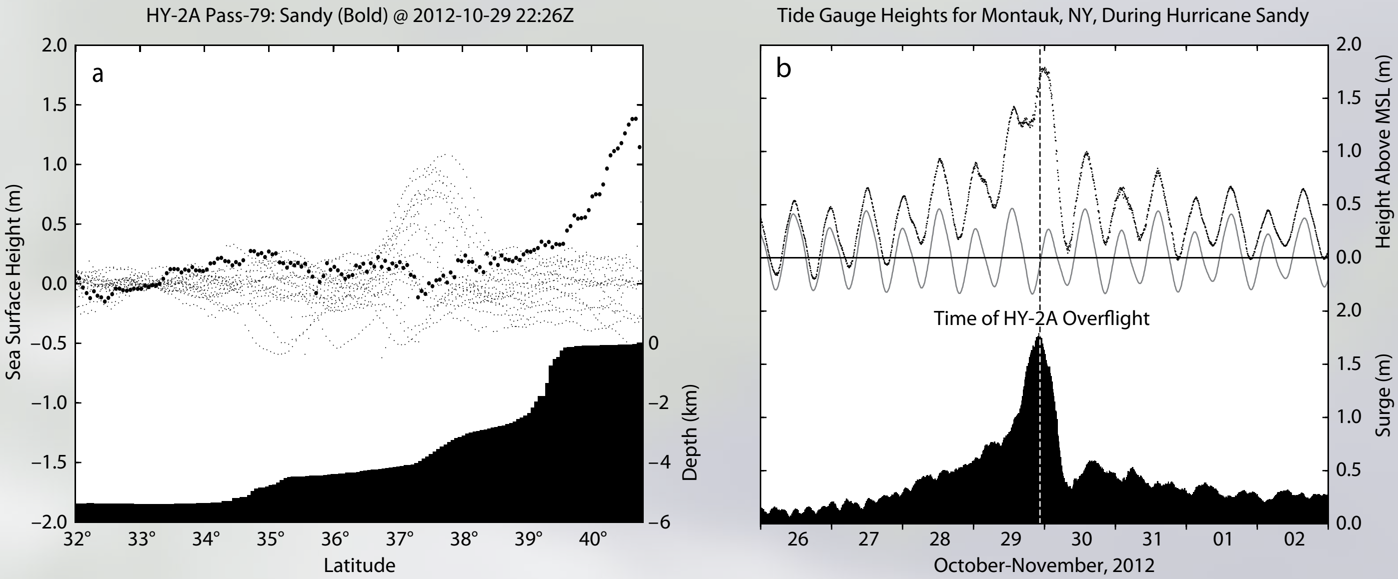

Figure 2. (a) Altimetric profiles of sea surface height from HY-2A pass-79. The bold dots are from October 29, 2012, just prior to Hurricane Sandy's landfall (cycle 29). Light dots are from earlier and later repeat cycles (13–16, 19–25, 30, 33–39). Ocean bottom topography is shown on the bottom in black. Sandy's storm surge is measured by the altimeter, with sea level rising over the continental shelf from 39.5° to 41°N. Further offshore, the meandering Gulf Stream causes one meter height variations around 37–38°N. (b) Tide gauge measurements from Montauk, NY, from October 26 to November 2, 2012. The dotted curve at the top shows the observed water levels, relative to mean sea level, every six minutes. The solid line below is the tidal prediction. Surge is defined as the difference between these curves, shown in black at the bottom. The timing of HY-2A's over flight (vertical dashed line) was extremely fortunate, passing over Long Island right at the peak of the storm surge.

one-second along-track values to suppress range noise in the HY-2A altimetry data, and each profile is offset relative to a zero-mean from 32–34°N to remove biases due to residual orbit error.

Altimetric sea surface heights can provide direct measurements of the spatial structure of storm surges for model validation and improvement when a satellite altimeter sees an event. Initiatives such as the European Space Agency's eSurge project (http://www.storm-surge.info) can benefit from altimetry data for retrospective analyses of storm events and for improving surge forecasts. Scharroo et al. (2005) and, more recently, Han et al. (2012), show that when an altimeter crosses a region impacted by strong storms, the altimeter can detect the surge's height signal.

The constellation of altimetric satellites currently in orbit (Jason-1, Jason-2, Cryosat-2, HY-2A, and SARAL/AltiKa) provides nadir-only measurements along each satellite's ground track. HY-2A was the only one of these satellites that crossed the New York Bight region near the time of Sandy's landfall. Although this constellation is inadequate for operational storm surge monitoring, when an altimeter captures the height signal from one of these events, it provides valuable spatial information of the surge's structure.

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