

Hurricane Sandy Inundation Probabilities of *Today and Tomorrow*

WILLIAM SWEET, CHRIS ZERVAS, STEPHEN GILL, JOSEPH PARK

NOAA NATIONAL OCEAN SERVICE

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Hurricane Sandy struck the U.S. mid-Atlantic seaboard on 29-30 Oct 2012 causing widespread and severe damage, resulting in mitigation expenditures of $60 billion. Sandy's devastating 2.7-m storm tide (MHHW) measured at the NOAA Battery, NY and Sandy Hook, NJ tide gauges is largely attributable to its rare onshore-impact angle and massive storm surge coincident with high tide.

Here we show how another less-salient factor – sea level rise (SLR) – attributed to Sandy's impacts and how it may change probabilities of future events leading to recurring economic losses.

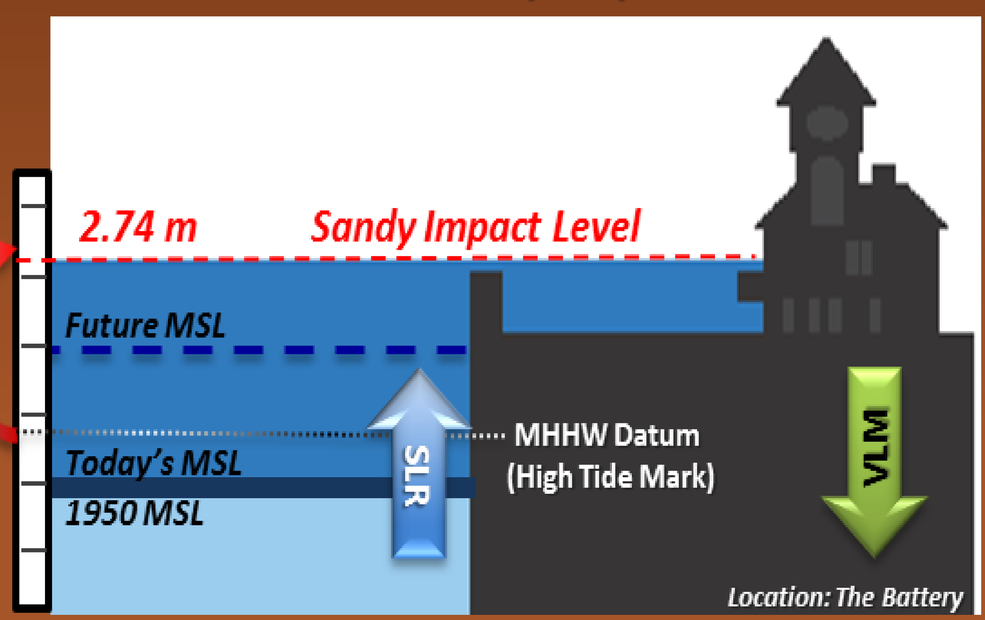


Figure 1: Schematic displaying how *freeboard* lessens as mean sea level (MSL) rises closer to Sandy-impact levels at the Battery, NY from a combination of SLR and downward vertical land motion (VLM).

How have return intervals for Sandy-impact levels changed since 1950?

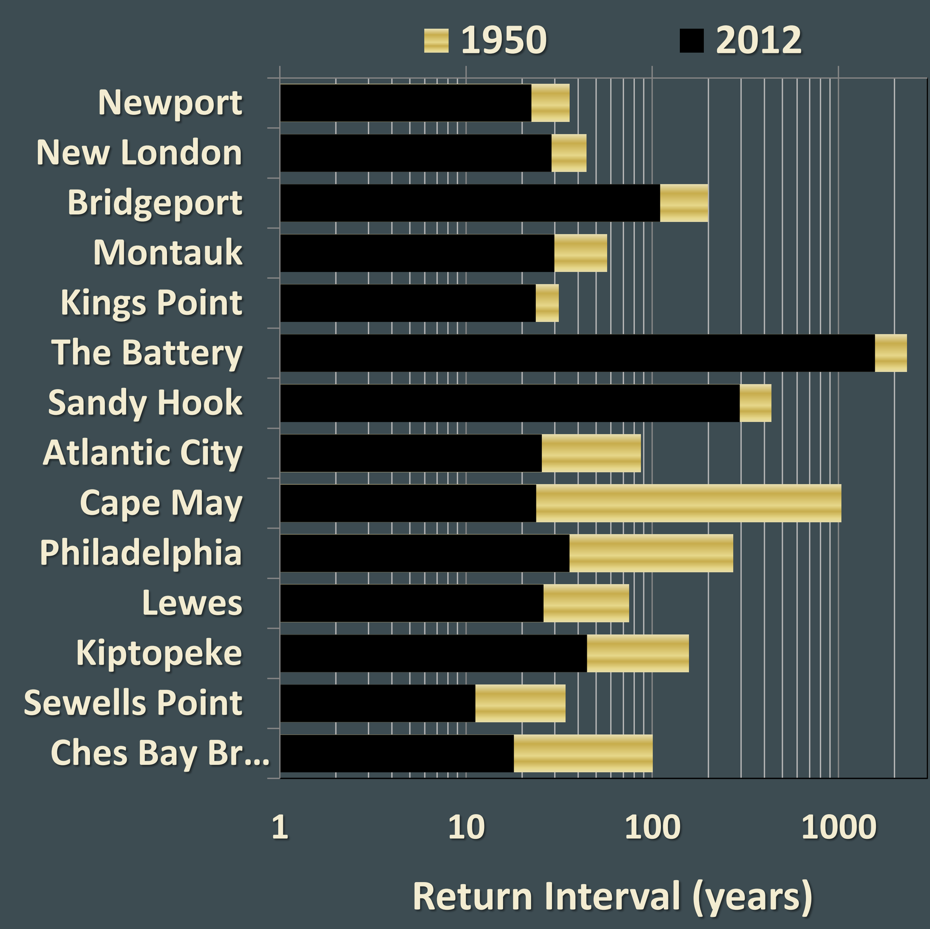


Figure 4: The rate of changes in RI between 1950 and 2012 for Sandy-impact levels is a function of historical SLR_{rel} trends and GEV model "shape" or flatness (i.e., Fig. 3).

SLR_{rel} has decreased the RI of Sandy-level inundation events. The 2012 RI of 295 and 1570 years at Sandy Hook and the Battery, respectively, was 435 and 2330 years in 1950 when MSL was lower and required a larger storm tide to reach Sandy-impact levels (~1/3 decrease at these locations). South of Atlantic City the model suggests that a once-in-a-century event or beyond in 1950 will now recur every couple of decades (~2/3 decrease).

NOAA tide gauge data is used to document impact factors, derive probabilities of Sandy-impact levels and estimate how these probabilities have changed over the 20th century and how they may vary in the future under SLR_{rel} scenarios of the 2013 US National Climate Assessment (NCA).

Figure 2: Impact levels at NOAA tide gauges shown as dots or stars (historical max. storm tide) relative to the 1983/01 mean higher high water (MHHW) tidal datum

with table showing:

- maximum storm surge
- phase of max. surge relative to peak storm tide level / high tide (± 6.4 hr implies near low tide)
- 2012 RI of Sandy-impact levels (1983-2001 RI & 95% confidence intervals: tidesandcurrents.noaa.gov/est/)
- record length for RI computation
- sinking VLM rates

	Surge (m)	Phase (hr)	2012 RI (yr)	Length (yr)	VLM (mm/yr)
Newport	1.63	-0.7	22	80	0.9
New London	1.98	-1.3	29	72	0.7
Bridgeport	3.00	-1.8	110	48	0.8
Montauk	1.79	-2	30	63	1.2
Kings Point	3.86	-3.1	24	78	0.7
The Battery	2.87	0	1570	120	1.2
Sandy Hook	2.61	0	295	80	2.3
Atlantic City	1.77	-3.7	26	97	2.2
Cape May	1.57	4.3	24	44	2.1
Philadelphia	1.78	1.2	36	109	1.1
Lewes	1.63	4.5	26	71	1.7
Kiptopeke	1.15	-5.1	45	60	1.6
Sewells Pt	1.39	-5.9	11	83	2.6
CBBT	1.33	-4.5	18	36	3.3

How might return intervals for Sandy-impact levels change in the future?

Year 2050 and 2100 RI for Sandy-impact levels using 4 NCA SLR_{rel} scenarios (global mean SLR in Fig. 5 + local VLM rates) initiate in 2013 following USACE (2011) guidelines:

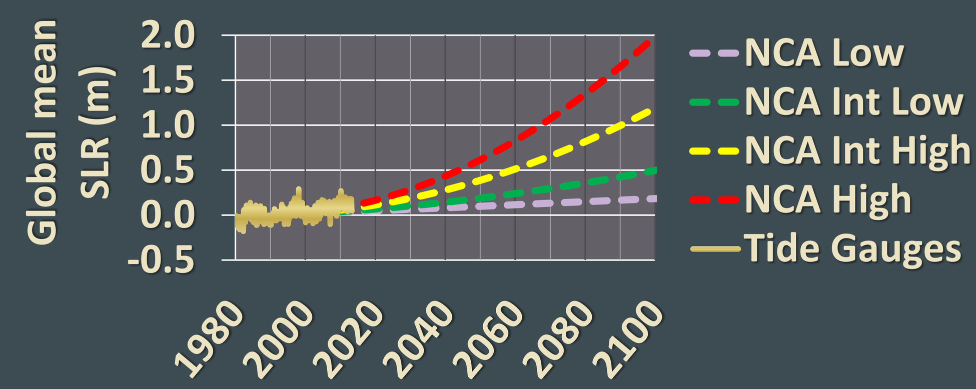


Figure 5: NCA global SLR scenarios with a mid-Atlantic tide-gauge MSL indicator tracking *current trajectory*:

- All monthly mean observations detrended by the trend quantified over record start through 1992
- Individual tide gauge time series are then group averaged
- 1.7 mm/yr trend (20th-century avg.) is applied

Figure 6: Time-dependent Sandy-impact level RI decrease as a function of NCA SLR_{rel} scenarios.

They decay more rapidly south of Atlantic City where VLM rates are higher (table, Fig. 2).

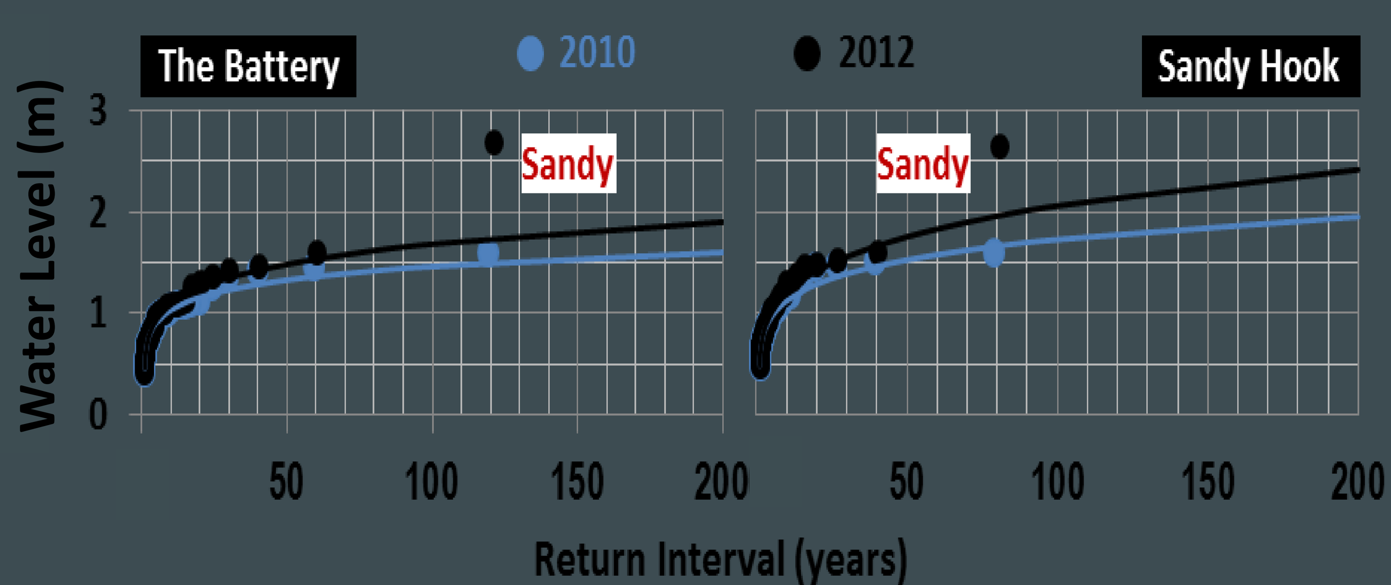
RI are ~annual under the High Scenario from Atlantic City southward by 2050 and by 2100 under the Int. High and Int. Low Scenarios. From Kings Point northward where VLM is less, RI of Sandy-impact level events decay more slowly. At the Battery and Sandy Hook, RI become ~50 and 20 years by 2100 under Int. High and ≤2 years under the High Scenario.

Probabilities from a nonstationary* generalized extreme value (GEV) model of annual maxima through 2010 (detrended relative to 1983-2001 datum) quantify Sandy RI. RI were recomputed through 2012 to include Sandy where applicable since GEV models are sensitive to the most extreme value in the distribution as well as record length (**below).

*Current (2012) and historical (1950) RI for Sandy-impact levels are obtained by raising or lowering, respectively, a tide-gauge station's GEV model by its historical SLR_{rel} trend (tidesandcurrents.noaa.gov/sltrends).

Figure 3: GEV model(s) with Sandy's RI as the x-axis value when the model intersects the y-axis value of Sandy.

** If Sandy Hook's record was as long as the Battery's, it GEV model shape would be flatter and Sandy's return interval would be longer



Sandy was a rare event (e.g., 1570-year RI at the Battery) as estimated by tide gauge records. While still rare, SLR_{rel} has decreased the RI of Sandy-impact level events by ~1/3 - 2/3 between 1950 and 2012 from an integrated SLR response (global SLR, VLM and ocean dynamics). Future scenarios not considering ocean dynamic changes (e.g., Gulf Stream slowdown) are concerning, implying events of less severity (from less powerful storms) will produce similar impacts. Coastal communities are facing a looming SLR_{rel} crisis manifested as increased frequency of Sandy-like inundation disasters in the coming decades along the mid-Atlantic and elsewhere.