A New Storm Impact Scale Used to Predict Coastal Erosion, Splash-over and Coastal Flooding

John Cannon
NOAA/National Weather Service
Maine Beaches Conference
17 July, 2015

Partnerships:

Maine Sea Grant
UMaine
NERACOOS
Wells National Reserve
Maine Geological Survey
City of Hampton and Saco
NOAA in New England Group
ME/NH Emergency Mgrs. & City Officials
NH Coastal Adaptation Workgroup
...And many others...
Coastal Hazards

- Severe thunderstorms
  - Damaging winds, hail and Lightning

- Marine Hazards
  - Hurricanes, Tsunamis, Rip Currents, Cold Water Drowning, Freezing Spray, Oil Spills, Arctic Sea Smoke

- Winter Storms
  - Ice Storms
  - Blizzards
  - Nor’easters…
  - Large Ocean Waves: Coastal Erosion and Coastal Flooding

- Fresh Water Flooding
Forecasting and Communicating Coastal Impacts

Complex: Requires several partnerships

- Modelers/Researchers/Social Scientists
- Meteorologists/Oceanographers/Climatologists
- Geologists/Emergency Managers (verification)

Long term Scale

Storm Scale
...Looking at the Whole Picture...
Sea Grant Project on SLR, Coastal Inundation, Surf Zone

1. Atmospheric models
2. Tide, surge & wave models
3. Surf zone models
Public Perception During Coastal Storms

Ocean Water is Actually the Greatest Threat

Public Perception (ERG Public Survey 2012)
The Wave vs. Coastal Inundation Paradox
Which is the greater threat for your location???
A Conceptual Model of a Storm that Produces Large, Battering Waves in ME/NH

Feb 26th, 2010 Intense Nor’ easter Produced Significant Erosion/Damage
Why Model Wave Run-up???

• “Waves contribute a significant amount to total water level during high impact events” (Stockdon)

• “Wave action is the ultimate cause of most structural damage and beach erosion” (Stockdon)
## Example of Wave Run-up Research

### Table I: Known combinations of storm tides (below flood stage) and wave heights that resulted in "Splash-over" damage (ME/NH)

<table>
<thead>
<tr>
<th>Date</th>
<th>Near-shore waves</th>
<th>Coinciding Storm Tide (Below FS)</th>
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<tbody>
<tr>
<td>3/4/91</td>
<td>7'</td>
<td>11.08' (Portland Harbor)</td>
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<td>1/4/94</td>
<td>6'</td>
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<td>3/2/10</td>
<td>10-13'</td>
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<td>3/3/10</td>
<td>7'</td>
<td>11.70' (Saco)</td>
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Coastal Flooding and The Relationship between High Storm Tides and Large Ocean Waves

A Dangerous Combination: As Wave Heights & Storm Tides Increase...the Threat of Coastal Damage Increases

Coastal Flooding and The Relationship between High Storm Tides and Large Ocean Waves

Wave Climatology Portland, Maine (2007)
### Saco Coastal Flooding and Splash-over Forecast Matrix

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<th>Forecast Wave Height (Ft) (Buoy “B” or “44007”)</th>
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**Ac** = Action stage. High water levels or wave action with limited or unknown impact.

**Mi** = Minor coastal flooding or splash-over along several roads and basements

**Md** = Moderate coastal flooding or significant splash-over along numerous roadways. Isolated structural damage.

**Mj** = Major coastal flooding with widespread flooding of vulnerable roadways. A few homes severely damaged.

**FS** = 12.75 ft

Forecast Storm Tide (Ft) (MLLW, Portland, ME)
Other Recent Wave Run-up Funded Projects

- **NART “Seed Money”: Funding Our Wave Run-up Project**
  - Funded the “Stockdon” visit (USGS Research Oceanographer)

- **Maine Sea Grant Program: Funding Wave Run-up Research**
  - NWS GYX is a CO-PI with UMaine School of Env. Eng.
    - Joint proposals led to $150,000 grant
    - Two Year study of Wave Run-up and coastal inundation

- **NERACOOS Funded Projects**
Elements of the storm-impact predictive model

Given offshore **forcing**: hurricane wind, pressure, waves ($H, T$)

and local beach/dune morphology

\[ R_{\text{high}} = \text{surge} + \text{runup} + \text{tide} \]
where runup = $f(H, T, \beta)$

\[ R_{\text{low}} = \text{surge} + \text{wave setup} \]
where setup = $f(H, T, \beta)$

\[ D_{\text{high}} = \text{dune crest} \]
\[ D_{\text{low}} = \text{dune toe} \]
Large Waves = “Wave Setup” + “Runup” Contributions
Modeling Wave Run-up

- Dune Crest
- Max Runup Level
- Wave Bore
- Dune Toe
- Setup
- Max Setup Level

Tide
Surge

Mignone 2013
Predicting Erosion, Overwash and Inundation
Stockdon (USGS) Empirical Collision Model

Elements of the storm-impact predictive model

Given offshore forcing: hurricane wind, pressure, waves (H, T)

And local beach/dune morphology

$R_{\text{high}} = \text{surge} + \text{runup} + \text{tide}$
where $\text{runup} = f(H, T, \beta)$

$R_{\text{low}} = \text{surge} + \text{wave setup}$
where $\text{setup} = f(H, T, \beta)$

$D_{\text{high}} = \text{dune crest}$

$D_{\text{low}} = \text{dune toe}$

Predict likely morphologic response - type and magnitude
Elements of Storm Impact Scaling Model

Swash Regime:
Minimal erosion/effect on the dunes

$R_{\text{high}} = \text{tide} + \text{surge} + R_2$

$R_{\text{low}} = \text{tide} + \text{surge} + <\eta>$
Collision Regime: *Erosion of dunes/ Some splash-over*

\[ R_{high} = \text{tide + surge + } R_2 \]

\[ R_{low} = \text{tide + surge + } <\eta> \]
Elements of Storm Impact Scaling Model

Overwash Regime: Splash-over & Backwater flooding

$R_{high} = \text{tide} + \text{surge} + R_2$

$R_{low} = \text{tide} + \text{surge} + <\eta>$

$dune\ crest$

$dune\ toe$

$D_{high}$

$D_{low}$

still water level
Inundation Regime: Coastal Flooding

\[ R_{\text{low}} = \text{tide} + \text{surge} + \langle \eta \rangle \]
\[ R_{\text{high}} = \text{tide} + \text{surge} + R_2 \]

Dunes are effectively underwater.
Parameterizing Runup Elevation

\[ R_2 = \left( 0.35 B_f \left( H_0 L_0 \right)^{1/2} + \frac{H_0 L_0 (0.563 \beta_f^2 + 0.004)}{2} \right)^{1/2} \]

- Deepwater Wave Height (20m Isobath)
- Deepwater Wave Length (20m)
- Before Shore Beach Slope
Parameterizing Runup Elevation

\[ R_2 = \left( 0.35B_f (H_0 L_0)^{1/2} + \frac{H_0 L_0 (0.563 \beta_f^2 + 0.004)}{2} \right)^{1/2} \]

- **Wave Setup**
- **Swash**
  - This is a time varying water level
  - Large waves making incursions up the beach
NART Wave Run-up Timeline

- September, 2012: First “Wave Run-up” survey sites in New England & Hindcasts Reviewed
- September, 2013: New surveys completed with Dr. Stockdon
- December, 2013: WFO GYX Spreadsheet output with WFO CAR auto-generating 2X daily forecast output
- 2014-2015: Additional Sites Surveyed: ME to VA
NART Train-the-Trainer Wave Runup Workshop (April 2014)

- Classroom and “field” training
Wave Run-up Surveyed Sites
...Stockdon’s Run-up Approach...

- Continuous Array of Run-up calculations
- Leverages use of LIDAR Data
Our “Northeast” Wave Run-Up Approach

- **Goal:** Establish test sites in coastal “hotspots” to evaluate performance of Stockdon wave run-up equations

- These are vulnerable locations with complex bathymetry and topography
  - Therefore: Individual sight surveys are preferred compared to Stockdon LIDAR based surveys
  - Also, Non-Pristine Dune Areas Surveyed
    - Seawalls, Rocky Shorelines, Manmade dune systems etc.
Surveying with Dr. Stockdon
Maine & New Hampshire

- Organized visits with EMA Directors
  - Use average of determined slopes
  (Breach occurring along Fortunes Rocks Beach)

High Risk Areas
Wave Run-up Hindcasts and Beach Profiles (verification)

- Use Beach Profiles as verification
- 2014-2015 season relatively quiet despite numerous snowstorms
- Most events had a north/northwest flow
Stockdon Equations: December 27th, 2012 Storm

- Seas 21-25 feet at high tide (nearshore buoys)

- Astronomical tide only 9.5’ in PWM Harbor + Storm surge 2.5’ = Yields Storm tide 12.0 feet (FS=12.0 ‘)

- On a sunny day, 12.0 feet = minimal issues
  - But not this day
Storm Impact and Surf Calculator

Choose one of the buttons below to forecast storm impacts or surf height.

- Storm Impact Model
- Surf Height
- Exit

Wave Height (m): 4.87

Period (s): 10

Surge (m): 0.73

Tide (m): 2.93

Dune Base Elevation (m): 5.27425920

Dune Crest Elevation (m): 6.1856120

Slope: 0.14000

Erosion: Expected

Overwash: Not Expected

Inundation: Not Expected

Total Water Level: M: 5.01 M

Total Water Level: R: 7.004 M

R25: 3.344 M

This is for point forecasting only! Impacts will vary significantly up and down the coast—See documentation for how to select input for this application.
Wave Runup Initiative - - “Sandy”

Hampton Beach, New Hampshire, October 2012

Correctly forecasted erosion and overwash

Waves ~31 ft
Hampton New Hampshire During Sandy
Back-Water Flooding
Wave Run-up Verification: “Storm Based” Beach Profiling Teams
(MGS, Sea Grant & Wells Reserve)
Sandy’s Impact: Oct. 28th 2012

Significant Erosion Wells Beach (Casino Point, WE00)

Beach Profile

Before

After

Note Date

BP - WE00 on 11/3/2012
BP - WE00 on 10/13/2012
BP - WE00 on 9/15/2012
BP - WE00 on 8/26/2012
A Note About Beach “Erosion”

Wells, Maine
(February 8th)
February 8th “Blizzard” Gooches Beach

- Tree stumps
- 3000-4000 yrs based on radiocarbon

“I'd estimate the waves were between 12-16 feet high and really rolling in. Our sea wall took a battering and various parts of it were floating around in the surf, including sections of our new ramp. The town BPW tried to protect it by piling sand on the seaward side of it, which took almost no time at all to wash away” – J. White
NNW Flow: Gain in profile near landward side of the dunes

CE01

Gain near dune structure

Loss below dune structure
January 3\textsuperscript{rd} 2014 Coastal Flood Event
3 January 2014 Wave Run-up (Excel)

Stockdon Equations...
- Accurately predicted Erosion and Overwash at Several Locations
- Had issues with over-forecasting inundation at Wells and Middle Beach
- Did not forecast “overwash” in Hampton
Ice Accretion Due to Splash-over (Saco)
January 27th, 2015 Blizzard
Runup and Setup Calculator For the Grays Area

**Input parameters**

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<td>Deep water wave period</td>
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<td>Tide in Feet above MLLW</td>
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<td>Storm Surge in Feet</td>
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### Biddeford
 Elevation of Dune = 20.36 ft MLLW

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<thead>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Setup Level ( R_{\text{low}} )</td>
<td>14.22</td>
</tr>
<tr>
<td>Max Runup Level ( R_{\text{high}} )</td>
<td>19.00</td>
</tr>
<tr>
<td>Max Runup ( R_{2%} )</td>
<td>6.90</td>
</tr>
</tbody>
</table>

Erosion: Erosion
Overwash: Not Expected
Inundation: Not Expected

### Jennis Beach
 Elevation of Dune = 13.57 ft MLLW

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Setup Level ( R_{\text{low}} )</td>
<td>13.26</td>
</tr>
<tr>
<td>Max Runup Level ( R_{\text{high}} )</td>
<td>17.43</td>
</tr>
<tr>
<td>Max Runup ( R_{2%} )</td>
<td>5.33</td>
</tr>
</tbody>
</table>

Erosion: Erosion
Overwash: Overwash
Inundation: Not Expected

### Camp Ellis
 Elevation of Dune = 17.03 ft MLLW

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Setup Level ( R_{\text{low}} )</td>
<td>16.38</td>
</tr>
<tr>
<td>Max Runup Level ( R_{\text{high}} )</td>
<td>23.13</td>
</tr>
<tr>
<td>Max Runup ( R_{2%} )</td>
<td>11.03</td>
</tr>
</tbody>
</table>

Erosion: Erosion
Overwash: Overwash
Inundation: Not Expected

### Popham Beach
 Elevation of Dune = 22.69 ft MLLW

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Setup Level ( R_{\text{low}} )</td>
<td>14.80</td>
</tr>
<tr>
<td>Max Runup Level ( R_{\text{high}} )</td>
<td>20.04</td>
</tr>
<tr>
<td>Max Runup ( R_{2%} )</td>
<td>7.94</td>
</tr>
</tbody>
</table>

Erosion: Erosion
Overwash: Not Expected
Inundation: Not Expected

### Ferry Beach
 Elevation of Dune = 18.05 ft MLLW

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Setup Level ( R_{\text{low}} )</td>
<td>15.18</td>
</tr>
<tr>
<td>Max Runup Level ( R_{\text{high}} )</td>
<td>20.77</td>
</tr>
<tr>
<td>Max Runup ( R_{2%} )</td>
<td>8.67</td>
</tr>
</tbody>
</table>

Erosion: Erosion
Overwash: Overwash
Inundation: Not Expected

---

Stockdon Empirical Equations to Estimate Erosion, Splash-over or Inundation Potential (Use 20M Isobath & Tide gage data):

<table>
<thead>
<tr>
<th>Beach Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jennis Beach (NH Seacoast)</td>
</tr>
<tr>
<td>Ferry Beach Saco</td>
</tr>
<tr>
<td>Camp Ellis Saco</td>
</tr>
<tr>
<td>Fortunes Rocks Beach Biddeford</td>
</tr>
<tr>
<td>Long Beach York</td>
</tr>
<tr>
<td>Wells Beach</td>
</tr>
<tr>
<td>Middle Beach KBunk</td>
</tr>
<tr>
<td>Gooches Beach KBunk</td>
</tr>
<tr>
<td>Hampton Beach</td>
</tr>
<tr>
<td>Popham Beach</td>
</tr>
</tbody>
</table>

Stockdon Equations for all Duned Beaches
TIDES/COASTAL FLOODING...
ASTRONOMICAL TIDES ARE AT THEIR PEAK FOR THE MONTH. THIS...IN
COMBINATION WITH STRONG SOUtherLY DEVELOPING GALES (WITH POSSIBLE
STORM FORCE GUSTs) WILL LIKELY ALLOW FOR ABOUT A 1 FOOT STORM
SURGE. WITH BUILDING WAVES IN THE 15 FOOT RANGE...EXPECT A FEW
AREAS TO HAVE COASTAL FLOODING...SPLASH-OVER AND BEACH EROSION.

NART WAVE RUN-UP MATRICES ARE ALREADY PREDICTING THE POTENTIAL FOR
COASTAL FLOODING...OVERWASH AND EROSION ACROSS MOST LOCATIONS IN
MAINE AND NEW HAMPSHIRE BASED ON OUR CURRENT STORM SURGE AND WAVE
PREDICTIONS.

THE QUESTION IS HOWEVER...WHEN WILL THE PEAK WINDS AND SEAS
ARRIVE? RIGHT NOW IT IS TOO EARLY TO TELL IF THIS PERIOD OF
INCLEMENT WEATHER/OCEAN CONDITIONS WILL ARRIVE NEAR THE TIME OF
HIGH TIDE. THE MIDDAY TIDES ON CHRISTMAS EVE AND CHRISTMAS DAY ARE
THE HIGHEST AT 11 FEET...WHILE THE 1 AM CHRISTMAS MORNING HIGH
TIDE IS LOWER AT 10 FEET.
Beach Profile

Vertical Distance from Stake (cm)

Horizontal Distance (M)

BP - GO01 on 5/22/2015
BP - GO01 on 3/13/2015
BP - GO01 on 3/11/2015
BP - GO01 on 1/16/2015
BP - GO01 on 12/13/2014
BP - GO01 on 11/15/2014
Changing Beach Profiles and Rip Current Locations

RIP CURRENTS
Break the Grip of the Rip!

Rip currents are powerful currents of water moving away from shore. They can sweep even the strongest swimmer out to sea.

Maine Lifeguard Contacts
Stockdon Equation and Predicted Wave Heights: A Dilemma

- Stockdon Equations Use Wave Heights at 20m isobath
  - This value is used to empirically relate wave runup in the breaker zone
- Need to leverage high res modeling in complex bathymetry
  - Maine Sea Grant Project with UMaine
Future Work/Next Steps...

- Establish new wave Run-up sites
- Outreach with local EMs & First Responders
- Develop Model Viewer/Communicate Products
- Test with Real-time events and Hindcasts
Ultimate Goal to Protect Life and Property
Coastal Flood Warning Metrics NWS Gray, Maine
Average Lead Time (2007-Present)
Thanks for your time !!!!!
Questions/Comments ???

john.w.cannon@noaa.gov