The Latest Science on High Tide Flooding

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NOAA Office for Coastal Management

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New Hampshire Climate Summit
Sea Level Rise Literature Review

Science and Technical Advisory Panel (NHCRHC, 2014)

1. **Determine** the time period over which the system is designed to serve (either in the range 2014 to 2050, or 2051 to 2100).

2. **Commit** to manage to the *Intermediate High* condition, but be **prepared** to manage and adapt to the *Highest* condition if necessary.

3. **Be aware** that the projected sea-level rise ranges may change and adjust if necessary. *(The scientific basis for these ranges should be reviewed regularly and the ranges updated as needed.)*

From USACE ETL 1100-2-1
Global Sea Level Rise Scenarios for the United States National Climate Assessment

From Parris et al., 2012

<table>
<thead>
<tr>
<th>Scenario</th>
<th>SLR by 2100 (m)*</th>
<th>SLR by 2100 (ft)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>2.0</td>
<td>6.6</td>
</tr>
<tr>
<td>Intermediate-High</td>
<td>1.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Intermediate-Low</td>
<td>0.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Lowest</td>
<td>0.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

* Using mean sea level in 1900 as a starting point.

Graph showing observed and modeled sea level rise scenarios from 1900 to 2100.
“Consensus Scenarios” that fed the NCA 3rd Assessment

From Parris et al., 2012
Sources of Uncertainty?

**Contributions to SLR in Boston (2003-2015)**

**Main Causes of Sea Level Rise 2002 - 2014**

- Antarctic ice sheet melt: 0.26 mm/yr
- Glacier melt: 0.38 mm/yr
- Greenland ice sheet melt: 0.73 mm/yr
- Expansion from ocean warming: 1.38 mm/yr

*Source: Rietbroek et al., Revisiting the contemporary sea-level budget on global and regional scales.*

New Global and Regional Scenarios

Advancements associated with:
- Probabilistic modeling considering RCP2.6, RCP4.5, and RCP8.5
- Relative sea level change driven by regional process modeling

From Sweet et al., 2017
## New Global and Regional Scenarios

From Sweet et al., 2017

<table>
<thead>
<tr>
<th>GMSL Scenario (meters)</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>2060</th>
<th>2070</th>
<th>2080</th>
<th>2090</th>
<th>2100</th>
<th>2120</th>
<th>2150</th>
<th>2200</th>
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</thead>
<tbody>
<tr>
<td>Low</td>
<td>0.03</td>
<td>0.06</td>
<td>0.09</td>
<td>0.13</td>
<td>0.16</td>
<td>0.19</td>
<td>0.22</td>
<td>0.25</td>
<td>0.28</td>
<td>0.30</td>
<td>0.34</td>
<td>0.37</td>
<td>0.39</td>
</tr>
<tr>
<td>Intermediate-Low</td>
<td>0.04</td>
<td>0.08</td>
<td>0.13</td>
<td>0.18</td>
<td>0.24</td>
<td>0.29</td>
<td>0.35</td>
<td>0.40</td>
<td>0.45</td>
<td>0.50</td>
<td>0.60</td>
<td>0.73</td>
<td>0.95</td>
</tr>
<tr>
<td>Intermediate</td>
<td>0.04</td>
<td>0.10</td>
<td>0.16</td>
<td>0.25</td>
<td>0.34</td>
<td>0.45</td>
<td>0.57</td>
<td>0.71</td>
<td>0.85</td>
<td>1.0</td>
<td>1.3</td>
<td>1.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Intermediate-High</td>
<td>0.05</td>
<td>0.10</td>
<td>0.19</td>
<td>0.30</td>
<td>0.44</td>
<td>0.60</td>
<td>0.79</td>
<td>1.0</td>
<td>1.2</td>
<td>1.5</td>
<td>2.0</td>
<td>3.1</td>
<td>5.1</td>
</tr>
<tr>
<td>High</td>
<td>0.05</td>
<td>0.11</td>
<td>0.21</td>
<td>0.36</td>
<td>0.54</td>
<td>0.77</td>
<td>1.0</td>
<td>1.3</td>
<td>1.7</td>
<td>2.0</td>
<td>2.8</td>
<td>4.3</td>
<td>7.5</td>
</tr>
<tr>
<td>Extreme</td>
<td>0.04</td>
<td>0.11</td>
<td>0.24</td>
<td>0.41</td>
<td>0.63</td>
<td>0.90</td>
<td>1.2</td>
<td>1.6</td>
<td>2.0</td>
<td>2.5</td>
<td>3.6</td>
<td>5.5</td>
<td>9.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GMSL Scenario Rates (mm/year)</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>2060</th>
<th>2070</th>
<th>2080</th>
<th>2090</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Intermediate-Low</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Intermediate</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Intermediate-High</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>13</td>
<td>15</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>High</td>
<td>6</td>
<td>8</td>
<td>13</td>
<td>16</td>
<td>20</td>
<td>24</td>
<td>28</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>Extreme</td>
<td>6</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
<td>44</td>
</tr>
</tbody>
</table>
Probabilities Related to RCPs

NOAA Global Mean Sea Level (GMSL) Scenarios for 2100

Table 4. Probability of exceeding GMSL (median value) scenarios in 2100 based upon Kopp et al. (2014).

<table>
<thead>
<tr>
<th>GMSL rise Scenario</th>
<th>RCP2.6</th>
<th>RCP4.5</th>
<th>RCP8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (0.3 m)</td>
<td>94%</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>Intermediate-Low (0.5 m)</td>
<td>49%</td>
<td>73%</td>
<td>96%</td>
</tr>
<tr>
<td>Intermediate (1.0 m)</td>
<td>2%</td>
<td>3%</td>
<td>17%</td>
</tr>
<tr>
<td>Intermediate-High (1.5 m)</td>
<td>0.4%</td>
<td>0.5%</td>
<td>1.3%</td>
</tr>
<tr>
<td>High (2.0 m)</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Extreme (2.5 m)</td>
<td>0.05%</td>
<td>0.05%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

From Sweet et al., 2017
Relative Sea Level Rise

GMSL adjusted for:
1. Oceanographic factors
2. Gravity changes due to melting land-based ice
3. Vertical land movement (VLM)

From Sweet et al., 2017
- Gauge 8419870, Seavey Island, ME
- RSL trend is 1.76 mm/yr from 1926-2001 (7” over 100 years)
- “More Likely” range is 1 to 4 feet
• Gauge 8419870, Seavey Island, ME
• Vertical Land Motion = 0.3 mm/year (rebound)
• “More Likely” range is 1.5 to 6 feet
• Projections extend to 2200 (not shown here)
High Tide Flooding

ANNOUNCING THE WINNERS OF THE #KINGTIDENH2017 PHOTO CONTEST
November 20, 2017 | By: Nathalie Morison
read more
NOAA NWS Flood Warnings

- **Minor**: more disruptive than damaging
- **Moderate**: damaging
- **Major**: destructive
Nationally Consistent High Tide Flooding Analysis and Projections

- Along the Northeast Atlantic, high tide flooding occurs in response to both tidal forcing and episodic nontidal effects.
- It is most frequent in the fall when the mean sea level cycle is at its highest, but it is relatively frequent throughout the cool season when northeasterly winds and nor’easters prevail.

From Sweet et al., 2018a
Flood Threshold Mapping

Sweet et al., 2018

NWS WFO derived map

[Color legend: High Tide Flood (Mostly Disruptive), Moderate Flood (Damaging), Major Flood (Often Destructive)]
Shifting Distributions

Between 2000 and 2015, annual flood frequencies have increased on average by about 75% (3.4 to 6.0 days/year) along the Northeast Atlantic.

From Sweet et al., 2017
High Tide Flooding Projections

- In many places, MHHW is expected to reach today’s minor high tide flood threshold by or before 2060.
- Under the Intermediate-Low and Intermediate SLR scenarios, by 2050, annual high tide floods along the Northeast Atlantic are expected to occur 45 and 130 days/year, respectively.

From Sweet et al., 2018a
2017 Meteorological Year in Review

- More than 25% of U.S. coastal locations broke records between May 2017 and April 2018
- Boston set a record with 22 days (NH had 13 but the record is incomplete)
- January 4, 2018 nor’easter set record water level of 1.49 meters above MHHW in Boston

From Sweet et al., 2018b
## 2018 Outlook

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Flood Height (m above MHHW)</th>
<th>Record as of 2016 (days/yr)</th>
<th>Typical Flood Frequency (circa 2000)</th>
<th>2017 High Tide Floods (observed)</th>
<th>2018 Outlook (trend)</th>
<th>Peak Season (1998-2016)</th>
<th>Main Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar Harbor</td>
<td>0.64</td>
<td>30</td>
<td>7</td>
<td>18</td>
<td>9±5</td>
<td>Winter</td>
<td>Tides</td>
</tr>
<tr>
<td>Portland</td>
<td>0.62</td>
<td>21</td>
<td>5</td>
<td>16</td>
<td>9±3</td>
<td>Winter</td>
<td>Tides</td>
</tr>
<tr>
<td>Boston</td>
<td>0.63</td>
<td>22</td>
<td>6</td>
<td>22</td>
<td>13±3</td>
<td>Winter</td>
<td>Tides</td>
</tr>
</tbody>
</table>

From Sweet et al., 2018b
Key Takeaways

• Scientific understanding of SLR and coastal flooding impacts is advancing rapidly
• Along regions of the Northeast Atlantic, relative sea level rise is projected to be greater than the global average for almost all future GMSL rise scenarios
• The frequency of intermittent flooding associated with unusually high tides has increased rapidly in response to increases in relative sea level.
• Freeboard between MHHW and flood thresholds is decreasing
• “Today’s flood will become tomorrow’s high tide.”
  – Margaret A. Davidson
Questions and Discussion

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GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES

PATTERNS AND PROJECTIONS OF HIGH TIDE FLOODING ALONG THE U.S. COASTLINE USING A COMMON IMPACT THRESHOLD

2017 State of U.S. High Tide Flooding with a 2018 Outlook