Geologic Site of the Month
December, 2014

Highest Astronomical Tide on the Maine Coast

Screaming Eagle Aviation

Pine Point and Scarborough River, Scarborough

Text by
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Introduction

The Gulf of Maine is home to the largest range in tidal elevations on the planet. In the Bay of Fundy (just north of the Maine coast) the height of the sea surface can shift by a staggering 50 feet between high and low tide (Thompson, 2010). Although the maximum tidal range in Maine is only about half that, the daily ocean fluctuations can have important implications for boaters, waterfront landowners, and coastal habitats. The control that the changing tides have on the distribution of Maine's salt marshes is of particular importance from an ecological standpoint (Slovinsky and Dickson, 2009). Additionally, storm surge and sea-level rise modeling efforts rely heavily on a precise understanding of how the tides drive changes in the elevation of the sea surface.

Figure 1. Weskeag River salt marshes in Thomaston, Maine.

The Maine Coastline

Due to Maine's unique coastal geology it has just under 3,500 miles of tidally-influenced coastline, more than the entire state of California (NOAA, 1975). There are 143 towns in the coastal zone all of which stand to be impacted by extreme high tides, sea level rise, and storm surge.

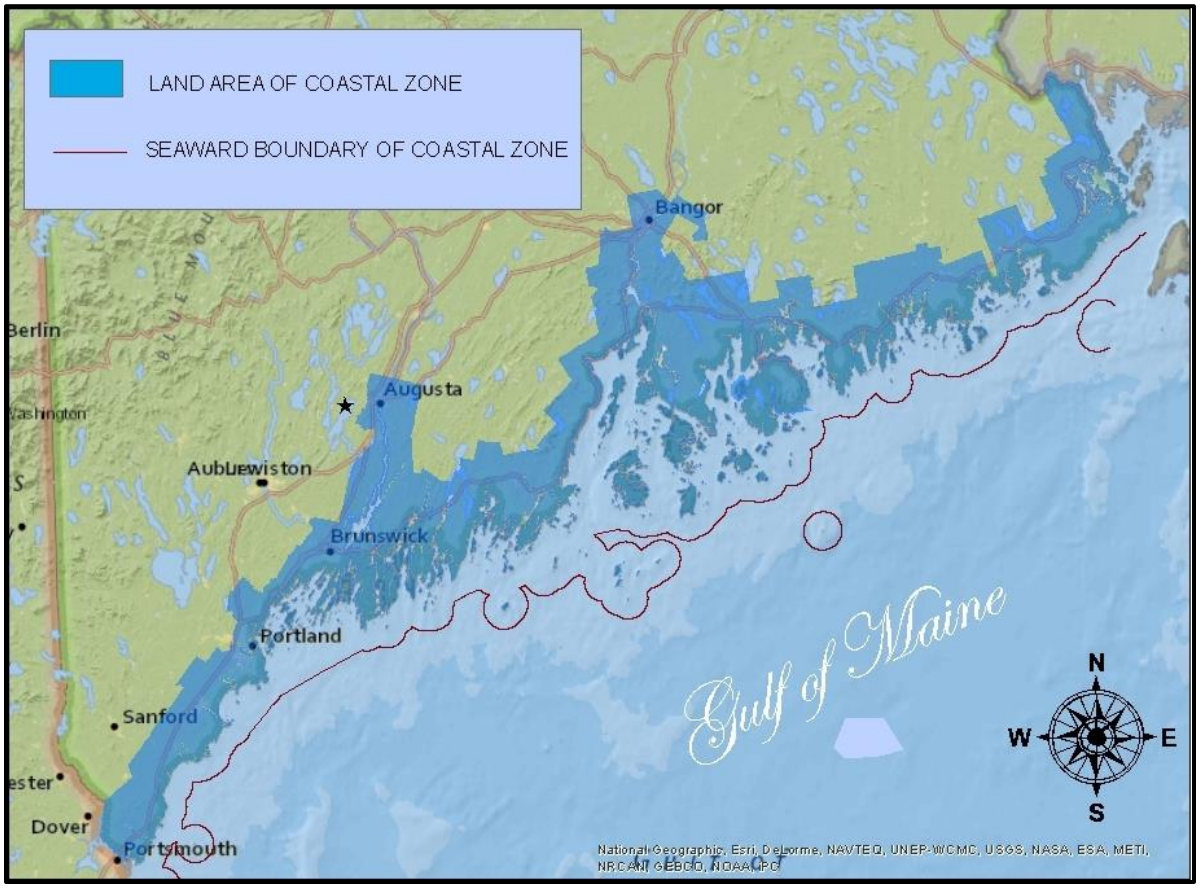


Figure 2. The Maine state coastal zone (courtesy of the Maine Coastal Program).

Forces Behind the Tides

It is widely known that the gravitational pull of the Moon plays a large role in generating Earth's tides. However, tidal dynamics are also shaped by the gravitation of the Sun, the centrifugal force from the orbit of the Earth, and the locations of the continents on the surface of our planet. The coast of Maine has a **semidiurnal tidal cycle** that produces two highs and two lows of similar magnitude each day (NOAA, 2013). Over the course of the year the tidal magnitudes can vary greatly based on the relative locations of the Sun and the Moon. When these two astronomical bodies are aligned relative to the Earth, their gravitational pull is additive and produces abnormally high **spring tides**. Conversely, when the two bodies exert their pull in opposite directions there is a cancelling effect that produces lower **neap tides**. There are two spring and two neap tides each month as the Moon completes its orbit around the Earth. Especially high tides are commonly referred to as **king tides**, though there is no scientific qualification for this term.

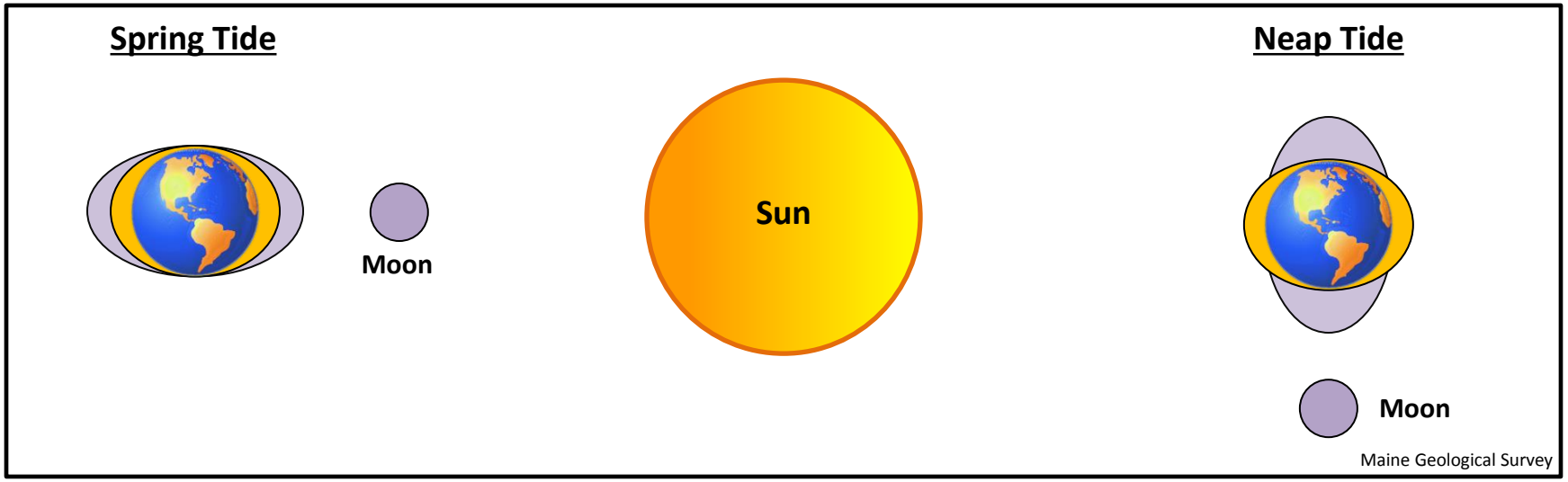


Figure 3. The influence of the Sun and Moon on the Earth's tidal cycle. Lunar tides are show in purple and solar tides are shown in yellow. Spring tides occur with both a New Moon and a Full Moon. King tides are similar to perigean tides.

Nuisance Flooding

Many developed areas of the Maine coast experience regular flooding during extreme high tides even in the absence of surge from a storm system. Most of the inundation is merely inconvenient to coastal communities and is therefore referred to as **nuisance flooding**. Sea level rise has contributed to the frequency of nuisance flooding in the Gulf of Maine and along the U.S. East Coast (Ezer and Atkinson, 2014; Sweet et al., 2014).

Figure 4a. Coastal flooding near Commercial Street in Portland from the king tide on October 9, 2014 .

Figure 4b. Nuisance flooding in Boothbay Harbor on October 8, 2014 .

Flooding from Extreme High Tides

During a king tide, unusual flooding can occur in areas indirectly connected to the ocean. Salt water can reach low-lying developed areas through adjacent marsh channels. The ocean can invade lowlands hundreds of feet from the coast through a subterranean network of storm drains. Instead of carrying fresh water to the ocean, some pipes can become artesian, flow backward, bringing salt water onto roads and sidewalks. For other king tide photographs, see King Tides Project (2014) in the references section.

Figure 5a. Salt water flooding during the king tide of October 27th 2011 at Pine Point Road in Scarborough.

Figure 5b. Salt water flooding during the king tide of October 27th 2011 at Somerset Street in Portland.

Annual *vs*. Astronomical High Tides

Astronomical positions and gravitational forces shift significantly over the course of a given calendar year, inevitably producing a single spring tide that exceeds all others in elevation. This peak tide is designated as the **highest annual tide** for that year. The elevation of the maximum tide will vary from year to year as the motions of the Earth, Moon, and Sun undergo predictable changes that affect tidal amplitudes. These astronomical changes complete a repeating cycle every 18.6 years, a period known as the **tidal epoch** (NOAA, 2000). The single highest tidal elevation predicted during a tidal epoch is known as the **Highest Astronomical Tide** (HAT; NOAA, 2013). The difference between the highest annual and highest astronomical tidal elevations varies slightly each year but is typically quite small (Table 1).

Tide Station	Highest Annual Tide 2015 Elevation (ft, MLLW)	Highest Astronomical Tide Elevation (ft, MLLW)	Difference in Elevation (inches)
Portland	11.8	12.0	**2.4**
Bar Harbor	13.6	13.7	**1.2**
Eastport	22.8	23.0	**2.4**

Maine Geological Survey

Table 1. The difference between the predicted highest annual tide for 2015 and the highest astronomical tide (HAT) at three of Maine's harmonic tidal stations. Values are given in the mean lower low water datum. Values from NOAA *Tides Online* and *Bench Mark Data Sheets* web sites.

Annual *vs*. Astronomical High Tides

The highest astronomical tide has a slightly larger extent than the highest annual tide in low lying areas. For most of the Maine coast, however, the difference between the two tidal elevations is extremely small.

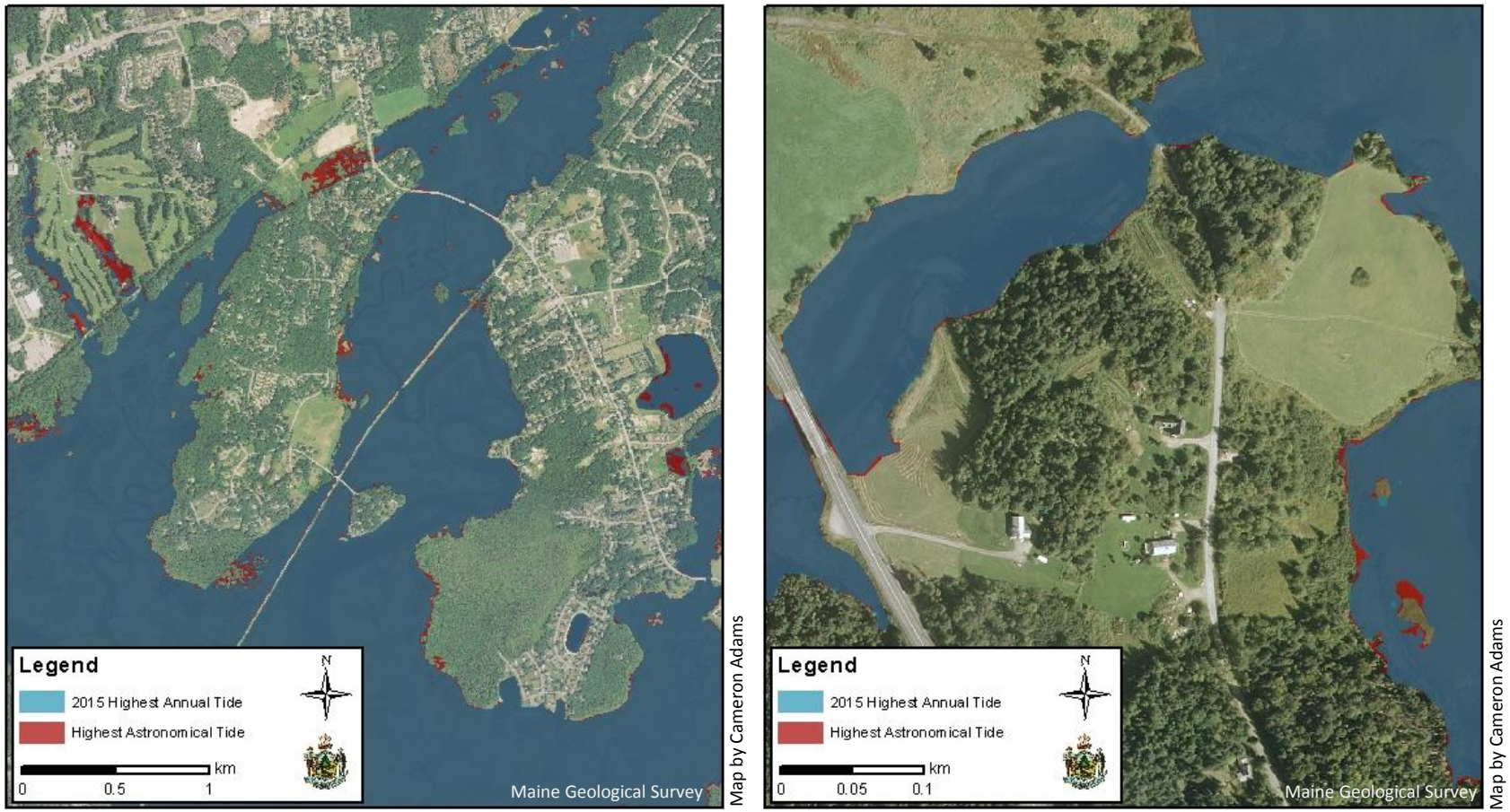
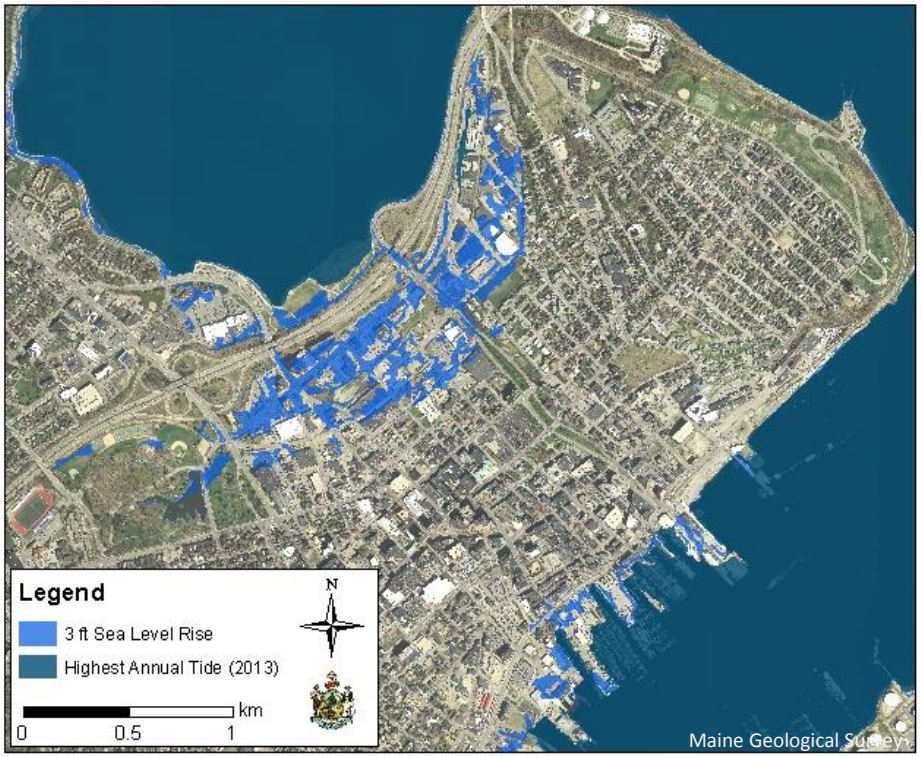


Figure 6. The extent of the highest astronomical tide and highest annual tide (2015) for the Scarborough marsh area (left) and Route 1 in Edmunds Township (right). Note the difference in scale. Images provided for general planning purposes only.

High Tides and Coastal Mapping

Maine planners and emergency managers have a vested interest in producing high-accuracy models for the potential impacts of extreme high tides, storm surge, or sea level rise. One of the most important components of such modelling efforts is a precise baseline sea level onto which predictions of future ocean changes may be superimposed. Maine uses highest annual tide elevations as a representation of present-day sea level and the upper boundary of coastal wetlands for shoreland zoning purposes (DEP, 2014). As a result, the highest annual tide elevation has become an implicit measure in a wide range of coastal building developments, environmental protections, and hazard analyses.



Map by Cameron Adams

Figure 7. Example of a sea-level rise model that is based off of highest annual tide elevations for Portland, Maine. The 2013 highest annual tide is shown in dark blue with 3 feet of sea level rise projected on top of it in light blue. Image for general planning purposes only.

Highest Astronomical Tide and Coastal Mapping

Highest annual tide elevations must be updated each year to account for changes in the maximum tidal elevation. In contrast, the National Oceanic and Atmospheric Administration (NOAA) calculates the highest astronomical tide and other tidal elevations as long-term metrics that do not require annual updates. Highest astronomical tide predictions can be utilized for up to two decades, but the 18.6 year National Tidal Datum Epoch (NTDE) may also be recalculated more frequently than this period if it is necessary to account for short term sea level rise. Typically this is only necessary in places like Louisiana and southern Alaska where local rates of sea level change are much higher than the global average (Gill et al., 2014).

Figure 8. A boat launch ramp in Edmunds Township in Washington County shows the large tidal range in eastern Maine within Cobscook Bay.

Highest Astronomical Tide and Coastal Mapping

Maps and inundation models that are based on the highest astronomical tide are beneficial for the following reasons:

1. The highest astronomical tide predicts the highest elevation of tidal influence along the coast and is therefore a good baseline for coastal mapping. Though the highest astronomical tide is slightly higher than the highest annual tide, the difference of a few inches is well below the ±9 inch combined uncertainty of the tidal predictions (VDATUM) and vertical resolution of the digital elevation model (Digital Coast).
2. The maximum extent of tidal influence is closely linked to the upper reach of the high salt marsh, *Spartina patens* (Slovinsky and Dickson, 2009), so mapping the highest astronomical tide is a good proxy for the landward boundary of a coastal wetland.
3. The highest astronomical tide is a constant, calculated, and predictable value for a given NTDE (and based on nearly 2 decades of data). This is especially important for coastal mapping and siting development.
4. Using the highest astronomical tide reduces the need for annual vertical adjustments that could result in minor year-to-year variability in setback lines for coastal construction.
5. The 20th Century rate of sea level rise in the Gulf of Maine, was about an inch a decade. Comparison of the current and previous NTDEs documents an upward trend in mean sea level upon which the highest astronomical tide is calculated.

References and Additional Information

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