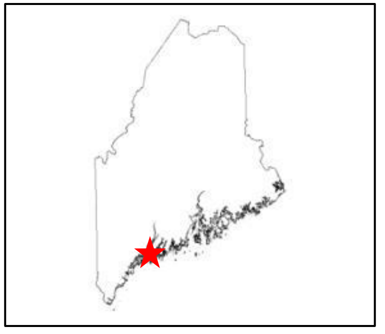
Geologic Site of the Month

May, 2012

Watching the Tides: The 100th Anniversary of the Portland, Maine Tidal Station



43° 39' 18.75" N, 70° 14' 43.78" W

Text by
Peter A. Slovinsky

Introduction

The Maine Geological Survey dedicated a previous site of the month (Dickson, 2007) to the Portland, Maine tidal station (Figure 1), a National Oceanic Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPs) tidal station which measures water levels in real-time 6-minute intervals, 24 hours a day. The Portland gauge is one of the longest continuously operating tidal stations in the United States, in operation since 1912. So, 2012 is the 100th anniversary of the Portland station!

Photo from NOAA's Tides & Currents website.

Figure 1. The small white building supports the operation of the Portland tide station. A vertical pipe or "stilling well" that removes the influence of small waves extends down below the pier into the ocean (to the left of the building).

Inspecting Sea Level Trends

One of the benefits of longer-term water level records is the ability to inspect sea level trends. For annualized data from 1912 through the end of 2011, the Portland tide gauge has shown an increase in mean sea level of approximately 1.9 mm per year (R^2 = 0.75), or about 7.5 inches over the past 100 years (Figure 2). This rate has mirrored global ocean sea level changes of 1.7 mm per year over about the last century, according to the IPCC (2007). Most of these global measurements have been derived from tidal station data until the mid-1990s.

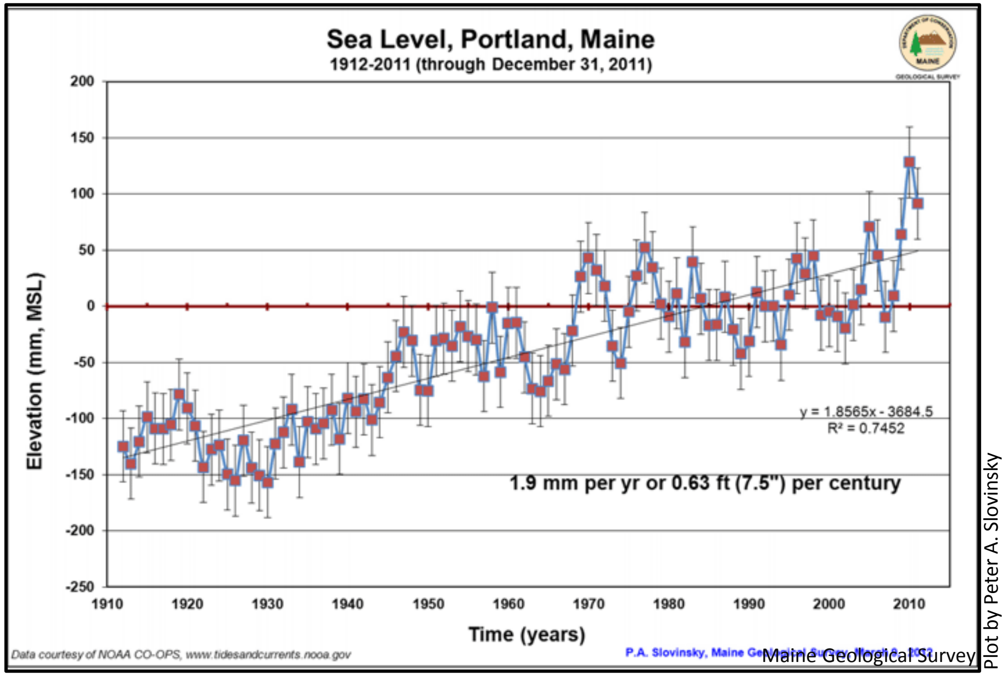


Figure 2. Annualized mean sea level changes from 1912 to 2011 at the Portland, ME tidal station, including seasonal signals. Sea level has been rising at a rate of about 1.9 mm per year over this time period, equal to about 7.5 inches per century. Error bars show the calculated standard error for the entire dataset.

Inspecting Sea Level Trends

Since 1993, satellite altimetry has been used to monitor global ocean sea level changes, as shown by the University of Colorado's Sea Level Research Group. This data shows that global sea level change rates have slightly increased to over 3 mm per year, or about 1 foot per century, based on data from 1993 to 2012 (Figure 3, Nerem and others, 2010), including seasonal variability.

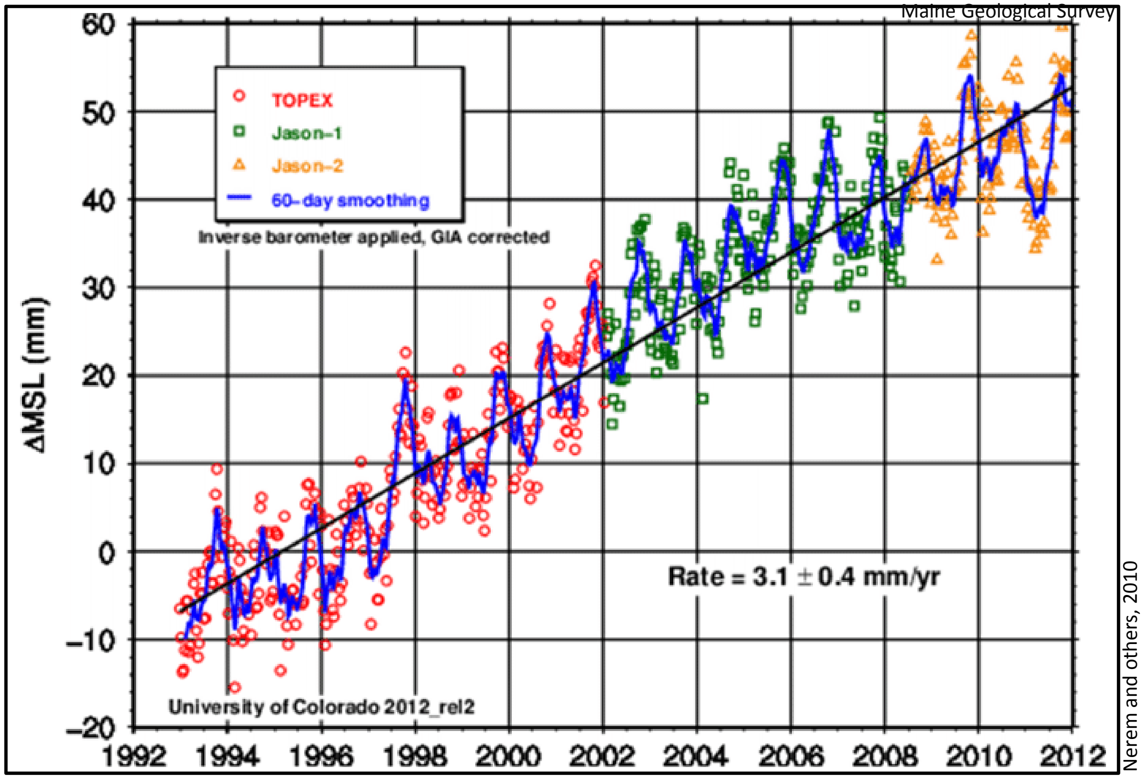
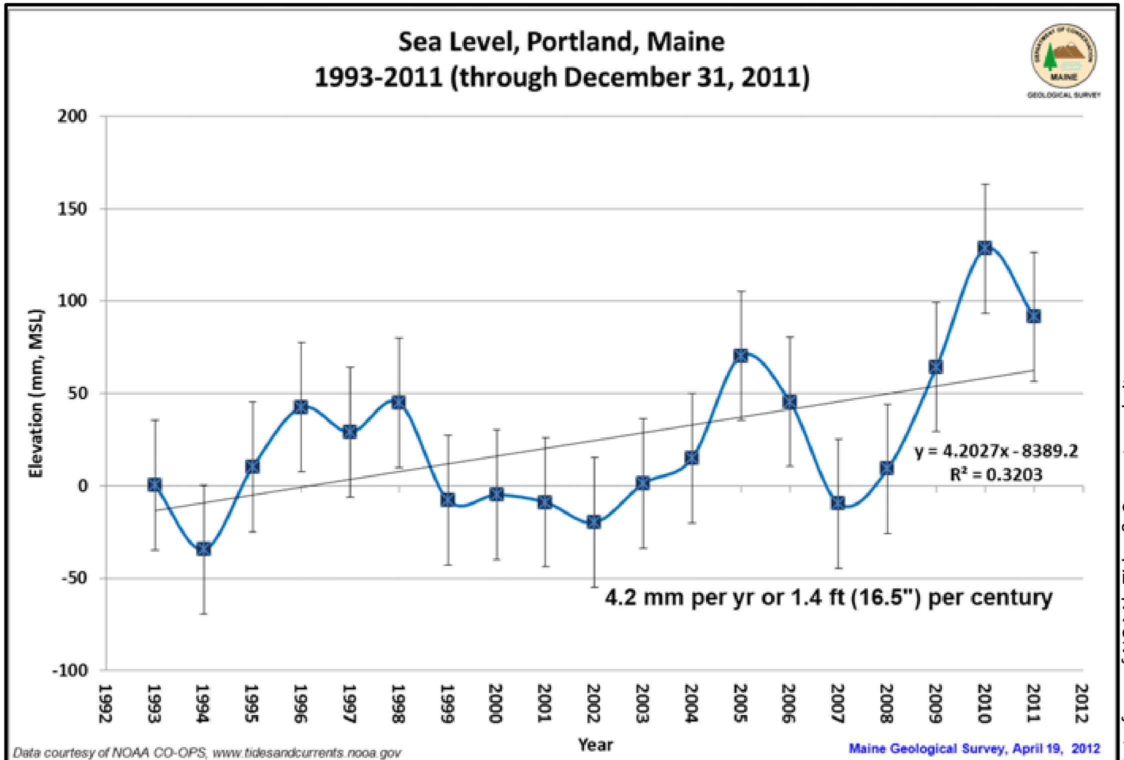


Figure 3. Global annualized mean sea level changes, including seasonal signals, as measured by satellite altimetry from 1993 to 2012 and compiled by the University of Colorado's Sea Level Research Group (Nerem and others, 2010).

Inspecting Sea Level Trends

During the same time period, however, sea level at the Portland tidal station rose at a rate of over 4 mm per year, or 1.4 feet per century (Figure 4). It is important to note that seasonal variability was left in these annualized sea levels over this shorter time period, resulting in a relatively low R^2 value (0.32). Seasonal variability will be discussed below.



Data from of NOAA's Tides & Currents website

Figure 4. Annualized mean sea level changes from 1993 to 2011 at the Portland, ME tidal station, including seasonal signals. Error bars show the calculated standard error for the entire dataset.

Seasonal Sea Level Variability

Global oceans undergo seasonal variability in terms of sea levels (Figure 3), mostly due to prevailing weather patterns. If desired, these signals can be removed, as shown in Figure 5.

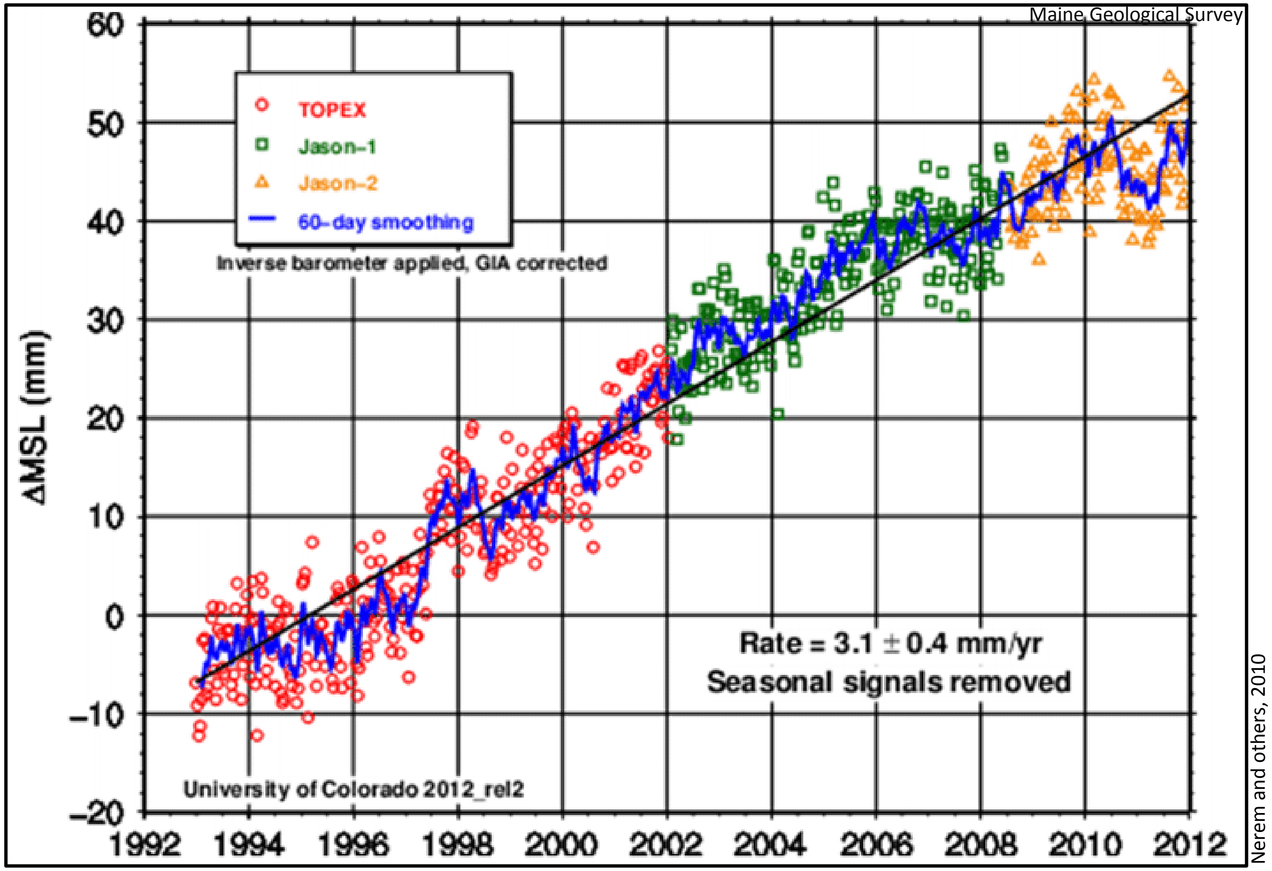
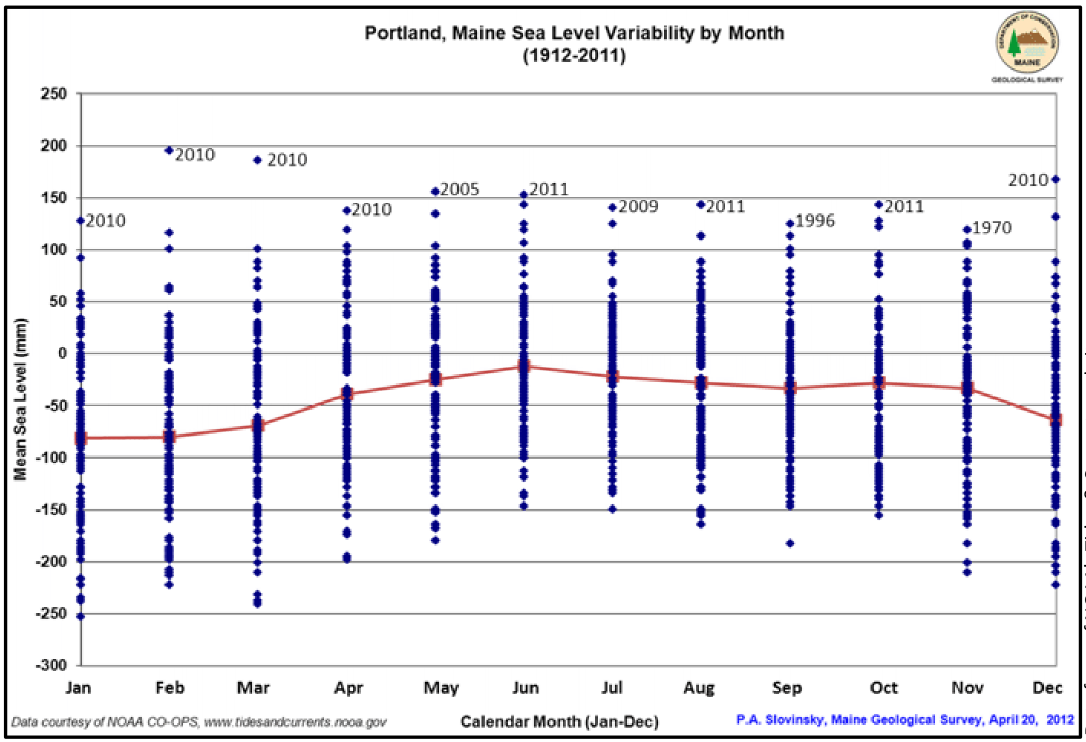


Figure 5. Global annualized mean sea level changes with seasonal signals removed, as measured by satellite altimetry from 1993 to 2012 and compiled by the University of Colorado's Sea Level Research Group (Nerem and others, 2010).

Seasonal Sea Level Variability

In general, sea levels along the Maine coastline also undergo seasonal variability, driven mostly by weather patterns. Typically, sea levels are lower in the winter months than the summer months, as shown in Figure 6. This figure shows the range of the mean sea level data values (by month) in blue dots from 1912 to 2011. It also shows each monthly average as a red line.



Data from of NOAA's Tides & Currents website

Figure 6. Variability in monthly mean sea levels from 1912 to 2011 at the Portland, ME tidal station; monthly averages for all data are shown in a solid red line.

Seasonal Sea Level Variability

Note that generally, sea levels are slightly higher (~ 4 inches or 10 cm) during the summer months than the winter months, though winter months show much greater variability in terms of highs and lows. Figure 6 also labels the highest average mean sea level values for each month; the two highest occurred in February and March, 2010. These were influenced by series of high water levels associated with northeast storms. The highest "summer" mean sea level values occurred in May 2005, June 2011, and June 2009. The May 2005 water levels were strongly influenced by a week-long series of northeaster storms, while the June 2009 and 2011 water levels were influenced by long periods of onshore winds and current anomalies.

It is clear that overall average monthly mean sea levels tend to be lower, but slightly more variable, during the winter months (December to March). This is mainly due to a strong northwesterly (offshore) flow during the winter months, which basically "blows" water away from the coast, and lowers sea levels (Sweet and Zervas, 2011). However, the increased winter month variability (larger range of low to high values) is due to the influence of more frequently occurring storm events and storm surges, which can elevate or depress water levels significantly (Wood, 2001a).

Seasonal Sea Level Variability

In February, a series of northeasters piled water up along the coast due to onshore winds and surges in the 1-2-foot or higher range for extended periods of time, elevating the overall water levels (both low and high tides) significantly for that month (Figure 7). It is also important to note the spring tide variation in the tidal range from ~12 feet (+6 ft to -6 ft) at the start and end of the month, to the neap-tide variation of ~8 feet (+4 ft to -4 ft) in the middle of the month. Storm surge during a period of larger tides can more easily flood low-lying coastal areas as opposed to days with smaller tidal ranges.

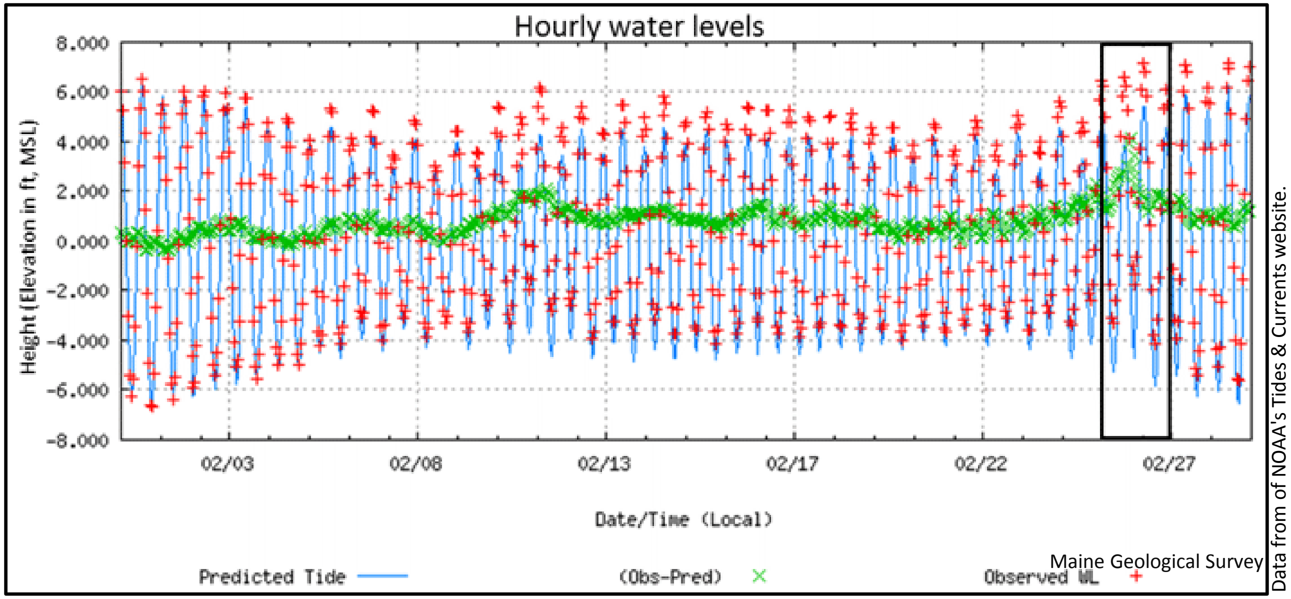


Figure 7. Hourly averaged water levels, referenced to Mean Sea Level, for the Portland, ME tidal station for February 2010. Predicted tidal elevations are represented by the blue line, while observed hourly averaged data is represented by red "+" signs. The difference between the observed and predicted water levels (marked by green "x" signs) is considered "surge." The high surge event between February 25 and 26, 2010 is shown in the black box (Figure 8).

Seasonal Sea Level Variability

During this month, the highest surge was over 4 feet above the predicted water level, occurring during a strong northeaster on February 26, 2010 (Figure 8); this was one of the highest measured surges in the past several decades, but luckily coincided with a falling tide. Higher than normal sea levels (both highs and lows) continued into March 2010 due to another series of storms, resulting in the second highest monthly mean water level for the entire record at the tidal station. The higher tides also had a dramatic geological impact at Popham Beach State Park (Dickson, 2011).

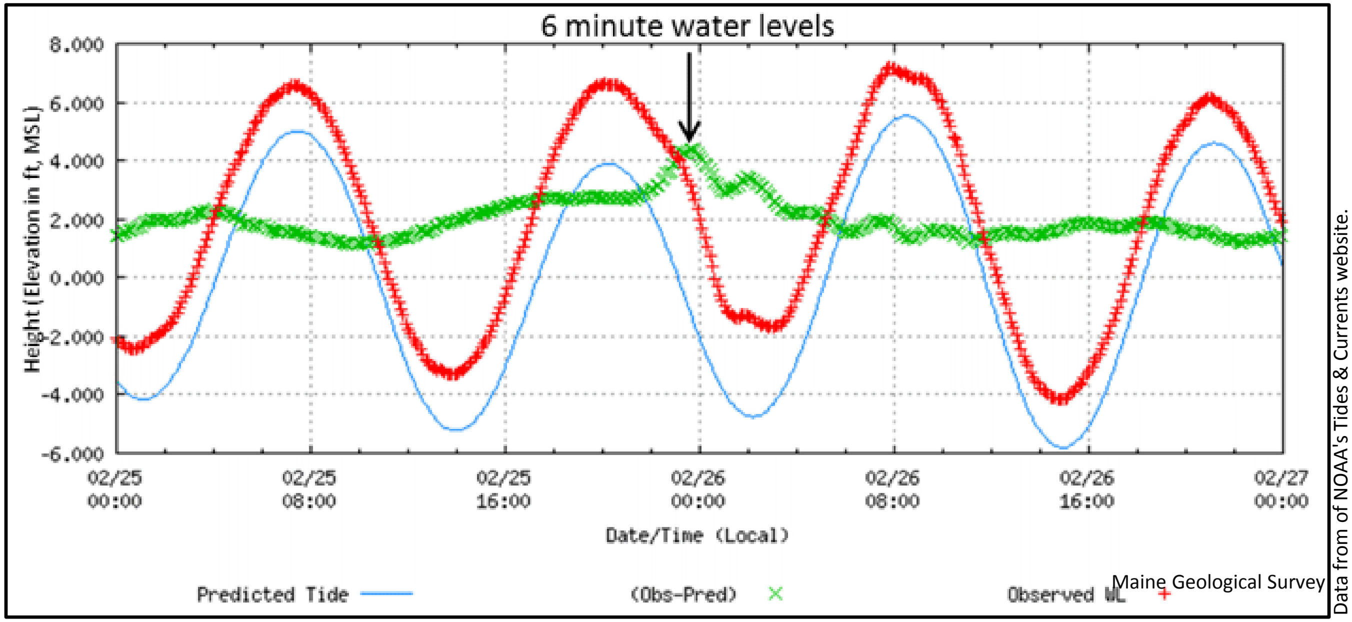


Figure 8. Six-minute water levels, referenced to Mean Sea Level, recorded at the Portland, ME tidal station from February 25 to 27, 2010. During this entire period, water levels were at least a foot higher than the predicted elevations, and peaked with a surge of 4.4 feet at around 11:36 pm Local Standard Time on February 25 (black arrow).

Seasonal Sea Level Variability

Interestingly, during the summer of 2009, mean sea levels along the entire eastern coast of the United States were higher than normal in the months of June and July (which typically correlate with Maine's highest mean sea levels). The NOAA CO-OPS prepared a special report (Sweet and others, 2009) regarding this anomaly. During this time, predicted tides were being exceeded by anywhere from half-a-foot in New England, to near 2-feet along the mid-Atlantic seaboard. NOAA attributed this anomaly to steady and persistent northeast winds, combined with a weakening of the Florida Current transport (a current leading to the Gulf Stream), and timing with astronomically high tides or perigean spring tides (Wood, 2001b). Additional analysis found tidal surges and northeasters are more common during strong El Niño years, including the winter of 2009-2010 (Sweet and Zervas, 2011).

During June 2009 in Maine, the Portland tide gauge recorded water levels that exceeded predicted water levels by an average of 0.35 feet (with a standard deviation of 0.3 feet) over the entire month of June, with a maximum value of 1.2 feet on June 29, 2009 (Figure 9). This, however, was exceeded by even higher water levels in June of 2011, which had water levels that exceeded predicted water levels by an average of 0.4 feet (with a standard deviation of 0.2 feet) over the entire month of June, with a maximum value of 0.98 feet on June 25, 2011. The June 2011 and June 2009 high values are represented by the two highest blue dots in the month of June as shown in Figure 6. However, this also isn't the highest averaged monthly "summer" water level recorded since 1912. That occurred in May of 2005 (see Figure 6) and resulted from a series of northeast storms that hit the Maine coast over the period of a week.

Seasonal Sea Level Variability

Predicted tidal elevations are represented by the blue line, while observed hourly averaged data is represented by red "+" signs. The difference between the observed and predicted water levels (marked by green "x" signs) is considered to be "surge." The highest exceedance from predicted values was 1.2 feet, and occurred on June 29, 2009.

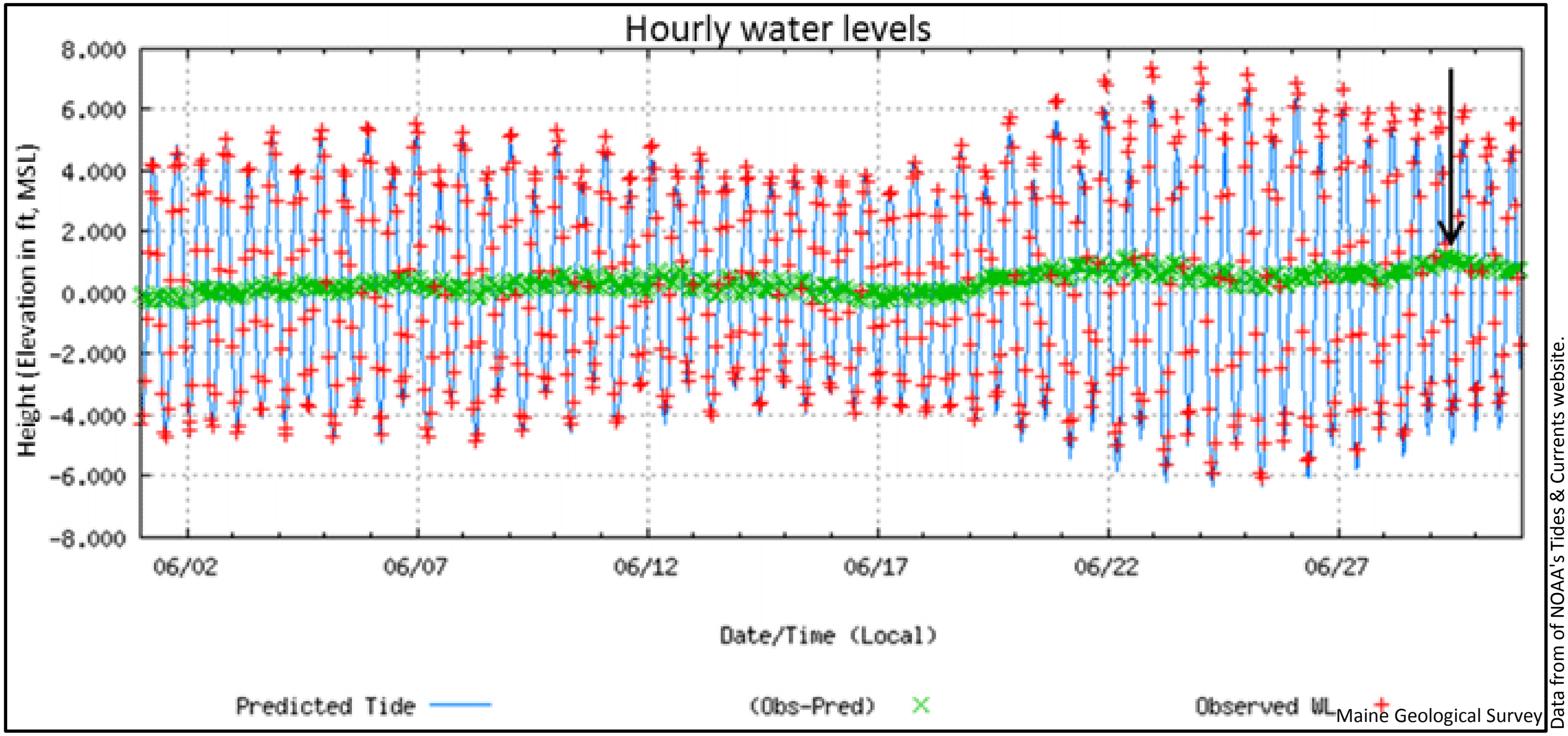


Figure 9. Hourly averaged water levels, referenced to Mean Sea Level, for the Portland, ME tidal station for the month of June 2009.

Highest Monthly Water Levels

If we take a look at all measurements since 1912, **ten of twelve, or 83% of the highest recorded average monthly mean sea level values occurred in the last decade**. In fact, nine of twelve (75%) of these were recorded **since 2009, with the *majority of these occurring in 2010 and 2011***. The year corresponding with the highest mean sea level measurement for each month is labeled in Figure 6. In addition, a summary table showing the highest and second highest recorded water levels (by month), and the corresponding year they were recorded, is shown in Figure 10. Based on this data, eighteen of the twenty four (75%) highest and second highest recorded water levels for each month occurred in the last 10 years.

Maine Geological Survey

Month	Highest Avg. MSL	2nd Highest Avg. MSL
January	2010	2011
February	2010	1998
March	2010	2005
April	2010	2005
May	2005	2011
June	2011	2009
July	2009	2011
August	2011	1968
September	1996	2010
October	2011	2009
November	1970	1983
December	2010	1970
In Last 10 years	10/12 (83%)	8/12 (67%)

Data from of NOAA's Tides & Currents website.

Figure 10. Table summarizing the highest average monthly mean sea levels (MSL) and the corresponding years in which they occurred at the Portland, ME tidal station since 1912.

Using Tidal Station Data to Analyze Flooding

In Portland Harbor, it is locally known that "flood stage" occurs when water levels meet or exceed 12 feet Mean Lower Low Water (MLLW), as described by Cannon and others (2009). This means that coastal flooding is expected once water levels reach this elevation. Using this elevation as a baseline, a tool developed by the NOAA CO-OPS called the Inundation Analysis Tool (IAT) can be used to look at the frequency of past flooding events, and how potential sea level rise may impact the frequency of those events. This tool can output the number of events that met or exceeded a given elevation, in addition to the duration (in hours) that the given elevation was met or exceeded. For this analysis, MGS used the IAT to find how many times, and for how long, the flood elevation of 12 feet MLLW was met or exceeded in just the 2011 calendar year.

Using Tidal Station Data to Analyze Flooding

As part of this analysis, the City of Portland asked MGS to look at the potential impacts of a range of different sea level rise (SLR) scenarios, including 1 foot (0.3 m), 2 feet (0.6 m), 3.3 feet (1.0 m), and 6 feet (1.8 m) of SLR. A table summarizing results from this analysis is show in Figure 11.

Flooding in Portland Harbor
(Flood Elevation = 12 ft MLLW)

Scenario	Flood Stage Elevation (MLLW)	# times flood stage exceeded	% of Total High Tides	Hours of Inundation (above flood level)
2011 Year	12 ft	11	1.6%	8
+0.3 m (1 ft) SLR	11 ft	98	13.9%	141
+0.6 m (2 ft) SLR	10 ft	281	39.8%	570
+1.0 m (3.3 ft) SLR	8.7 ft	612	86.7%	1759
+1.8 m (5.9) ft SLR	6.1 ft	702	99.4%	3782

Maine Geological Survey

Data from of NOAA's Tides & Currents website.

Figure 11. Table summarizing the frequency that flood stage (12 feet MLLW) was met or exceeded based on 2011 data from the Portland, ME tidal station using the NOAA CO-OPS Inundation Analysis Tool. For each scenario, sea level rise was added to determine the changes in flood frequency, based on using 2011 data as a proxy for an "average" year.

Using Tidal Station Data to Analyze Flooding

Data indicates that **in 2011, flood stage was exceeded 11 times**, for a duration of about only 8 hours. This represented about 1.6% of all high tides that occurred in 2011, meaning only about 2% of the tides that occurred in 2011 exceeded the flood stage. However, if sea level rose 1 foot (0.3 m), the frequency of flooding would increase to 98 times, for a duration of 141 hours total, and account for roughly 14% of all high tides. In a 2 foot SLR scenario, these numbers increased to 281 times flooding would occur, for a duration of 570 hours, and almost 40% of high tides. It is important to note that these estimates are based simply on a repeat of the 2011 tide and storm surge history.

This kind of analysis is vital to understanding how sea level rise may impact the frequency of static flooding. Much of this data was presented to the City's Transportation, Energy, and Sustainability Committee by MGS scientists in February 2012 as part of a Vulnerability Assessment completed by MGS for the City, highlights of which are available on the City of Portland website.

Tidal stations are invaluable in helping to understand short term and seasonal variation of water levels, impacts of storms, and longer term sea level trends. Continued operation of the Portland, Maine tidal station will help ensure sound scientific planning in response to flood hazards now and into the future. Happy 100th Birthday Portland, Maine Tidal Station 8418150!

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Additional Information

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