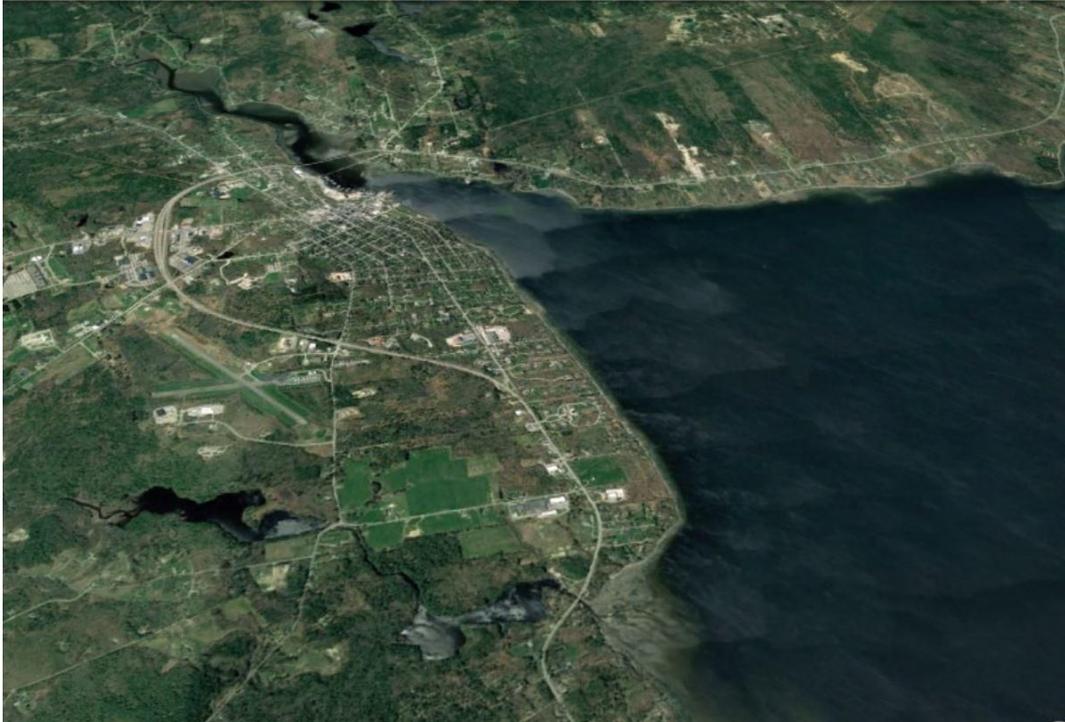


**SEA CHANGE IN THE GULF OF MAINE:
THE OUTLOOK FOR BELFAST**



Part One: What We Can Expect

**A Report to the City Council
by the
Climate Change Committee
Belfast, Maine**

Members

Mayor Samantha Paradis, RN, *Chair*
City Councilor Eric Sanders

Jon Beal, *Vice-Chair*
Barbara Bell, *Secretary*
Sally Bennett
Phil Brown

Lucky Greenleaf
Hank Reisner
Bev Roxby
Emma Swartz

September, 2018

Executive summary
Part One: What We Can Expect

Sea-level rise is occurring worldwide as a result of increasing atmospheric and sea surface temperatures. Climatologists' consensus projections for global sea-level rise, over the next 80 years, range from under 1 foot to over 6 feet, depending on the amount of greenhouse gases released into the atmosphere in the near future.

Ocean temperatures in the Gulf of Maine, including in Belfast Bay, are rising faster than in 99% of the world's oceans. Sea levels in the Gulf of Maine are projected to rise faster than the global average. Already, as a result of sea level rise, tidal flooding at normal (nonstorm) high tides has increased significantly in the northeast Atlantic region, and is projected to become worse.

Several climate change scenarios upon which NOAA scientists agree, depending on the amount of greenhouse gases released, are illustrated in the second graph on page 10, concerning predictions for sea level change in Bar Harbor. The predicted sea level rise in Bar Harbor is between 1.5 and 11 feet by the year 2100.

Given the trajectory of greenhouse gas emissions likely in the rest of the 21st century, planners should assume that global sea level will increase as envisioned in one of the three Intermediate scenarios or the High scenario. The Intermediate-High scenario in the Bar Harbor chart (moderate reductions in GHG emissions) would result in a 2 foot sea level rise by 2050 and a 6 foot rise by 2100.

In addition to sea level rise, the intensity, frequency, and duration of severe storms will increase as a result of the warming of the planet, resulting in higher storm surges and storm tides as well as waves of greater height and force. Belfast has in the past experienced storm tides in excess of 4.5 feet, and a study shows that a Category 1 hurricane with winds from the southeast can produce waves up to 10 feet in height.

We need to plan for these changes. We have identified the areas of our coast that are low-lying, exposed to storm paths, and/or on unstable shorelines, which are most vulnerable to the combined effects of these environmental changes, and have recognized particular information gaps for Belfast to address. *The pessimist complains about the wind; the optimist expects it to change; the realist adjusts the sails.* By developing a place-based understanding of sea change in the Gulf of Maine, Belfast can adjust the sails, i.e. adapt, proactively and creatively.

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1. Introduction

Belfast's midcoast location has been intrinsic to its identity, history, and economy from the time when the Abenaki people fished here for sturgeon up to the present. That heritage naturally leads to concern for the threat of rising sea levels and other coastal impacts of climate change. The damage caused recently in Belfast Harbor by the wind, waves, and flooding of three severe storms from October 30, 2017 through March 3-4, 2018 highlighted the vulnerability of the City's coast to inevitable changes in what have always been taken for granted – the climate, the weather, and the ocean.

The City Council approved the formation of the Belfast Climate Change Committee (CCC) in March 2018 and directed the CCC to report on the potential impacts to the City of one critical aspect of climate change: sea-level rise. This report, entitled *Sea Change in the Gulf of Maine: The Outlook for Belfast*, comprises three parts with distinct objectives:

Part One. Characterization of the nature and probable consequences of changing sea levels in the specific context of Belfast's harbor and shoreline. (September, 2018)

Part Two. Characterization of damages from erosion and flooding and estimates of economic implications for Belfast of the projected sea-level rise scenarios. (December, 2018)

Part Three. Analysis of the city's options for adaptation in the face of these projections and recommendation of a strategy for increased resilience. (March, 2019)

2. Sources

CCC members read numerous articles and publications, as cited below, attended presentations and workshops related to climate change, and made contacts through emails and personal interviews with experts at state agencies, the University of Maine, and private non-profit organizations. We talked with local experts, such as Belfast's harbormaster and members of the Belfast Harbor Advisory Committee, and we made our own direct observations

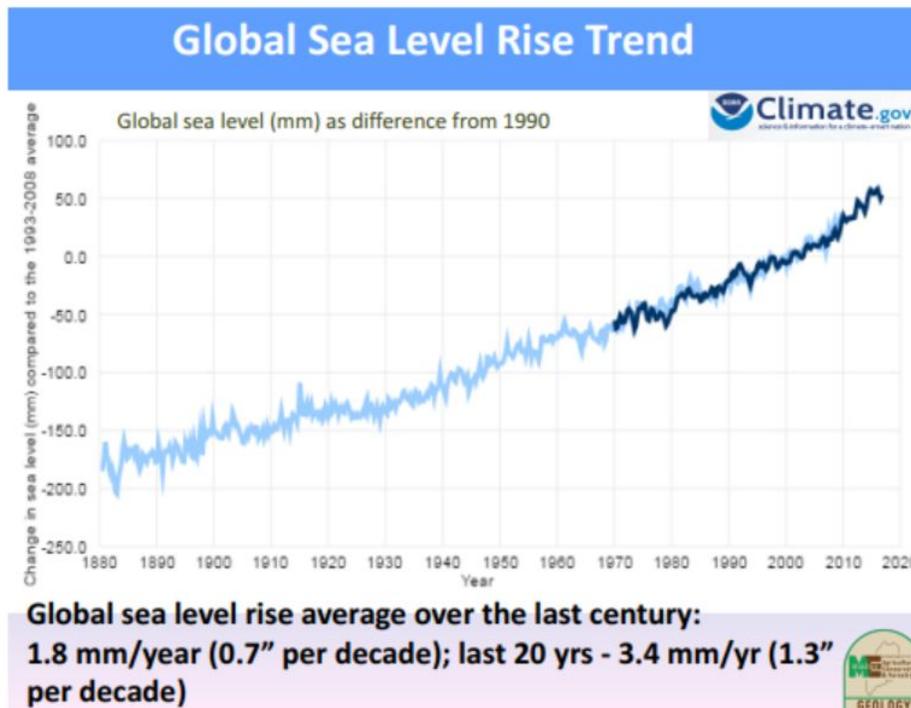
by walking and boating along Belfast’s west, east, and upriver shores, ground-truthing Maine Geological Survey maps and taking photographs. To facilitate the development of site-specific data for Belfast, we initiated or supported local contributions to data-gathering for University of Maine faculty and graduate students, and are working to catalyze more such collaborative research.

The CCC minutes (on the City of Belfast website, <https://www.cityofbelfast.org/>) document the committee’s outreach and networking activities, and a CCC digital library that is being compiled provides public access to references and literature consulted.

3. General Findings - Climate Change and the Gulf of Maine

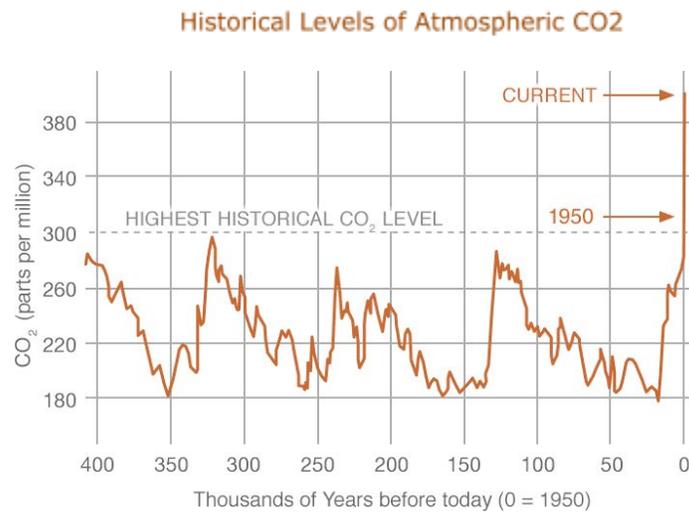
3.1 Climate change and changing oceans

Sea levels are rising worldwide. Since the 1880s they have risen 8 inches on average. Satellite data indicate that the rate of global sea level rise has almost doubled over the last 20 years.¹



(Slovinsky, "Trends", 13)

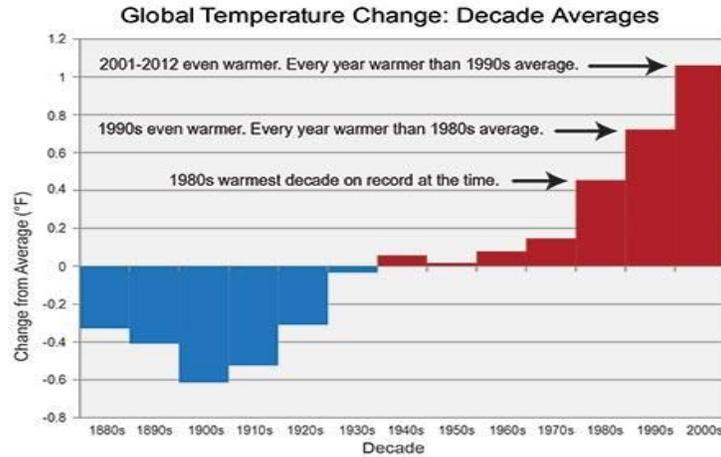
This rise is closely related to increasing air and ocean temperatures, correlated with the increase of CO₂ and other greenhouse gases in the Earth's atmosphere that started in the Industrial Age, accelerated sharply in the 1950s, and continues to accelerate in the present. Over a very long period, Earth's atmospheric concentration of greenhouse gases has fluctuated greatly, with global temperature and ice formation and loss changing in tandem. The following chart shows that for 400,000 years before 1950, greenhouse gas concentrations fluctuated from 180-300 parts per million (ppm). However, since 1950 it has rocketed to its current level of 400 ppm,² and that increase shows no sign of ending or slowing.



Data source: Reconstruction from ice cores. Credit: NOAA

(NASA, "Carbon Dioxide")

The following chart shows the gross global change in temperature since the 1880s. Global temperature has increased by 1.4 F° since the 1890s.



(Walsh et. al., Appendix 4)

The following figure shows that Maine’s average temperature has increased by more than twice the average global amount.

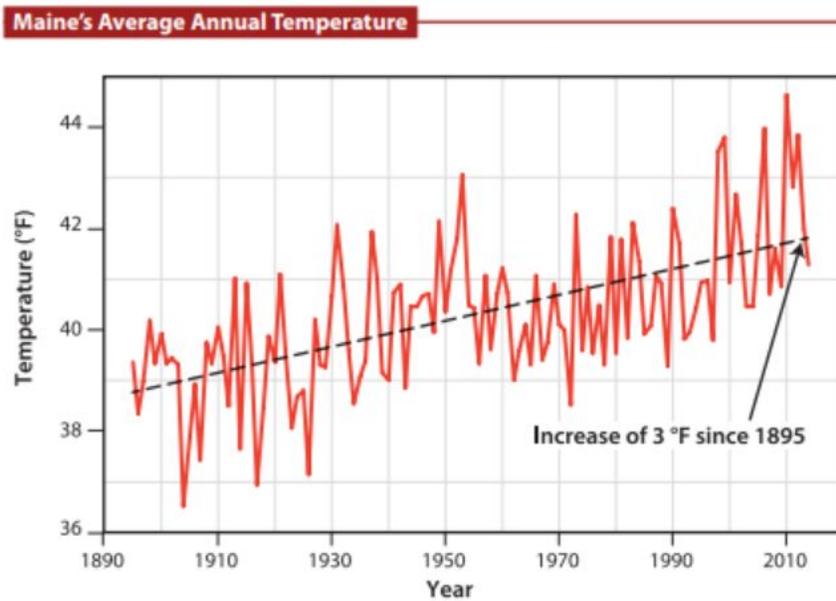
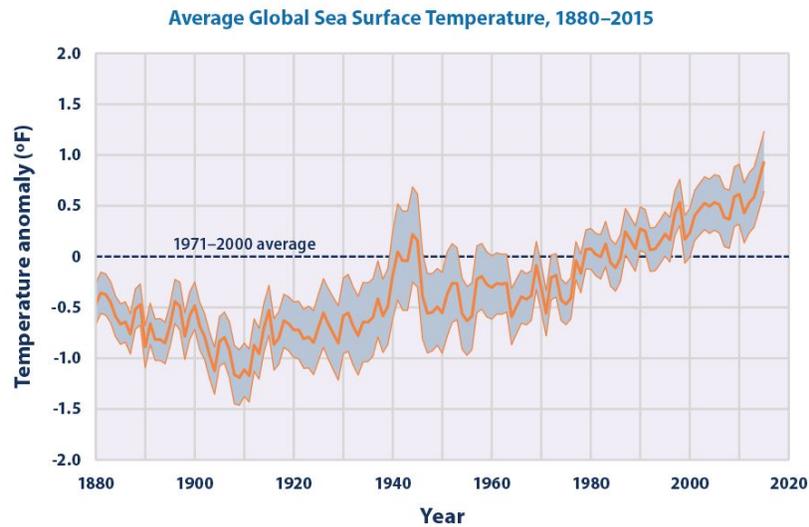


Figure 1. Mean annual temperature, 1895–2014, averaged across Maine from gridded monthly station records from the U.S. Climate Divisional Dataset (ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php). A simplified linear trend (black line) indicates that temperature increased 3 °F over the record period.

(“Maine’s Climate Future”, 2)

As atmospheric temperatures rise, so do sea surface temperatures. The volume of the world's oceans increases due mostly to the melting of glacial ice (50%) and to the thermal expansion of water (40%) (Just as in a mercury thermometer, the volume of water increases with increasing temperature.)

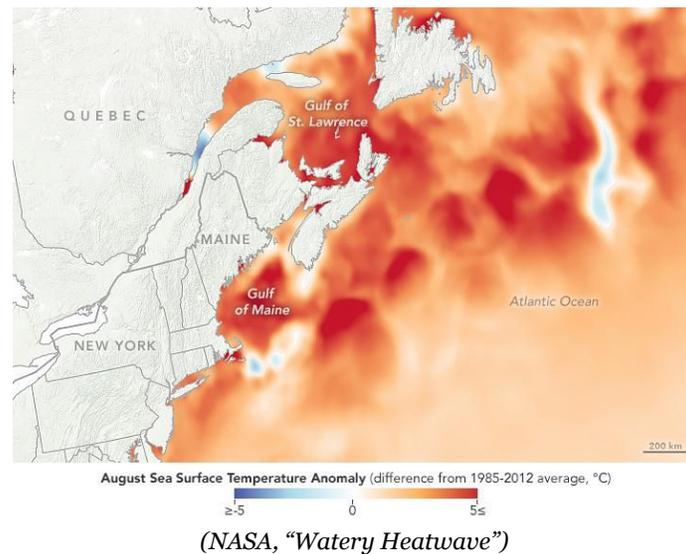


Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. Extended reconstructed sea surface temperature (ERSST.v4). National Centers for Environmental Information. Accessed March 2016.
www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

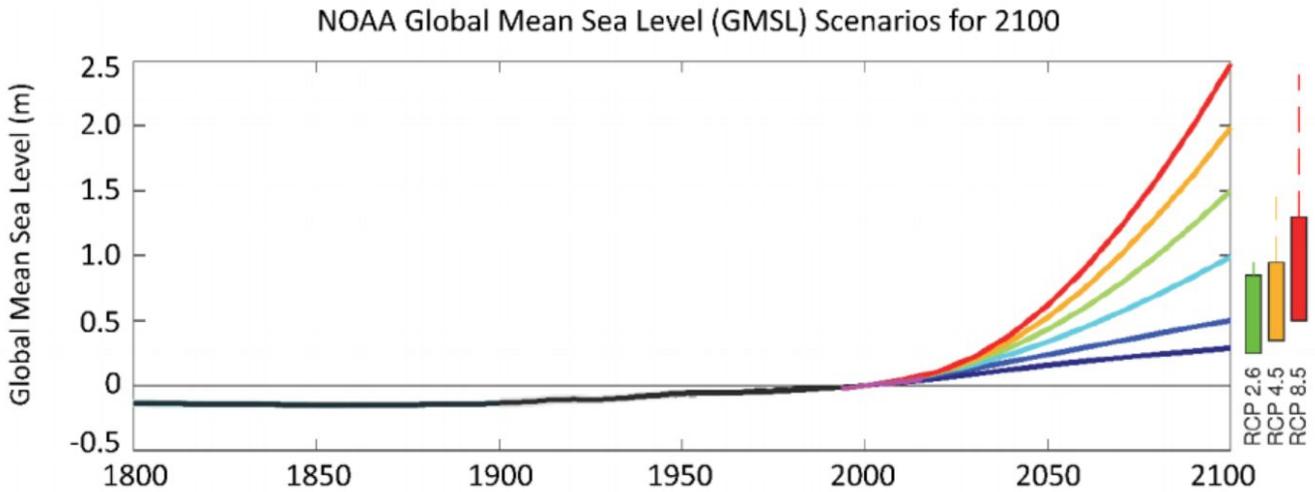
(EPA, "Sea Surface Temperature")

Over the past 30 years, the Gulf of Maine has warmed at a rate of 0.06°C (0.11°F) per year, three times faster than the global average. This is a faster rate than in 99% of the world's oceans. The warming trend in the Gulf of Maine likely has two main causes: the overall warming of the global ocean as greenhouse gas concentrations rise, and the melting of ice in Greenland and the Arctic Ocean, providing pulses of fresh water that can alter ocean circulation patterns in the region. The following map shows the anomalously high rate of warming:

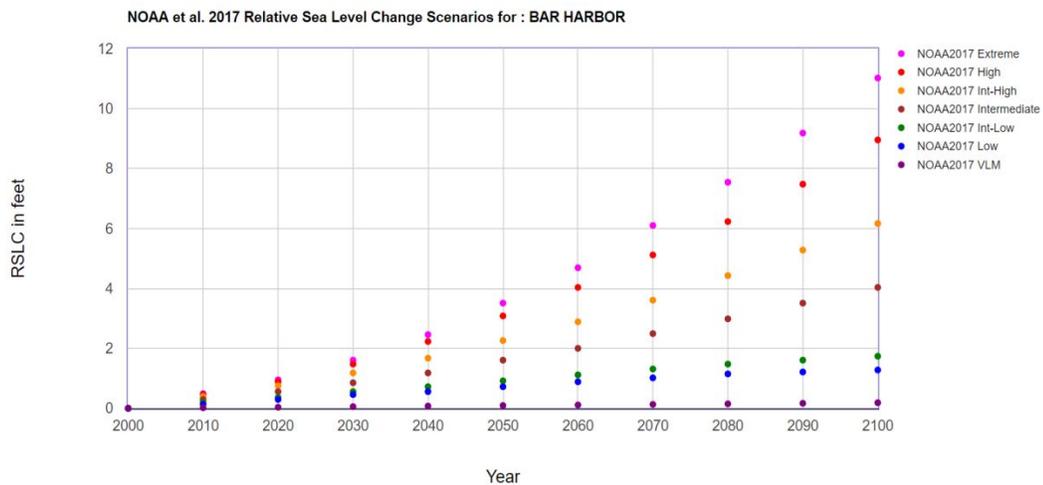


3.2 Projections for sea level rise globally and in Maine

3.2.1 Global Scenarios The National Oceanographic and Atmospheric Administration (NOAA) has calculated scenarios based on different projections of changes in atmospheric CO₂ and their direct effects on world ocean levels. These range from about 1 foot to 8+ feet of sea level rise during the 21st century. The lowest scenario projects sea level rise extrapolated from historical trends. The others include the results of projected thermal expansion and volumetric increase with increasing concentrations of greenhouse gases, in terms of the climate community's standardized Representative Concentrations Pathways (RCP).³



3.2.2 Regional scenarios for Maine “The Gulf of Maine is especially susceptible to fluctuations in sea level due to changes in the strength of the Gulf Stream and seasonal wind patterns. Sea levels in the Gulf of Maine are projected to rise faster than the global average.”⁴ The following graph derives from the Army Corps of Engineers tool for illustrating the NOAA 1917 scenarios for Bar Harbor.⁵ (Tidal predictions for Belfast are extrapolated from Bar Harbor by NOAA; there is no tide gauge at present in Belfast Bay.)



The predicted sea level rise in Bar Harbor is 1.5 to 11 feet by the year 2100, contingent upon the success and timing of the global community in reducing greenhouse gas emissions. The extreme scenario is extrapolated from “business as usual” greenhouse gas emissions.

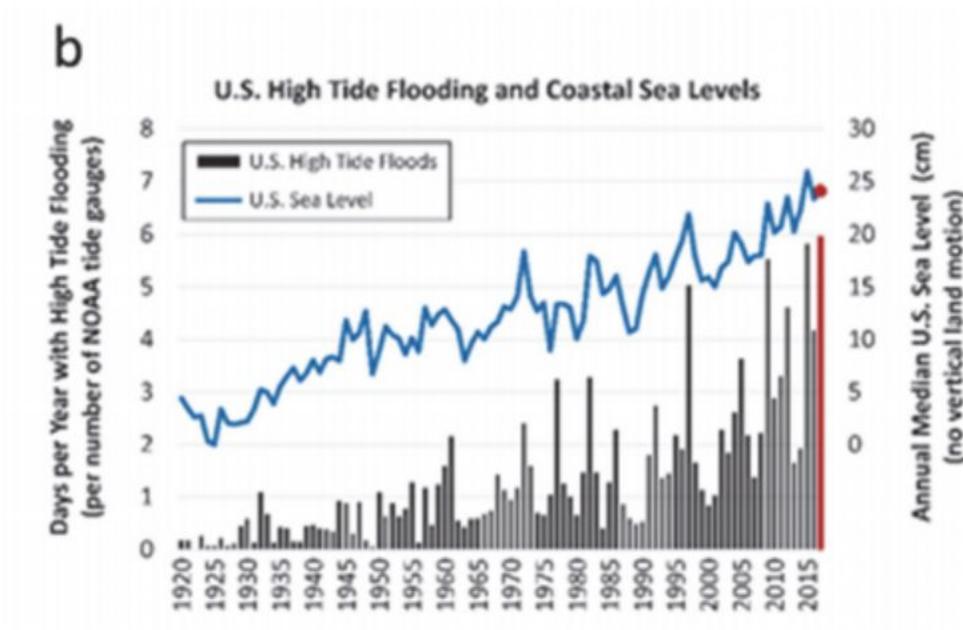
3.2.3 Choosing a scenario for risk assessment In the 2015 Paris Agreement, the international community agreed to make immediate and serious reductions in greenhouse gas emissions in order to maintain global temperature well below 2° Celsius (3.6° F) higher than pre-industrial levels. So far, no major industrialized nations are implementing the policies they had envisioned and none have met their pledged emission reduction targets. The sum of all member pledges, even if met, will be insufficient to maintain global temperature rise “well below 2° C.”

According to UNEP (United Nations Environment Programme), the targets agreed to in Paris will result in a temperature rise of 3° C (5.4° F) above pre-industrial levels, far above the 2° goal. On September 10, 2018 António Guterres, the Secretary General of the United Nations, stated, *“If we do not change course by 2020, we risk missing the point where we can avoid runaway climate change.”*⁶

3.3 Sea Level Rise and High Tide Flooding

There are increasing numbers of High Tide Flooding events across the US, defined by the National Weather Service as a “coastal water level reaching or exceeding a median height of 0.54 meters (21.3 in) above the long-term average daily highest tide.” In general, and throughout the US: “Though year-to-year and regional variability exist, the underlying trend is quite clear: due to sea level rise, the national average frequency of high tide flooding is double what it was 30 years ago.”⁷

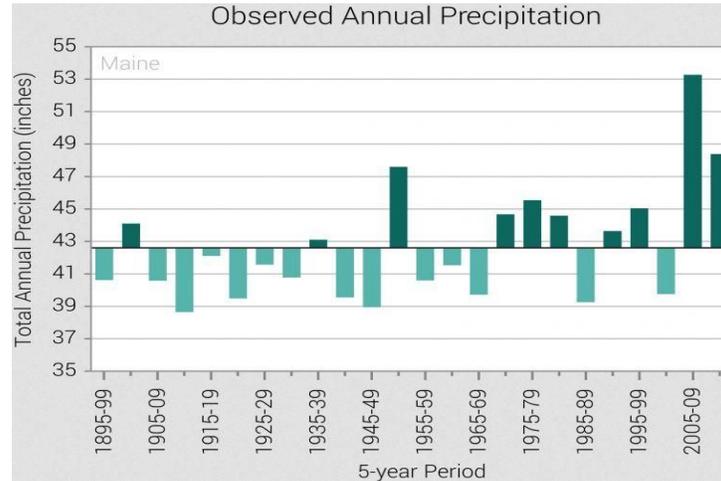
We see this increase at least in part because rising sea levels result in a change in Mean Sea Level at each coastal site and corresponding increases in the water levels at high and low tides. In addition, the complex resonance patterns arising from the basin geometry of the Gulf of Maine result in enhancement of coastal flooding Downeast. Eastport flooding events are more extreme than in Portland, where they are greater than in Boston.⁸



(Sweet, 2)

3.4 Precipitation

Slowly rising temperatures in Maine during the last century have been paralleled by rising precipitation. Particularly over the last 10 years, precipitation has been the highest ever recorded⁹:

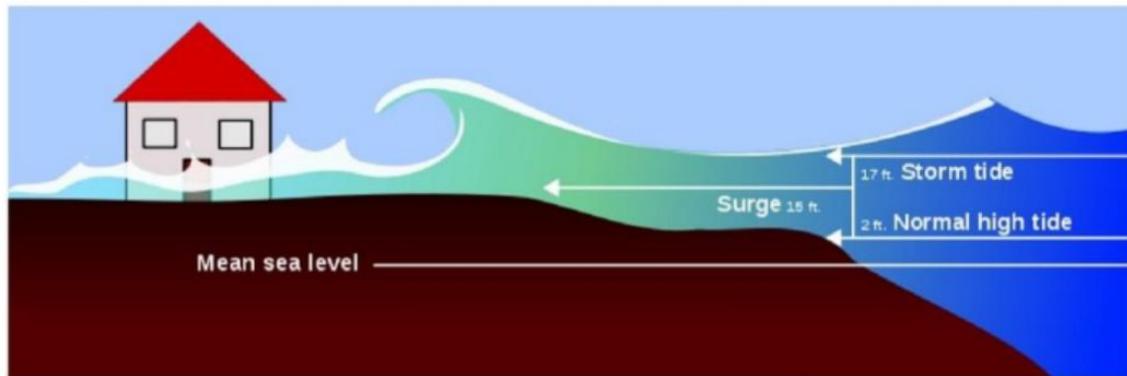


At the same time, precipitation events have increased in magnitude. An extreme precipitation event is defined by Maine meteorologists as “one in which two or more inches (five or more centimeters) of precipitation falls within a 24-hour period.”¹⁰ This is especially significant for estuarine harbors and coastlines, particularly at times of snow melt.

3.5 Storm Surge

One of the well-established predictions by climate scientists is that warming air will increase the frequency, intensity, and duration of storms.¹¹ Storms amplify the effect of sea-level rise through waves and storm surge. Storm surge is “an abnormal rise of water generated by a storm, over and above the predicted astronomical tides.”¹² The longer the distance, or “fetch”, over which wind travels without interruption before hitting, the greater the height of the surge.

The storm surges generated by the 10 worst storms to hit Portland range from 3.1 feet to 4.3 feet.¹³



(“Sensing Storm Surge”, University of Maine)

Surge height depends on additional factors besides wind strength. Among these are the width and slope of the ocean floor; higher storm surge is associated with wide and gently sloping continental shelves and lower storm surge with narrow, steeply sloping shelves. The angle of storm approach to a coastline also affects the height of storm surge, with a perpendicular onshore approach resulting in greater surge than a storm moving at an oblique angle or parallel to the coast. Coastline shape is one more important factor in the generation of storm surge; concave coasts generally experience higher surge than convex ones. The generation and behavior of storm surge in estuarine vs. non-estuarine harbors is more complex due to interactions of volume and intensity of precipitation, the size, shape, and soil saturation of the watershed, and the timing of rainfall and runoff relative to the tidal cycle.

How do these factors apply to Belfast? Penobscot Bay is a long, funnel-shaped, deepwater estuarine system with a north-south orientation and significant freshwater input from a watershed that includes a large part of Maine. Its converging shape allows for amplification or lessening of storm surge, depending on wind direction and storm path. The

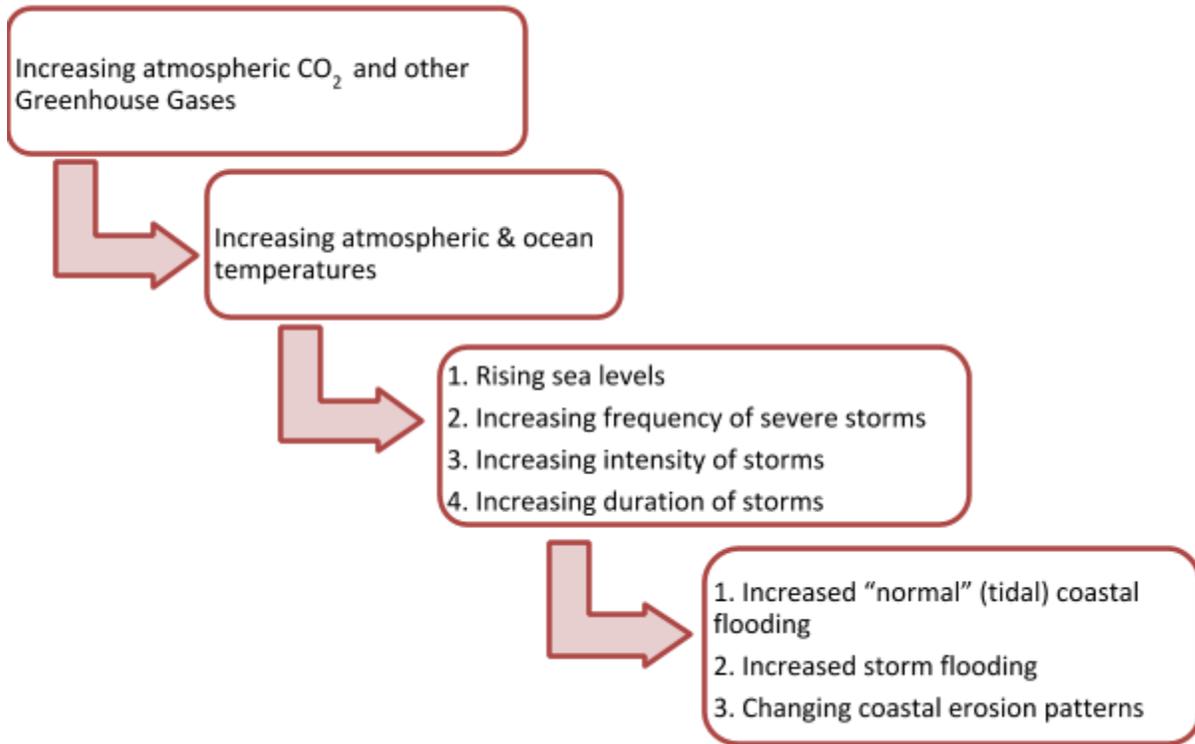
October 30, 2017 storm, with winds of 43 mph from the SE, **enhanced** the surge propagation up the bay: storm surge in Belfast Bay measured 3.3 feet and in Bangor, 7.0 feet. During the January 4, 2018 storm, winds of 36 mph were from the N and worked **against** surge propagation up the bay: storm surge in Belfast Bay then measured 2.8 feet and in Bangor, 3.3 feet.¹⁴ On February 2, 1976, Bangor experienced a historic flood in which downtown water level reached 17.46 feet, a storm surge of approximately 10.5 feet above the predicted astronomical tide.

3.6 Time and Tides

Maine coasts experience a daily cycle of two high and two low tides and a large tidal range (average distance between high and low tides is 11.3 feet in Belfast). This is superimposed on a monthly cycle corresponding to lunar phase, with higher spring tides at new and full moons and lower neap tides at quarter moons. Sea-level rise is additive to these tidal parameters. There is a larger-scale pattern (the 18.6 year lunar nodal cycle resulting from the incongruent planes of ecliptic of the earth and moon) that affects the extent of sea-level rise effects on flooding, *i.e.*, it is greater or lesser than average during alternating decades.

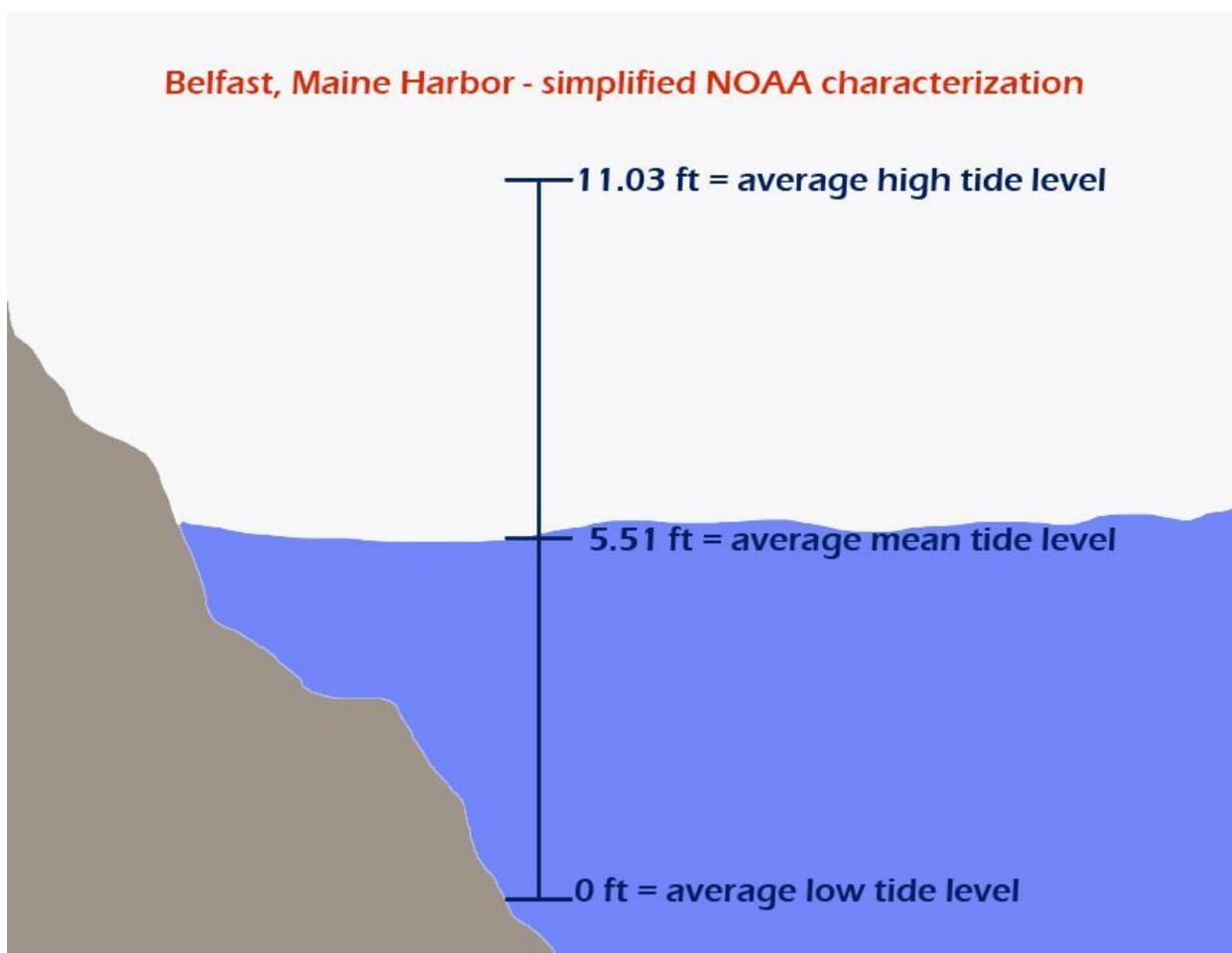
All these cycles modulate the probability and extent of coastal flooding. A plurality of historic flood events in Boston—including floods in 1851, 1978, and 2018—occurred near the peak of the lunar nodal cycle¹⁵. Almost all extreme floods in Portland have coincided with anomalously high tides¹⁶. The 1976 Bangor flood described above resulted not only in surge propagated by the strong, prolonged south-southeasterly winds (46 mph with gusts up to 92 mph), but their serendipitous coincidence with a high astronomical tide. Fortunately, storm rainfall, ice jams, and streamflow were not further major contributing factors.

3.7 Graphic Summary of the Predicted Changes for the Coast of Maine



4. The Outlook for Belfast

4.1 Overview



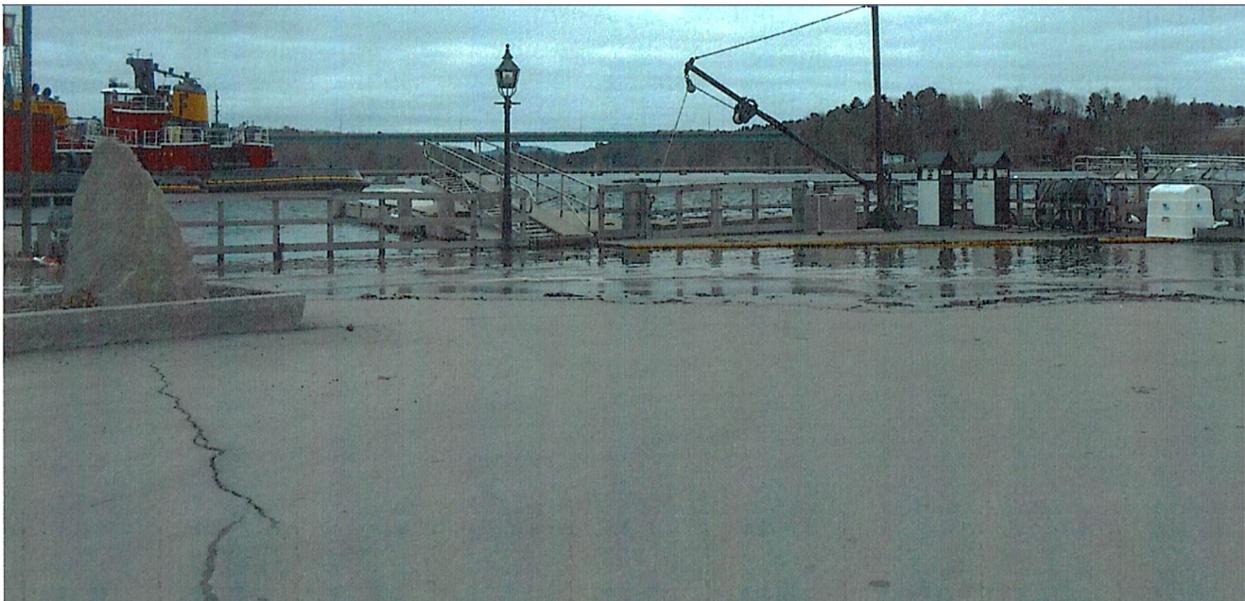
(NOAA, "Datums")

The 2018 "normal" state of Belfast Bay is shown in the following standardized NOAA diagram indicating the average heights of high tide and low tide, with the average mean tide in between (i.e. for six hours in any 12-hour tide cycle, the tide level is below the mean, and for six hours it is above). The general findings presented in prior sections for projected effects of climate change on sea level globally and in the Gulf of Maine provide an estimate for parameters of a "new normal" for the Belfast harbor and coast:

- Sea level will rise 0.5 to 1.5+ feet over the next 20 years; 1 to 6+ feet over the next 80 years.
- There will be more severe and more frequent storms of longer duration.
- Surface sea temperature in the Gulf of Maine will continue to rise at a rate higher than the rest of the world.

4.2 Flooding

High tide flooding of the harbor parking area by the Belfast Harbormaster's office already occurs on some spring tides. The lack of a public-access system in place for tidal record-keeping in Belfast makes it difficult to quantify how often this occurs. There will be a total of four normal ≥ 13 foot tides in Belfast during 2018, none above 12.9 feet in 2019, and one of 13.1 feet in 2020.¹⁷



(03-03-'18, 11:43 am)

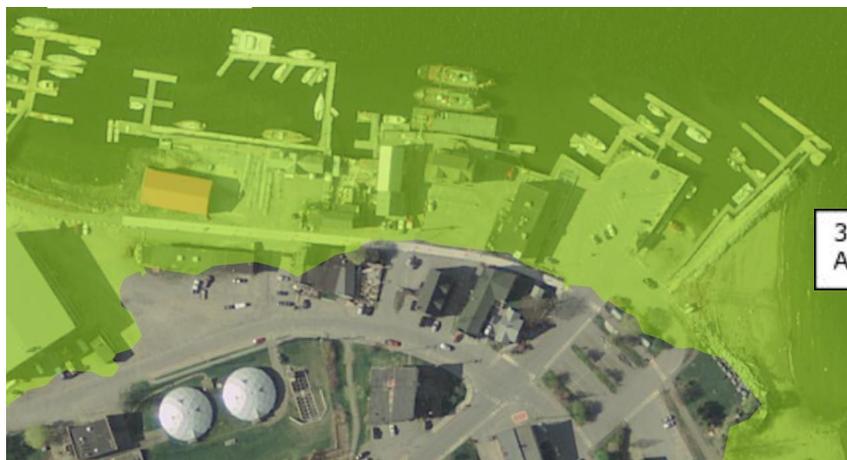
The most low-lying areas of public and private infrastructure along the Belfast coastline, and thus most likely to be affected by future tidal or storm flooding, are detailed in the FEMA FIRM maps available on the City of Belfast website. They are highlighted in red below in a visualization from the Maine Geological Survey model showing inundation depths up to 6 feet above Highest Annual Tide 2015 in shades of blue.¹⁸



The same Maine Geological Survey model provides greater magnification of the effect of potential future inundation from sea level rise, storm surge or storm tides in the harbor area:



Downtown harbor area



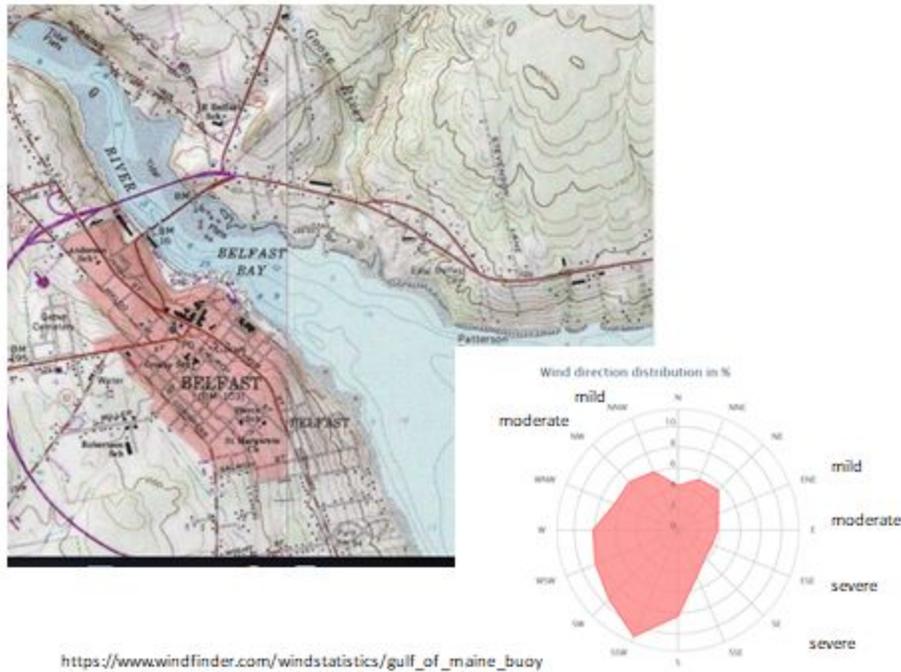
3.3 feet above High Annual Tide 2015



6 feet above High Annual Tide 2015

4.3 Winds

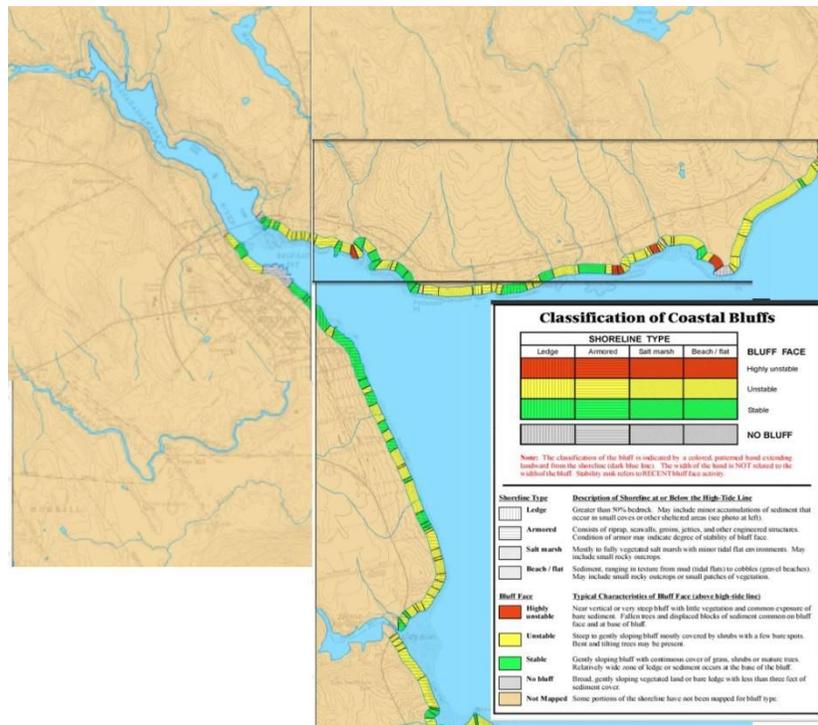
The annual pattern of wind directions in the Gulf of Maine expressed in percentages is illustrated below, indicating the relative threat from each direction to the central harbor area¹⁹. Our harbor is well-situated in this respect since the prevailing wind direction is of relatively low threat to the downtown area. The East Belfast shoreline is directly exposed to the prevailing winds, though the negative effects of this are lessened by a relatively short fetch. A study of the Belfast Boathouse location by an engineering firm under contract to MBNA in 1997 modeled wind speeds of 43, 67, 76, and 83 mph (Category 1 Hurricane), of varying angle, fetch length, time traveled by the wave, and average velocity. The maximum wave height was just over 10 feet high, which results from the highest velocity wind heading from slightly south of east at 100° degrees, with a fetch of about 8 miles.²⁰



4.3 Coastal Stability

Coastal erosion is a normal and ongoing process that continually refigures landforms in patterns depending on the stability of shoreline sediments relative to currents, waves, and storms.

The Belfast shoreline has been characterized by the Maine Geological Survey in terms of coastal bluff stability, as shown below. Stable areas are depicted in green, unstable in yellow, and highly unstable in red. (Gray areas indicate no bluff.); areas with armoring are distinguished from those without. Without more precise data and modeling it is not possible to predict where sediments will be removed and at what rate, incorporating varying scenarios of rising sea levels and more storms. It is also unclear where the rubble will end up and whether big pieces of eroded flotsam (boats, logs) are likely to batter stable infrastructure (bridge pilings) during a storm before coming to rest.



(Adapted from MGS, Coastal Bluffs)

4.4 Severe Storm Events

The storm surge experienced by Belfast during the 1976 storm that caused such extreme flooding in Bangor ranged from 6.25 feet above predicted high tide at the Northport town line, 4.52 feet at Marshall Wharf, and 7.63 feet at the railroad crossing in Searsport. This past winter season Belfast experienced three serious storms, none of which was classified as a severe weather event, but all of which resulted in significant storm damage, both public and private. The October 30 surge was 3.3 feet, the January 4 surge was 2.8 feet, and the March 3-4 surge was .8 feet.²¹ In the October storm, lower than average high tides (9.5 and 9.9 feet) reduced the storm tide, even though the storm hit only half an hour after high tide, and even though the winds were coming from the southeast, the most dangerous direction for Belfast. In the January storm, a classic Nor'easter, the wind worked against the surge, and the storm arrived two to two-and-a-half hours after high tide. In the March storm, the predicted spring tides were high, and even a foot of surge added on top of that could have caused significant damage; fortunately, winds were out of the north, opposing and limiting the surge.



January 4, 2018 - flooded area
around Marshall Wharf
(Ferguson, *BDN*)

Most meteorologists agree that Nor'easters ("non-tropical" cyclones; the meteorological term for "hurricane" is "tropical cyclone") will continue to be the most common extreme weather events in New England.²² However, the Waldo County Emergency Management Agency currently uses a Category 2 hurricane (winds of 96-110 mph)²³ as its worst-case storm scenario, though one has not yet occurred here; the last Category 1 hurricane to hit was in 1985.²⁴

The most vulnerable areas in Belfast to high tide or storm-related flooding, wind/wave damage, and shoreline erosion will be those low-lying areas and areas with unstable shorelines shown previously, especially those with E to SE exposure, including the downtown harbor area.

The following is a hypothetical example. A less-than-worst-case scenario for Belfast might be a Category 1 hurricane approaching from ESE to E (100°-130°) coinciding with an astronomical high tide (13+ feet), which produces a storm surge of 4 feet (storm tide of 17+). Assuming a high intermediate GHG scenario by 2050, SLR may be at 2 feet.

The result of such a scenario might be:

2018 Highest Annual Tide: 13.1 feet

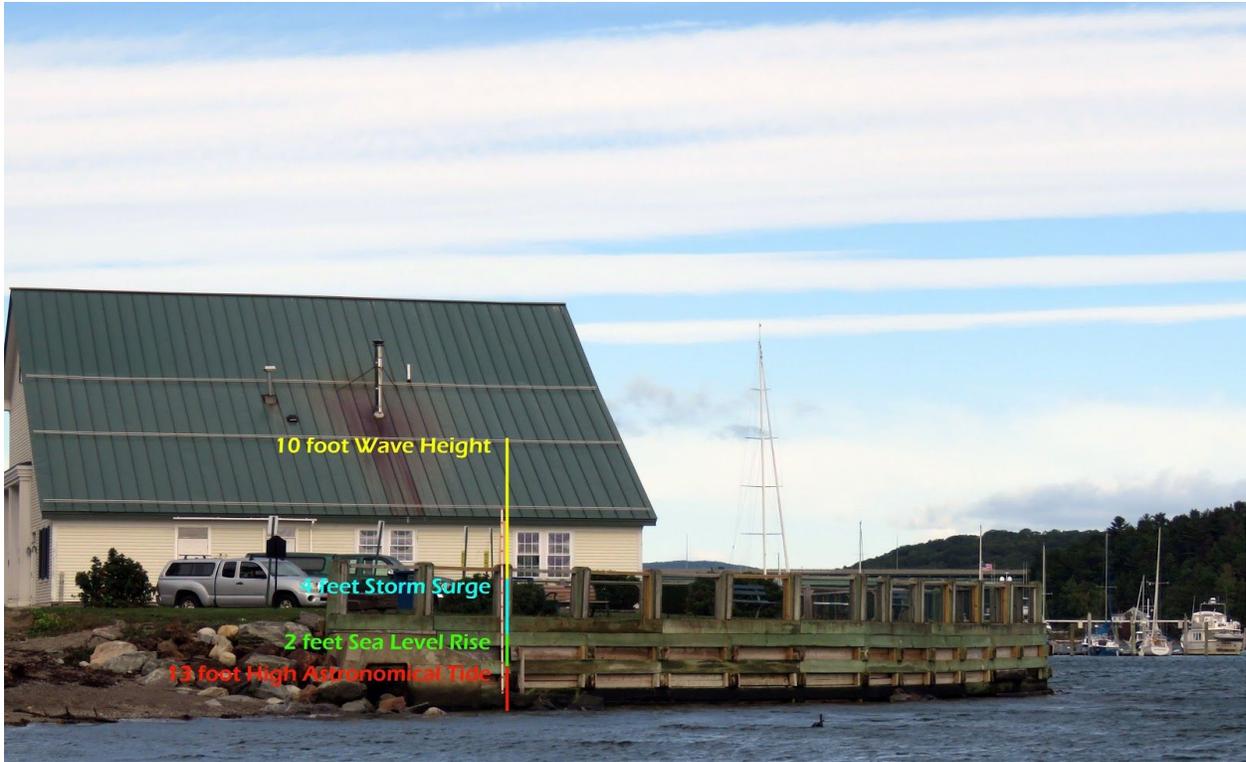
Sea-level rise: 2 feet

Storm surge: 4+ feet

Category 1 hurricane winds 83 mph: 10 foot wave height

Overall Result: waves 20+ feet above 2018 Highest Annual Tide

This would cause a Horrible Mess.



Belfast Boathouse on a Bad Day
9-22-'18, 10 am; High Tide = 9.8 feet

5. Conclusion

Sea-level rise is occurring worldwide as a result of increasing atmospheric and sea surface temperatures. Ocean temperatures in the Gulf of Maine (including Belfast Bay) are rising faster than in 99% of the world's oceans, and sea levels in the Gulf of Maine will rise faster than the global average. Tidal flooding at normal (nonstorm) high tides has increased significantly in the northeast Atlantic region, and is projected to become worse.

The 2015 Paris Agreement, which Belfast has signed on to as part of the “We Are Still In” pledge, is intended to maintain global temperature well below 2° (3.6 F°) higher than pre-industrial levels. The major industrialized nations have not met their pledged emission reduction targets, but even if they did meet their emission reduction targets for the rest of this

century, this will not keep global temperature rise "well below 2° C", but rather in a temperature rise of 3°C (5.4° F) above pre-industrial levels.

In choosing among the several scenarios reflected in the second graph on page 10, planners may wish to assume that the Paris Agreement goals will not be met, since that is the current trajectory. It may be prudent to assume the Intermediate-High scenario (moderate global reductions in GHG emissions), with a 2 foot sea level rise by 2050 and a 6 foot rise by 2100.

In addition to sea level rise, Belfast should expect increased intensity, frequency, and duration of severe weather with higher storm surges and storm tides as well as waves of greater height and force. Belfast has in the past experienced storm surges in excess of 4.5 feet, and the MBNA study shows that a Category 1 hurricane with winds from the southeast can produce waves up to 10 feet in height.

We need to develop an adaptive management plan for those areas of the Belfast coastline that are low-lying, exposed to storm paths, and/or subject to increased erosion, *i.e.*, those most vulnerable to the combined effects of these environmental changes. We need precise, site-specific information and analyses in order to make higher-resolution and real-time local predictions.

To summarize, we can expect higher sea level and more inundating storm tides and waves, as the 21st century unfolds. Our exposure to these aspects of climate change is serious, though not on the same scale as North Carolina or Louisiana, or even parts of Southern Maine like Saco.

We have time to make adjustments and preparations for these changes. While there is evidence that some past climatic changes have occurred relatively suddenly, we can hope for a gradual rate of change over the next 80 years, as reflected in the charts above. This will allow us

to make immediate adjustments as urgently required, to make long-range plans for adjustments with longer time horizons, and to observe all the while the changes achieved in greenhouse gas emissions, and the actual climatic and oceanic changes which occur, as compared with projections.

Endnotes

1. Schmitt and Uteuova, 49
2. United Nations
3. NOAA CO-OPS o83
4. Arnold, “Sea Level”
5. US Army Corps
6. Sengupta
7. Sweet, 2
8. Woodruff
9. Runkle, Kunkle, 2
10. “Maine’s Climate Future”, 9
11. Walsh, et. al., “Introduction”
12. Slovinsky, “Trends”, 28
13. Slovinsky, “Trends”, 33
14. Storm Surge Team, UMaine
15. Talke, 18
16. Woodruff, J., 20 July 2018 presentation at Darling Center
17. NOAA “Datums”
18. adapted from MGS, SLOSH
19. adapted from “Waterfront Design ‘97”
20. “Waterfront Design ‘97”, 17
21. Andrews, Republican Journal
22. Talke et al., 13; Runkle, Kunkle et. al, 3
23. Saffir-Simpon
24. 2018 Waldo County Emergency Management Plan

Citations

2018 Waldo County Emergency Plan. “Severe Summer Storms,” Attachment 12, p. 1.
http://www.waldocountyme.gov/ema/user/Waldo_County_EOP.pdf

Andrews, Ethan. “High tides, ‘weird storms’ a puzzle for waterfront workers.” Republican Journal (3-8-’18), pp. A1, A9.

Arnold, Susie, Ph.D. and Heather Deese, Ph.D., Island Institute. [Talk on sea-level rise]. Available through Island Institute. (Last updated 7-18-2017) www.islandinstitute.org/ [checking on citation]

Arnold, Susie, Ph.D., Island Institute. “Sea Level Rise and Coastal Flooding: The Basics for Maine Communities.” (2018). 2 pp.
<http://www.islandinstitute.org/sites/default/files/II%20Pager%20-%20Sea%20Level%20Rise.pdf>
[Accessed 9-22-’18] [checking on date]

{Belfast, Maine, Official website} Agendas & Minutes → Climate Change Committee.
<https://www.cityofbelfast.org/archive.aspx> [Accessed 9-7-’18]

{Belfast, Maine, Official website} Boards and Committees → Climate Change Committee webpage.
<https://www.cityofbelfast.org/index.aspx?NID=373> [Accessed 9-7-’18]

“Belfast, Maine.” {Wikipedia} [Accessed 8-31-’18]

Bowness, Gayle, Gulf of Maine Research Institute. “Sea-Level Rise: Our Changing Coastline and Community.” Talk given at the Northeast Harbor Library [Mt. Desert Island], ME (August 30, 2018).
[Checking to see if slides will be available online via *Climate to Thrive, MDI*]

Bowness, Gayle, Gulf of Maine Research Institute. Personal e-mail to Barbara Bell, 9-4-’18.

EPA. “Climate Change Indicators: Sea Surface Temperature.”
<https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature>
[Accessed 9-25-’18]

Ferguson, Callie and Bill Trotter. “Maine Hunkers down for Thursday Blizzard that Could Drop Over a Foot of Snow.” Bangor Daily News, 1-4-’18. [The image shown is a screen-shot of the first frame in the video at the start of the article.]
<http://bangordailynews.com/2018/01/04/weather/maine-hunkers-down-for-thursday-blizzard-that-could-drop-over-a-foot-of-snow/> [Accessed 9-6-’18]

Fernandez, I.J.; C.V. Schmitt; S.D. Birkel; E. Stancioff; A.J. Pershing; J.T. Kelley; J.A. Runge; G.L. Jacobson; and P.A. Mayewski. Maine’s Climate Future: 2015 Update. Orono, ME: University of Maine. [February 2015, Revised March 2015 with corrected Figure 2 and Figure 9 legends and captions. 24 pp.]
climatechange.umaine.edu/research/publications/climate-future [Accessed 9-6-’18]

“Hurricane Gloria.” {Wikipedia}. https://en.wikipedia.org/wiki/Hurricane_Gloria [Accessed 9-25-’18]

“Maine Coastal Storm and Flood of February 2, 1976.” Morrill, R.A.; Chin, E.H.; and Richardson, W.S. Geological Survey Professional Paper #1087 for USGS and NOAA, 1979. 29 pp.
<https://pubs.usgs.gov/pp/1087/report.pdf> [Accessed 9-22-’18]

Maine Geological Survey. “Online Coastal Bluffs Maps.”
<https://www.maine.gov/dacf/mgs/pubs/online/bluffs/bluffs.htm>

A. [Belfast Quadrangle] Bryant, Marita; Barnhardt, Walter A.; Dickson, Stephen M.; Kelley, Joseph T. "Coastal bluffs in the Belfast quadrangle, Maine": Maine Geological Survey (2002). Open-File Map 02-172, map, scale 1:24,000.

B. [Searsport Quadrangle] Bryant, Marita; Barnhardt, Walter A.; Murray, Kendra; Keblinsky, Corinn C.; Dickson, Stephen M.; Kelley, "Coastal bluffs in the Searsport quadrangle, Maine: Maine Geological Survey, (2003). Open-File Map 03-24, map, scale 1:24,000.

Maine Geological Survey. "Sea Lake and Overland Surges from Hurricanes (SLOSH) Maps", Interactive GIS Visualization tool. <https://www.maine.gov/dacf/mgs/hazards/slosh/index.shtml>

Maine Geological Survey. "Sea Level Rise/Storm Surge", Interactive GIS Visualization tool. https://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml

NASA. "Carbon Dioxide." (August 2018). <https://climate.nasa.gov/vital-signs/carbon-dioxide/> [Accessed 9-22-'18]

NASA. Earth Observatory. Carlowicz, Michael, "Watery Heatwave Cooks the Gulf of Maine" (9-12-'18) <https://climate.nasa.gov/news/2798/watery-heatwave-cooks-the-gulf-of-maine/> [Accessed 9-23-'18]

NERACOOS. <http://www.neracoos.org> [Accessed 9-7-'18]

NOAA. Technical Report NOS CO-OPS 083. "Global and Regional sea Level Rise Scenarios for the United States" (January 2017). P 22. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf [Accessed 9-26-'18]

NOAA. Tides and Currents. "Datums." <https://tidesandcurrents.noaa.gov/datums.html?id=8415191> [Accessed 9-25-'18]

NOAA. Tides and Currents. "Sea-Level Trends." <https://tidesandcurrents.noaa.gov/sltrends/faq.shtml#q4> [Accessed 9-7-'18]

Rogej, Joeri. "Paris Agreement Climate Proposals Need a Boost..." Nature, v. 534, #7609 (June '16), pp. 631-639. <https://www.nature.com/articles/nature18307> [Accessed 9-18-'18]

Runkle, Jennifer and Kunkle, Kenneth E, with Sarah Champion, Rebekah Frankson, Brooke C. Stewart, Arthur T. Degaetano. "State Summaries 149-ME", NOAA National Centers for Environmental Information (2017). 4 pp. <https://adaptationworkbook.org/sites/default/files/resources/ME-screen-hi.pdf> [Accessed 9-23-'18]

"Saffir-Simpson scale." {Wikipedia}. https://en.wikipedia.org/wiki/Saffir-Simpson_scale [Accessed 9-19-'18]

Schmitt, Catherine and Uteuova, Aliya. "Sea Monsters", UMaine Today (Spring/Summer 2018), pp. 44-52. <https://umainetoday.umaine.edu/stories/2018/sea-monsters/> [Accessed 9-22-'18]

Sengupta, S. "UN Chief Warns of a Dangerous Tipping Point on Climate Change", New York Times (9-10-'18), p. A6. <https://www.nytimes.com/2018/09/10/climate/united-nations-climate-change.html> [Accessed 9-22-'18]

[Storm Surge Team, University of Maine.] "Sensing Storm Surge." PowerPoint Presentation. Available by request at <http://sensingstormsurge.acg.maine.edu> [Accessed 9-7-'18]

Slovinsky, Peter A. "Latest trends in sea level rise and storm surges in Maine." (November, 2017; PowerPoint presentation, 38 slides).
http://www.islandinstitute.org/sites/default/files/Pete_%20Slovinsky_SLR_Historic%20Storm%20Surge.pdf [Accessed 9-7-'18]

Sweet, William V., et al. "2017 State of U.S. High Tide Flooding with a 2018 Outlook", [NOAA Center for Oceanographic Products and Services], June 6, 2018; 12 pp.
https://www.ncdc.noaa.gov/monitoring-content/sotc/national/2018/may/2017_State_of_US_High_Tide_Flooding.pdf [Accessed 9-7-'18]

Talke, S. A., Kemp, A.C., & Woodruff, J. "Relative sea level, tides, and extreme water levels in Boston harbor from 1825 to 2018." *Journal of Geophysical Research: Oceans*, v. 123, #6 (01 June 2018), pp. 3895-3914. <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2017JC013645> [Accessed 9-6-'18]

Taylor, Alan. "*Sprung Up In A Day*": Belfast, Maine Emerges as a Market Town." Introduction to Early Histories of Belfast, Maine (Picton Press: Camden, Maine, 1989), pp. v-xii.

Union of Concerned Scientists USA, Underwater: Rising Seas, Chronic Floods, and the Implications for US Coastal Real Estate (June 2018), 28 pp. Online at
<https://www.ucsusa.org/global-warming/global-warming-impacts/sea-level-rise-chronic-floods-and-us-coastal-real-estate-implications>. Tools available at site for exploring locations by zip code and Congressional districts. [Accessed 9-6-'18]

United Nations. "Concentration of CO2 in Atmosphere Hits Record High" (10-30-'17). Video.
<https://www.msn.com/en-za/news/watch/concentration-of-co2-in-atmosphere-hits-record-high-un/vp-AAueWug> [Accessed 9-22-'18]

US Army Corps of Engineers. "Sea-Level Change Curve Calculator (Version 2017.55)."
http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html [Accessed 9-26-'18]

Victor, et al. "Prove Paris Was More Than Paper Promises." *Nature News*, v. 548, #7665, p. 25. (8-3-'17)
<http://www.nature.com/news/prove-paris-was-more-than-paper-promises-1.22378> [Accessed 9-18-'18]

Walsh, J.; D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014. Our changing climate. In Climate change impacts in the United States: The third national climate assessment, edited by J.M. Melillo, T.C. Richmond, and G.W. Yohe. Washington, DC: US Global Change Research Program. Introduction, pp. 19-67.
<http://nca2014.globalchange.gov/report/ourchanging-climate/introduction> [Accessed 9-5-'18]

Walsh, J.; D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014. Our changing climate. In Climate change impacts in the United States: The third national climate assessment, edited by J.M. Melillo, T.C. Richmond, and G.W. Yohe. Washington, DC: US Global Change Research Program. Appendix 4, p. 796.
<https://nca2014.globalchange.gov/report/appendices/faqs> [Accessed 9-22-'18]

Waterfront Design Associates, Oceanographic Studies, Inc. "Wind Wave Climate Study: Belfast Harbor, Maine." 1997, Medfield MA. 21 pp. [This is a proprietary report done by an engineering firm under contract to MBNA, but CCC has a digital copy in its Library. In this copy, the last (discussion) portion of the study is incomplete, but all the data tables are complete.]

Woodruff, Jon. Unpublished data presented in talk entitled “High Water, Extreme Floods and Coastal Systems” 7-20-’18 at University of Maine Darling Marine Center, Walpole, ME.

Interactive Mapping Tools Useful for Visualization

FEMA Flood Zone Map. City of Belfast website. <https://www.cityofbelfast.org/> Go to City of Belfast website and enter *FEMA Flood Zone Map* or similar key words into Search Box. The map is somewhat interactive in that you can zoom in or out to see any properties of interest.

FIRM Maps (Flood Insurance Rate Maps). City of Belfast website. <https://www.cityofbelfast.org/> Go to the City of Belfast website and enter *FIRM Maps* or similar key words into Search Box. FIRM Maps are available covering all locations in Belfast; they are typically indexed by the names of certain roads. You can find the area you’re interested in and zoom in to see the extent of flooding across several different types of flood zones.

Maine Geological Survey. “Sea Lake and Overland Surges from Hurricanes (SLOSH) Maps”, Interactive GIS Visualization tool. <https://www.maine.gov/dacf/mgs/hazards/slosh/index.shtml>

Maine Geological Survey. “Sea Level Rise/Storm Surge”, Interactive GIS Visualization tool. https://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml

Union of Concerned Scientists USA, [Underwater: Rising Seas, Chronic Floods, and the Implications for US Coastal Real Estate](https://www.ucsusa.org/global-warming/global-warming-impacts/sea-level-rise-chronic-floods-and-us-coastal-real-estate-implications) (June 2018), 28 pp. Online at <https://www.ucsusa.org/global-warming/global-warming-impacts/sea-level-rise-chronic-floods-and-us-coastal-real-estate-implications>. Tools available at site for exploring locations by zip code and Congressional districts. [Accessed 9-6-’18]

Endnotes

1. Schmitt and Uteuova, 49
2. United Nations
3. NOAA CO-OPS o83
4. Arnold, “Sea Level”
5. US Army Corps
6. Sengupta
7. Sweet, 2
8. Woodruff
9. Runkle, Kunkle, 2
10. “Maine’s Climate Future”, 9
11. Walsh, et. al., “Introduction”
12. Slovinsky, “Trends”, 28
13. Slovinsky, “Trends”, 33
14. Storm Surge Team, UMaine
15. Talke, 18
16. Woodruff, J., 20 July 2018 presentation at Darling Center
17. NOAA “Datums”
18. adapted from MGS, SLOSH
19. adapted from “Waterfront Design ‘97”
20. “Waterfront Design ‘97”, 17
21. Andrews, Republican Journal
22. Talke et al., 13; Runkle, Kunkle et. al, 3
23. Saffir-Simspon
24. 2018 Waldo County Emergency Management Plan