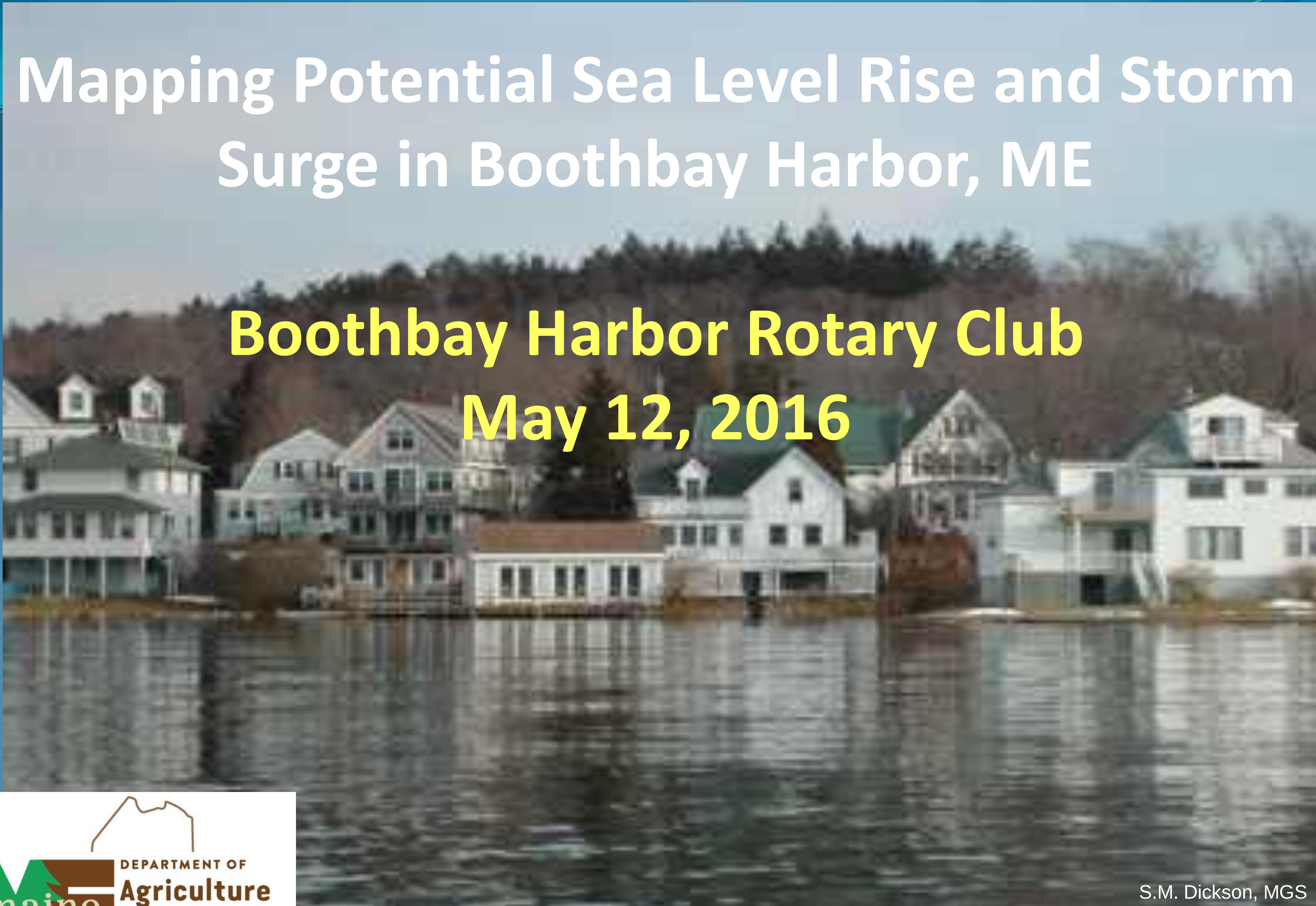
Mapping Potential Sea Level Rise and Storm Surge in Boothbay Harbor, ME

Boothbay Harbor Rotary Club
May 12, 2016



S.M. Dickson, MGS

DEPARTMENT OF Agriculture Conservation & Forestry

Peter A. Slovinsky, Marine Geologist
Maine Geological Survey

Quickly, I'll cover….

- What drives sea level rise change?
- Setting the stage: Maine's glacial geology and historic sea level rise trends
- Current sea level trends from Portland, Maine
- Where might sea levels go in the future?
- Storm surges
- Sea Level Rise and Hurricane inundation mapping

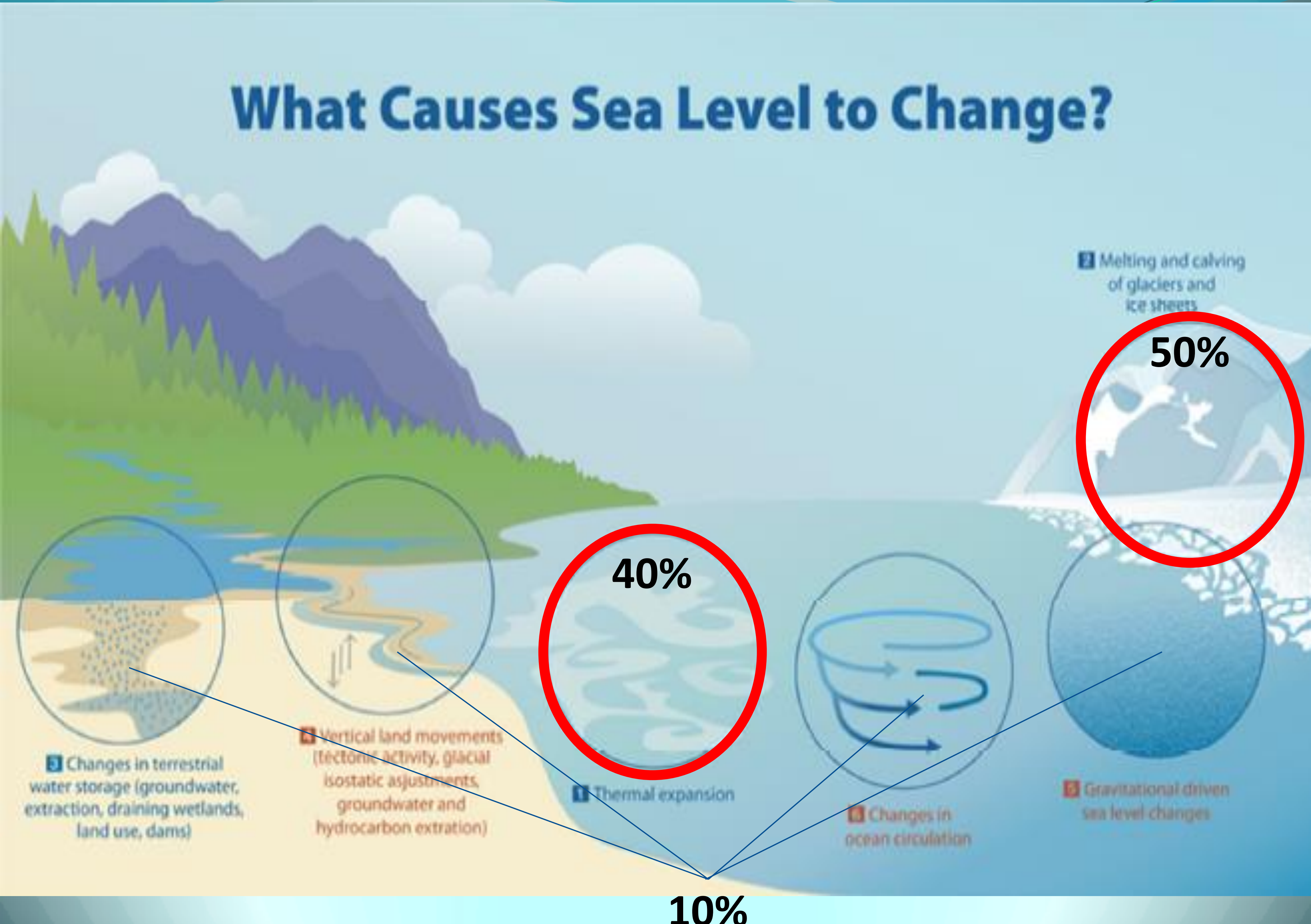
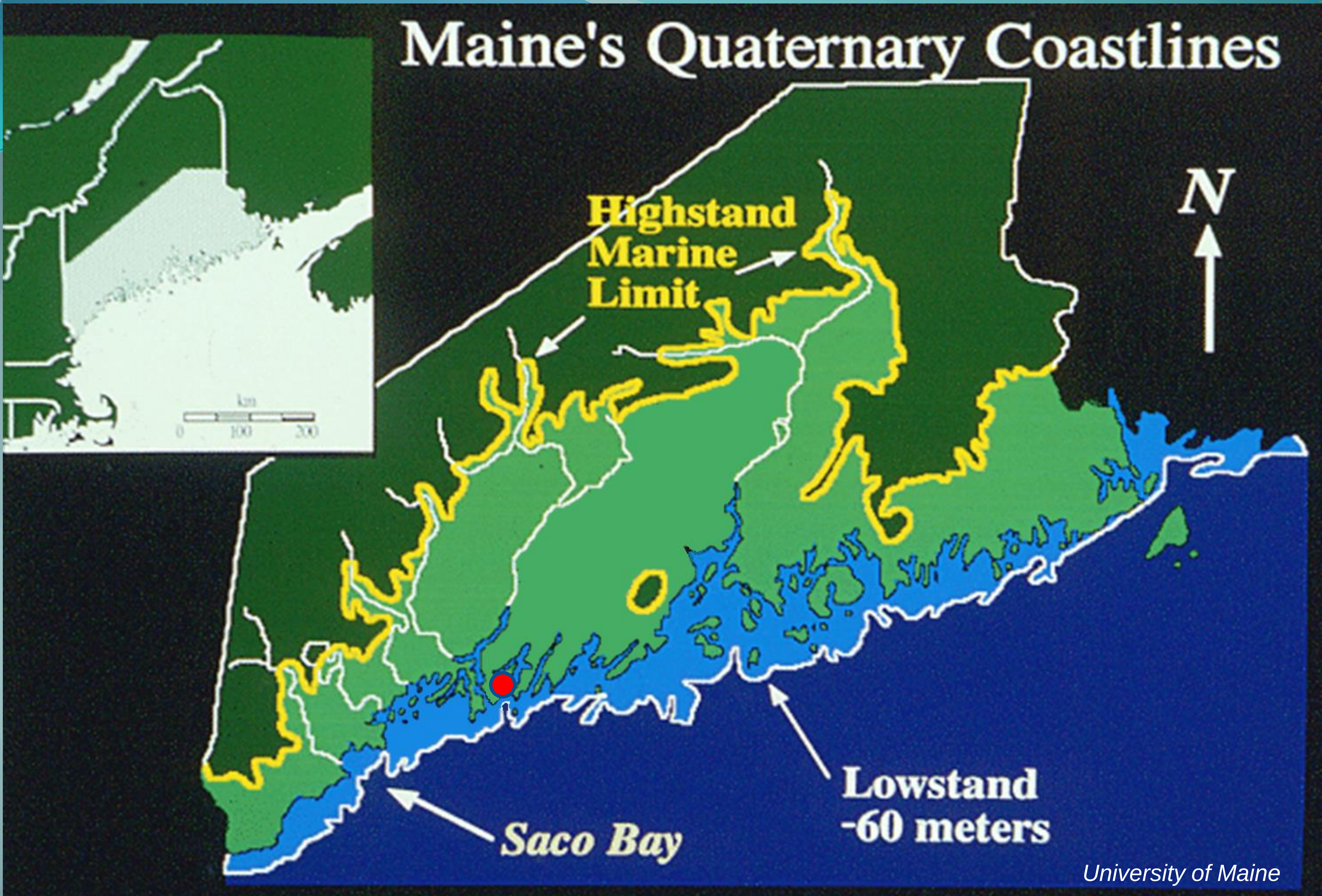
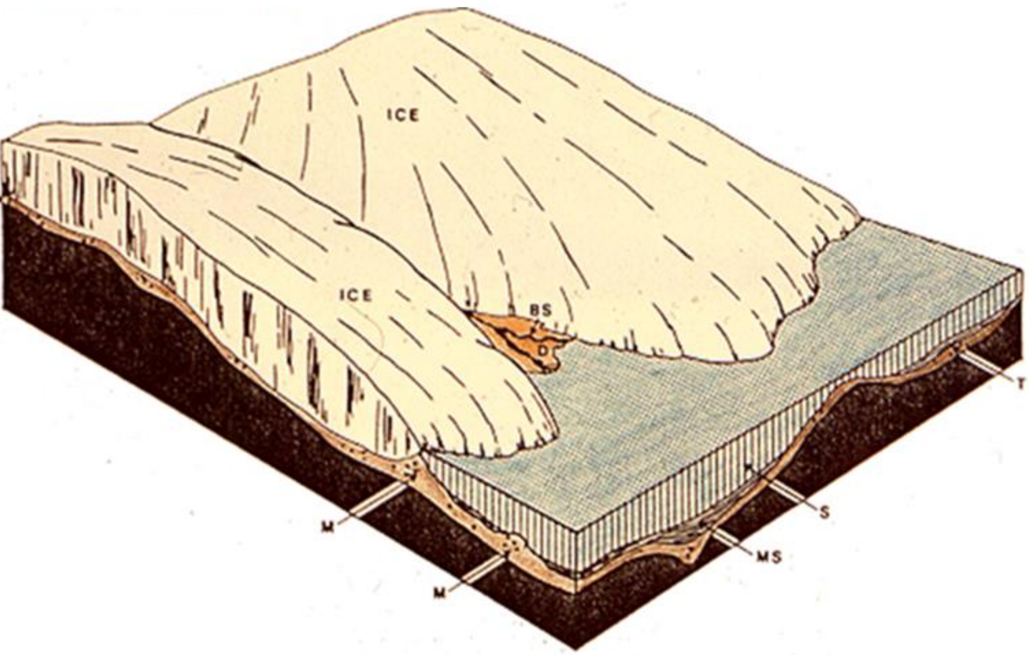


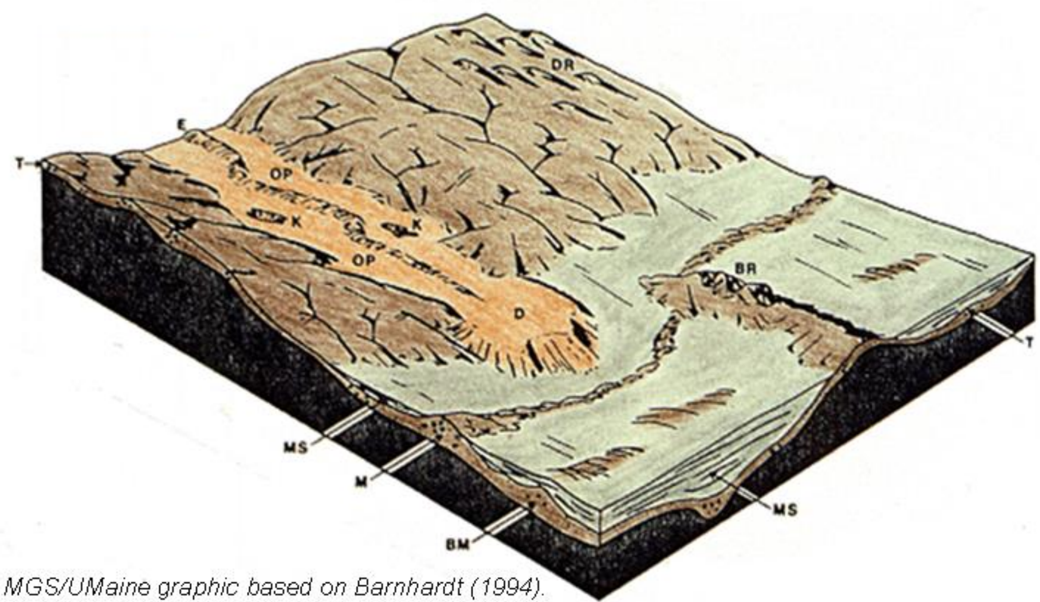
Figure modified from Griggs, 2001



In the past, massive adjustments of earth's crust in response to glaciation drove much of Maine's sea level changes…

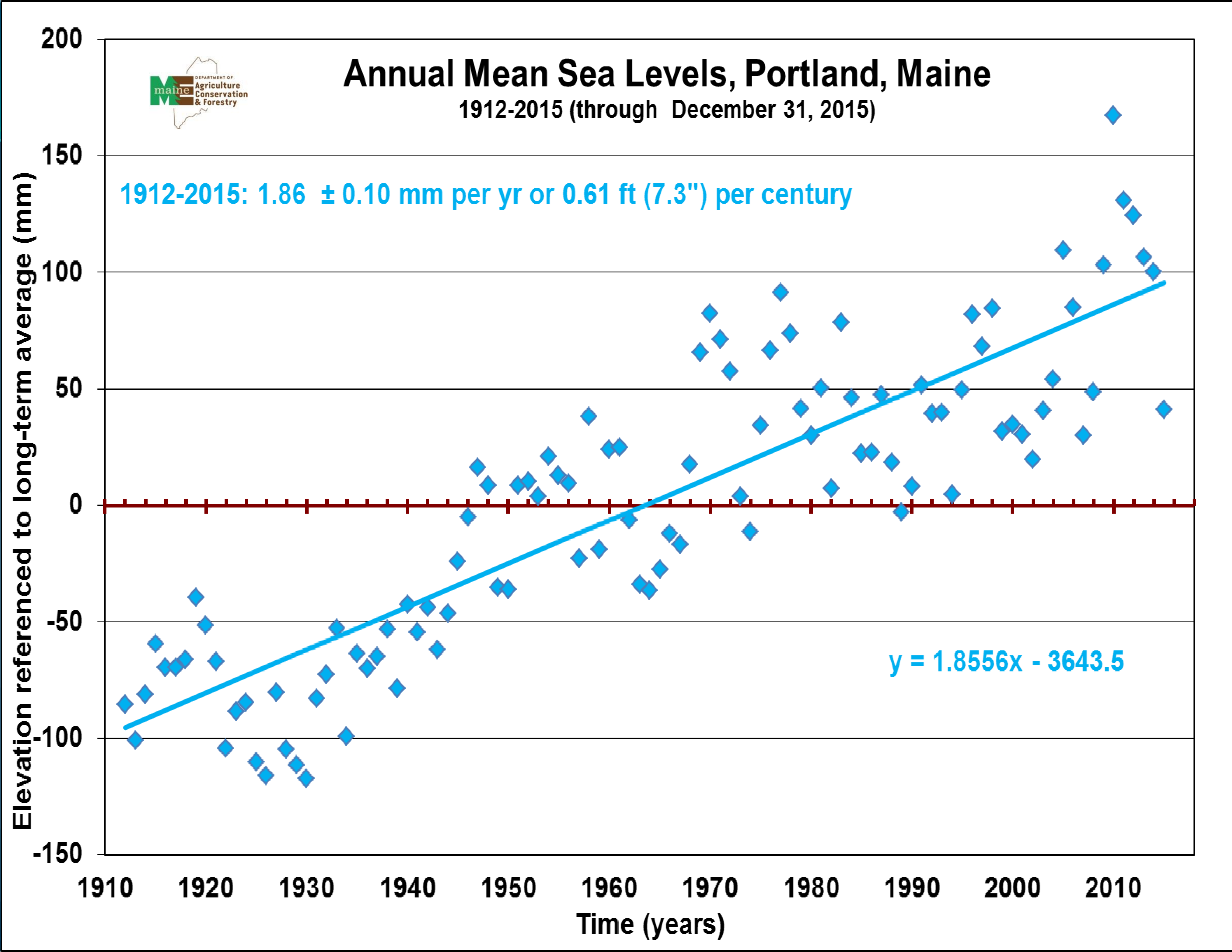


13,000 yrs ago, glaciers covered most of Maine, compressing the land surface so it was below sea level!

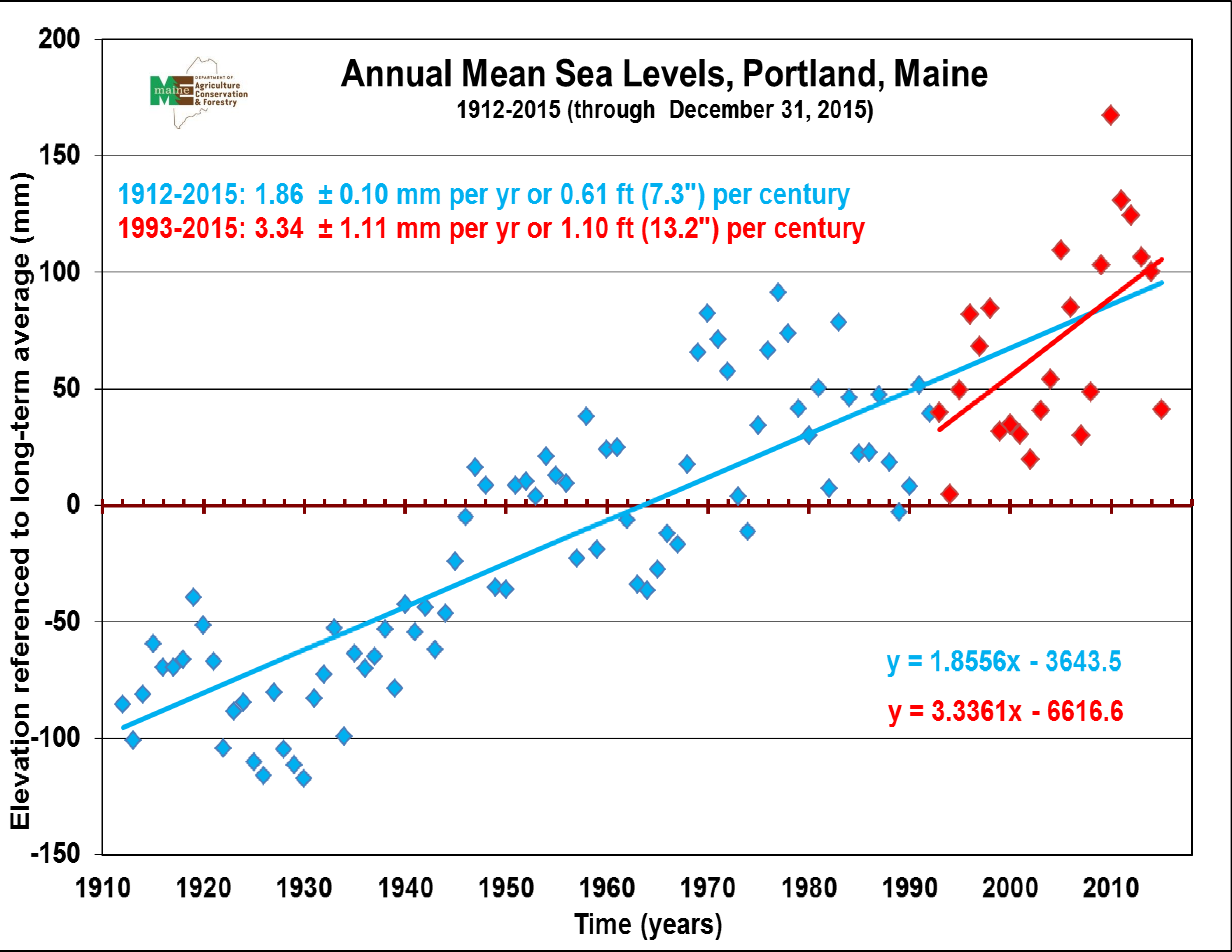


MGS/UMaine graphic based on Barnhardt (1994).

By 11,000 yrs ago, the glaciers had rapidly (geologically speaking) receded, and the land "rebounded" in response.



Annual Mean Sea Levels, Portland, Maine
1912-2015 (through December 31, 2015)
maine Department of Agriculture Conservation & Forestry
1912-2015: 1.86 ± 0.10 mm per yr or 0.61 ft (7.3") per century
y = 1.8556x - 3643.5
Elevation referenced to long-term average (mm)
200
150
100
50
0
-50
-100
-150
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Time (years)



maine Department of Agriculture Conservation & Forestry
Annual Mean Sea Levels, Portland, Maine
1912-2015 (through December 31, 2015)
1912-2015: 1.86 ± 0.10 mm per yr or 0.61 ft (7.3") per century
1993-2015: 3.34 ± 1.11 mm per yr or 1.10 ft (13.2") per century
y = 1.8556x - 3643.5
y = 3.3361x - 6616.6
Elevation referenced to long-term average (mm)
200
150
100
50
0
-50
-100
-150
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Time (years)

…if current [Antarctic and Greenland] ice sheet melting rates continue for the next four decades, their cumulative loss could raise sea level by 15 centimeters (5.9 inches) by 2050. When this is added to the predicted sea level contribution of 8 centimeters (3.1 inches) from glacial ice caps and 9 centimeters (3.5 inches) from ocean thermal expansion, total sea level rise could reach 32 centimeters **(12.6 inches) by the year 2050**.

Rignot and others, March 2011

http://www.agu.org/news/press/pr_archives/2011/2011-09.shtml

Image from www.swisseduc.ch

ARTICLE

doi:10.1038/nature17145

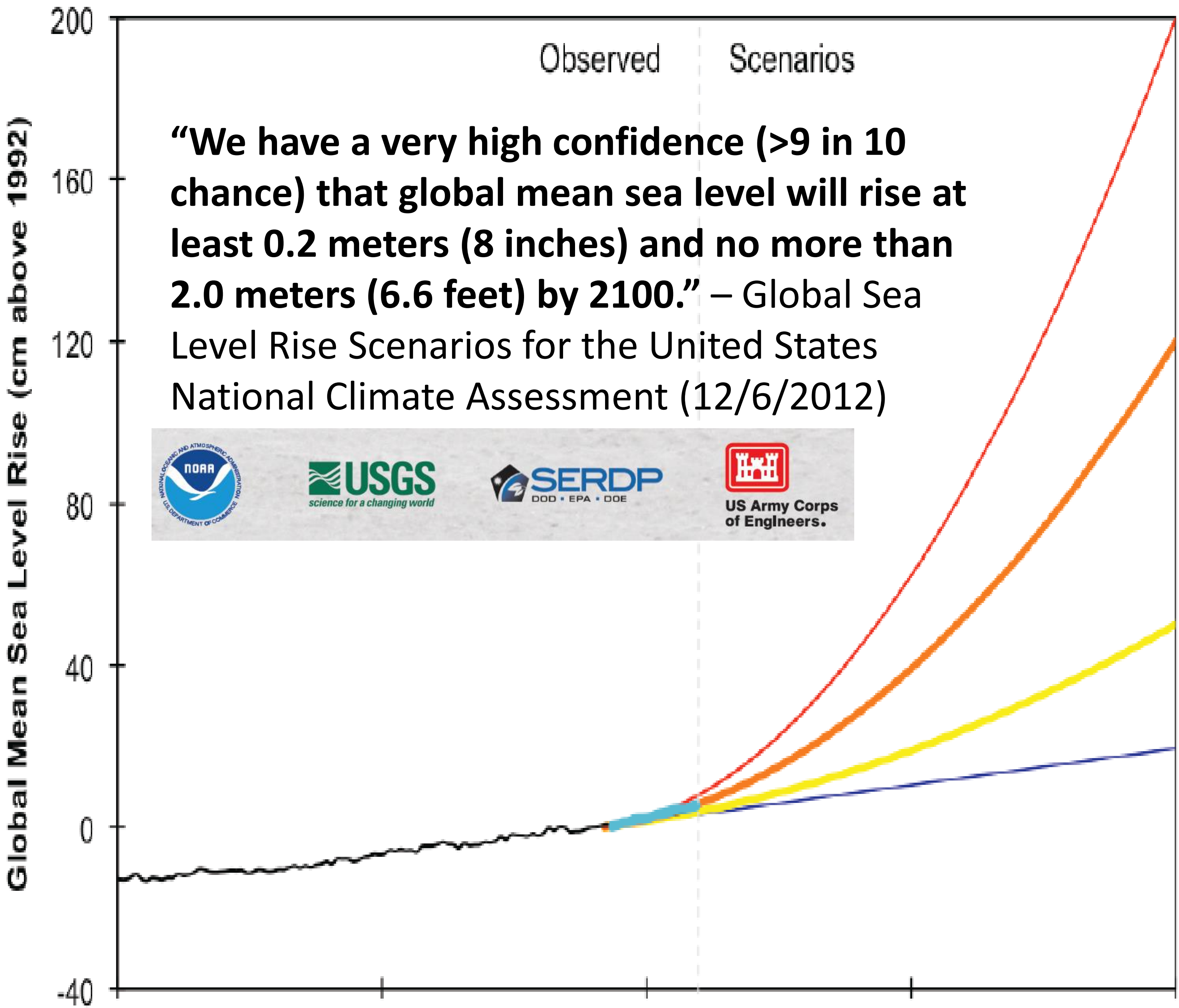
Contribution of Antarctica to past and future sea-level rise

Robert M. DeConto[1] & David Pollard[2]

Polar temperatures over the last several million years have, at times, been slightly warmer than today, yet global mean sea level has been 6–9 metres higher as recently as the Last Interglacial (130,000 to 115,000 years ago) and possibly higher during the Pliocene epoch (about three million years ago). In both cases the Antarctic ice sheet has been implicated as the primary contributor, hinting at its future vulnerability. Here we use a model coupling ice sheet and climate dynamics—including previously underappreciated processes linking atmospheric warming with hydrofracturing of buttressing ice shelves and structural collapse of marine-terminating ice cliffs—that is calibrated against Pliocene and Last Interglacial sea-level estimates and applied to future greenhouse gas emission scenarios. Antarctica has the potential to contribute more than a metre of sea-level rise by 2100 and more than 15 metres by 2500, if emissions continue unabated. In this case atmospheric warming will soon become the dominant driver of ice loss, but prolonged ocean warming will delay its recovery for thousands of years.

Antarctica has the *potential* to contribute more than a meter of sea-level rise by 2100…

Nature, March 30, 2016



"We have a very high confidence (>9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100." – Global Sea Level Rise Scenarios for the United States National Climate Assessment (12/6/2012)

Highest
(2.0 m, 6.6 ft)
***Combines maximum warming, thermal expansion, and possible ice sheet loss from semi-empirical models.**

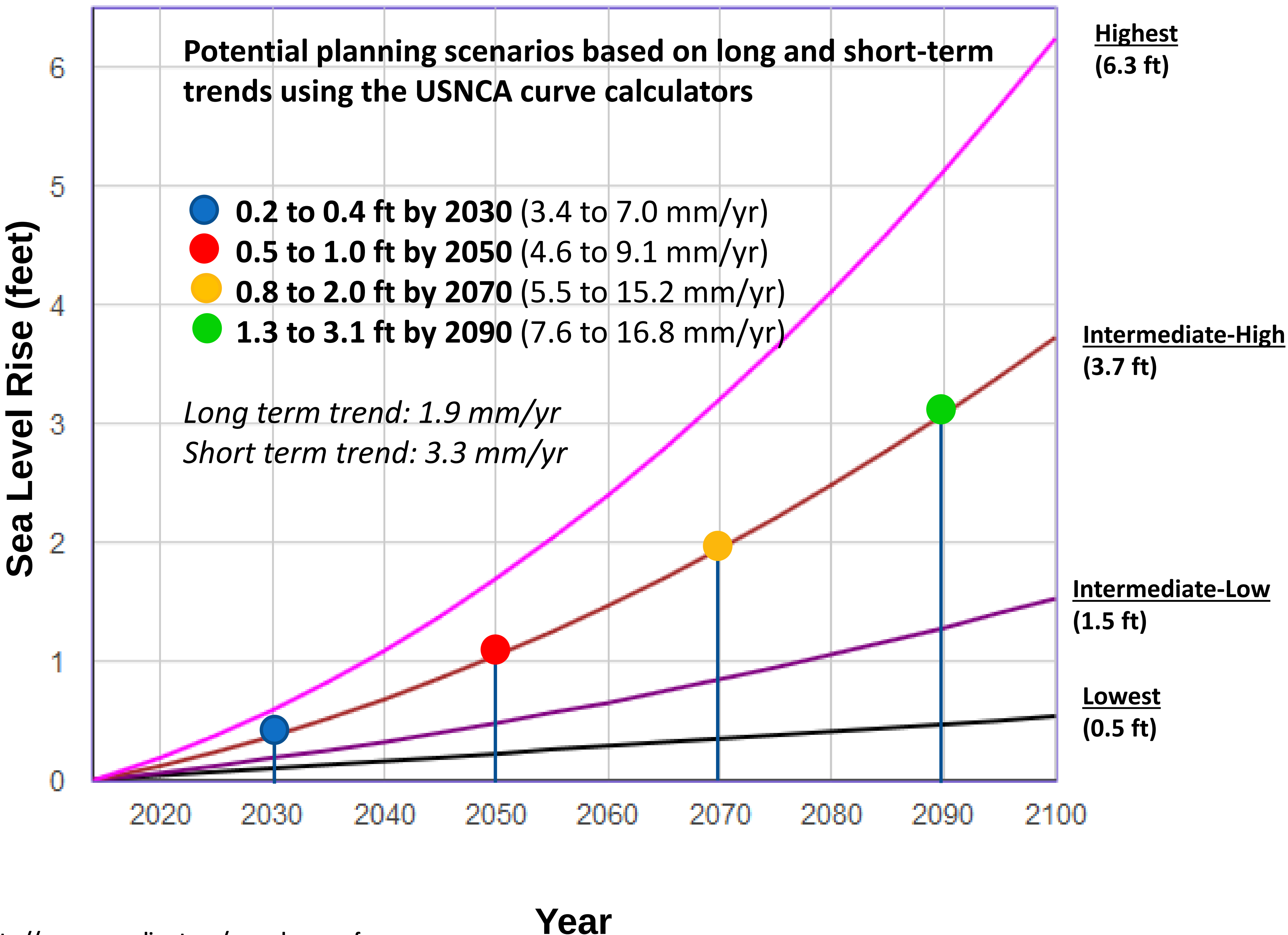
Intermediate-High
(1.2 m, 3.9 ft)
***Average of high end global predictions, combines recent ice sheet loss and thermal expansion**

Intermediate-Low
(0.5 m, 1.6 ft)
***Includes only thermal expansion from warming from IPCC AR4.**

Lowest
(0.2 m, 0.7 ft)
*** Historical trend continued; no additional thermal expansion from warming**

Recommend using a "Scenario" Based Approach

Sea Level Rise Projections for Portland, ME



http://www.corpsclimate.us/ccaceslcurves.cfm

P.A. Slovinsky, MGS, March 23, 2016

Abrupt short-term sea level rise in the North Atlantic

nature COMMUNICATIONS

ARTICLE

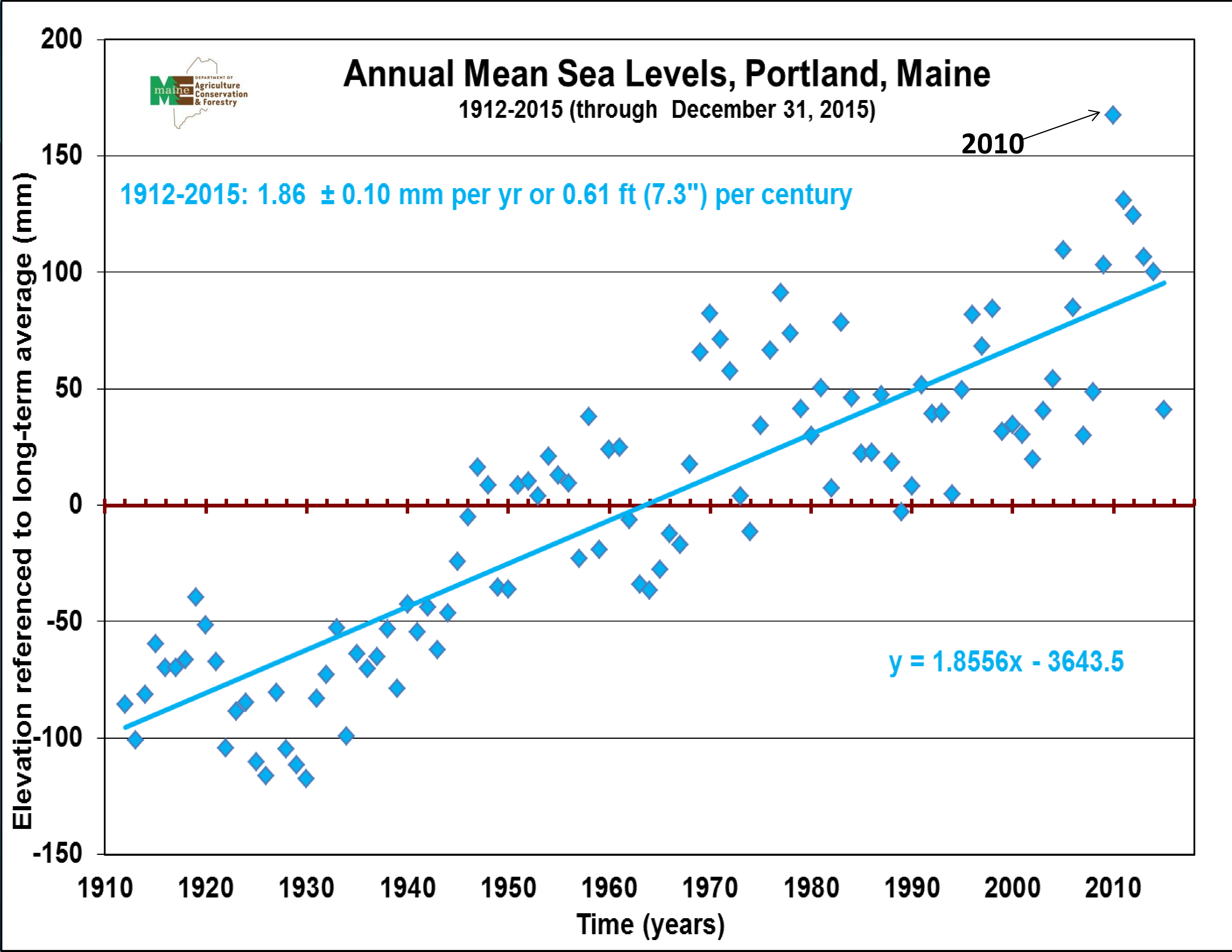
Received 6 Aug 2014 | Accepted 21 Jan 2015 | Published 24 Feb 2015

DOI: 10.1038/ncomms7346

An extreme event of sea-level rise along the Northeast coast of North America in 2009–2010

Paul B. Goddard[1], Jianjun Yin[1], Stephen M. Griffies[2] & Shaoqing Zhang[2]

Maine saw an <u>average</u> of approximately 5” higher than normal tides in the summer of 2009, and, especially in winter of 2010.


Annual Mean Sea Levels, Portland, Maine
1912-2015 (through December 31, 2015)
maine
DEPARTMENT OF
Agriculture
Conservation
& Forestry
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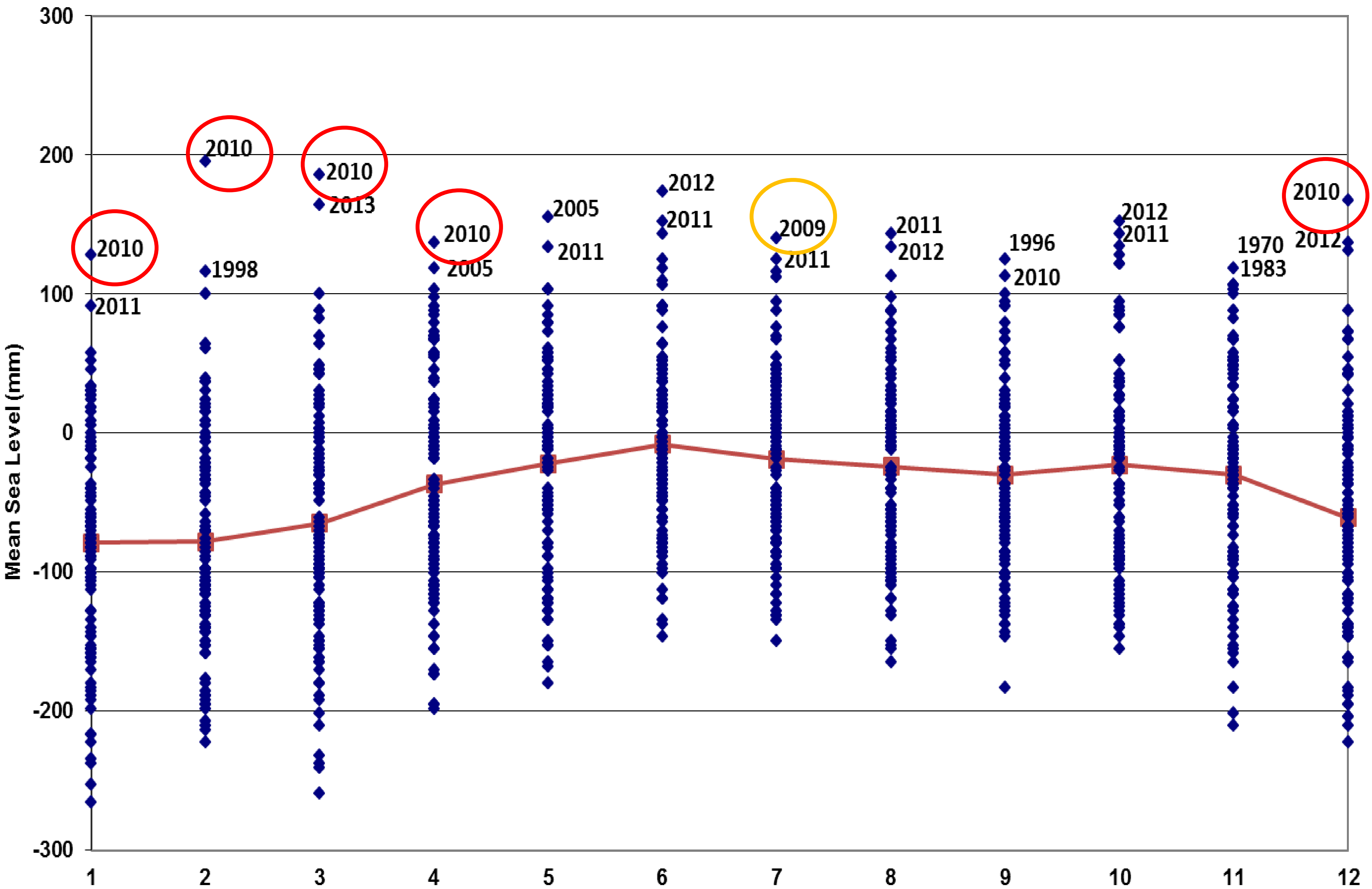
-100
-150
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Time (years)

Portland, Maine Sea Level Variability by Month
(1912-2014)



Data courtesy of NOAA CO-OPS, www.tidesandcurrents.nooa.gov

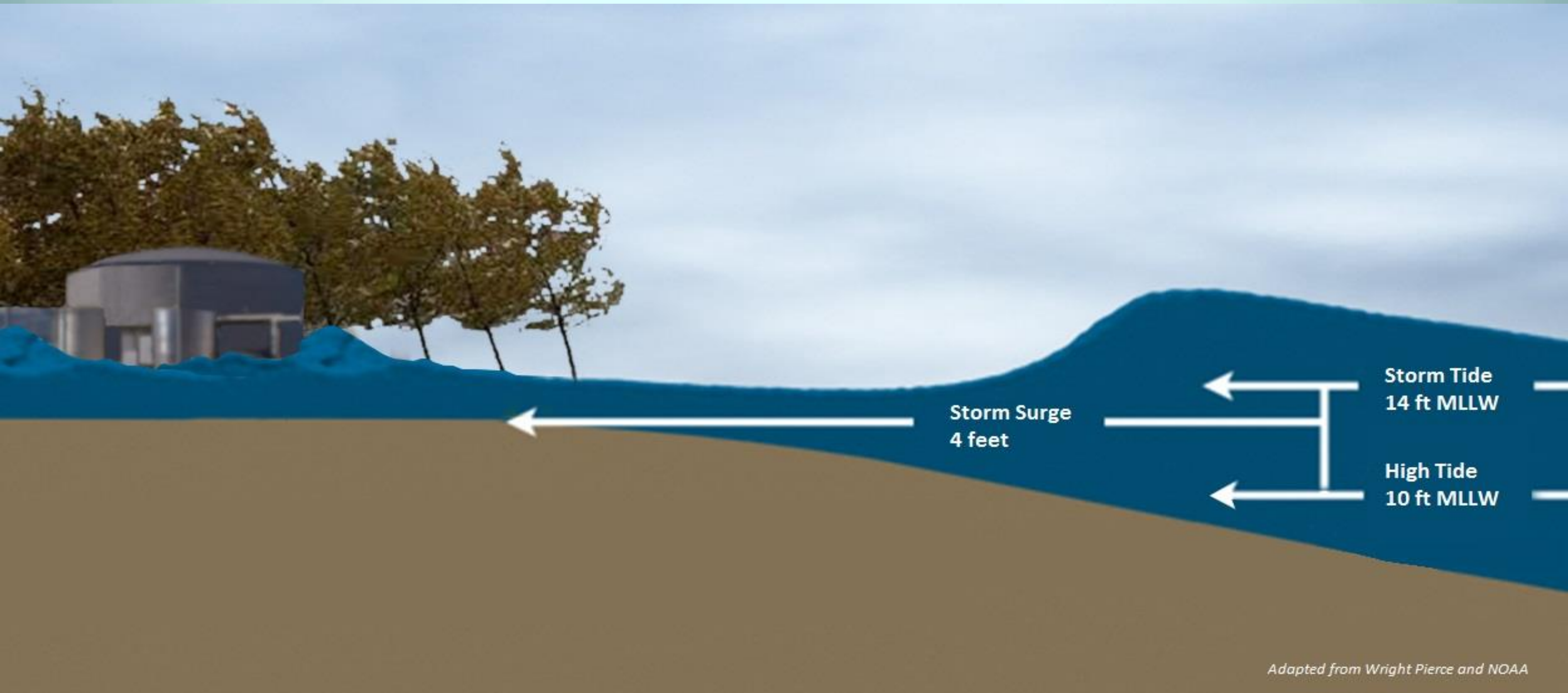
Calendar Month (Jan-Dec)

P.A. Slovinsky, Maine Geological Survey, March 3, 2015

What about storm tides and storm surges?

So what is storm surge?

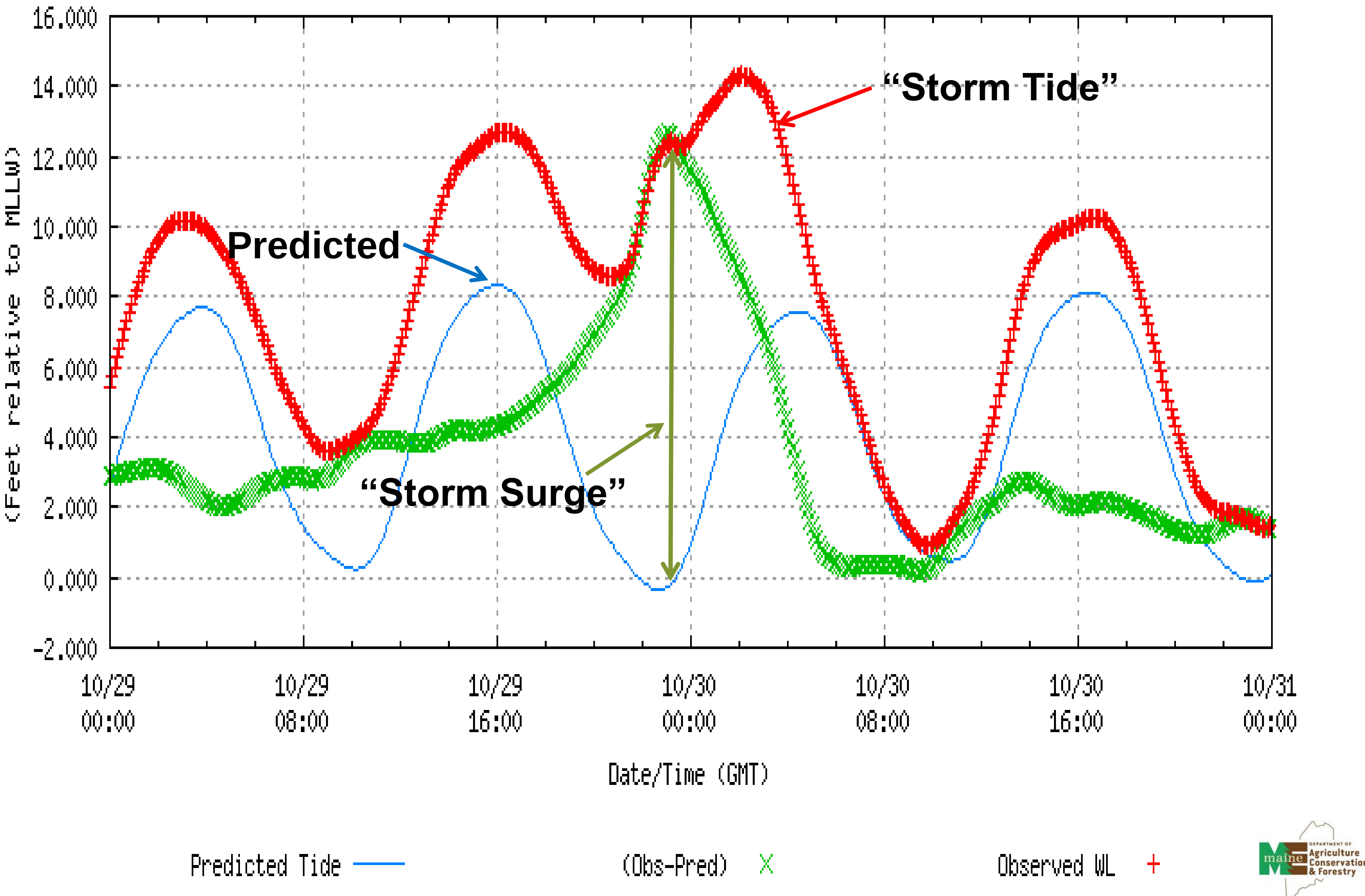
Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Storm surge should not be confused with storm tide, which is defined as the water level rise due to the combination of storm surge and the astronomical tide (National Hurricane Center)



Storm Surge
“Superstorm Sandy”

NOAA/NOS/CO-OPS
Verified Water Level vs. Predicted Plot
8516945 Kings Point, NY
from 2012/10/29 - 2012/10/30

Kings Point, NY
10/29-10/30/2012



Storm Surges at Portland, ME 1912-2012, at any tide

Time Interval (years)	Surge Height (feet)
1 (100 %)	1.8
5 (20%)	3.3
10 (10 %)	4.0
25 (5%)	4.9
50 (2 %)	5.6
100 (1%)	6.3

P.A. Slovinsky, MGS

maine Department of Agriculture Conservation & Forestry

Storm Tides at Portland, ME
1912-2012

Time Interval (years)	Height (ft, MLLW)
1 (100 %)	11.7
5 (20%)	12.6
10 (10 %)	12.9
25 (5%)	13.4
50 (2 %)	13.7
100 (1%)	14.1

P.A. Slovinsky, MGS

Storm Tides at Portland, ME 1912-2012

Time Interval (years)	Height (ft, MLLW)
1 (100 %)	11.7
5 (20%)	12.6
10 (10 %)	12.9
25 (5%)	13.4
50 (2 %)	13.7
100 (1%)	14.1

1 foot difference!

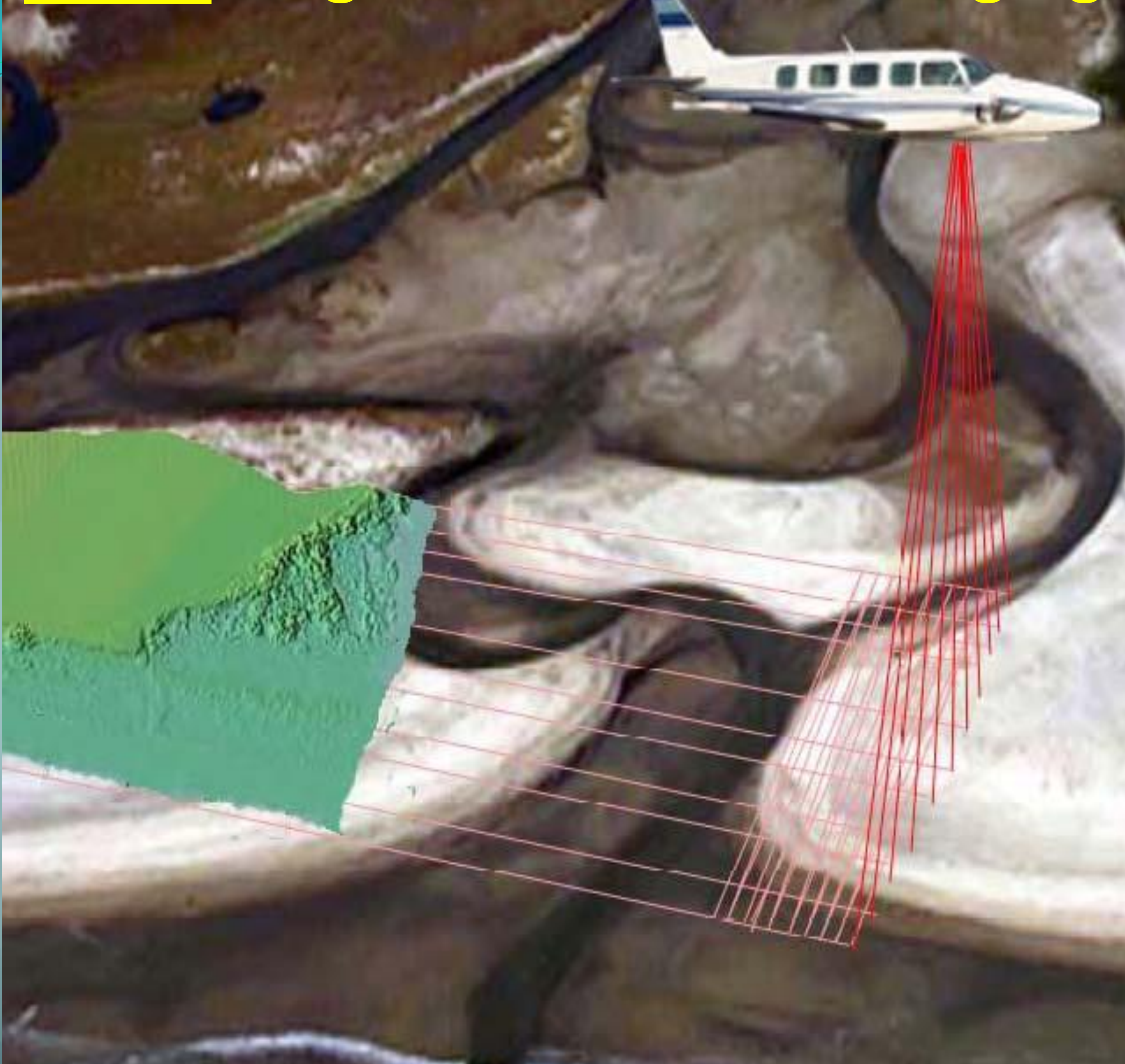
P.A. Slovinsky, MGS

SLR scenarios selected for mapping

- Latest Scenarios:
  - Short Term: approximately 1 ft by 2050
  - Long Term: 2-3 ft *but potentially more* by 2100;
- We decided to examine scenarios of **1 foot, 2 feet, 3.3 feet, and 6 feet** on top of the **highest annual tide (HAT).**
- These SLR scenarios relate well to the National Climate Assessment, and also **correspond well with evaluating potential impacts from storm surges that may coincide with higher tides today.**
- **Storms and storm surges can be exacerbated by Sea Level Rise, whether long-term or abrupt.**

Highest Annual Tide, Sea Level Rise and Hurricane Storm Surge Mapping

LiDAR - Light Detection & Ranging Data

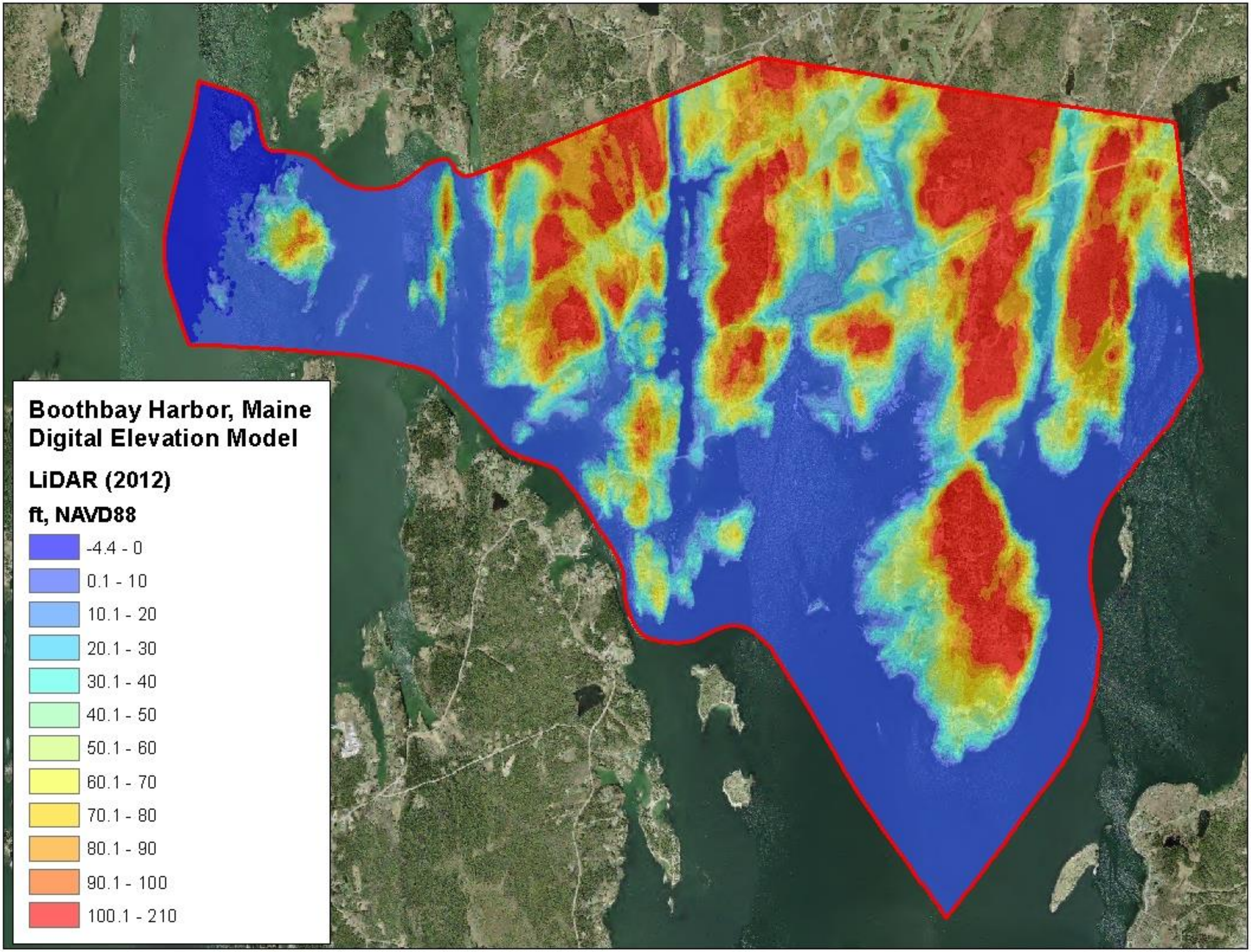


100,000 pulses of laser light per second are sent to the ground in sweeping lines

Sensors measure how long it takes each pulse to reflect back to the unit and calculates an “elevation”

Algorithms are used to “remove” buildings and vegetation types to create a “bare earth” digital elevation model (DEM)

Image from the Kelly Research and Outreach Lab, California Coastal LiDar Project


Boothbay Harbor, Maine
Digital Elevation Model
LiDAR (2012)
ft, NAVD88
-4.4 - 0
0.1 - 10
10.1 - 20
20.1 - 30
30.1 - 40
40.1 - 50
50.1 - 60
60.1 - 70
70.1 - 80
80.1 - 90
90.1 - 100
100.1 - 210

Coastal wetlands

"Coastal wetlands" means all tidal and subtidal lands; all areas with vegetation present that is tolerant of salt water and occurs primarily in salt water or estuarine habitat; and any swamp, marsh, bog, beach, flat or other contiguous lowland that is subject to tidal action during the **highest tide level for each year** in which an activity is proposed as identified in tide tables published by the National Ocean Service. Coastal wetlands may include portions of coastal sand dunes.

Required in Maine's Municipal Shoreland Zoning

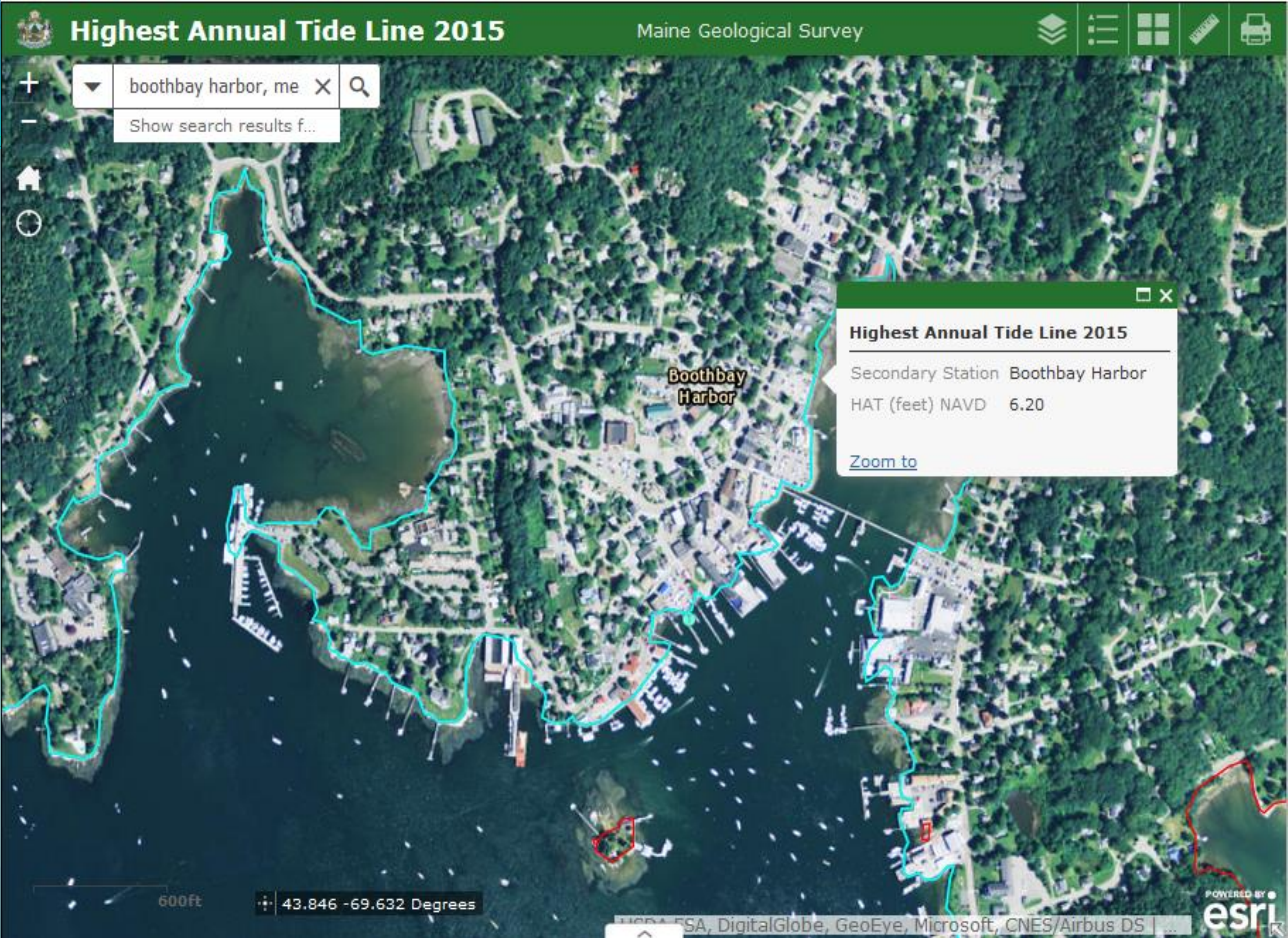
P.A. Slovinsky, MGS

Some Assumptions and Limitations

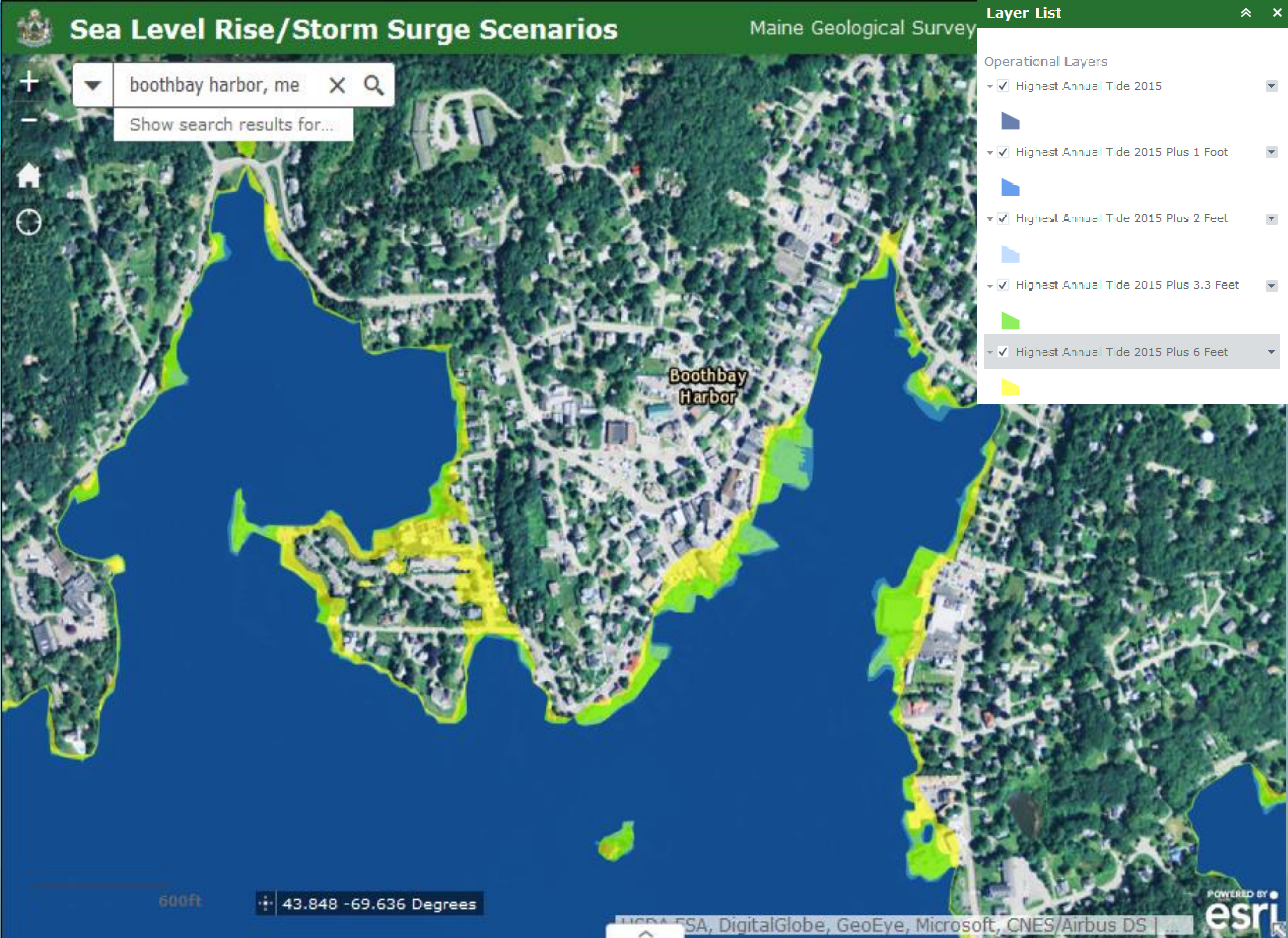
- We use a “bare earth” LiDAR DEM that represents a “snapshot” of topography that **may have changed since the data was captured**. Also, many **bridges have been removed.**

- Our simulations use a **bathtub approach that assumes a static rise in water, and doesn’t account for erosion, sedimentation, or freshwater flow or waves**.

- We use NOAA’s VDATUM to convert from MLLW to NAVD88 to translate elevations across water surfaces. This helps adjust tidal predictions, but also **adds additional vertical error (13.2 cm)**



http://www.maine.gov/dacf/mgs/hazards/hat/index.shtml



http://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtm

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- Lincoln County Sea Level Rise »

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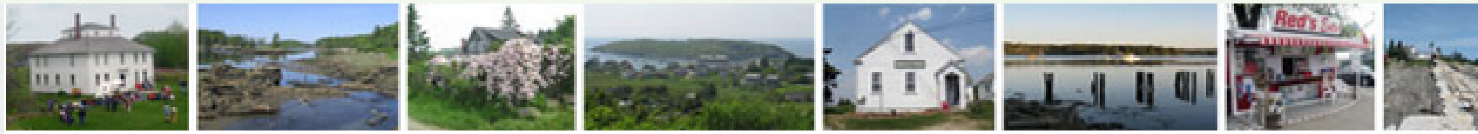
03.16 | Beginning Farmer Workshops - Mar, Apr, Jul 2016

CURRENT PROJECTS

Waldoboro Commercial Properties For Sale - February 2016
Wiscasset Commercial Properties For Sale - March 2016



LINCOLN COUNTY SEA LEVEL RISE

Lincoln County Sea Level Rise - Coastal Hazard Study

Lincoln County Regional Planning Commission
Lincoln County Commission
Maine Geological Survey
Maine Coastal Program

Maine Coastal Program

This presentation was prepared by the LCRPC under award NOAA CZM NA11NOS4190077 and NA11NOS4190188 to the Maine Coastal Program from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce.

http://lcrpc.org/coastal-projects-planning/sea-level-rise-scenarios

BOOTHBAY HARBOR SEA LEVEL RISE SCENARIOS

The following scenarios were developed by the Maine Geological Survey in conjunction with the Lincoln County Regional Planning Commission for general planning purposes only. They are based on a "bathtub" simulation model and do not take into account impacts associated with erosion, accretion, or wave action. Though local, regional, and national data indicates that sea level is continuing to rise, scientific authorities cannot predict with certainty the precise increase that will be experienced along Lincoln County's tidal shoreline. Communities are advised to consider the information provided by this project as part of a "scenario-based approach" and create adaption strategies to mitigate impacts on natural systems, public infrastructure and facilities and existing and future development.

Please note the following when viewing the scenarios:

- When a road segment or a rail line is predicted to become inundated it is usually highlighted in black or gray. On occasion the highlighting may be absent so the best indicator of inundation is whether water is shown crossing a road or rail line.

- Buildings are highlighted in red when water is predicted to be present at the building's foundation during a given scenario. The scenarios themselves do not present information on the depth of water, only that some level of water is present at the building's foundation.

100yr Storm

100yr Storm
100yr Storm + 0.3m
100yr Storm + 0.6m
100yr Storm + 1m
100yr Storm + 1.8m

Highest Annual Tide

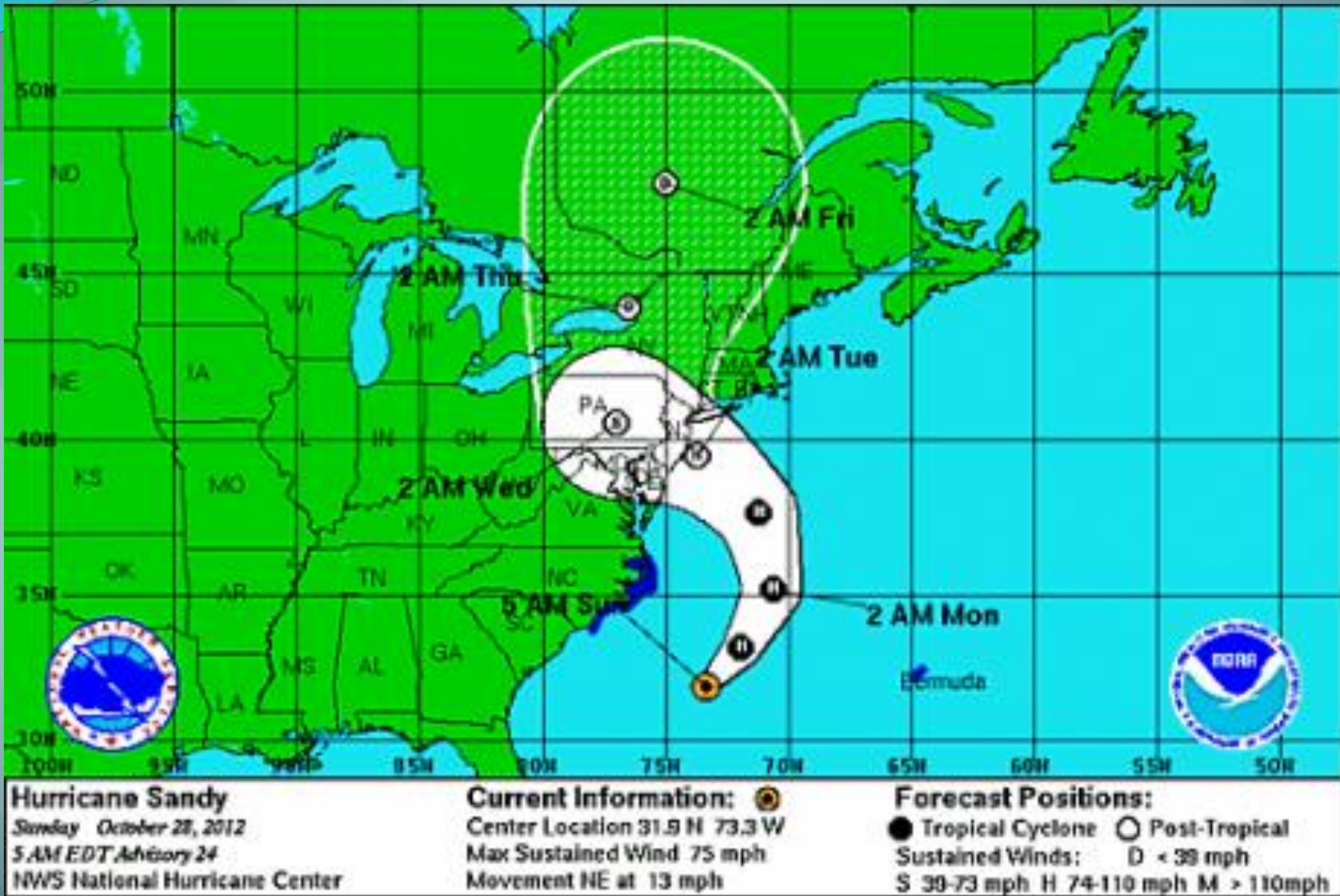
HAT
HAT + 0.3m
HAT + 0.6m
HAT + 1m
HAT + 1.8m ←

Complete Scenarios Zip - download

Legend
Google Earth Download and Instructions
Arc Explorer Download and Instructions
Disclaimer

Highest Annual Tide + 6 feet of storm surge or sea level rise

Hurricane Inundation Mapping



Why Worry?

Past "land-falling" hurricanes

1869 - Not Named (Cat 2 and 1, east of Portland)
1944 – Not Named (Cat 1, near Isle au Haut)
1954 – Hurricane Edna (Cat 1, near MDI)
1969 – Hurricane Gerda (Cat 2, near Eastport)
1991 – Hurricane Bob (Cat 2 to TS, off Southport)

What if a Sandy-like storm hit Maine today?

www.nhc.noaa.gov/surge/slosh.php

Sea, Lake, and Overland Surges from Hurricanes (SLOSH)

Contents

SLOSH Model

Introduction

The Sea, Lake and Overland Surges from Hurricanes (SLOSH) model is a computerized numerical model developed by the National Weather Service (NWS) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account the atmospheric pressure, size, forward speed, and track data. These parameters are used to create a model of the wind field which drives the storm surge.

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... location and timing of a hurricane's landfall is crucial in determining which areas will be inundated by the storm surge. Small changes in track, intensity, size, forward speed, and landfall location can have huge impacts on storm surge. At the time emergency managers must make an evacuation decision, the forecast track and intensity of a tropical cyclone are subject to large errors, thus a single simulation of the SLOSH model does not always provide an accurate depiction of the true storm surge vulnerability. Click here to view the National Hurricane Center's (NHC) official annual forecast track error for Atlantic tropical cyclones.

Probabilistic Approach - The Probabilistic Surge (P-Surge) product incorporates statistics of past forecast performances to generate an ensemble of SLOSH runs based on distributions of cross track, along track, intensity, and size errors. The latest version explicitly models the astronomical tide.

Composite Approach - Predicts surge by running SLOSH several thousand times with hypothetical hurricanes under different storm conditions. The products generated from this approach are the Maximum Envelopes of Water (MEOWs) and the Maximum of MEOWs (MOMs) which are regarded by NHC as the best approach for determining storm surge vulnerability for an area since it takes into account forecast uncertainty. The MEOWs and MOMs play an integral role in emergency management as they form the basis for the development of the nation's evacuation zones.

Sea **L**ake and **O**verland **S**urges from **H**urricanes Model

Sea
Lake and
Overland
Surges from
Hurricanes

Model

www.nhc.noaa.gov/surge/slosh.php

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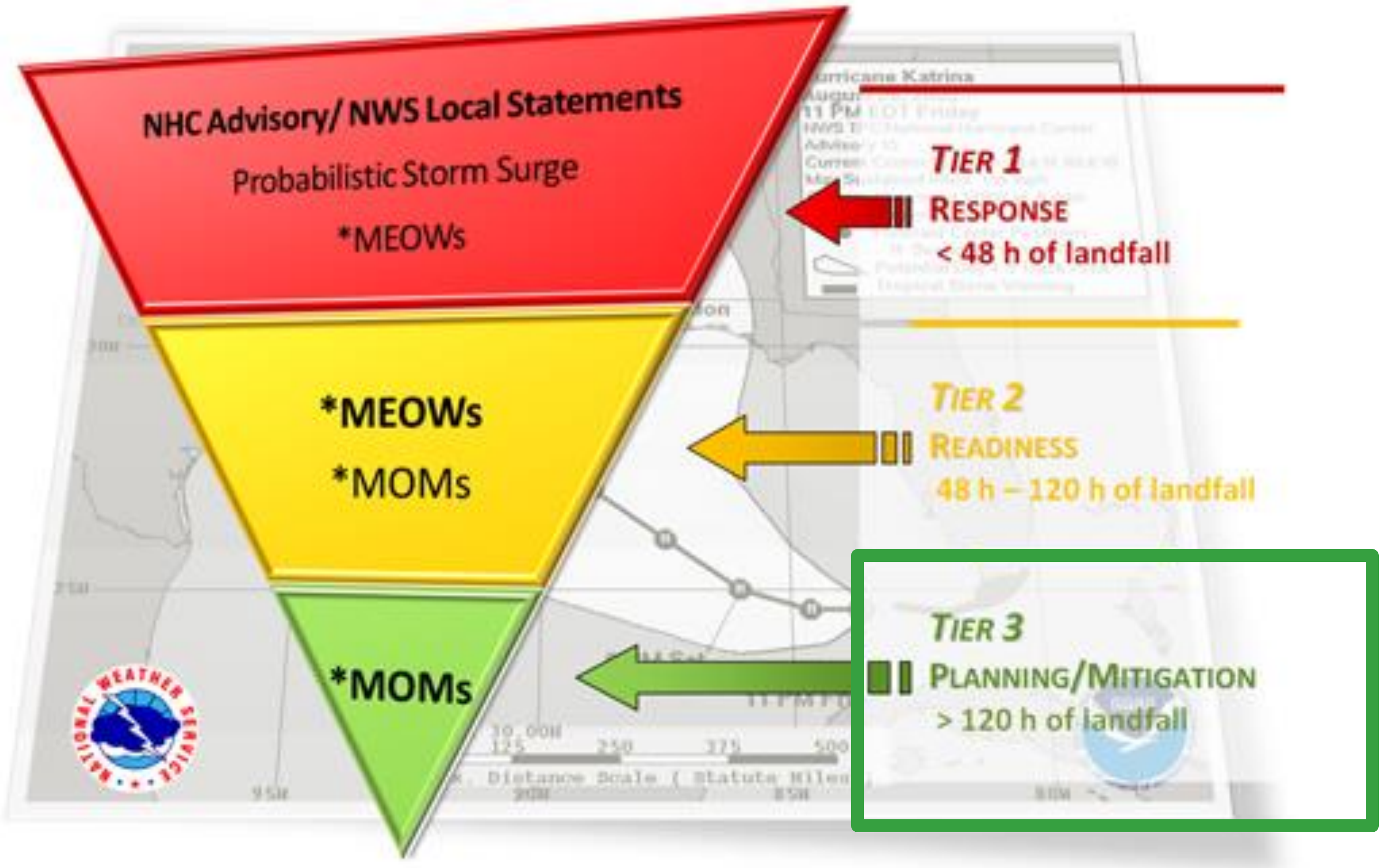
Storm Surge Product Decision Support Wedge

Which storm surge product should I use when?



Important assumptions and limitations

1) SLOSH model only outputs an anticipated **STORM TIDE and SURGE onto a predicted tide for a Category 1-4 event making landfall at mean high tide.**

2) SLOSH Model **does not include impacts of waves**, **normal river flow, or rain flooding on top of surge**, nor changes in the astronomical tide. The model may thus **under-predict coastal flooding**, *especially in areas open to wave attack.*

3) Results from SLOSH simulations is especially geared towards **emergency management planning and response**.

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LINCOLN COUNTY HURRICANE MAPS

LINCOLN COUNTY CATEGORY 1 HURRICANE MAPS

LCRPC, the Maine Geological Survey and the Maine Coastal Program cooperated to develop maps of coastal areas within the Lincoln County that could be impacted by a Category 1 hurricane. The predicted areas of inundation reflect worst-case conditions of forward speed, trajectory and tide level. The maps were developed to help support emergency planning and preparedness efforts in Lincoln County. Areas predicted to be inundated with some level of water are shown in blue while potentially impacted buildings and public and private roads are highlighted in red and green, respectively. These maps do not provide information on predicted water levels, only that some level of water is projected to be at a building's foundation or on a road surface. To view the maps, click **here.**

http://lcrpc.org/coastal-projects-planning/lincoln-county-hurricane-maps

BOOTHBAY HARBOR

Areas of Potential Inundation from a Category 1 Hurricane

Maximum of Maximum Envelopes of Water (MOM) from a Category 1 Hurricane at Highest Mean Tide

SLOSH Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model was developed by the National Weather Service for estimating storm surge from Hurricanes

The SLOSH model outputs worst-case storm tide elevations (called MOMs), which are a combination of predicted normal mean high tide and storm surge associated with a Category 1 storm event. Outputs do not take into account the potential impacts from waves, abnormal tides, freshwater flow, precipitation, or potential future scenarios of sea level rise.

These maps were developed using data from the Potential Hurricane Inundation Maps (PHIMs) developed by the Maine Geological Survey. PHIMs were developed using outputs from the latest NHC SLOSH model and the most recently available LiDAR datasets for the Maine coastline. PHIMs are currently not approved products from the National Hurricane Center, but represent the best available information for the Maine coastline.

0 0.5 1 1.5 2
Miles

This project was designed for use by Lincoln County Emergency Management Administration to assist with disaster preparedness.

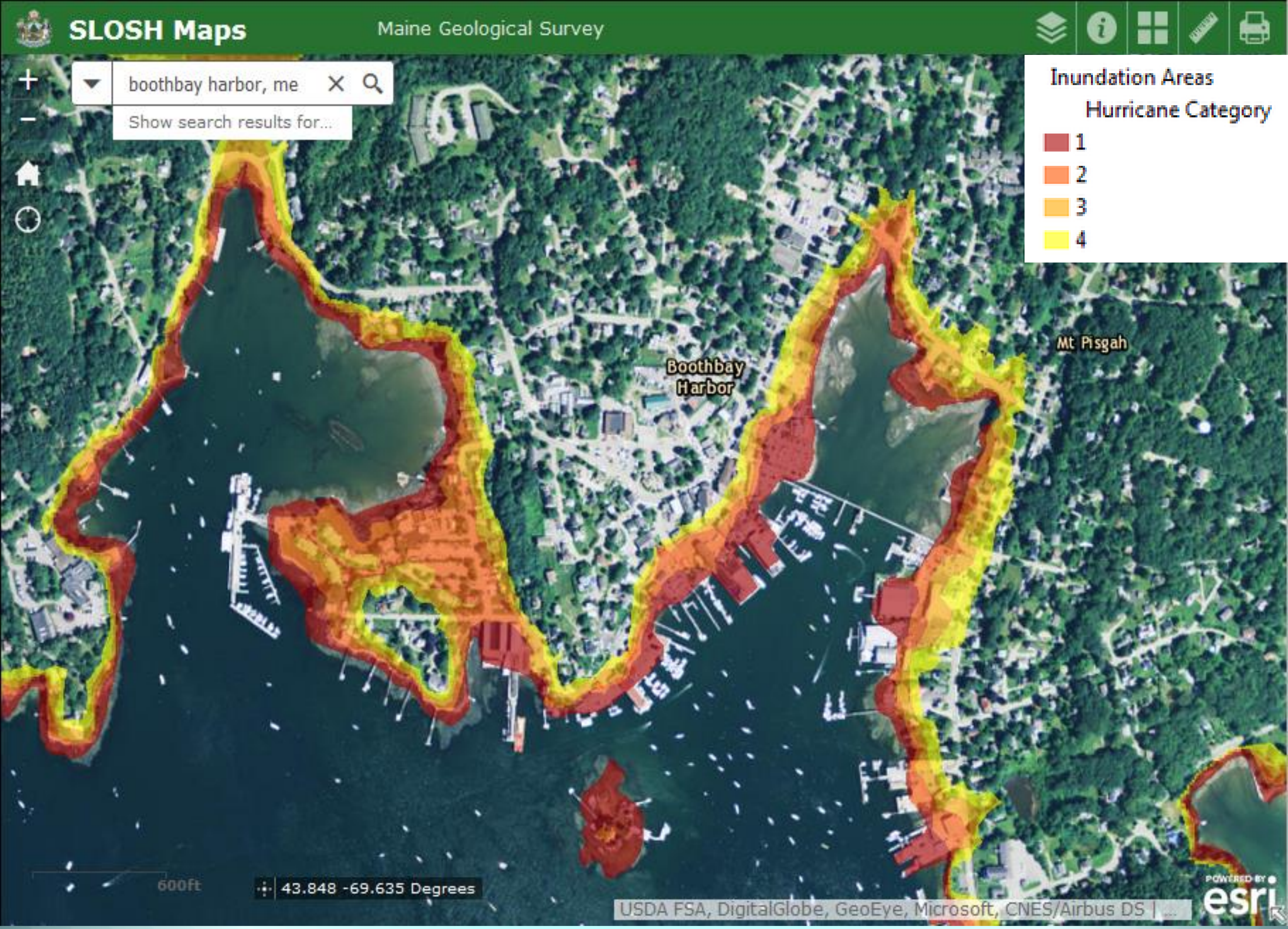
Made possible by...

LCRPC
Lincoln County
Regional Planning Commission

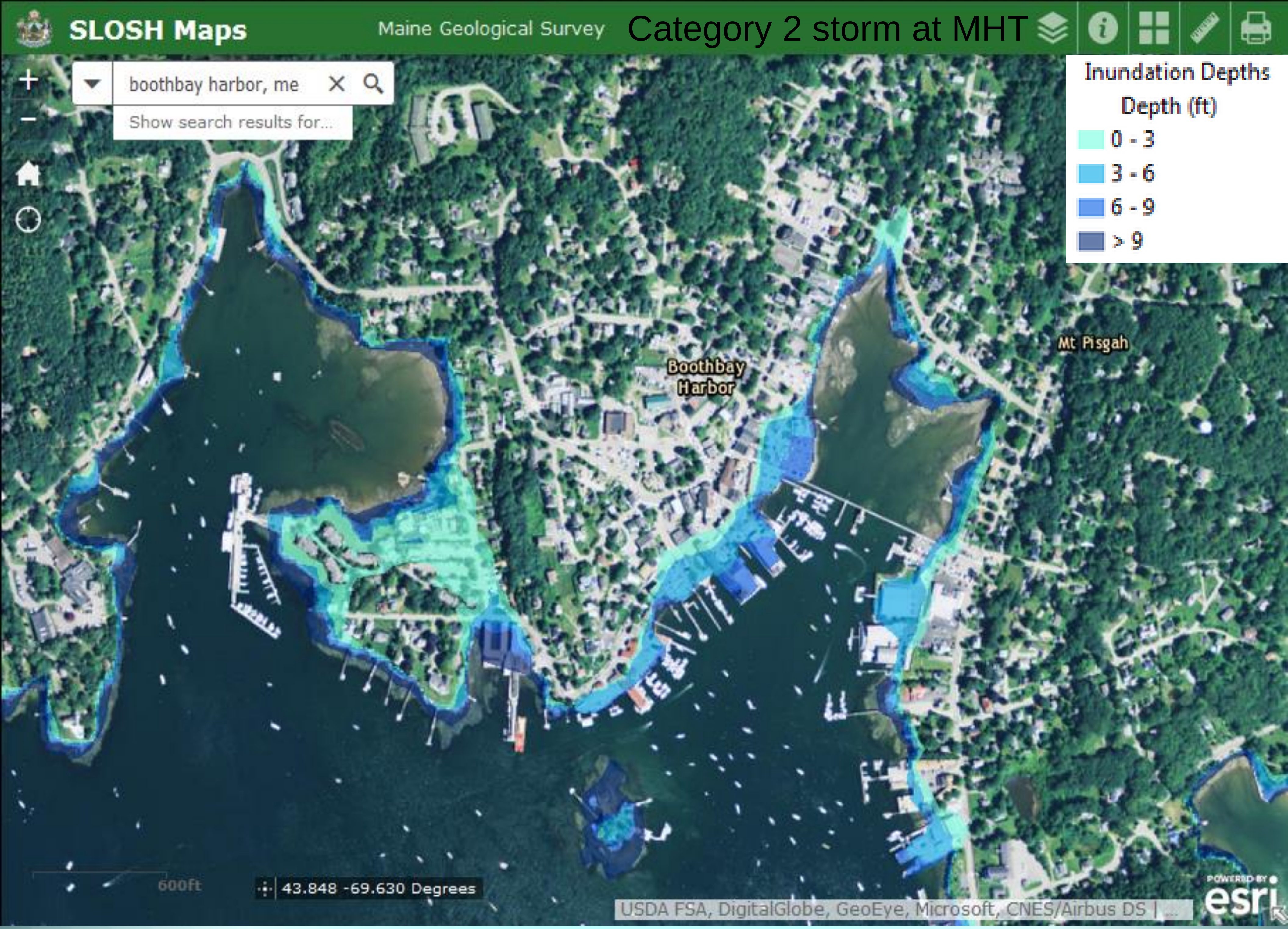
Source: Maine Geological Survey, 2014

EBDC
Emily Brook
Design & Consulting

The project was funded jointly by the Lincoln County Commission and a grant from the Maine Coastal Program under award NOAA CZM NA11NOS4190066 and NA11NOS4190188 to the Maine Coastal Program from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce.



http://www.maine.gov/dacf/mgs/hazards/slosh/index.shtml



http://www.maine.gov/dacf/mgs/hazards/slosh/index.shtml

Thank you!

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Boothbay Harbor High Tide and Flood Heights

February 11, 2016

Boothbay Harbor High Tide and Flood Heights

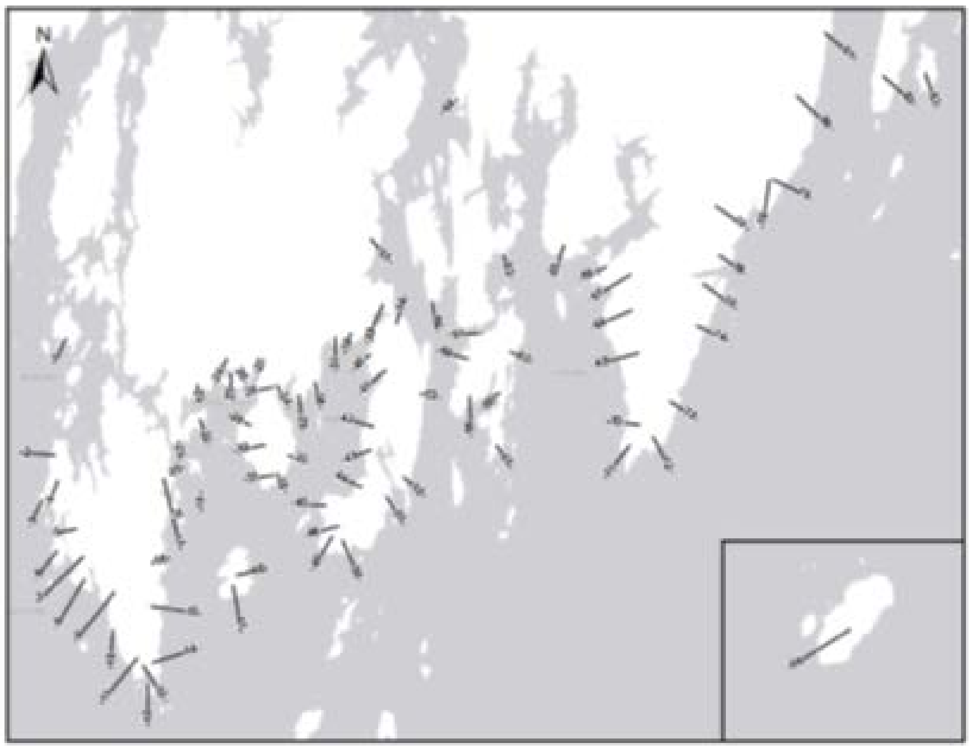
February 11, 2016 was the highest tide for the month at 10.7’ MLLW. MLLW is Mean Lower Low Water or the average lower low water height. This is the datum that is used to reference elevations from the NOAA Tide Tables, like the one that is printed for BBH.

New FEMA Flood Insurance Rate Maps are referenced to NAVD88, which is the North American Vertical Datum 1988 and is used for vertical control for most land surveying. In order to understand high tide elevations in reference to the FEMA flood maps a common datum is needed, in this case NAVD88. The FEMA flood maps show areas that would be affected during a "100-year" flood, or the flood that has a 1% chance of happening in any year.

The 10.7’ MLLW from February 11 is equal to about 5.4’ NAVD88. The HAT (highest annual tide) in BBH in 2016 will be 11.6’ MLLW or 6.3’ NAVD88. The “stillwater” 100-year (1% storm) flood, which is the average water level before waves or surge are taken into consideration, would be about 15’ MLLW or about 9.7’ NAVD88. This elevation is the basis for the calculation of different flood zones, which then additional surge or wave impacts , depending on whether it is an “AE-zone” or a “VE-zone”.

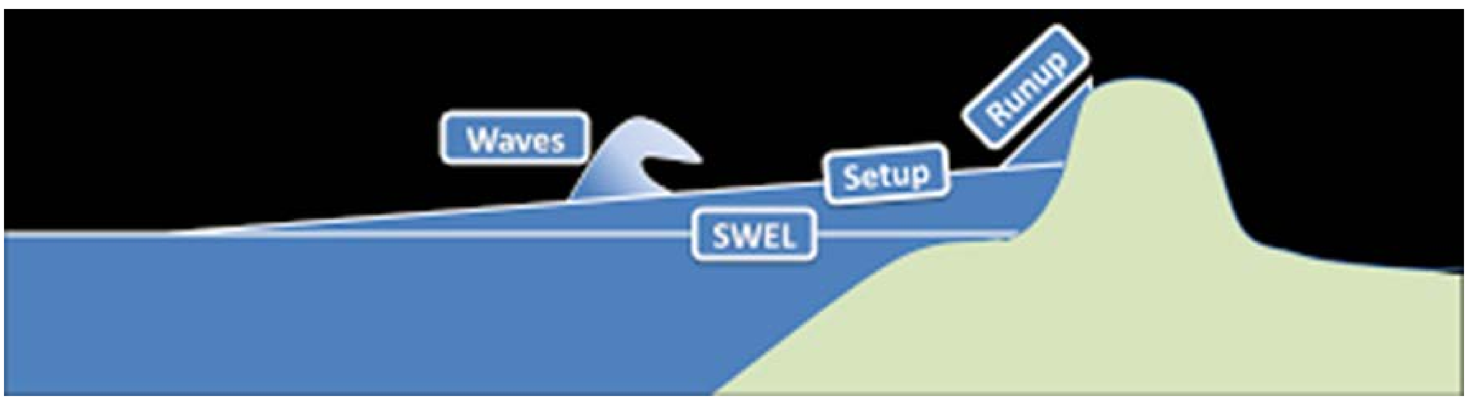
The new FEMA flood maps differ from the previous maps in several important ways. First, previous maps were referenced to NGVD1929, which is a different vertical datum than NAVD88. Second, the new maps are based on LiDAR topographic mapping, which is accurate to about 1’ in elevation. The previous maps were based on the old USGS mapping, which was accurate to about 5’. That makes a lot of difference when determining areas potentially impacted by flooding.

The new maps are also based on several hundred transects or horizontal profiles along the county coastline. The transects are topographic profile of locations along the coast, allowing FEMA to better understand how flood waters will move up the shore and to develop estimates of wave setup and run-up.



Wave setup and run-up represent increases in flooding beyond the 9.7’ NAVD88 stillwater elevation of water in a 100-year flood.

Wave setup is additional increase in the water level due to waves pushing water up against the coast. Wave run-up is an additional increase in the water level, over and above wave setup, due to waves breaking along the shoreline.



The new maps include determinations of several different "flood zones".

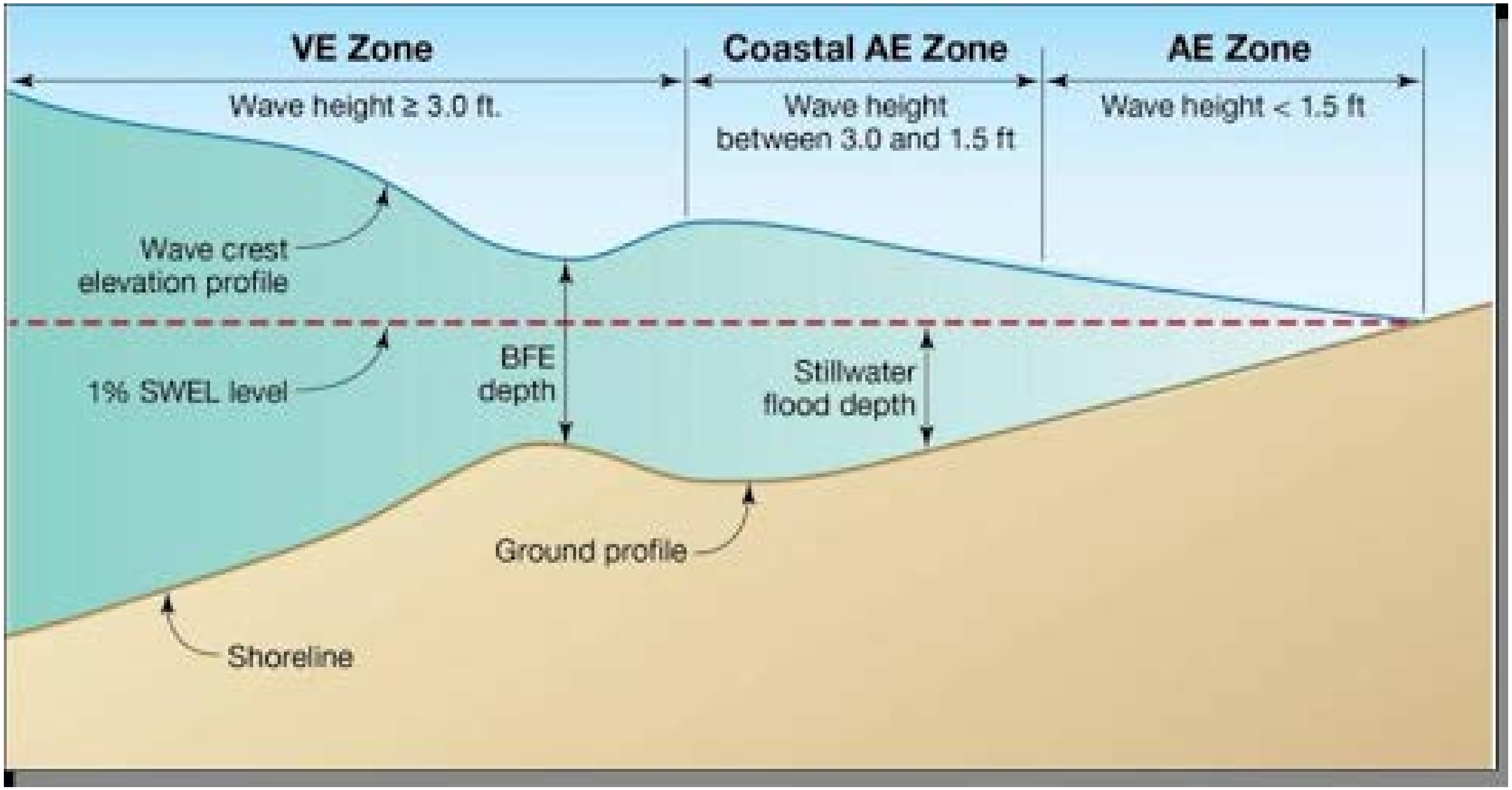
VE zones are "Velocity" zones with calculated flood elevations. These are generally the most at-risk zones, and include wave setup and wave run-up. VE zones expect to have waves greater than 3 feet during the 1% storm event. So a VE zone of elevation 15 ft NAVD88 means that during the 100-year storm, that zone can expect water levels to reach about 15 feet NAVD88, and include waves greater than 3 feet in height.

The next zone in terms of risk is called a "Coastal A-zone", and is defined using what is called the "LiMWA", or "Limit of Moderate Wave Action". These zones expect to have flood heights that include waves between 1.5 and 3 feet in height during the 1% storm event.

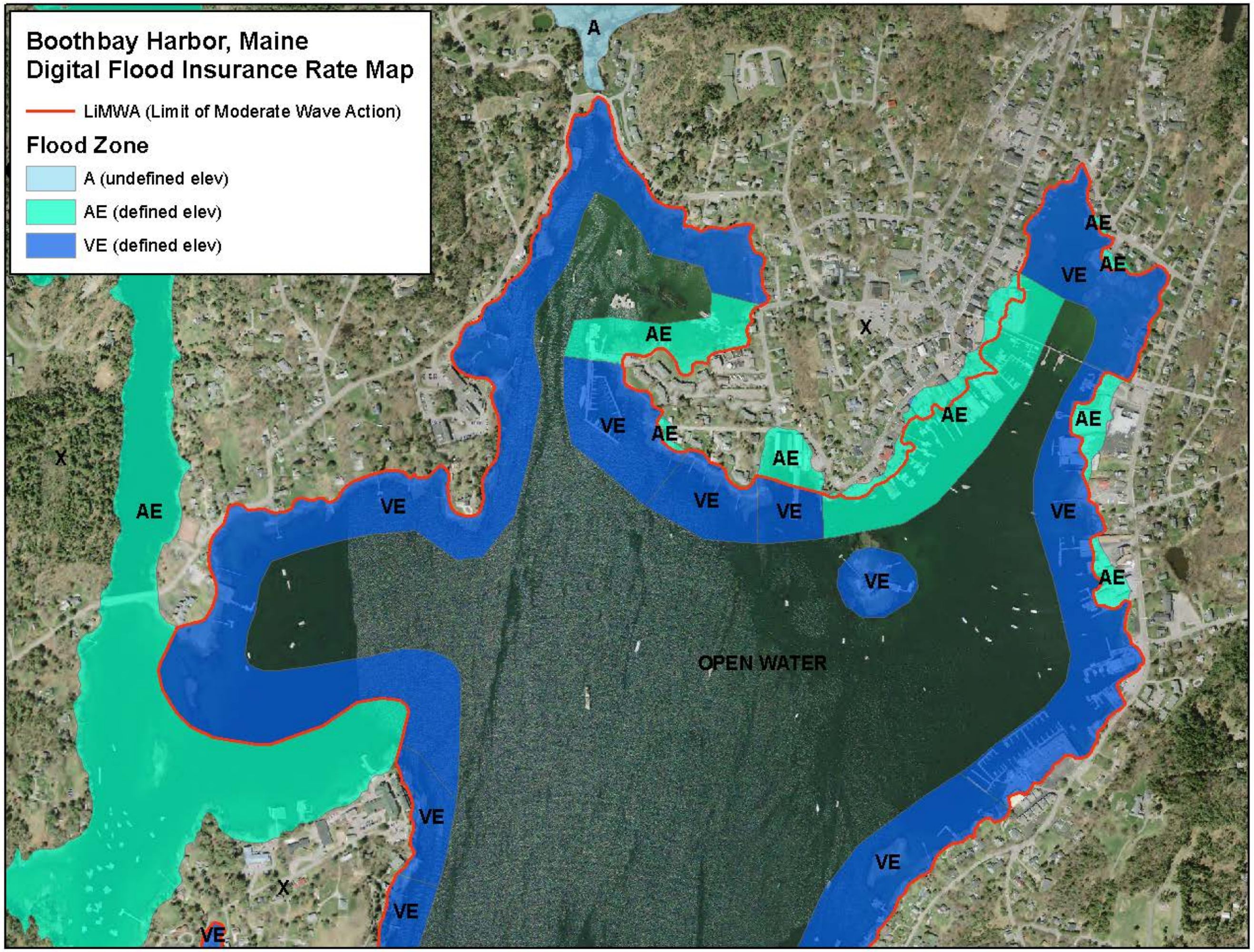
AE zones, or A-zones with a calculated flood elevation, are generally lower-energy flood zones, where waves will be less than 1.5 feet during the 1% storm event. So an AE zone of 10 feet NAVD means that flood waters, including waves less than 1.5 feet, will reach 10 feet NAVD88.

Then, some areas have "A-zones" with no calculated elevation. That means these areas expect to see flooding, but no flood elevation has been calculated.

Finally, X-zones are areas that are outside of the 100-year flood area, but may see flooding during the 500-year, or 0.2% annual chance, flood event.

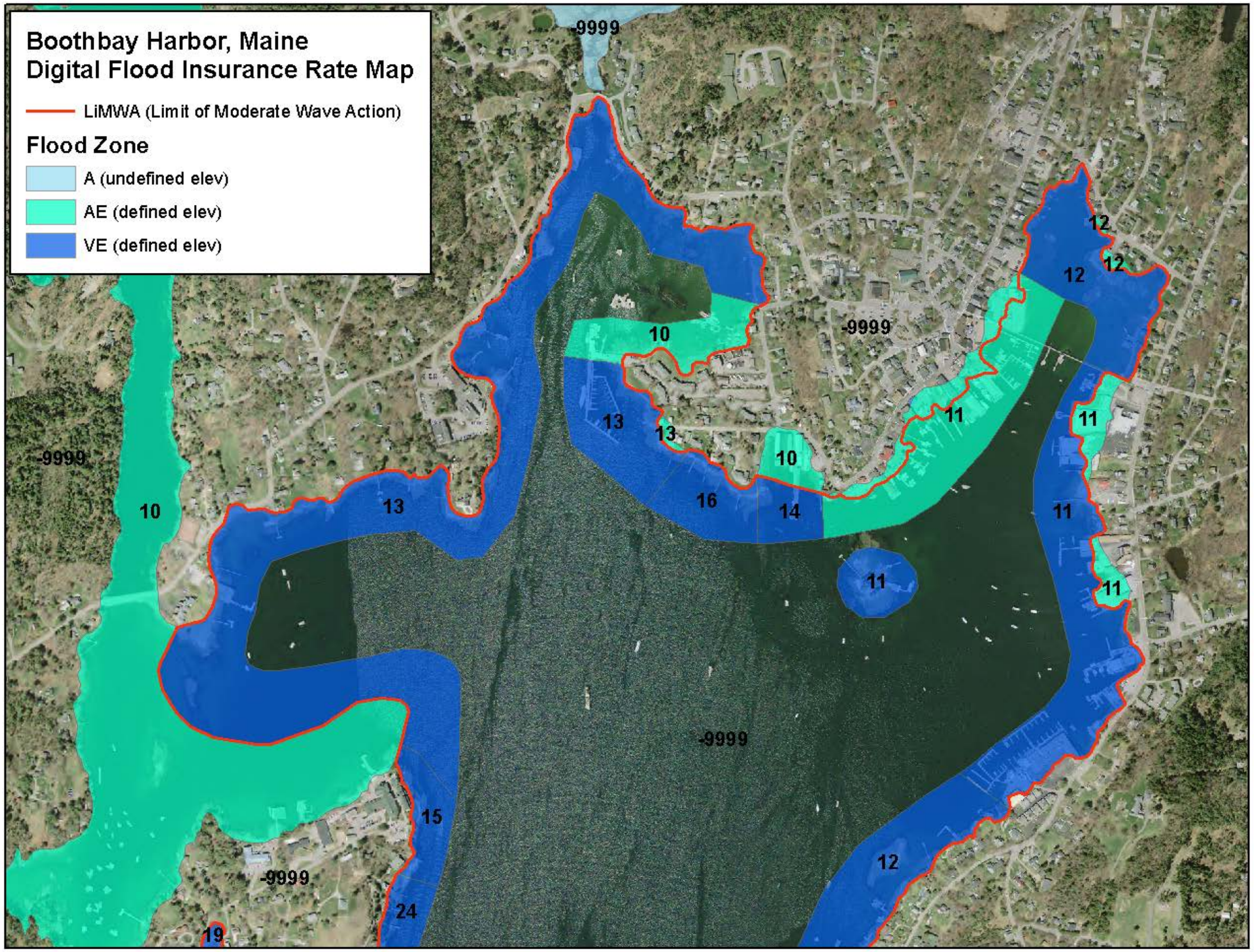

VE Zone
Coastal AE Zone
AE Zone
Wave height ≥ 3.0 ft.
Wave height between 3.0 and 1.5 ft
Wave height < 1.5 ft
Wave crest elevation profile
1% SWEL level
BFE depth
Stillwater flood depth
Ground profile
Shoreline

This map shows the new flood zones in a portion of BBH.



This map shows the actual 100-year flood elevations in feet in NAVD88

(areas outside the 100-year flood zone have a default elevation of 9999)



February 11, 2016 High Tide Water Level	100-year Storm Water Level
5.4’ NAVD88	12’ NAVD88

February 11, 2016 High Tide Water Level	100-year Storm Water Level
5.4’ NAVD88	11’ NAVD88

February 11, 2016 High Tide Water Level	100-year Storm Water Level
5.4’ NAVD88	11’ NAVD88

February 11, 2016 High Tide Water Level	100-year Storm Water Level
5.4’ NAVD88	12’ NAVD88

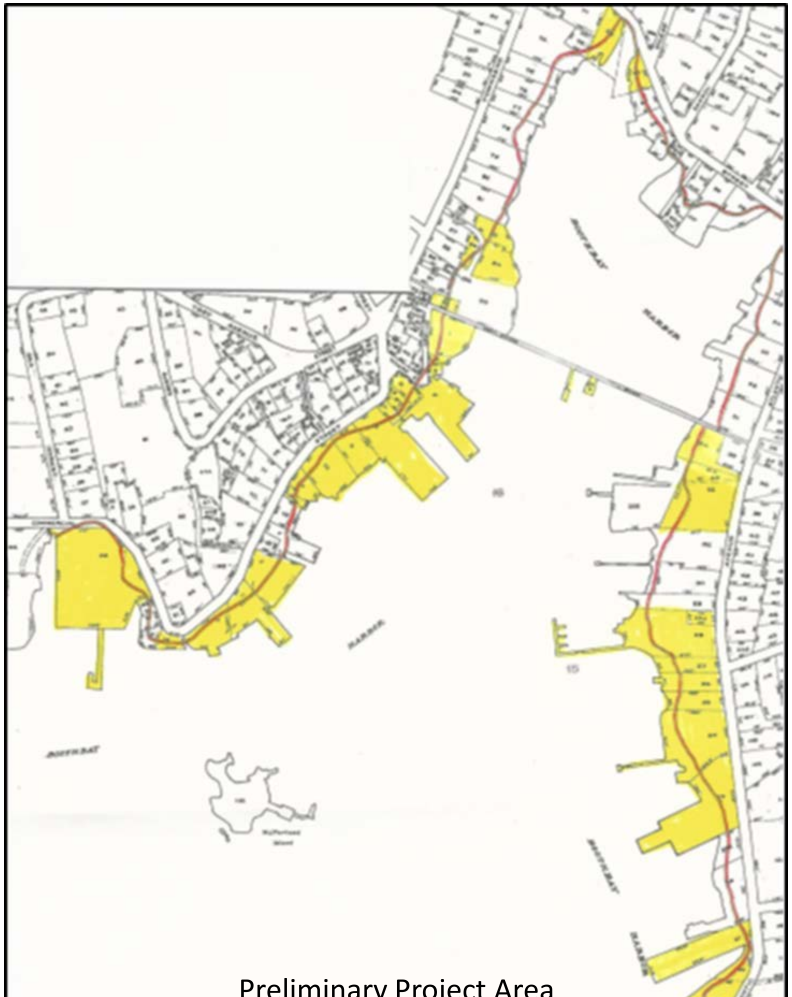
February 11, 2016 High Tide Water Level	100-year Storm Water Level
5.4’ NAVD88	12’ NAVD88

February 11, 2016 High Tide Water Level	100-year Storm Water Level
5.4’ NAVD88	11’ NAVD88

February 11, 2016 High Tide Water Level	100-year Storm Water Level
5.4’ NAVD88	12’ NAVD88

February 11, 2016 High Tide Water Level	100-year Storm Water Level
5.4’ NAVD88	10’ NAVD88 (building)
	14’ NAVD88 (pier)

Downtown Boothbay Harbor Flood Impact Preliminary Engineering Study and Adaption Options to Protect Governmental and Commercial Structures From Flooding Associated with a 1% Storm



Preliminary Project Area

Project Tasks

Retain an engineering consultant and surveyor to:

- Determine the 1% flood elevation at all participating properties
- Determine the elevations of potential points of water access into buildings as well as critical at-risk building infrastructure such as fuel tanks, electrical entrances, furnaces, etc.
- Identify and evaluate potential adaptions techniques to make buildings and infrastructure more resilient to flooding
- Estimate costs associated with such adaption techniques.
- Recommend ordinance changes to improve flood resiliency of future buildings and major additions to existing buildings

Assessment of Options to Mitigate the Impacts of Long-Term Sea Level Rise and Storm Surge on the Boothbay Harbor Wastewater Treatment Facility

County-Wide Coastal Flood with SLR Study