

Synthesis of Coastal Flood Hazards and Uncertainty in Sea Level Rise

2018 Maine Sustainability & Water Conference

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Acknowledgements

- Town of Islesboro, Maine
- Town of Vinalhaven, Maine
- Maine Coastal Program
- The Island Institute
- National Oceanic & Atmospheric Administration

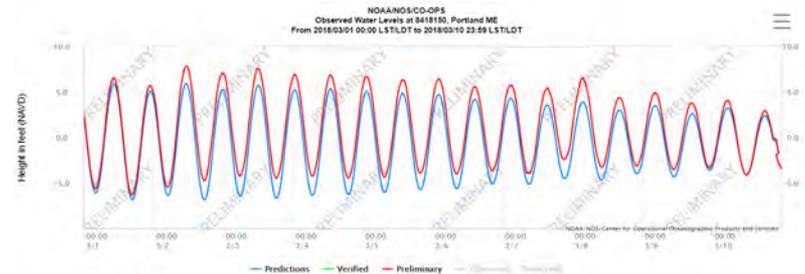
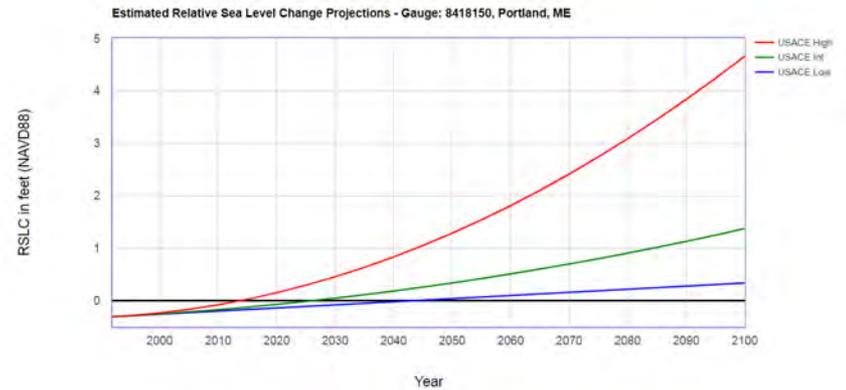


Also Thanks to:
Leila Pike, P.E.
Kevin Trainor, P.E.



The Mouse in the Room

A little perspective on time and space



The Mouse in the Room

An imaginary conversation with your friendly neighborhood coastal engineer

Concerned Citizen: “How much sea level rise should we plan for?”

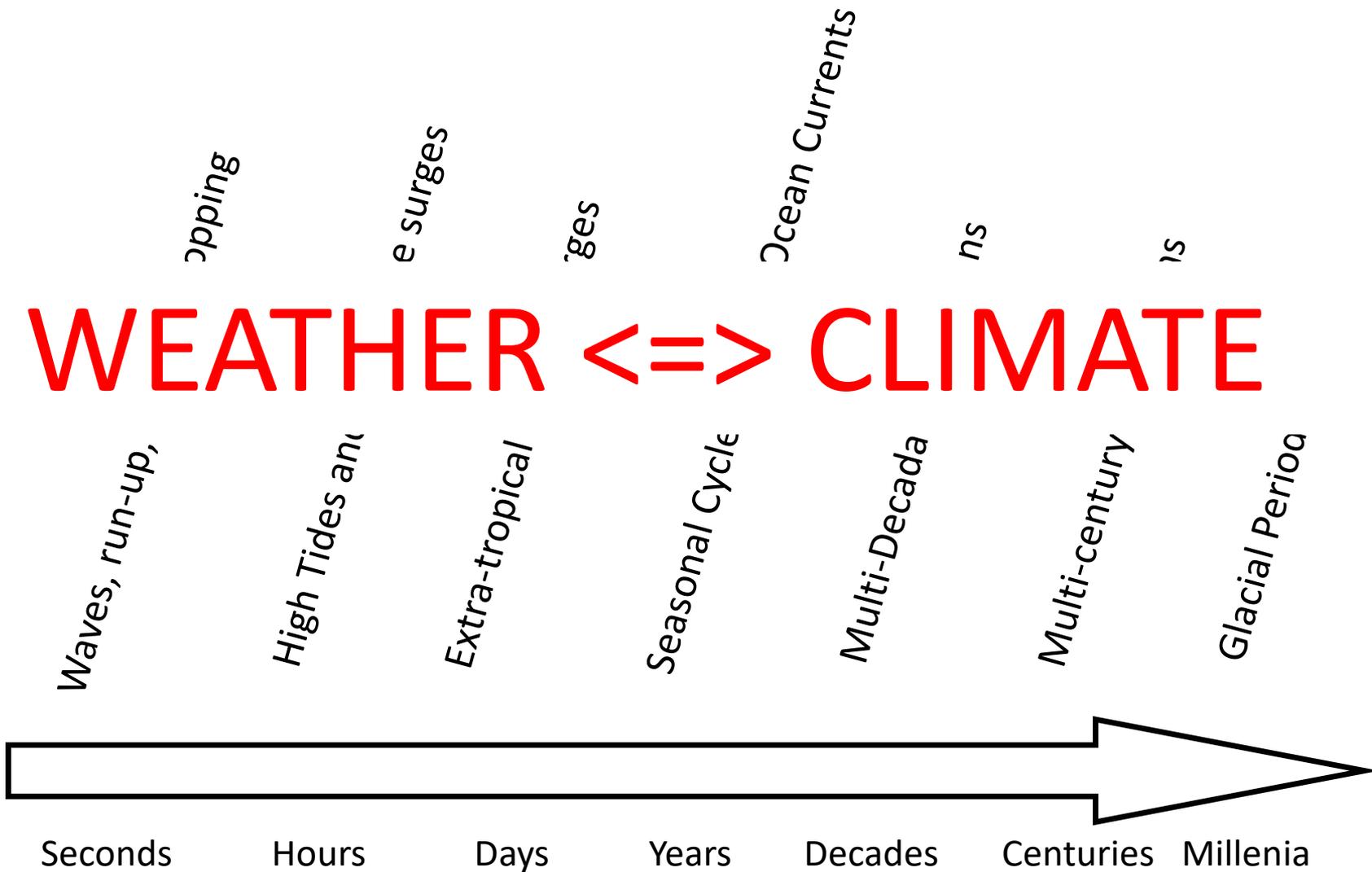
Snarky Coastal Engineer: “Here in Maine? Eight to twelve feet, probably.”

Concerned Citizen: “Gee, that sounds like a lot. Is that the high scenario for 2120?”

Snarky Coastal Engineer: “No, I’m talking about the next twelve hours. I didn’t realize you were asking about the mean sea level?”

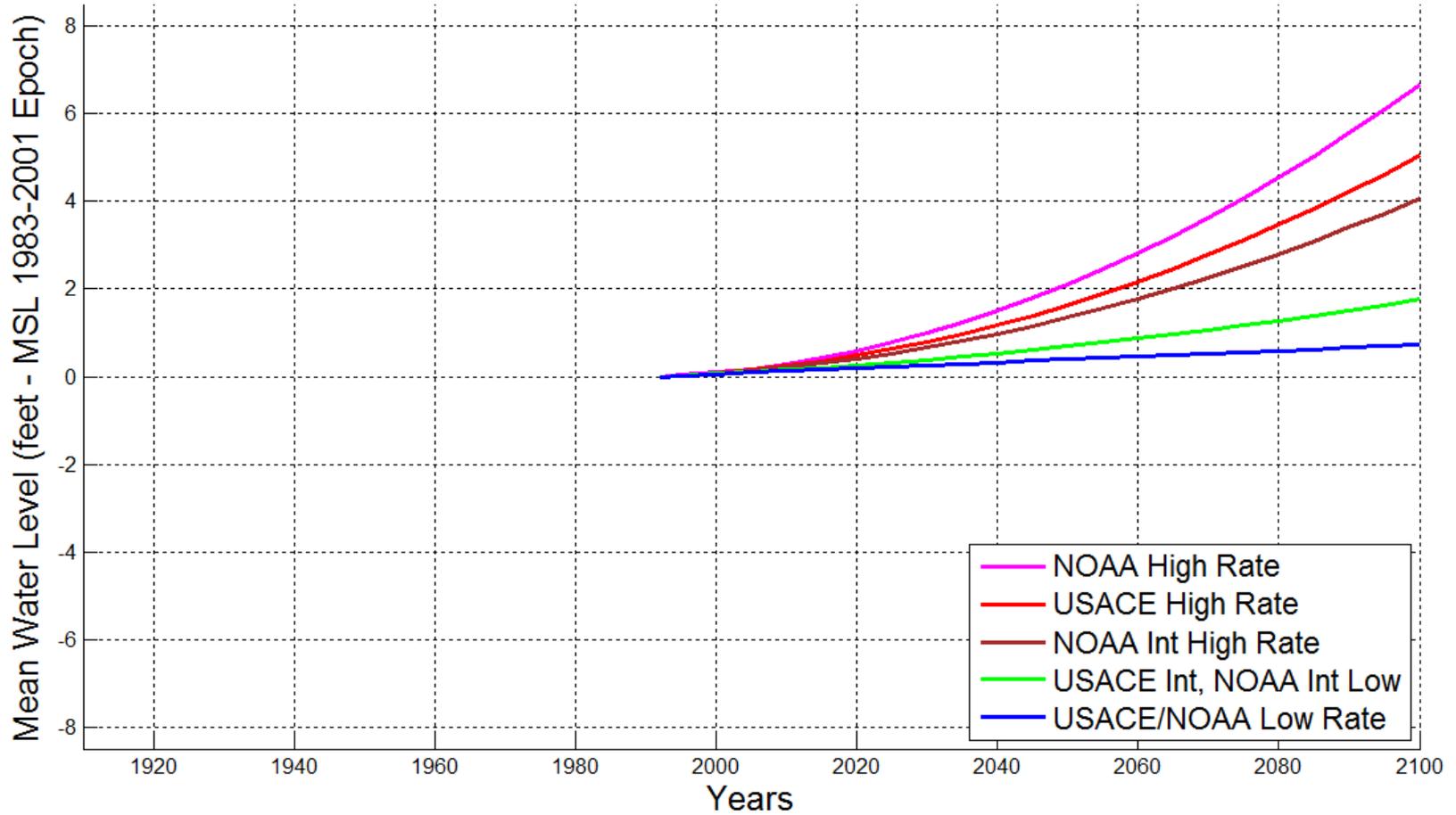
The Mouse in the Room

Sea level change on a range of time scales



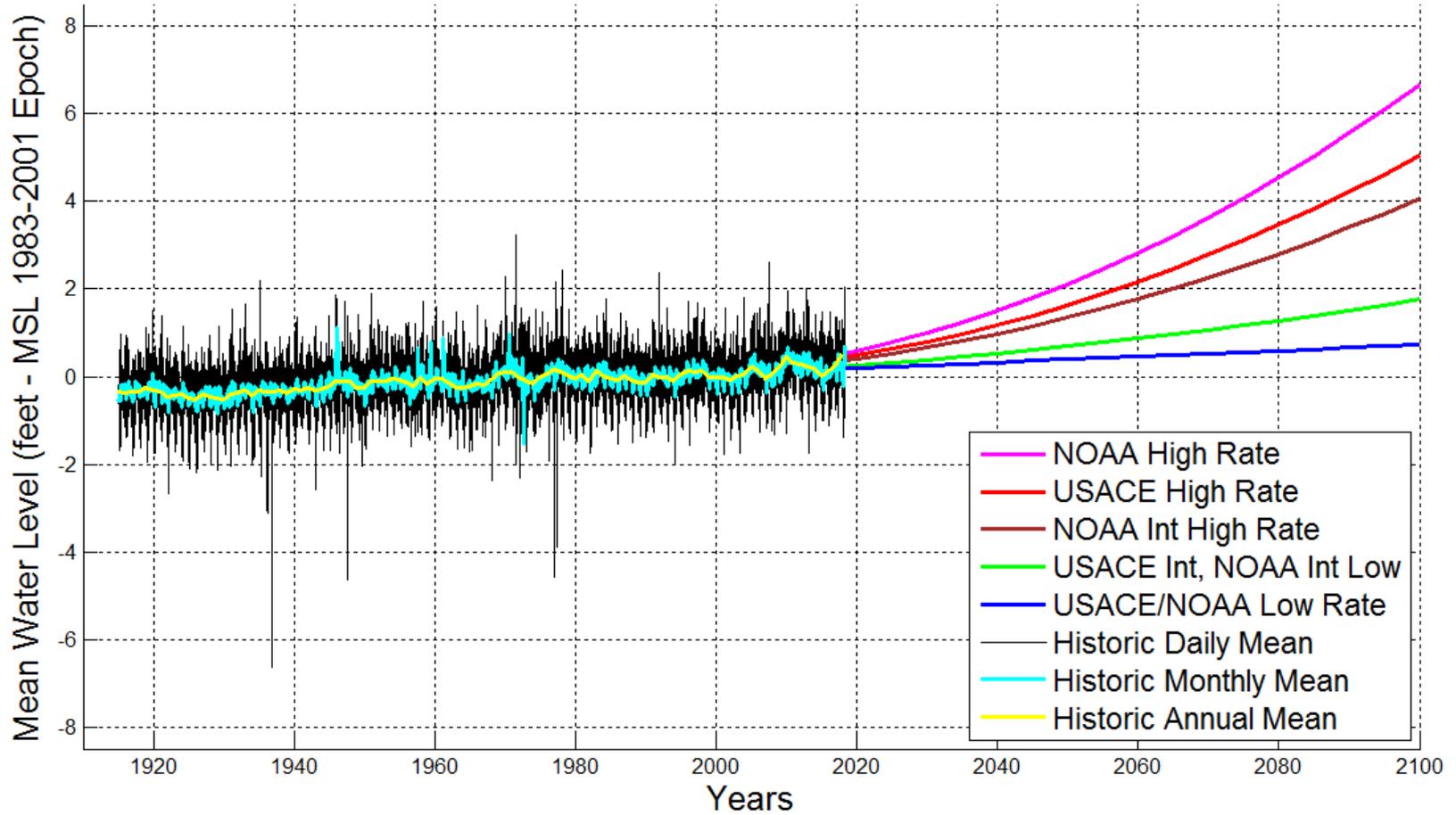
Sea Level Rise

Portland (NOAA ID 8418150), Past, Present, and Future Mean Sea Level



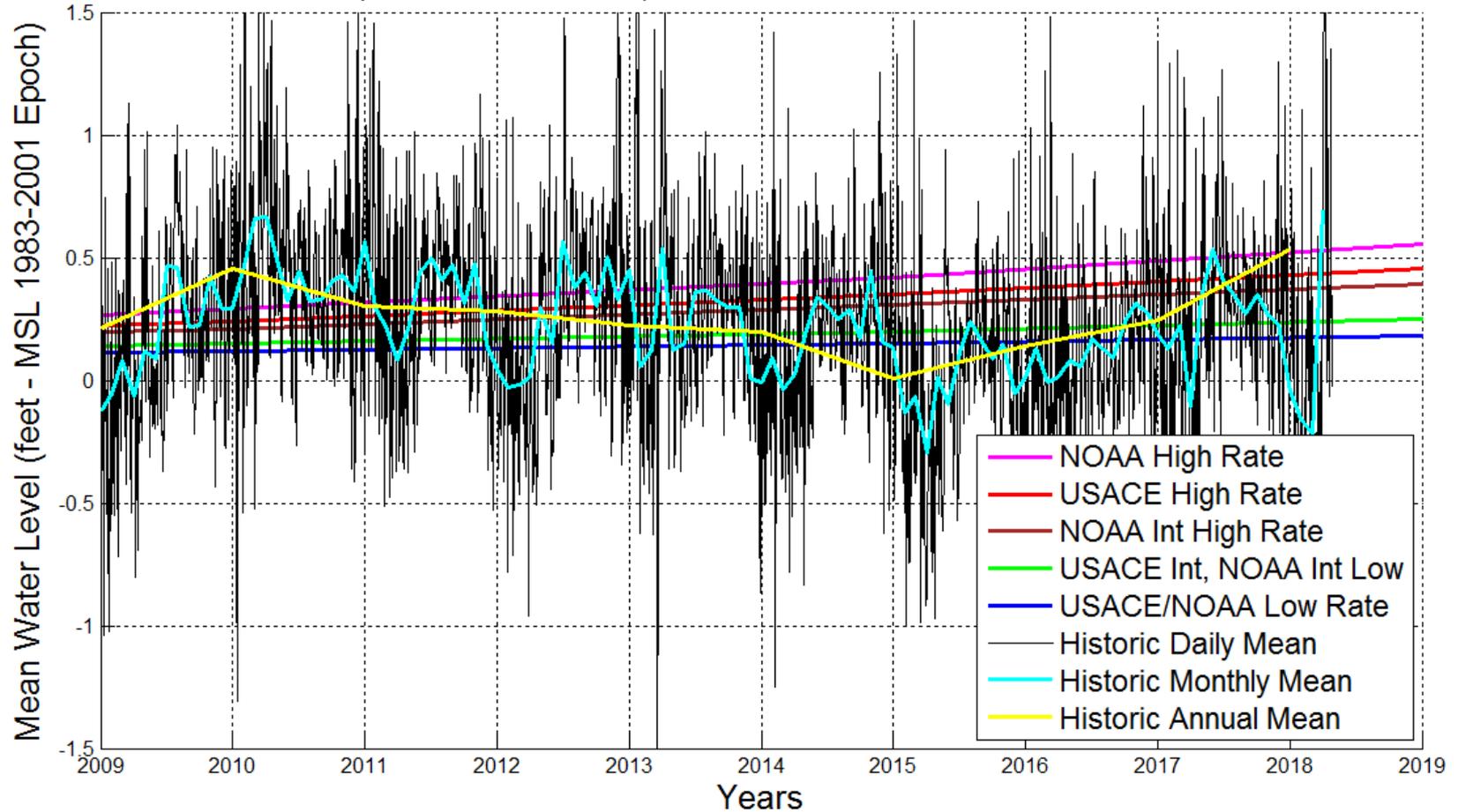
Sea Level Rise

Portland (NOAA ID 8418150), Past, Present, and Future Mean Sea Level

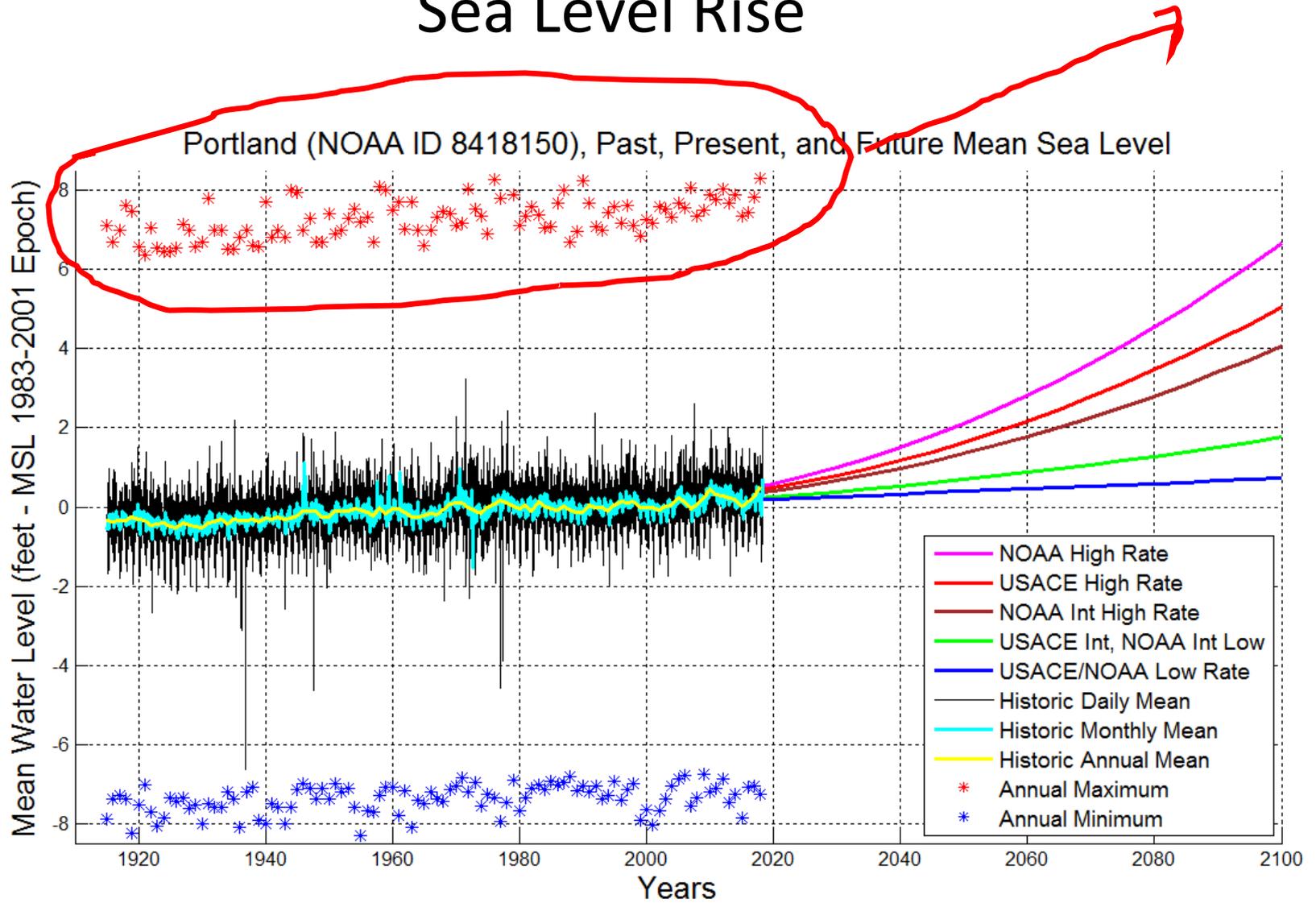


Sea Level Rise

Portland (NOAA ID 8418150), Past, Present, and Future Mean Sea Level



Sea Level Rise



Sea Level Rise



Volatility

: a tendency to change quickly and unpredictably

Merriam-Webster.com. Merriam-Webster, n.d. Web. 28 Mar. 2018.

: a statistical measure of the dispersion of the returns for a given security or market index

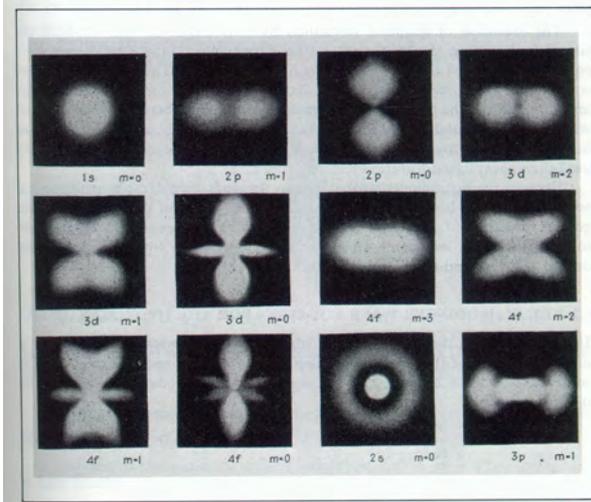
Investopedia.com

Some Basic Statistics...

Deterministic vs Probabilistic

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{8\pi^2 m}{h^2} (E - V) \Psi = 0$$

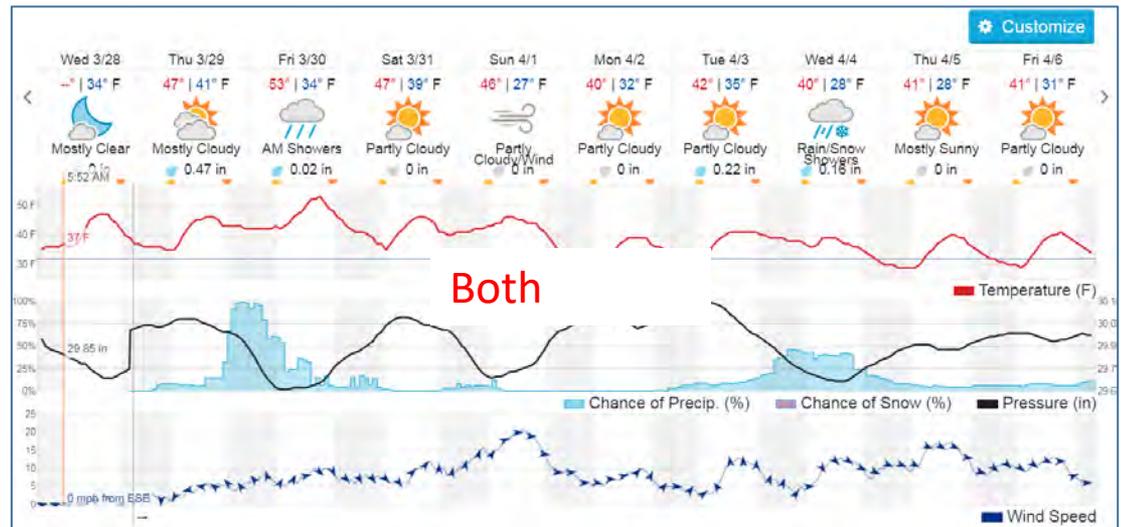
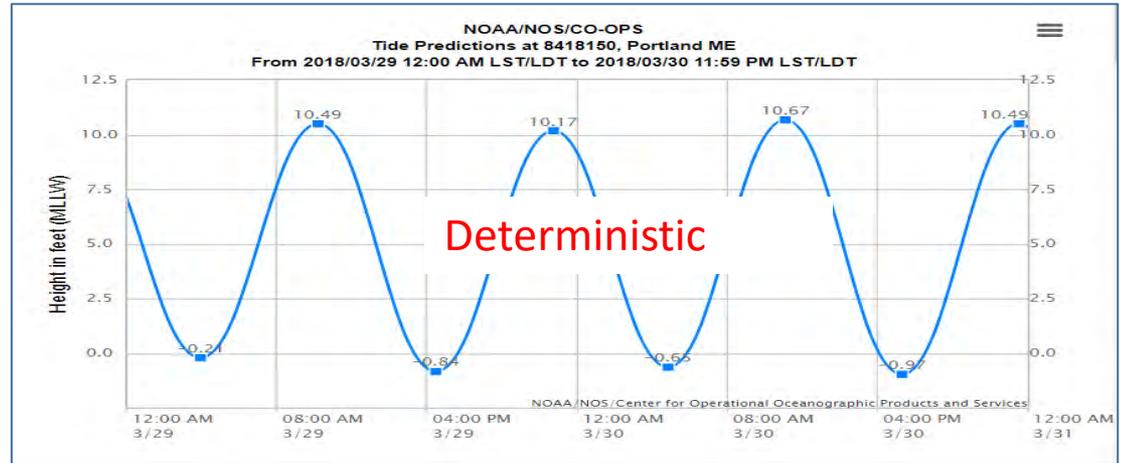
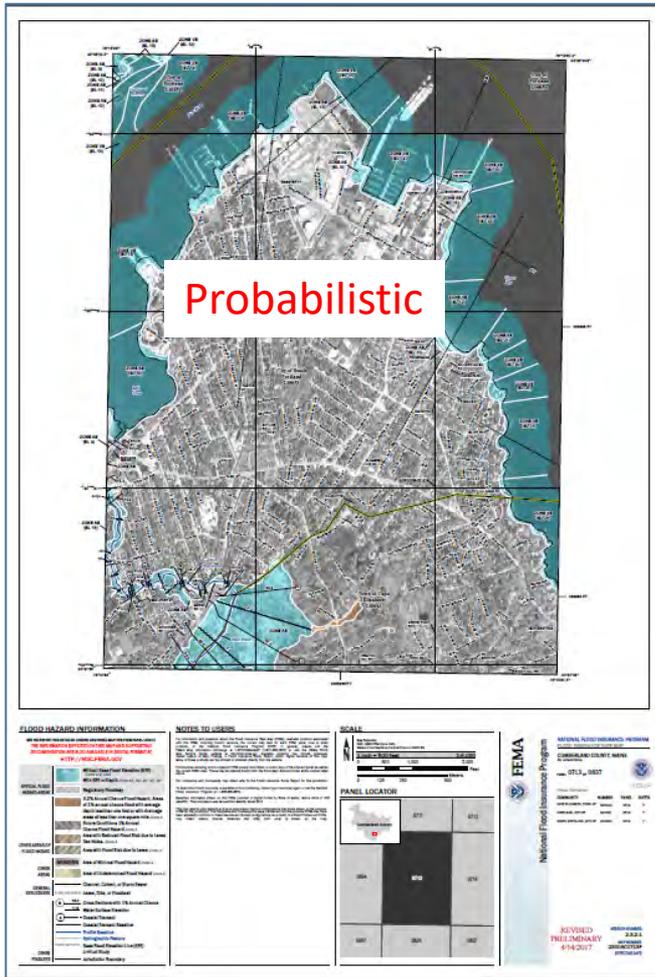
$$\nabla^2 \Psi + \frac{8\pi^2 m}{h^2} (E - V) \Psi = 0$$



Einstein discovers that God does indeed play dice. Unpublished T-shirt design. By John C. Holden

Some Basic Statistics...

Deterministic vs Probabilistic

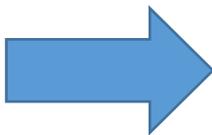


Some Basic Statistics..

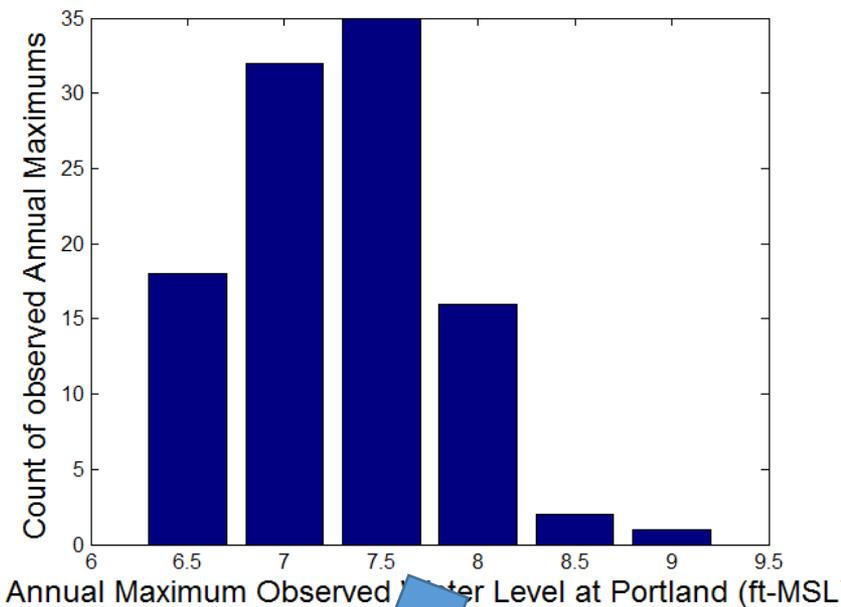
Probability Distributions and Hazard Curves

Maximum Observed Water Level - Portland, Maine (1915-2015)
(Elevation in feet NAVD88)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Historic Annual Maximum	Observed Sea Level Rise Since	Annual Maximum Adjusted for Observed Sea Level Rise
1915	6.2	5.1	5.3	6.1	6.6	5.8	5.6	5.3	5.2	5.2	6.1	6.8	6.8	0.7	7.5
1916	6.3	6.0	6.3	5.4	6.4	6.4	6.0	6.1	5.0	5.1	5.3	5.9	6.4	0.7	7.1
1917	6.2	5.7	5.6	5.4	5.3	5.5	5.7	5.9	5.8	6.1	5.4	6.7	6.7	0.7	7.4
1918	7.1	5.9	6.5	6.2	5.9	5.6	5.5	5.2	5.5	5.8	7.3	5.5	7.3	0.7	8.0
1919	5.5	5.6	5.5	6.8	6.7	6.2	5.7	5.3	5.8	6.1	7.2	7.2	7.2	0.7	7.8
1920	5.9	5.9	6.0	6.1	6.0	6.3	6.1	5.8	5.7	6.0	6.3	6.3	6.3	0.6	6.9
1921	6.1	6.1	5.0	5.9	5.9	5.6	5.7	5.7	5.7	6.1	6.1	5.9	6.1	0.6	6.7
1922	5.5	5.8	6.0	6.8	5.7	5.5	5.5	5.5	6.1	5.6	5.9	5.2	6.8	0.6	7.4
1923	5.9	6.2	6.2	5.8	6.2	6.1	5.4	5.3	5.1	2.8	4.6	6.2	6.2	0.6	6.9
1924	5.7	6.0	5.3	5.9	5.9	6.0	6.1	5.5	5.3	6.0	6.0	5.7	6.1	0.6	6.8
1925	5.9	5.5	4.7	5.2	5.1	6.1	5.9	5.7	5.6	5.4	5.9	5.6	6.1	0.6	6.8
1926	6.2	6.0	5.6	4.9	5.2	5.3	5.4	5.9	5.6	6.0	6.1	4.9	6.2	0.6	6.8
1927	5.8	5.3	6.0	5.6	5.6	5.7	5.0	5.6	5.6	6.0	5.9	6.8	6.8	0.6	7.4



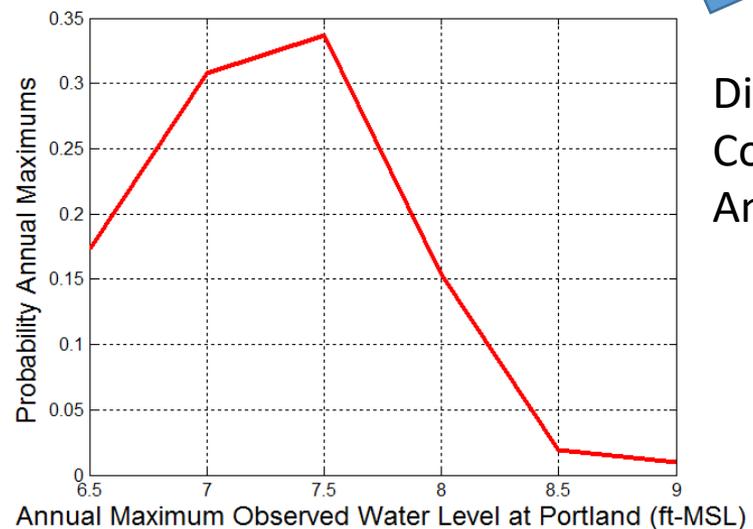
Count how many in each 1/2 foot bin



Divide by the total Count and we have An estimate of likelihood

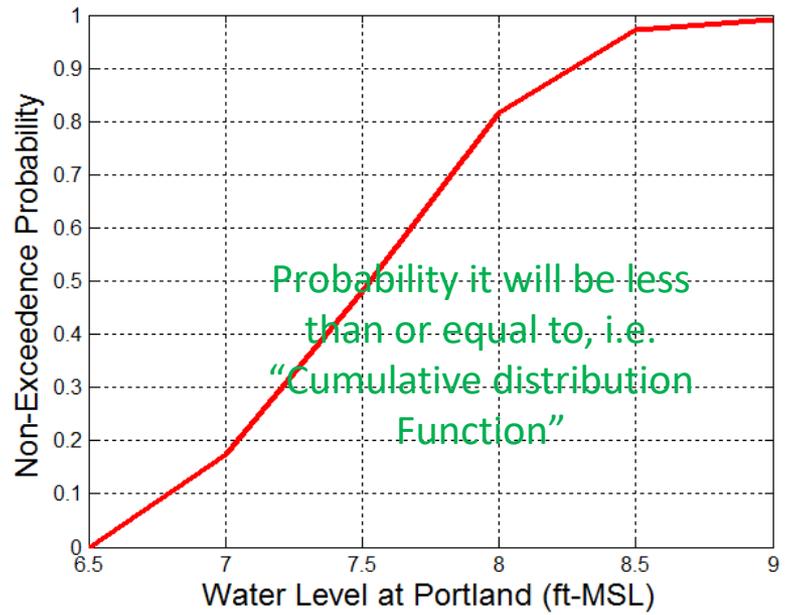
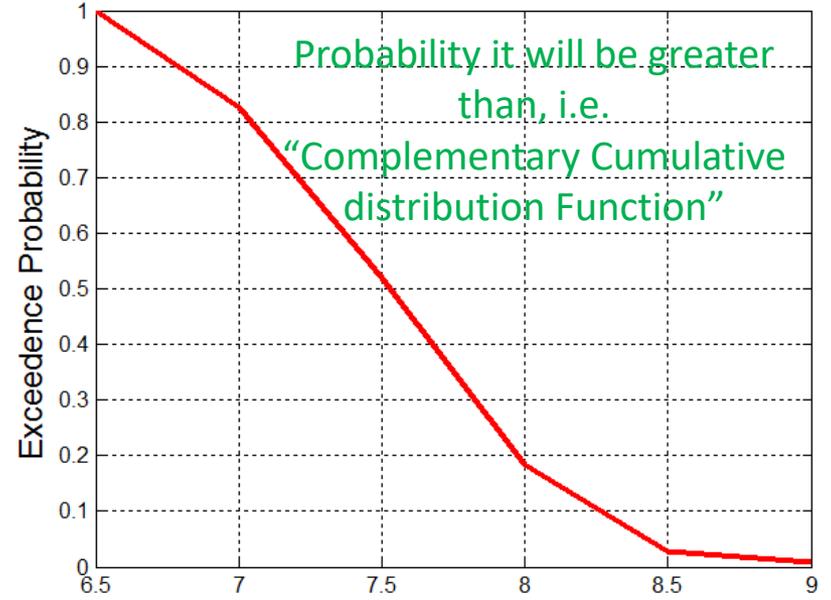
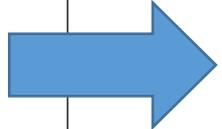
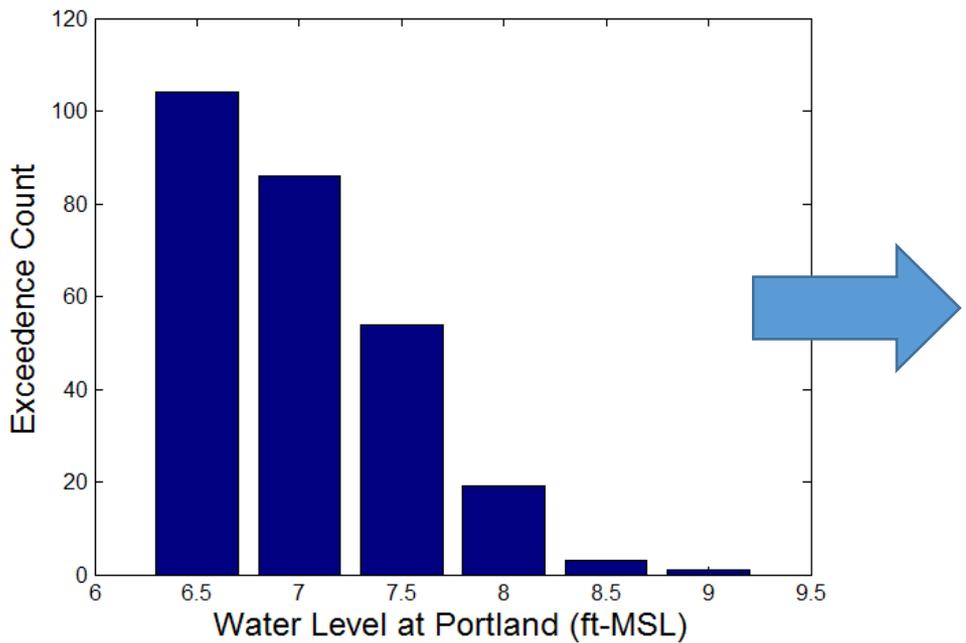
...

2012	0.0	1.0	0.1	0.8	0.7	2.8	0.0	0.3	0.8	0.8	2.2	0.0	1.0	0.0	1.0	0.0000000000	
2011	1.0	0.7	0.2	0.7	0.7	0.2	0.1	0.4	0.6	0.2	0.4	0.6	1.0	0.0	1.0	0.0000000000	
2010	1.0	0.2	0.0	0.4	1.4	0.0	1.1	0.2	2.8	0.7	0.1	0.1	1.2	1.2	0.0	1.4	0.0000000000
2009	0.2	2.8	0.2	0.0	0.0	1.1	0.0	0.4	0.1	0.0	0.0	0.0	1.1	1.0	0.0	1.1	0.0000000000
2008	1.2	0.1	0.2	0.2	0.2	0.1	0.1	1.0	0.0	1.0	0.2	1.2	0.0	0.0	1.2	0.0000000000	
2007	0.8	0.4	0.0	0.1	0.1	1.1	0.1	2.8	0.2	0.2	0.1	1.7	1.7	0.0	1.7	0.0000000000	
2006	2.2	2.8	0.0	2.0	0.1	0.0	0.0	0.0	2.3	0.3	0.0	1.0	1.0	0.1	1.1	0.0000000000	
2005	2.1	0.7	2.0	1.1	1.0	0.2	0.0	2.0	0.7	0.2	0.7	0.0	1.1	0.1	1.2	0.0000000000	
2004	1.7	1.7	0.4	2.0	0.7	2.1	0.7	0.0	0.3	0.1	0.2	1.7	0.1	1.7	1.7	0.0000000000	



Some Basic Statistics

Probability Distributions and Hazard Curves



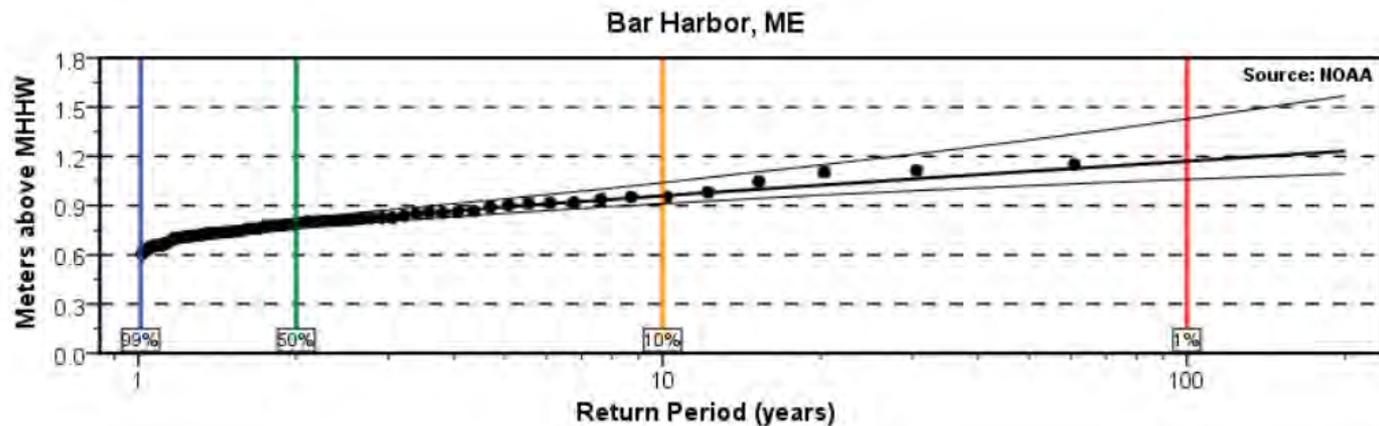
Some Basic Statistics...

Annual Exceedance and Average Recurrence Interval (aka Return Period)

$$P = \frac{(\mu t)^k * e^{-\mu t}}{k!}$$

$$1 - P = 1 - \frac{(1 * 1)^0 * e^{-1*1}}{0!} = 1 - e^{-1} = 0.6321$$

Average Recurrence Interval (ARI)	Annual Exceedance Probability (AEP)
1-year	63%
2-year	39%
5-year	18%
10-year	9.5%
20-year	4.9%
50-year	2.0%
100-year	1.0%
200-year	0.5%
500-year	0.2%
1000-year	0.1%



Back to Sea Level Rise

Probabilistic Guidance - Global

United States
Environmental Protection
Agency

Office of Policy,
Planning, and Evaluation
(2122)

EPA 230-R-95-008
October 1995

EPA

The Probability of Sea Level Rise

⁴Focusing on probability distributions may also foster scientific cohesion by enabling scientific panels to avoid choosing sides in matters of scientific uncertainty, and instead lend partial credence to competing, contradictory viewpoints, until one or the other is disproved. For example, unlike previous EPA reports, this study does not reject out of hand the view of some “greenhouse skeptics” that greenhouse warming will be negligible. As discussed in Chapter 3, our simulations include the views of a representative skeptic.

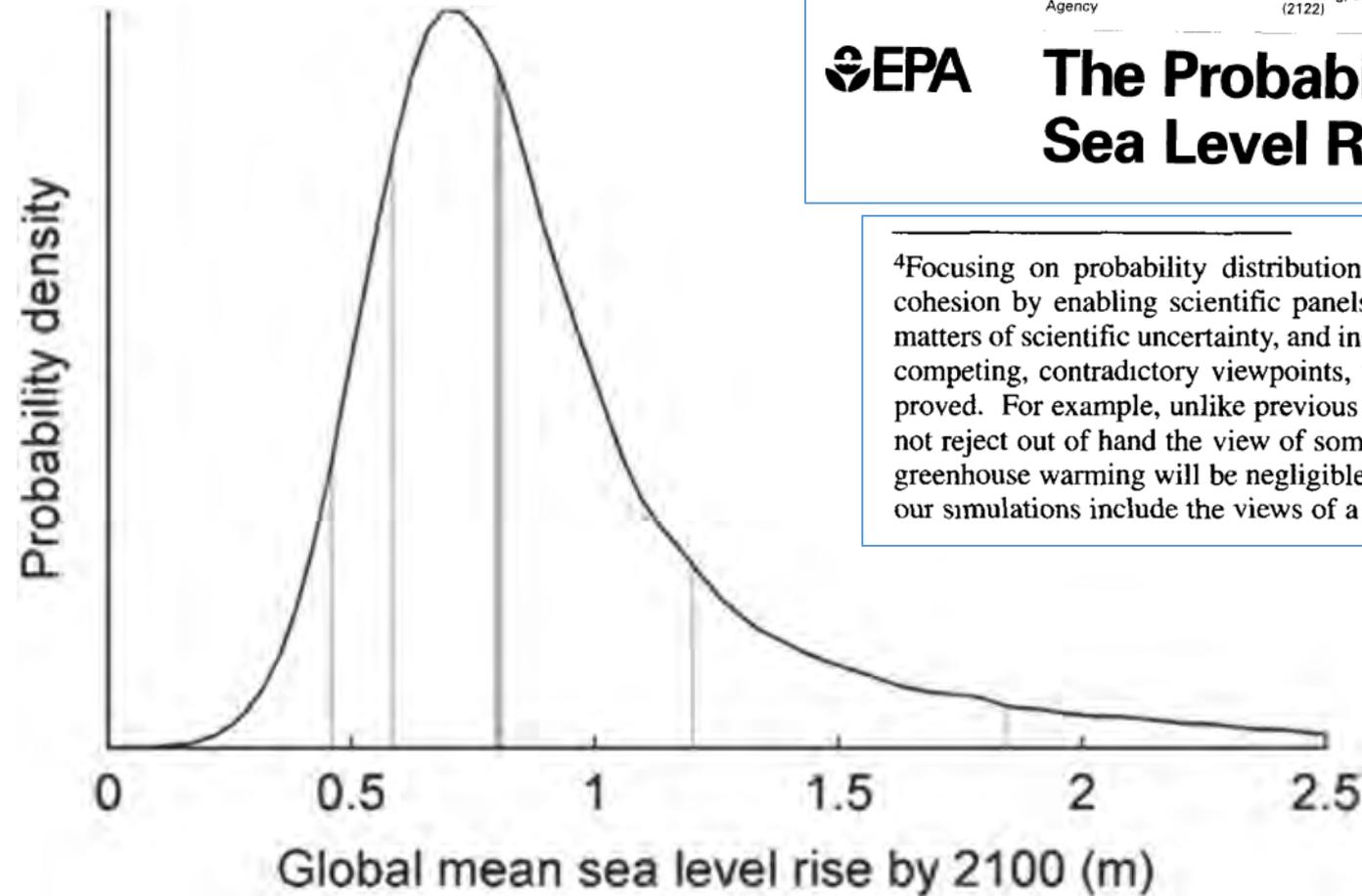
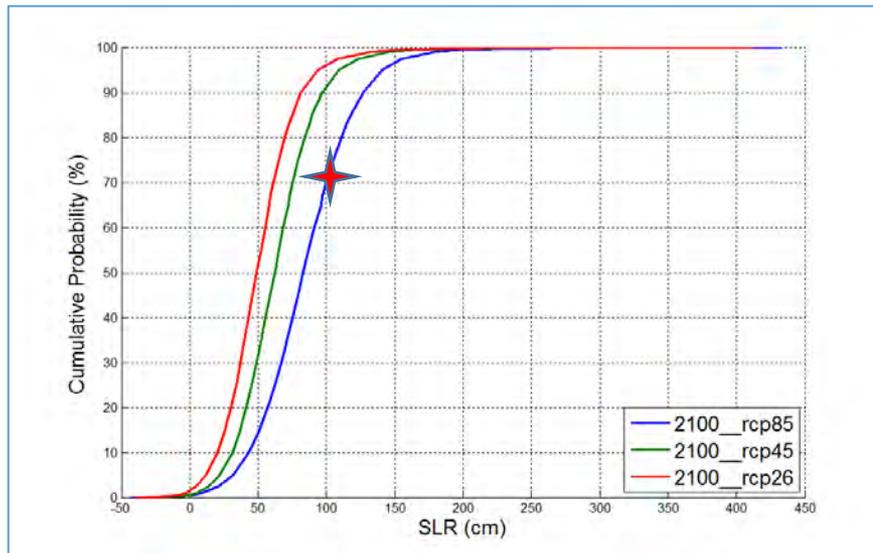
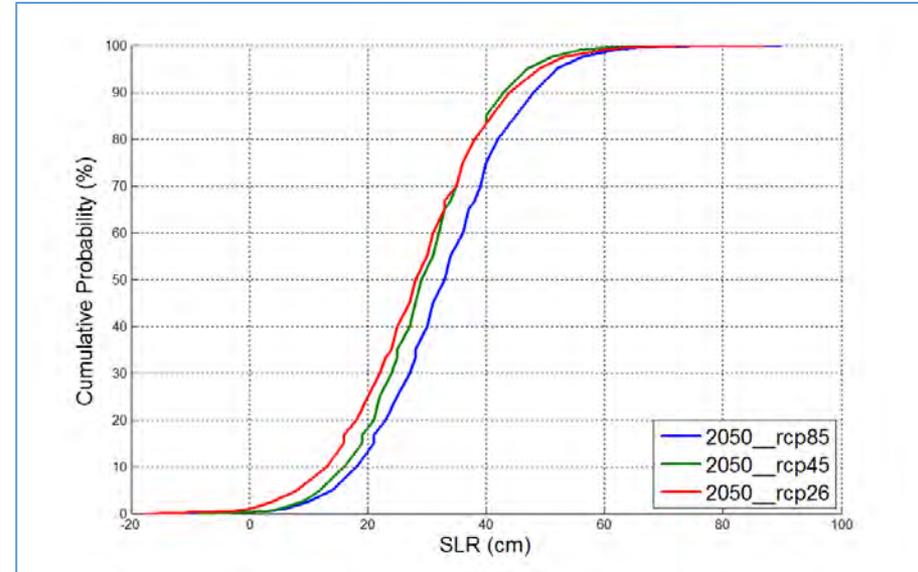
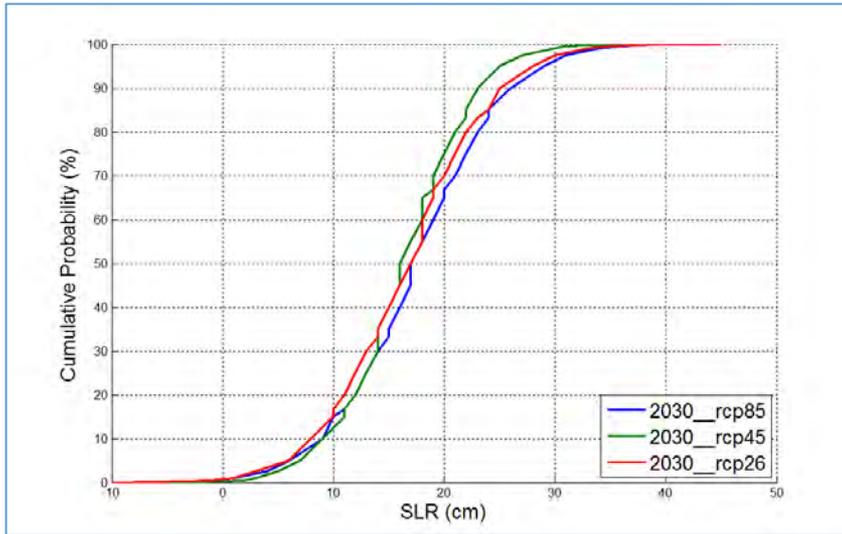


Figure from Grinsted, Aslak, S. Jevrejeva, R. E. M. Riva, and D. Dahl Jensen. *Sea level rise projections for northern Europe under RCP8.5*. Climate Research. Vol 64: 15-23. June 17, 2015.

Back to Sea Level Rise

Probabilistic Guidance - Local for Maine



Data From:

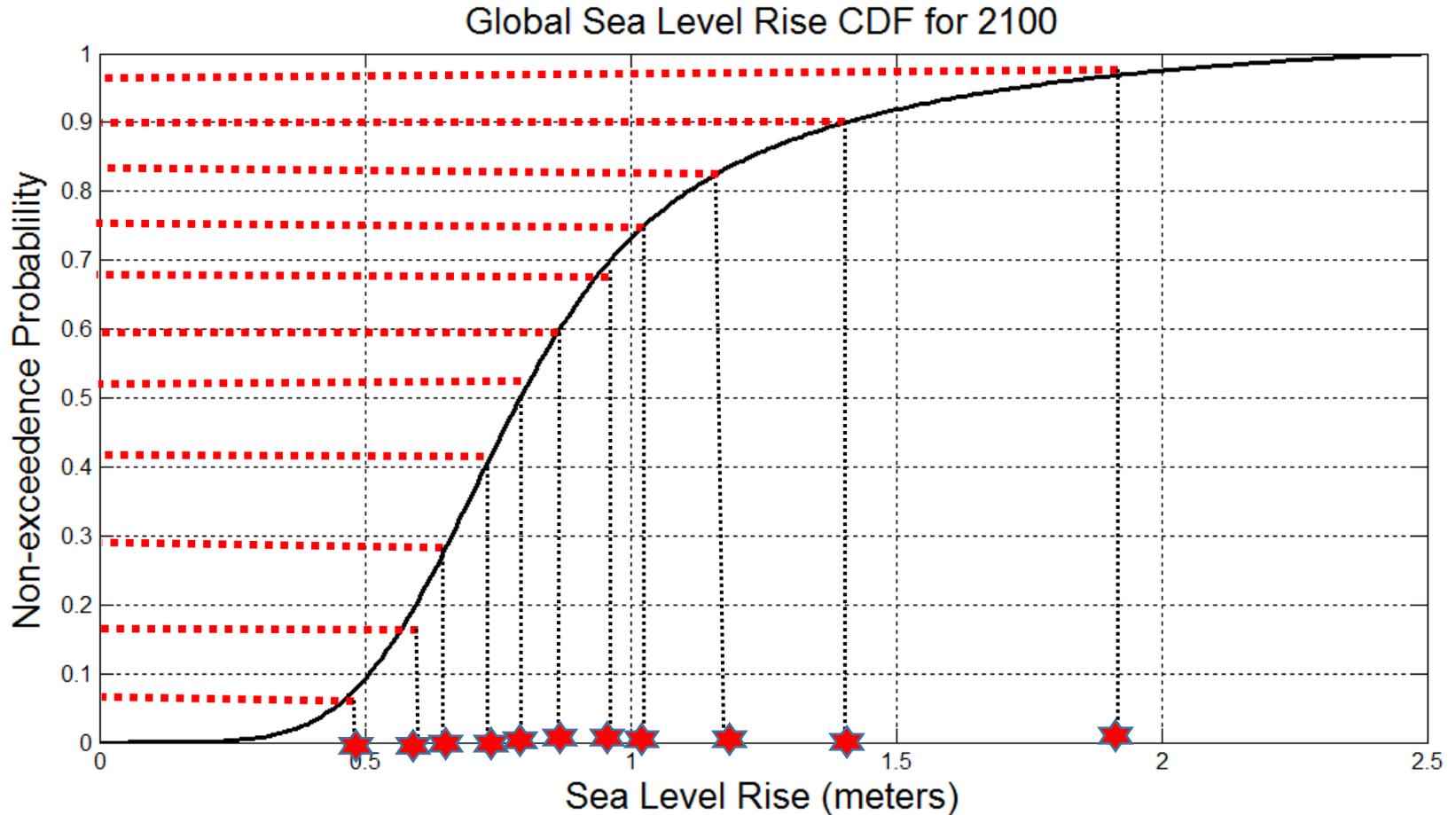
Kopp, R. E., R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, and C. Tebaldi (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites, *Earth's Future*, 2, 383–406, doi:10.1002/2014EF000239.

- Local
- Multiple future years
- Multiple RPC scenarios
- Switch to CDF (non-exceed)

Back to Sea Level Rise

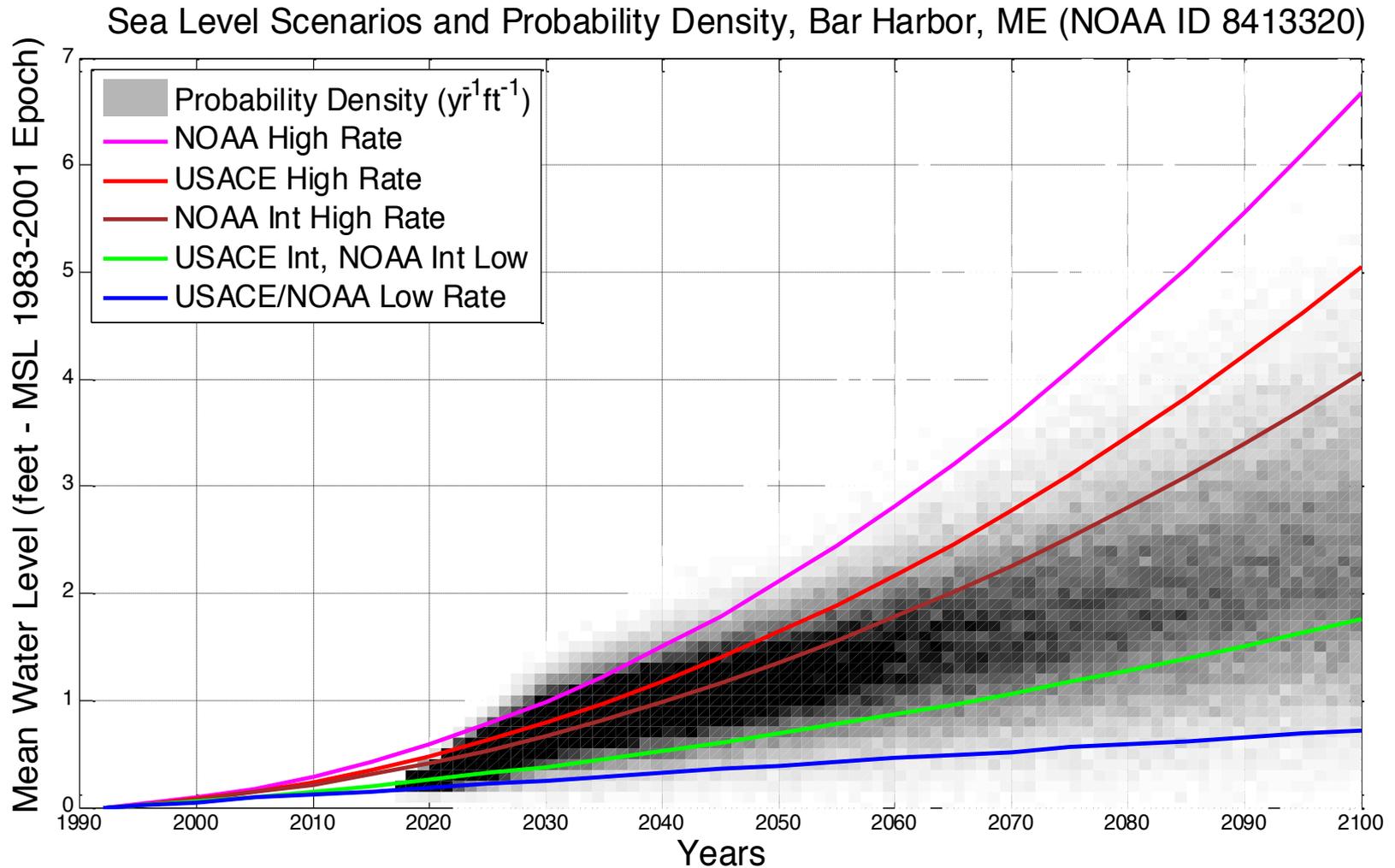
Probabilistic Guidance - Monte Carlo Method

Randomly guess at future sea level rise values following the estimated distribution



Back to Sea Level Rise

Many random guesses -> A fuzzy cloud of uncertainty



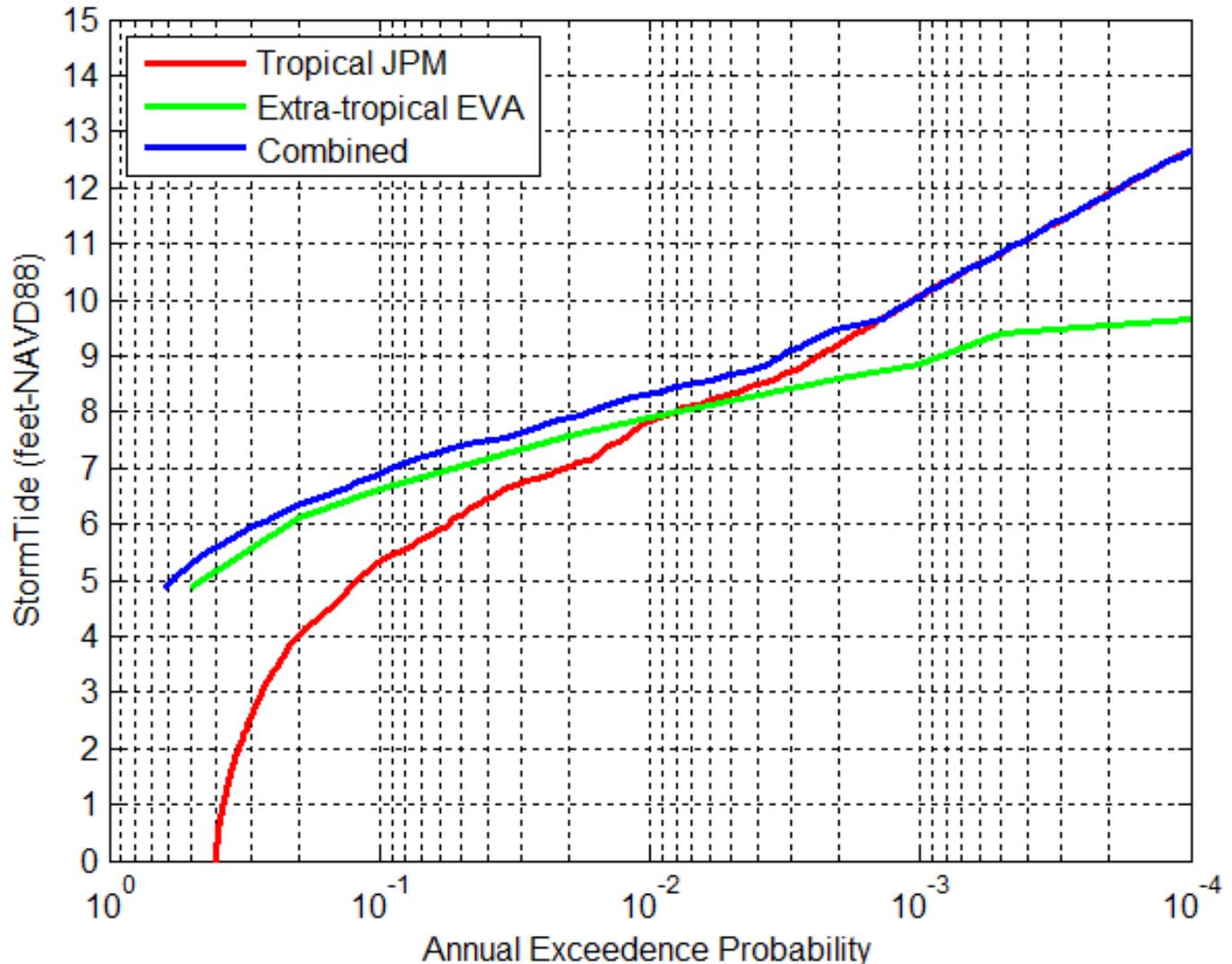
Now Add The Flood Hazard

Numerical Modeling + Joint Probability Methods + Extreme Value Analysis

$$\frac{du}{dt} - f_c$$
$$\frac{dv}{dt} + f_c$$

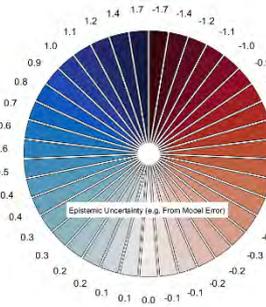
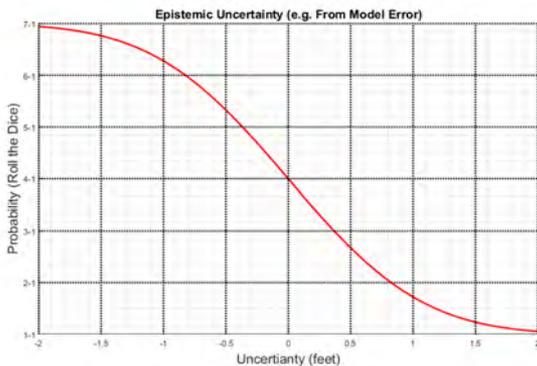
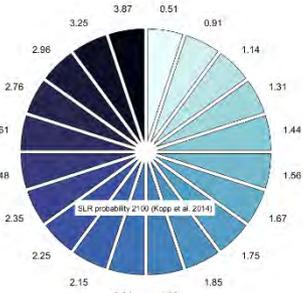
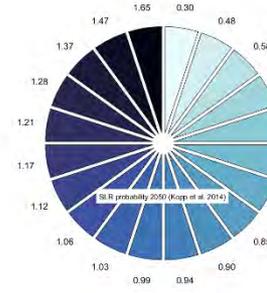
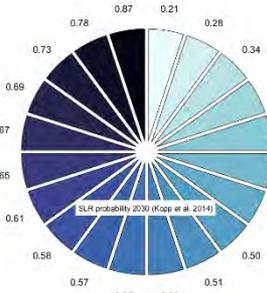
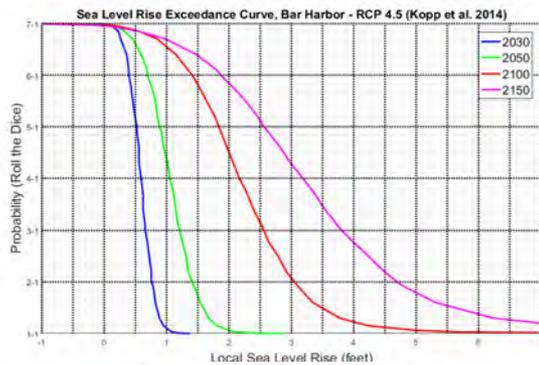
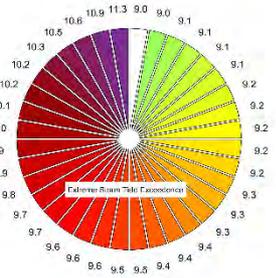
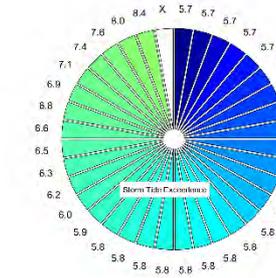
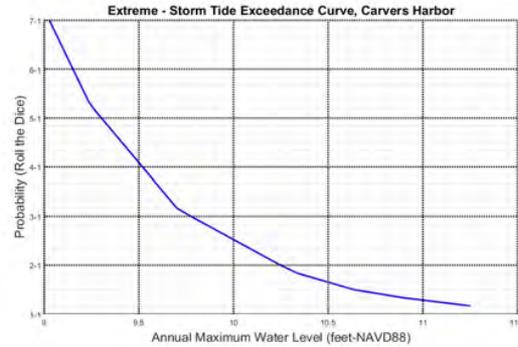
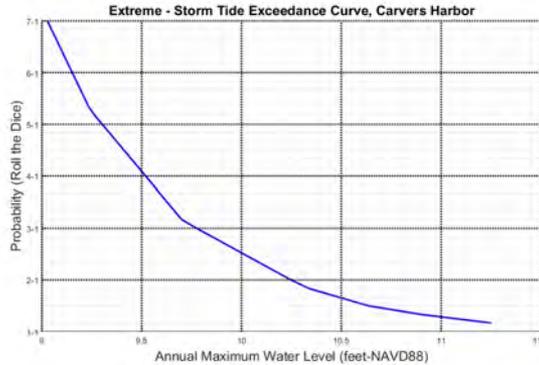
Acceleration
Coriolis

function
return
parameters
for
end



Now Add The Flood Hazard

Probabilistic Guidance - Monte Carlo Method –Storm Surge Slot Machine



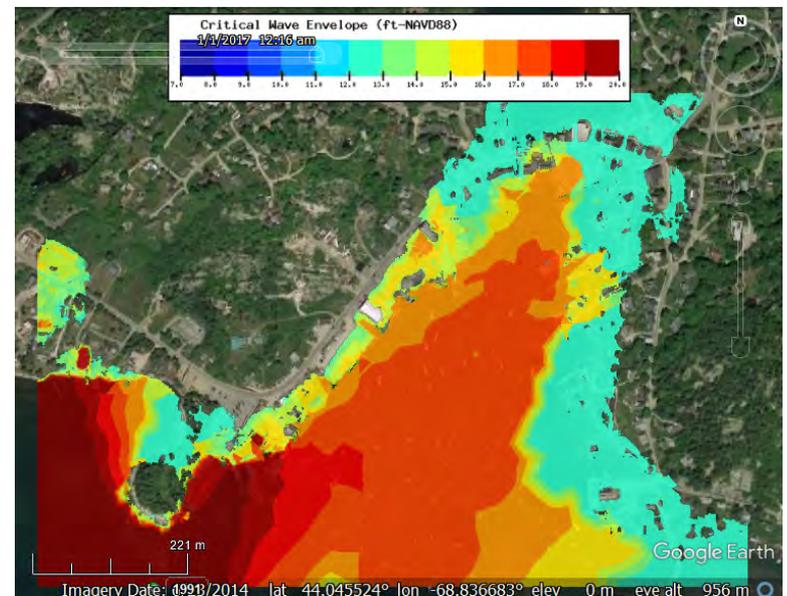
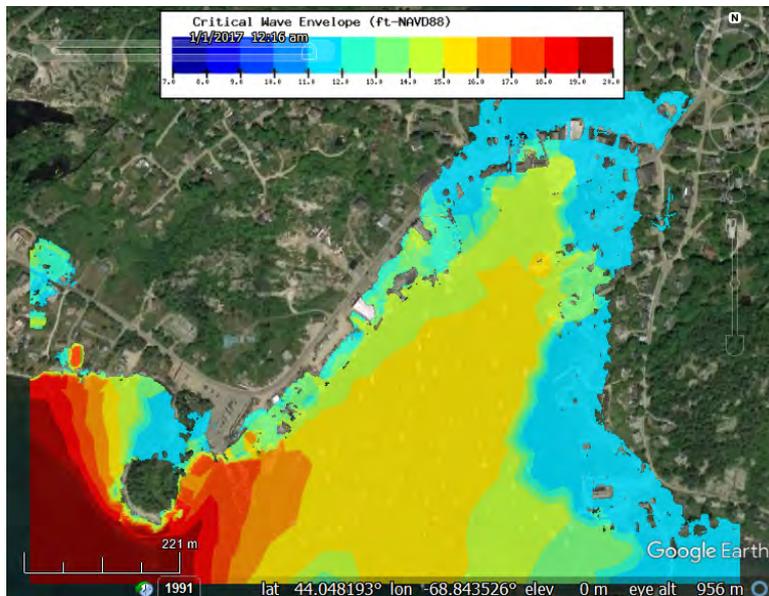
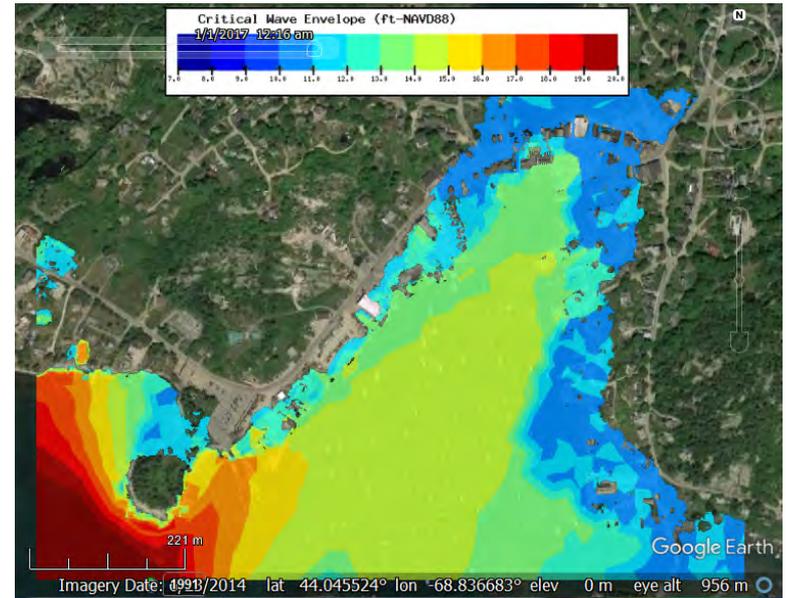
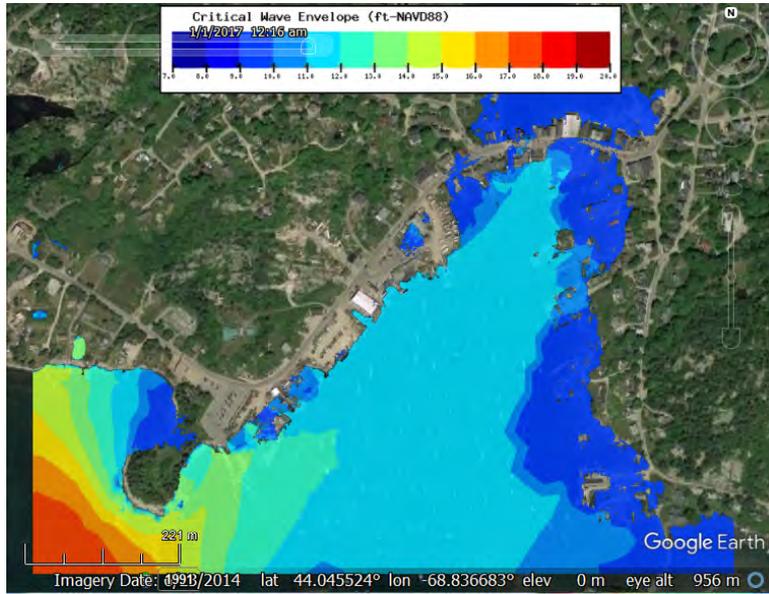
Add together:

- Random Storm Tide
- Random SLR
- Random Uncertainty

Do this many times for many locations

Now Add The Flood Hazard

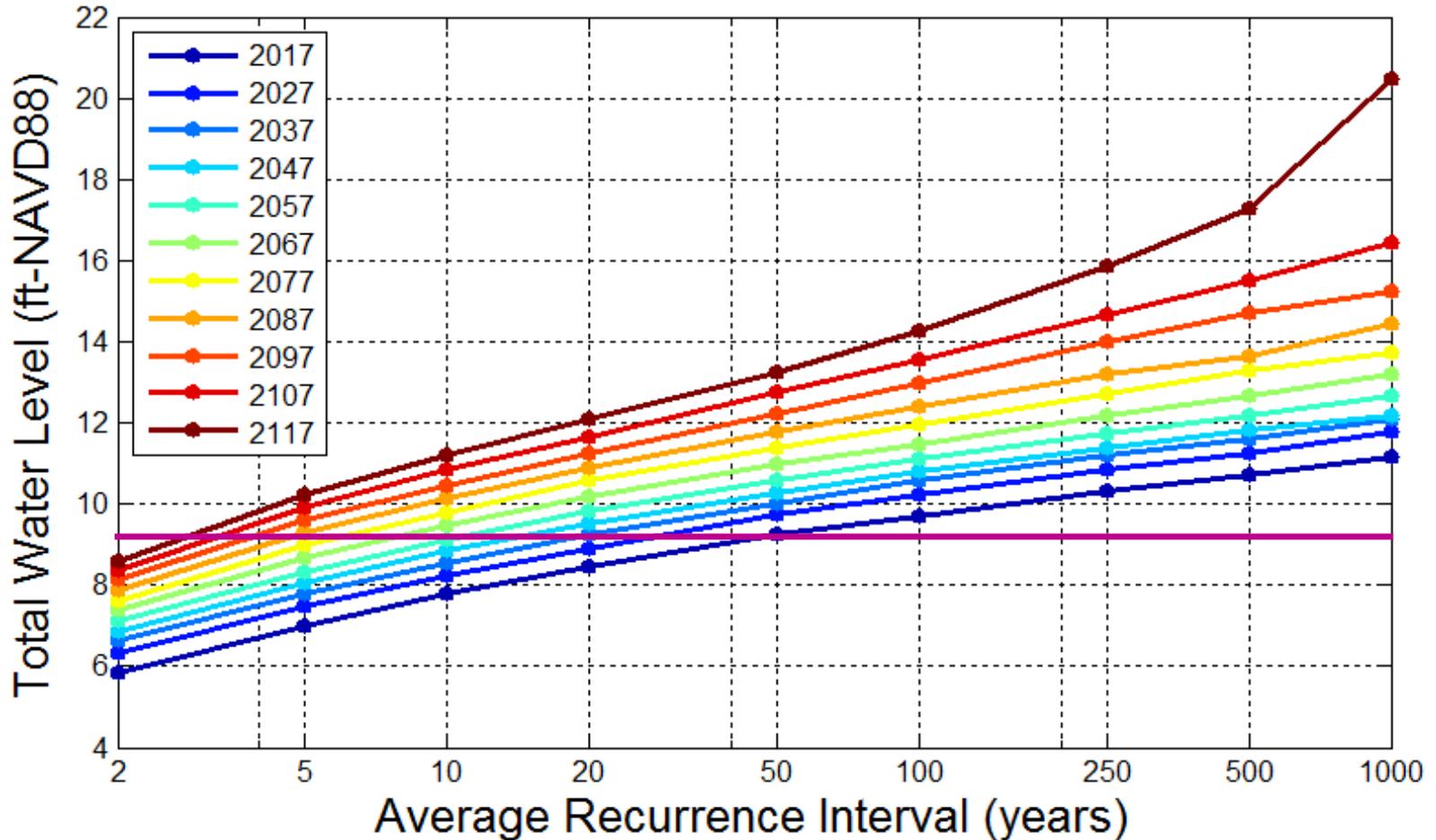
Combined SLR + Surge + Wave Hazard – Any Future Year – Any Return Period



Now Add The Flood Hazard

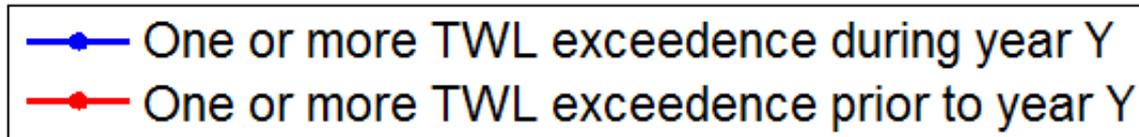
Pick a Site

The Carvers harbor Future Flood Hazard Curves

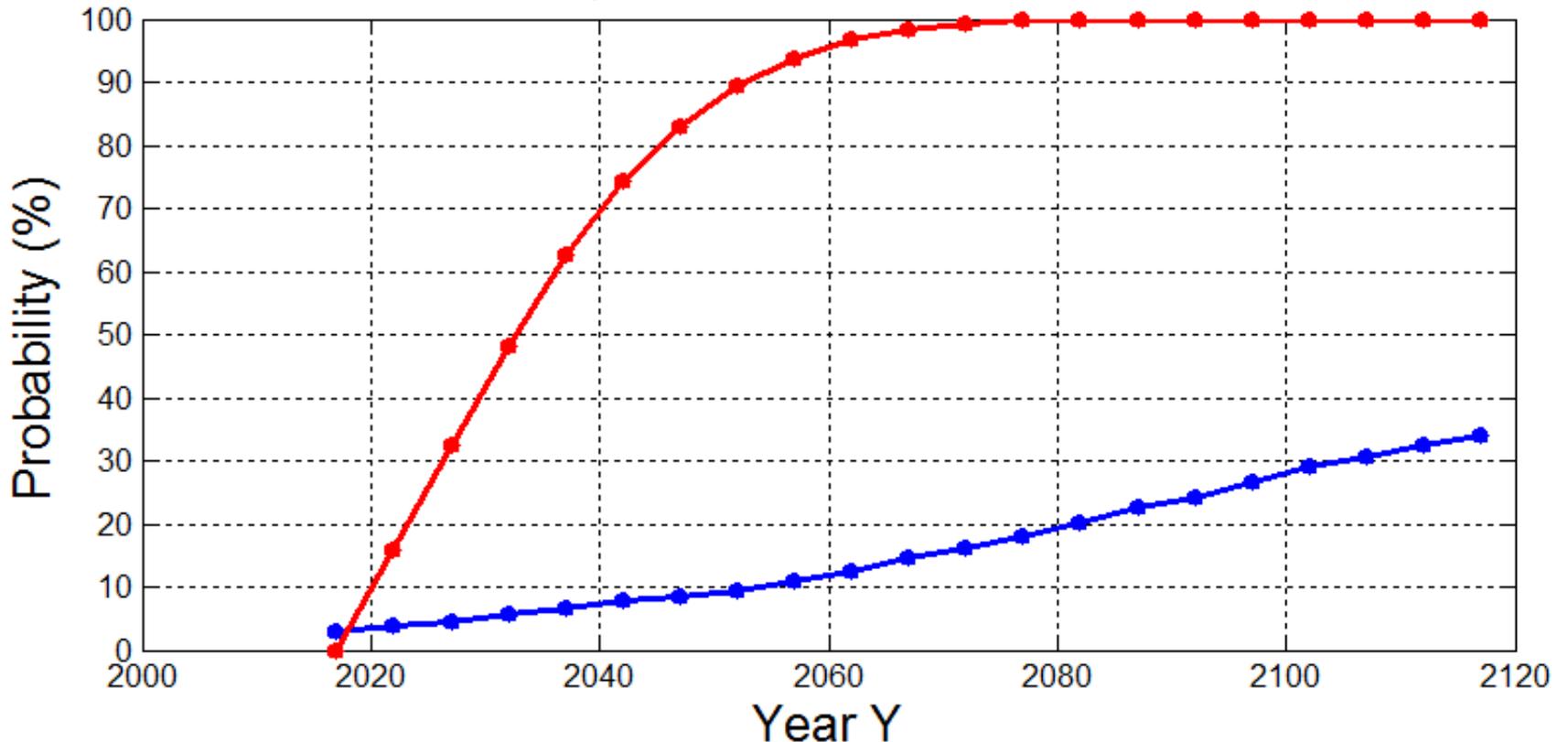


Now Add The Flood Hazard

Pick an elevation



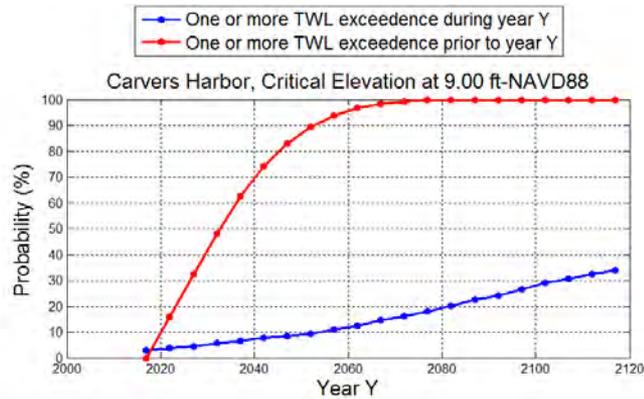
Carvers Harbor, Critical Elevation at 9.00 ft-NAVD88



What's the Cost?

From Hazard to Risk

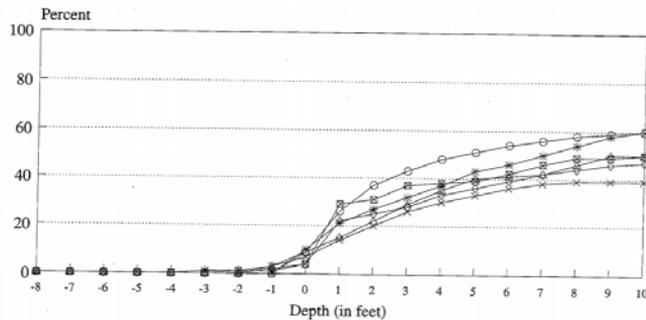
$$\text{Risk} = \sum [(\text{Probability of Hazard}) \times (\text{Cost of Damage})]$$



sum over all possibilities
sum over lifetime

\$\$\$

Percent Damage to Structure Value
ONE STORY, NO BASEMENT

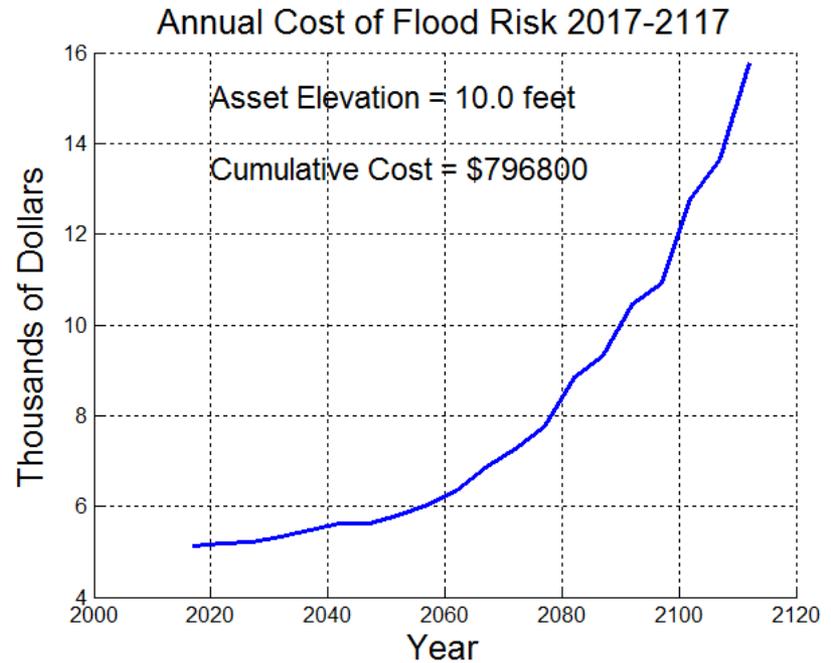
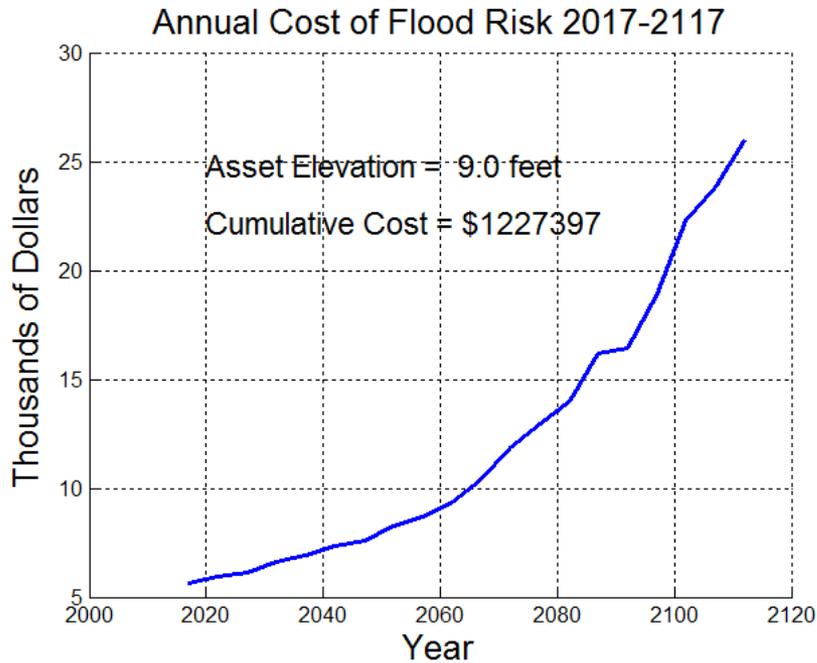


What's the Cost?

Annualized ?

lifetime ?

Example for a \$500,000 asset at Carver's Harbor



Synthesis of Coastal Flood Hazards and Uncertainty in Sea Level Rise

Concerned Citizen: “Yeah, but what sea level rise scenario is that for?”

Less Snarky Coastal Engineer: “All of them at once”

Thank You!