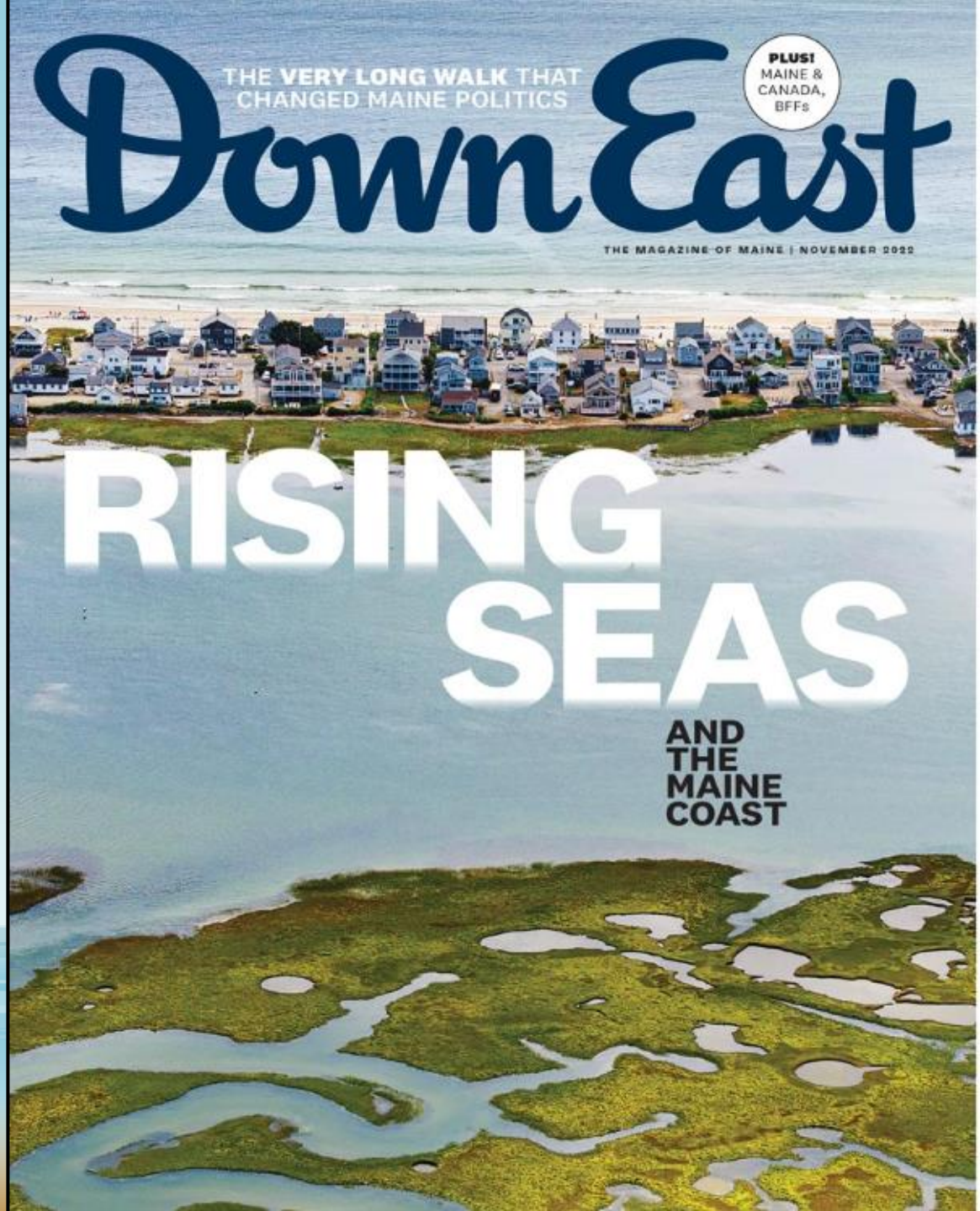
Sea Level Rise

DOUG BURNS, 36 WINONA AVE,
OCEAN PARK, MAINE

Photo credit: Liz Gotthelf, sacobaynews.com



What I Plan to Discuss

- Basics about sea level – how it has varied over time, drivers of change, natural and human factors
- Latest information on sea level change – how much, why
- Different types of sea level associated flooding – tidal, extreme events, compound flooding
- What can we expect in the future?
- Adaptation and management – what can we do about changing sea level?
- Different spatial scales – global, US, eastern US, Maine coast, Ocean Park
- My goal – bring you the most recent and best scientific information on sea level

Background

- I am not a marine scientist
- I have been working extensively over the past 2 years on a New York State Climate Change Assessment – co-chairing the chapter on ecosystem impacts, extensive text on sea level
- I am not an expert in climate change adaptation – not directly involved in any adaptation activities in coastal Maine
- I am not an engineer – sea walls, levees, pump systems, etc.
- Adaptation and management – provide food for thought

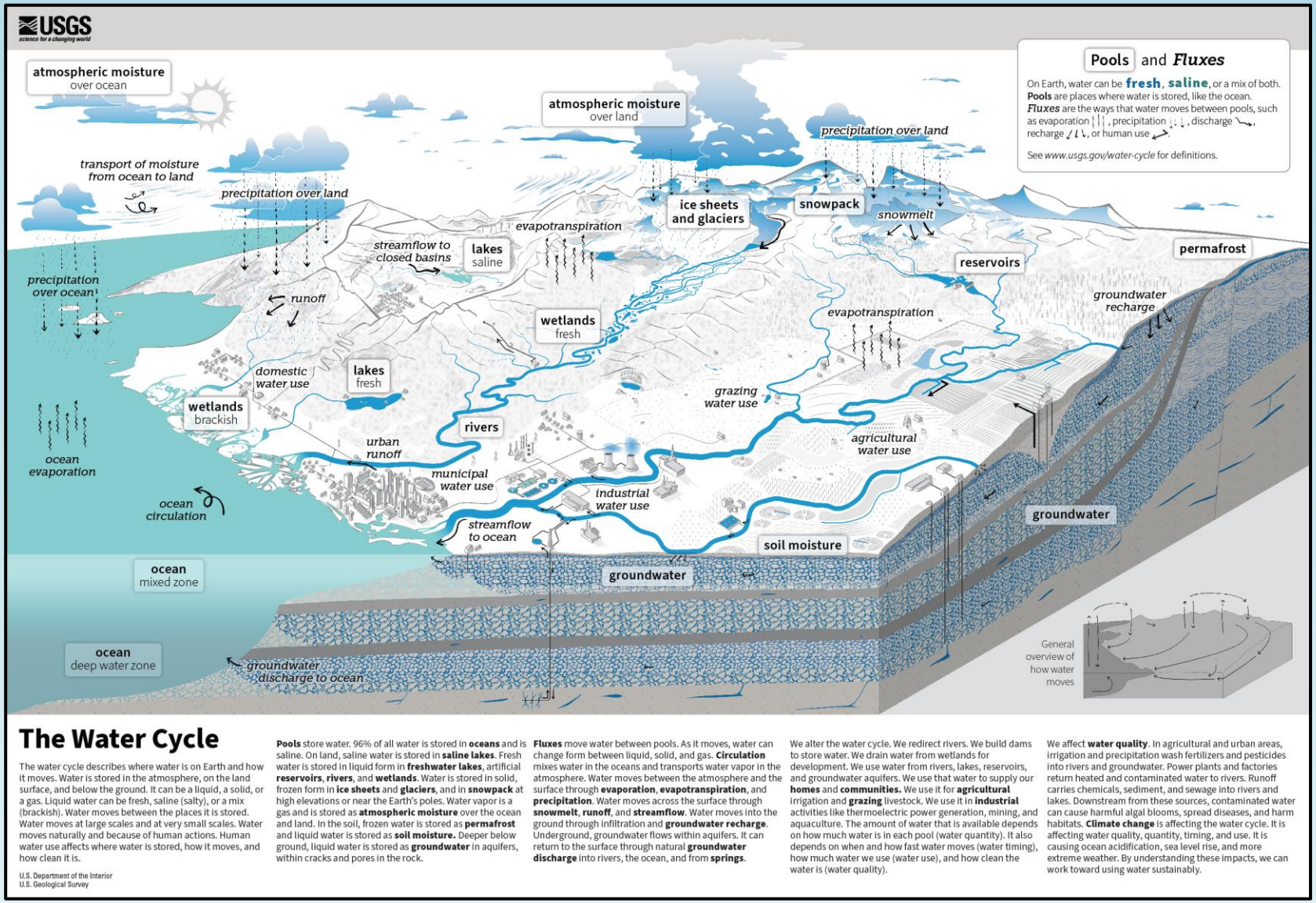
Start with a Positive Message

- Restoration of the primary dune in Ocean Park has been a huge success and has helped to limit storm surge

Photo by Betty Olivolo, Kittery, Maine, https://www.nrcm.org/my-maine-this-week/ocean-park-by-betty-olivolo/

Water Cycle

- Where is the Earth's water stored?
  - Oceans – 96.5%
  - Ice/snow – 1.7%
  - Groundwater – 1.7%
  - Lakes – 0.013%
  - Atmosphere – 0.001%



The Water Cycle

The water cycle describes where water is on Earth and how it moves. Water is stored in the atmosphere, on the land surface, and below the ground. It can be a liquid, a solid, or a gas. Liquid water can be fresh, saline (salty), or a mix (brackish). Water moves between the places it is stored. Water moves at large scales and at very small scales. Water moves naturally and because of human actions. Human water use affects where water is stored, how it moves, and how clean it is.

U.S. Department of the Interior
U.S. Geological Survey

Pools store water. 96% of all water is stored in **oceans** and is saline. On land, saline water is stored in **saline lakes**. Fresh water is stored in liquid form in **freshwater lakes**, artificial **reservoirs**, **rivers**, and **wetlands**. Water is stored in solid, frozen form in **ice sheets** and **glaciers**, and in **snowpack** at high elevations or near the Earth's poles. Water vapor is a gas and is stored as **atmospheric moisture** over the ocean and land. In the soil, frozen water is stored as **permafrost** and liquid water is stored as **soil moisture.** Deeper below ground, liquid water is stored as **groundwater** in aquifers, within cracks and pores in the rock.

Fluxes move water between pools. As it moves, water can change form between liquid, solid, and gas. **Circulation** mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the surface through **evaporation**, **evapotranspiration**, and **precipitation**. Water moves across the surface through **snowmelt**, **runoff**, and **streamflow**. Water moves into the ground through infiltration and **groundwater recharge**. Underground, groundwater flows within aquifers. It can return to the surface through natural **groundwater discharge** into rivers, the ocean, and from **springs**.

We alter the water cycle. We redirect rivers. We build dams to store water. We drain water from wetlands for development. We use water from rivers, lakes, reservoirs, and groundwater aquifers. We use that water to supply our **homes** and **communities.** We use it for **agricultural** irrigation and **grazing** livestock. We use it in **industrial** activities like thermoelectric power generation, mining, and aquaculture. The amount of water that is available depends on how much water is in each pool (water quantity). It also depends on when and how fast water moves (water timing), how much water we use (water use), and how clean the water is (water quality).

We affect **water quality**. In agricultural and urban areas, irrigation and precipitation wash fertilizers and pesticides into rivers and groundwater. Power plants and factories return heated and contaminated water to rivers. Runoff carries chemicals, sediment, and sewage into rivers and lakes. Downstream from these sources, contaminated water can cause harmful algal blooms, spread diseases, and harm habitats. **Climate change** is affecting the water cycle. It is affecting water quality, quantity, timing, and use. It is causing ocean acidification, sea level rise, and more extreme weather. By understanding these impacts, we can work toward using water sustainably.

https://www.usgs.gov/special-topics/water-science-school/science/where-earths-water
https://www.usgs.gov/special-topics/water-science-school/science/water-cycle-diagrams

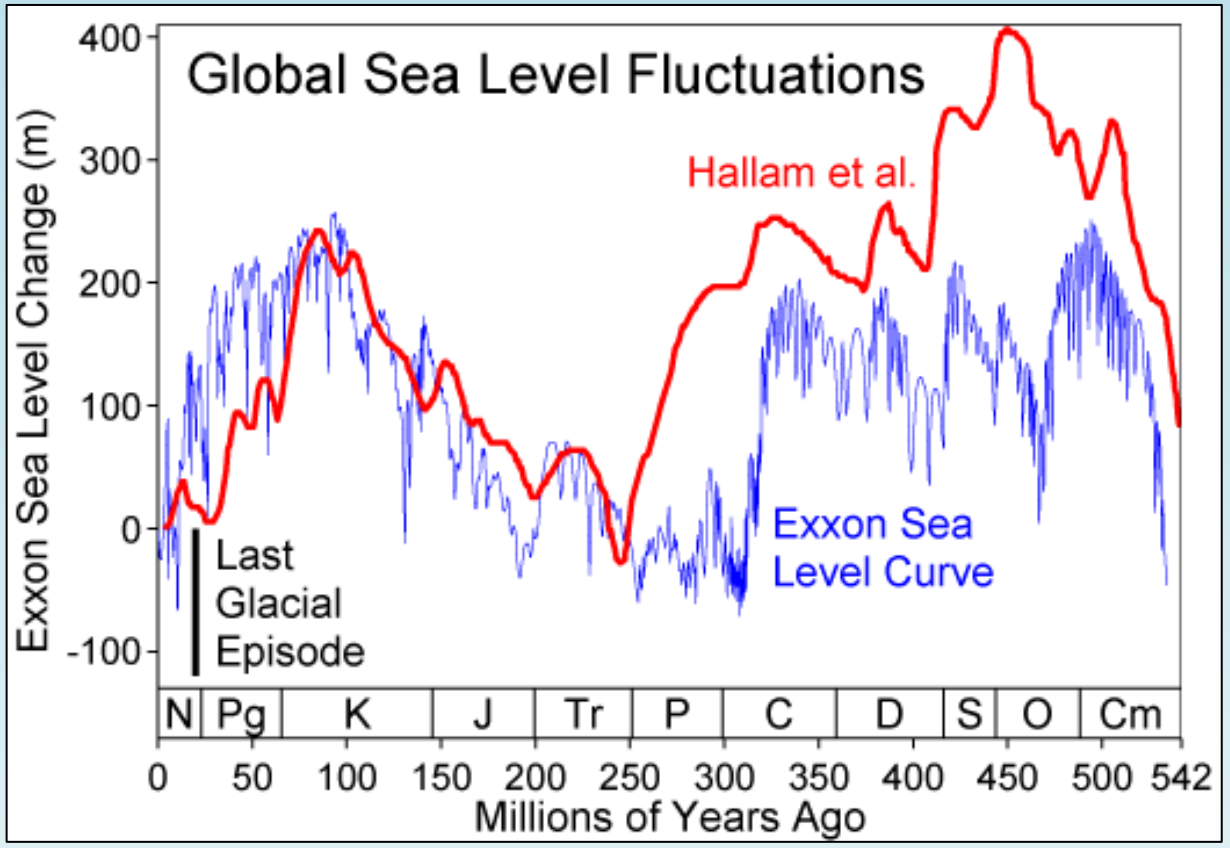
Notion #1: Sea Level Remains Pretty Constant, Right?

No!

Let’s Start with the Long View – a geologist’s perspective

Deep time – tens to hundreds of million years ago

Sea Level has been Highly Variable over Geologic Time



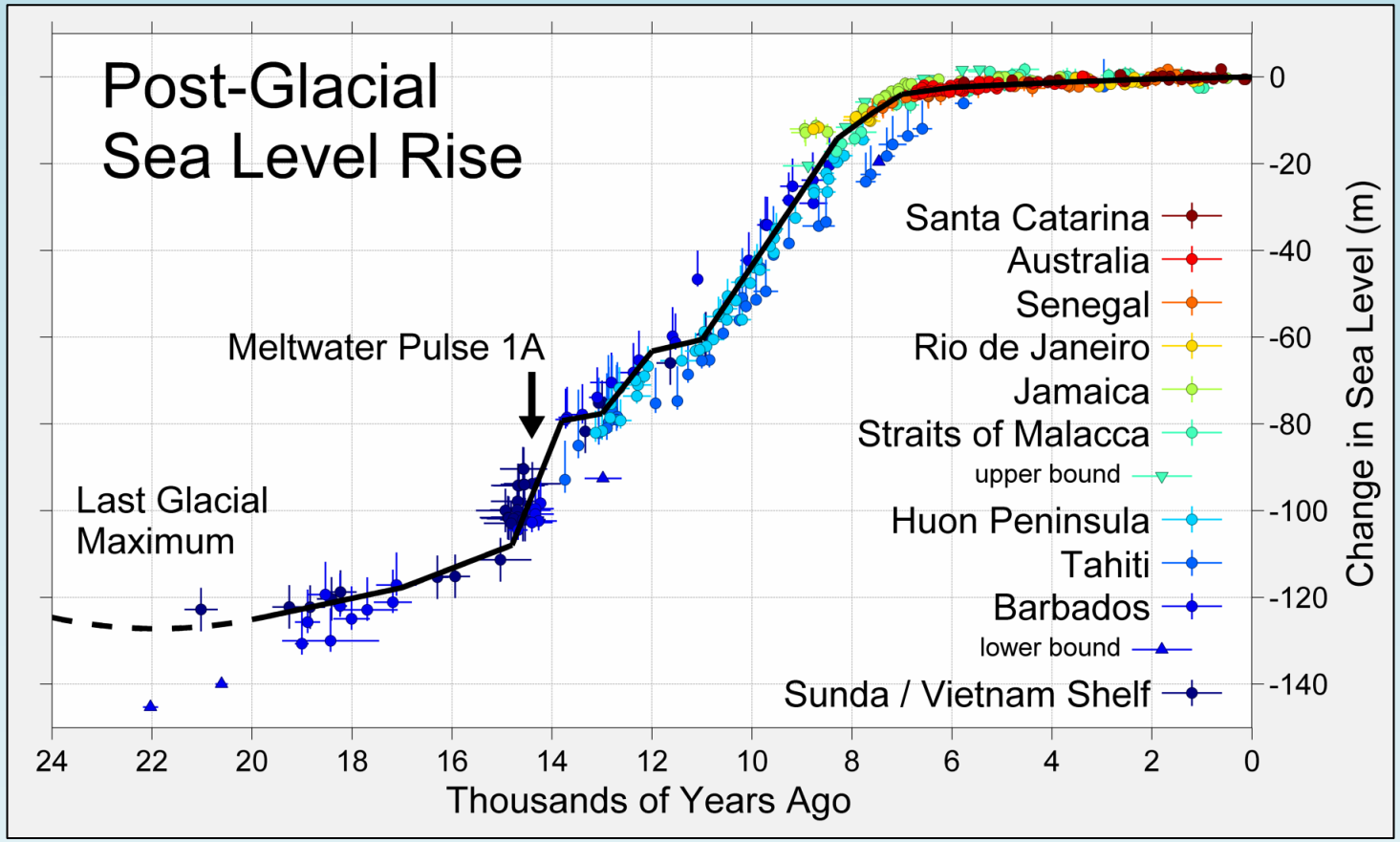
Sea Level Varies Naturally

- Sea Level has varied over geologic time for many different reasons – changes in the strength of the sun, plate tectonics, volcanic activity, asteroid impacts, major changes in the influence of living organisms on the atmosphere
- Variation in sea level is linked to variation in the earth's climate
- How much solar radiation reaches the earth's surface? Solar energy, interaction of solar energy with gases in the atmosphere
- Ice age – most recent began about 2 million yrs ago, we are currently in this ice age, variations in the earth's orbit appear to be a principal cause
- Human activities have short circuited the ice age – we are now in an era when humans have altered the earth's climate

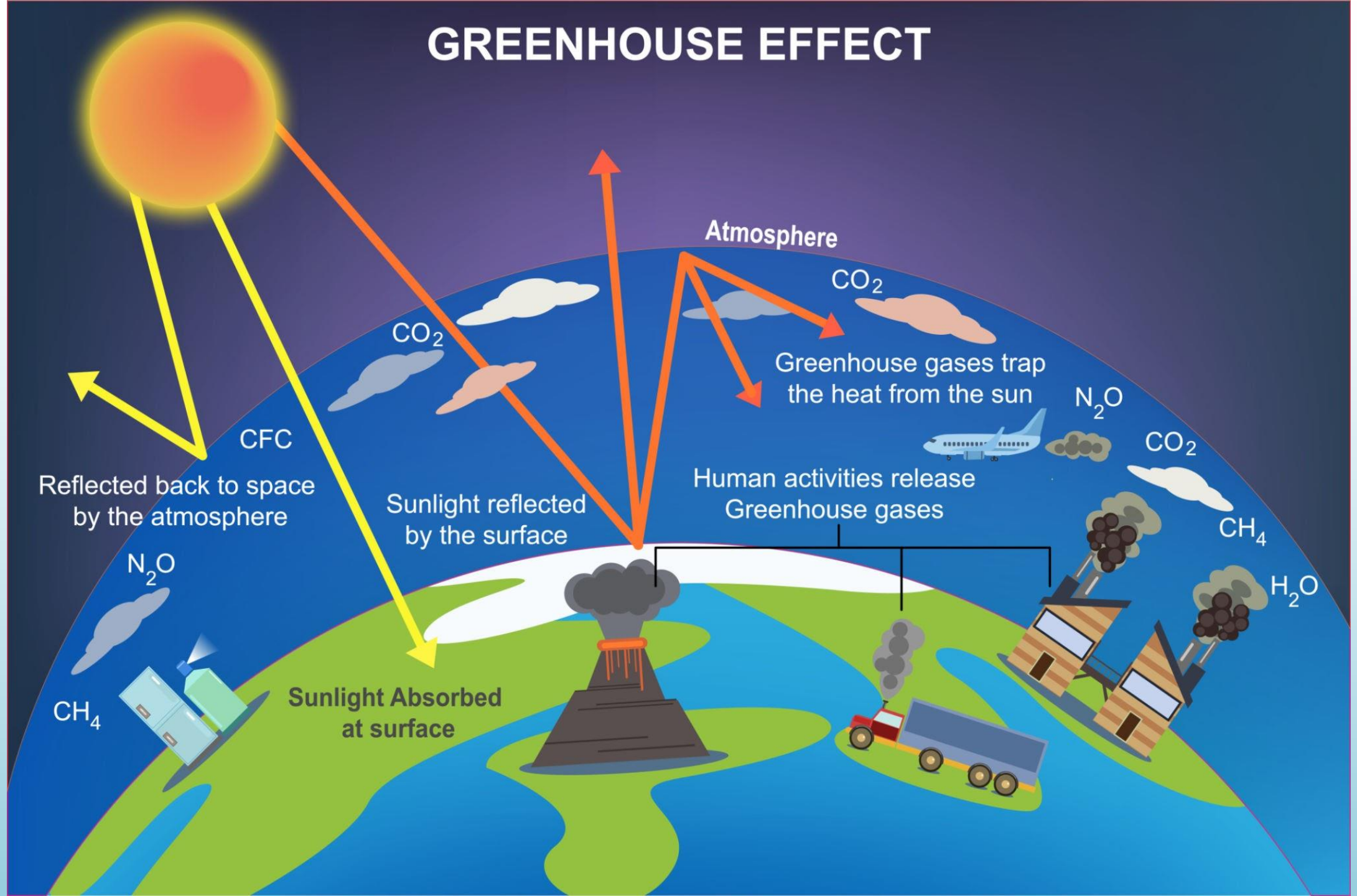
Most Recent Glacial Advance

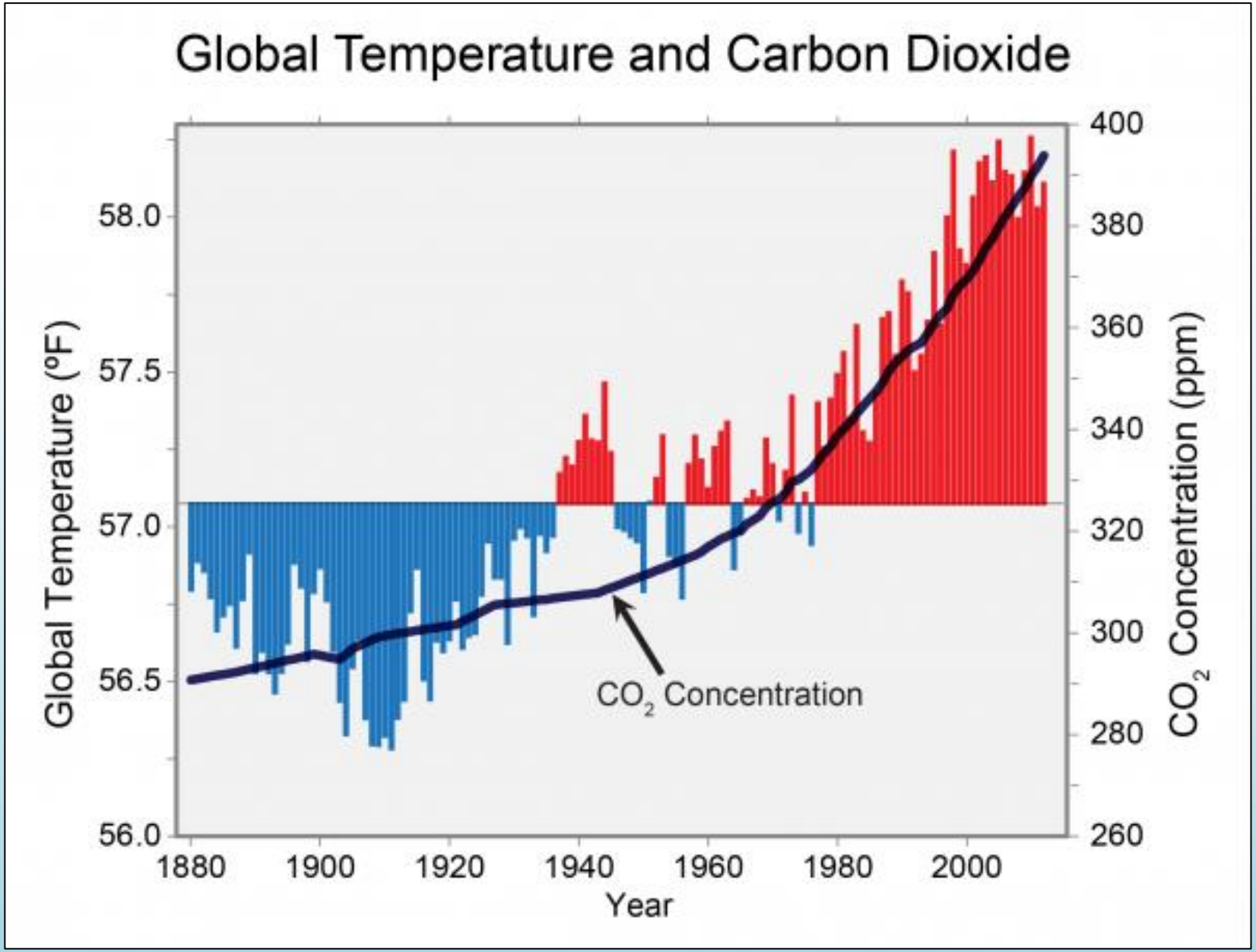
- Peaked about 20 thousand years ago
- As the amount of ice increases, the volume of the oceans decline
- Therefore, sea level declines
- As the ice melts, sea level rises

Sea Level since the Most Recent Glaciation



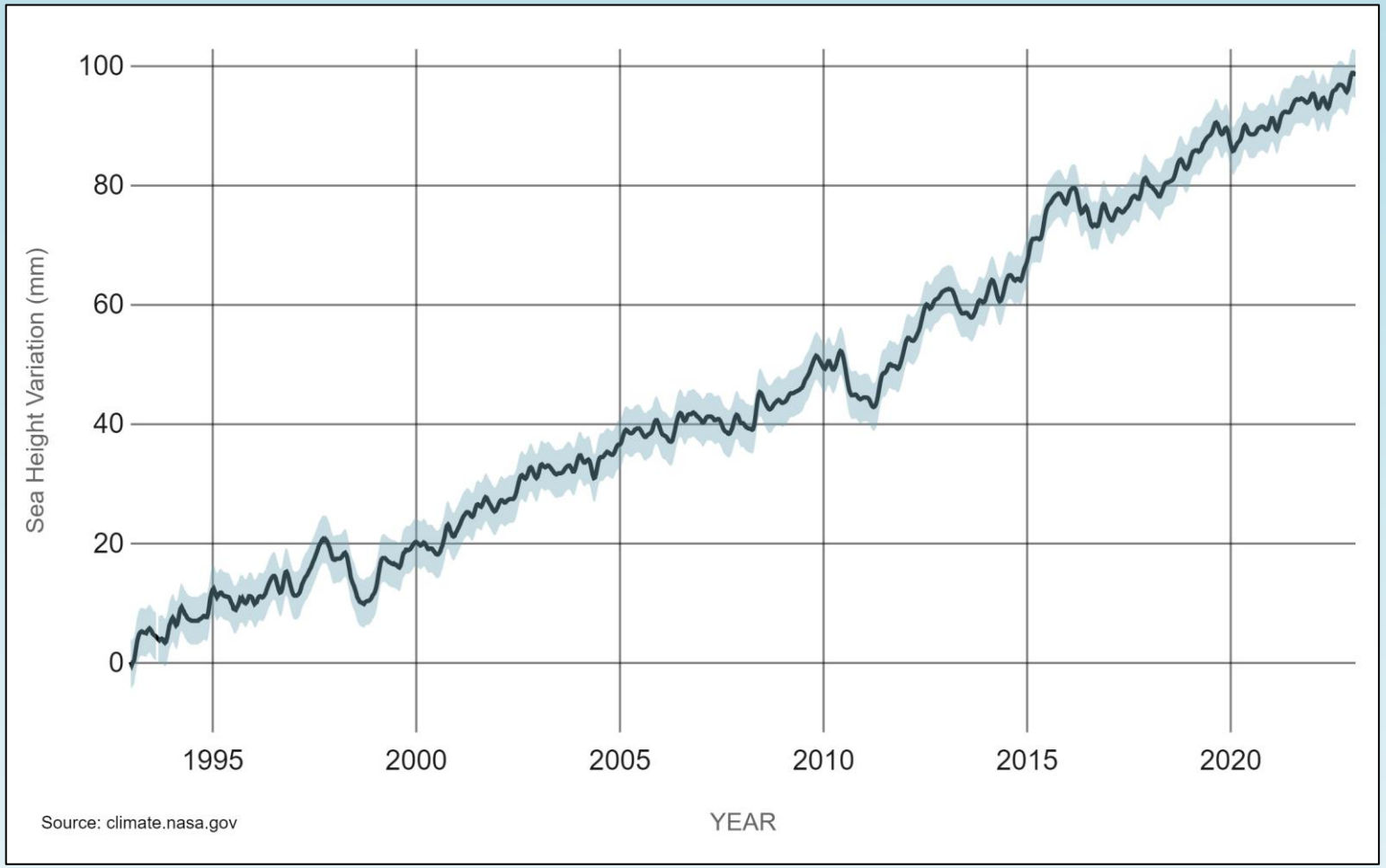
How are Human Activities Impacting the Climate?


GREENHOUSE EFFECT
Atmosphere
CO_2
CO_2
Greenhouse gases trap
the heat from the sun
N_2O
CO_2
CFC
Reflected back to space
by the atmosphere
Sunlight reflected
by the surface
Human activities release
Greenhouse gases
CH_4
N_2O
H_2O
CH_4
Sunlight Absorbed
at surface



https://www.globalchange.gov/browse/multimedia/global-temperature-and-carbon-dioxide

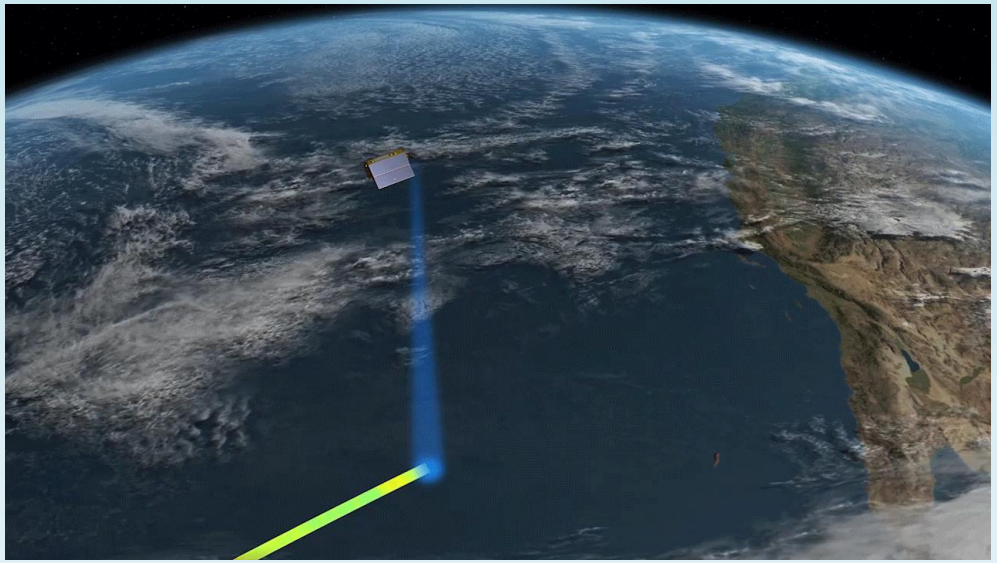
Global Sea Level has Risen by 4 inches over Past 30 Years



https://climate.nasa.gov/vital-signs/sea-level/

Global and Local Sea Level

- Global mean sea level – average height of the entire ocean surface
- Local sea level – height of the ocean surface at a specific location (e.g. – Portland, ME)
- Distinction is important because local sea level change over time may differ from global sea level change

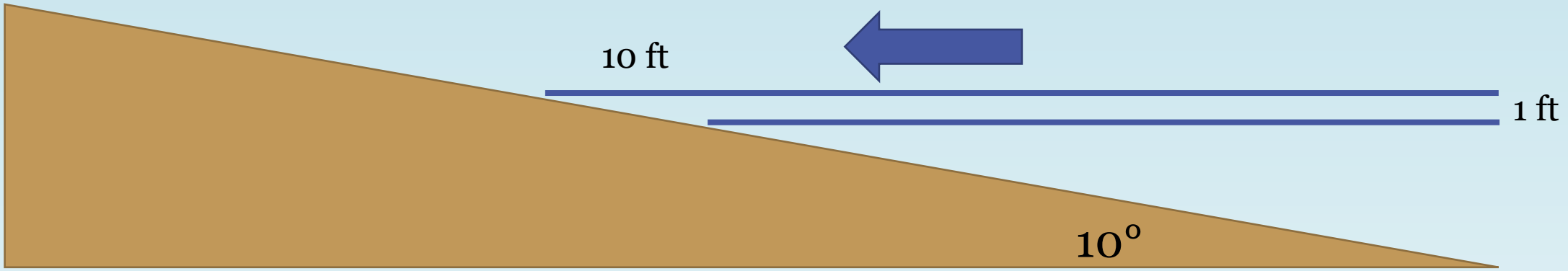


Tide gauge at Camp Ellis

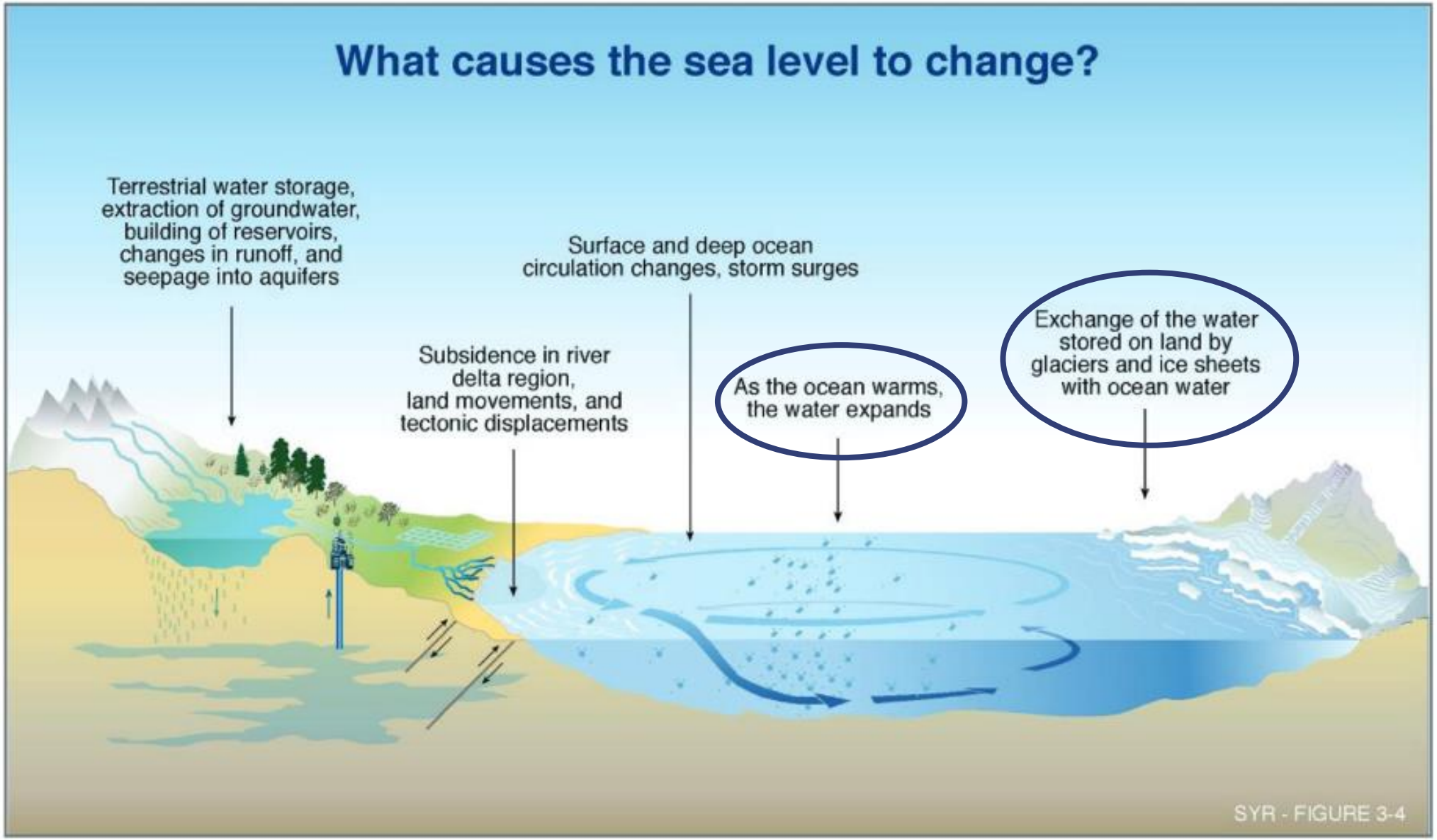
https://sealevel.nasa.gov/faq/19/how-do-satellites-measure-sea-level-change/

Sea Level Rise and Storm Surge

Multiplying Effect



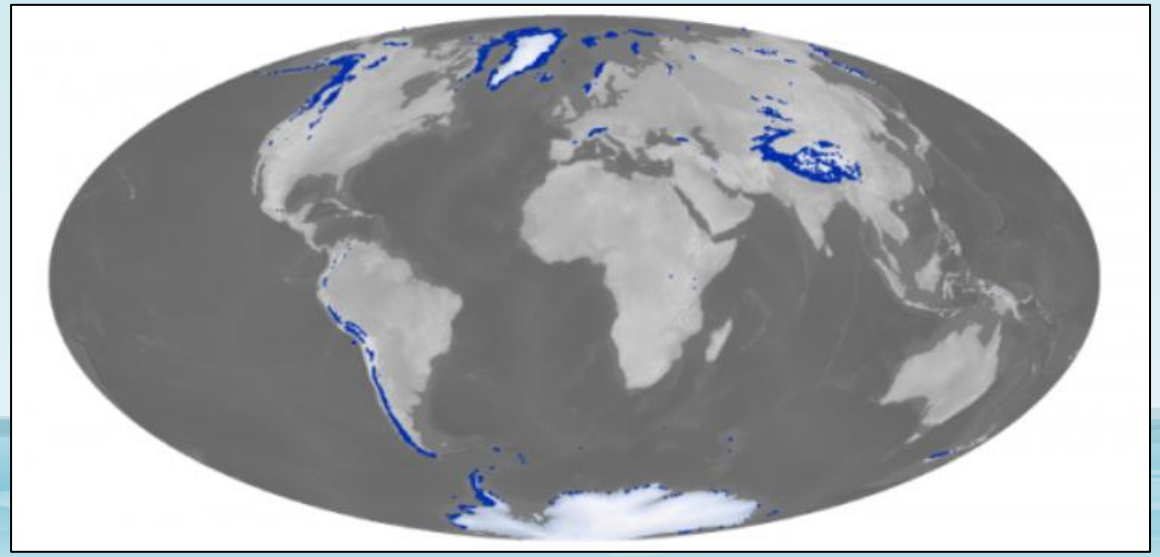
If sea level rises by one foot, storm surge rises by 10 feet



https://climate.nasa.gov/explore/ask-nasa-climate/3002/sea-level-101-part-two-all-sea-level-is-local/

Why is Global Mean Sea Level Rising?

- The climate is warming – by about 2 deg F over past century
- Thermal expansion – as oceans warm, volume expands as water becomes less dense
- Melting of glacial ice – Antarctica and Greenland
- Secondary factors – storage or depletion of freshwater, changes in ocean circulation
- Sea level change can vary from year-to-year – short-term variations in climate, El Nino – Southern Oscillation (ENSO)



Antarctica = 90% of global ice

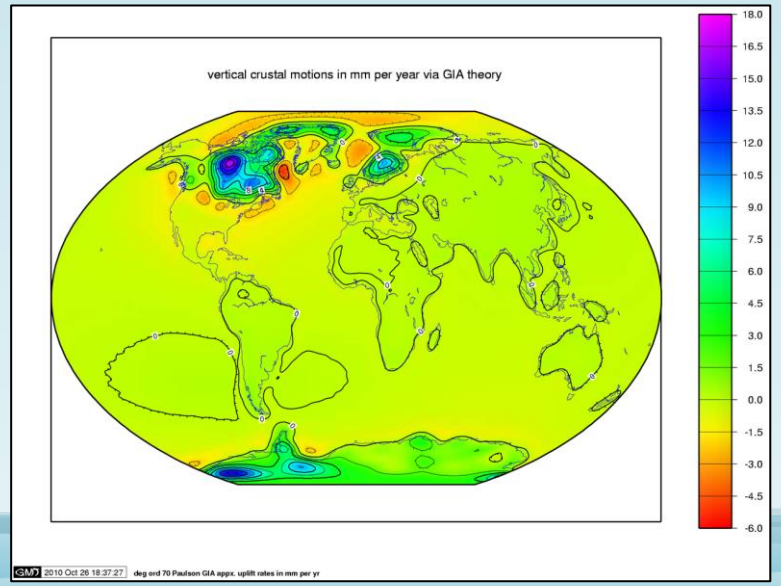
Greenland = 10% of global ice

All other glaciers <1% of global ice

https://www.e-education.psu.edu/earth107/node/1500

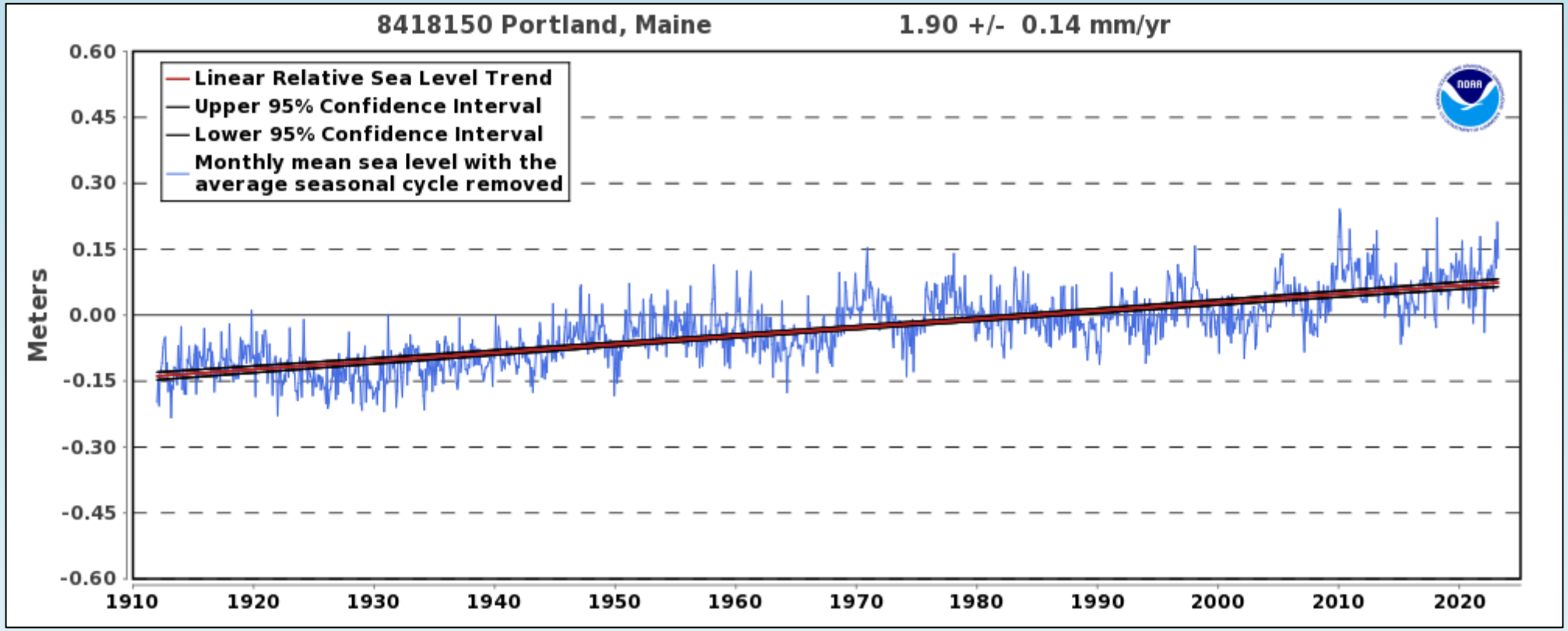
Local Sea Level Change

- May differ from global sea level change
- Local climate change may differ from global climate change
- Subsidence – compaction of land, weight of built structures, tectonic activity, groundwater pumping
- Land may rise – glacial isostatic adjustment, as glaciers recede and weight is lifted, the land recovers



https://en.wikipedia.org/wiki/Post-glacial_rebound

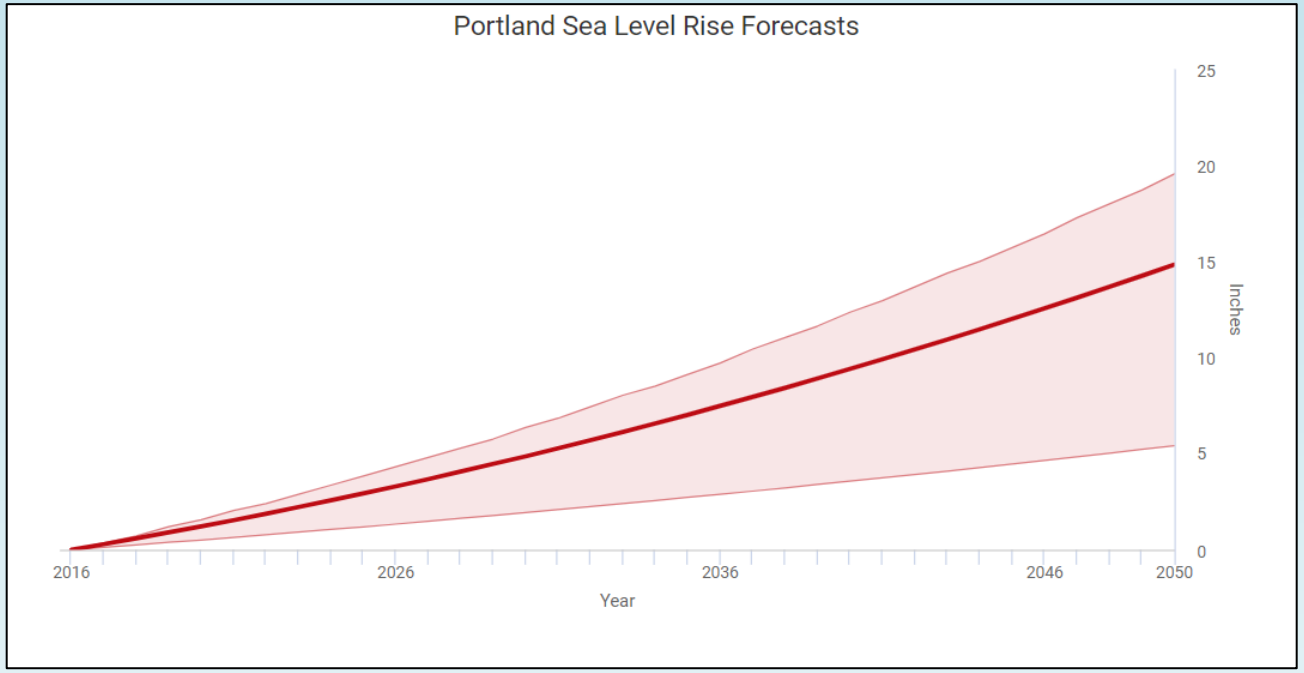
Sea Level Rise – Portland, Maine



1912 – 2022 trend is +7.5 inches per century

Recent and Future Sea Level Rise in Maine

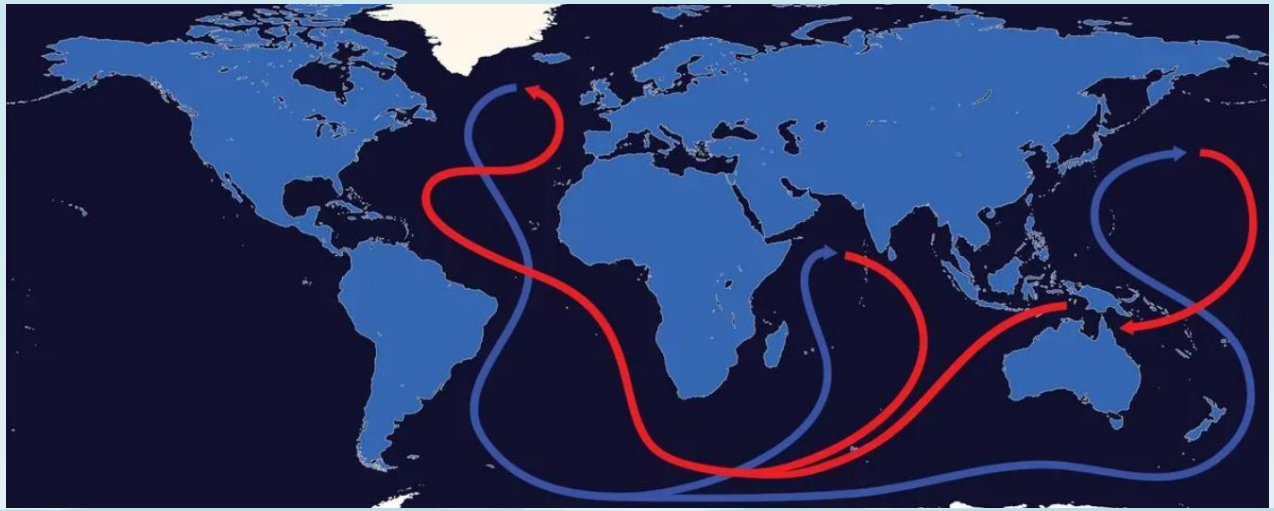
- Rate of sea level rise accelerating since 1990s – one inch every 8 yrs
- Recent acceleration caused by increased melting rate of Greenland ice sheet, slowing of the Gulf Stream
- State of Maine official projections:
- 1.5 ft by 2050
- 4 ft by 2100
- Rising faster than global avg



https://sealevelrise.org/states/maine

Sea Level Rise in Maine Greater than Global Rate

- Warming ocean and melting of ice in Greenland is slowing the Gulf Stream
- Part of ocean circulation pattern called the Atlantic Meridional Overturning Circulation (AMOC)
- Weakening of the Gulf Stream allows water to “pile up” along the Atlantic coast which amplifies sea level rise



Sea Level Rise and Coastal Flooding

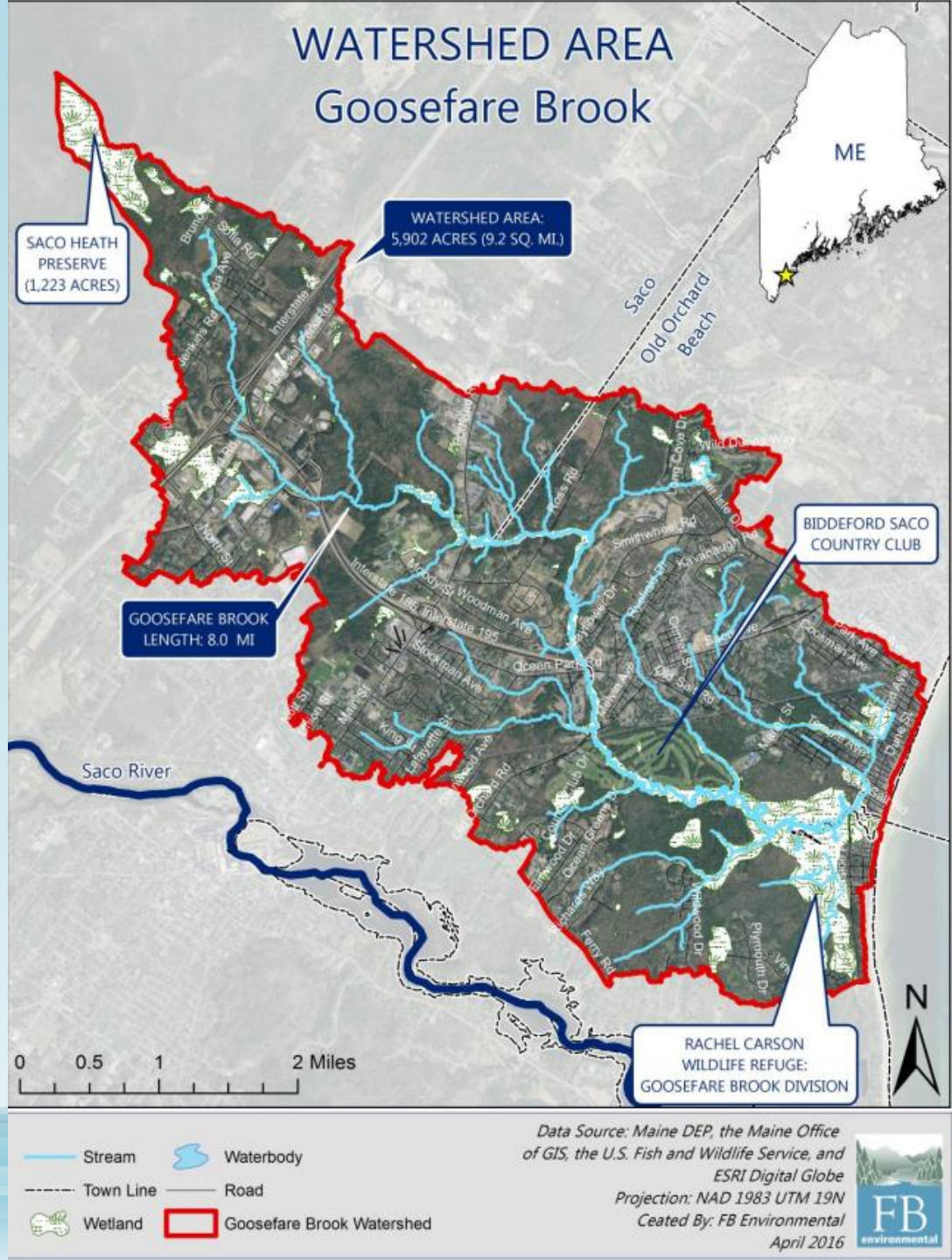
- Rising sea level increases the risk of coastal flooding
- Types of floods:

1. Storm surge – wind direction and speed, timing
2. Freshwater river flood – rain amount, intensity
3. Compound flood – combination of storm surge plus river flood, these are often the worst floods
4. Sunny day flood – high tide, full moon (king tide)

- Timing – wind speed and direction, rainfall, high tide, moon phase

Ocean Park

- Partially built on filled salt marsh
- Most of the village is very close to sea level
- Susceptible to many types of coastal flooding
- Goosefare Brook watershed
- Tide gate on New Salt Rd. – operational practices can influence floods



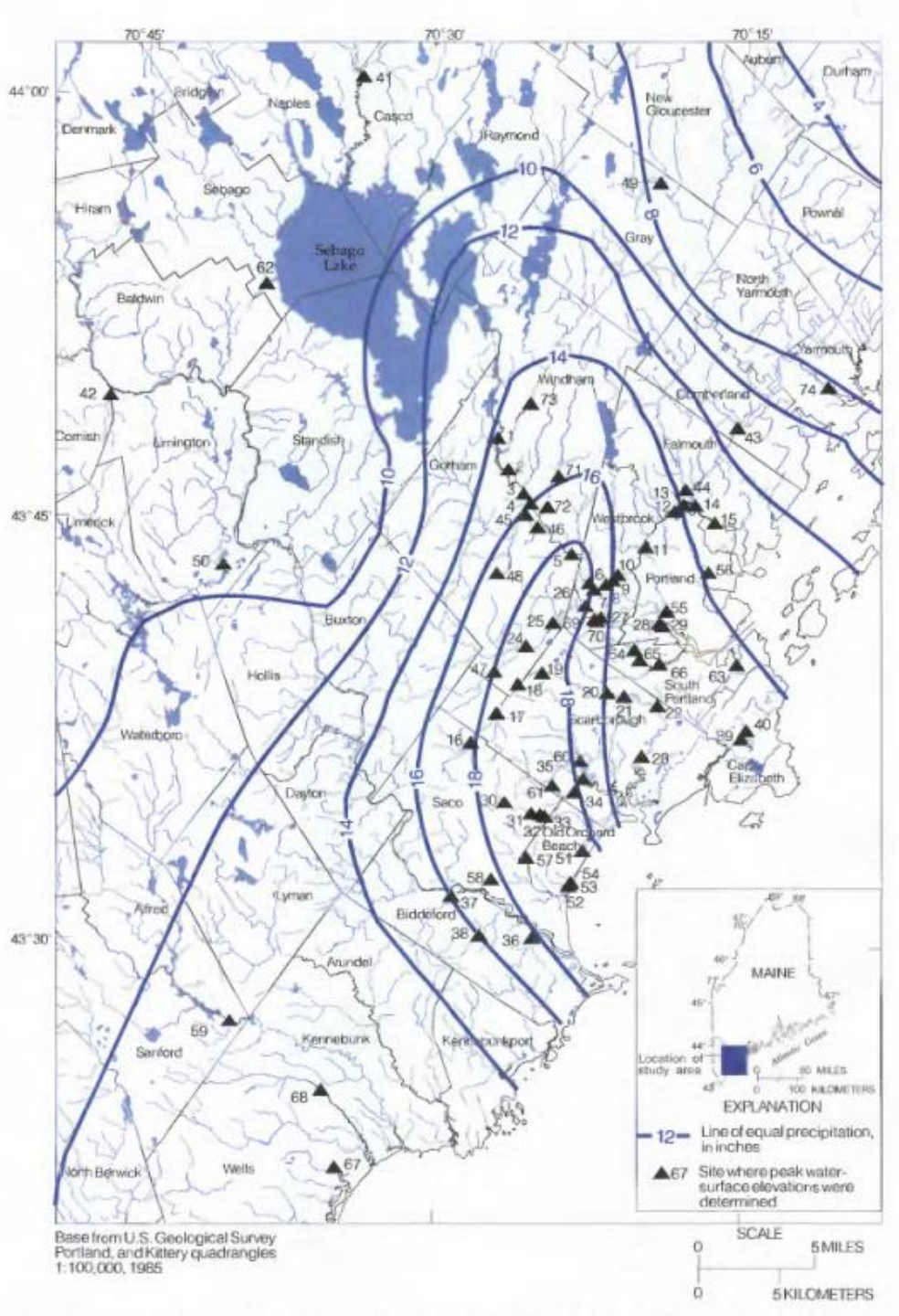
Dec. 23, 2022 Flood

- 4th highest water level in Portland since 1912
- Southeaster – Ocean Park vulnerable, peak wind gust 64 mph

Photo by Jeff Chute

Oct. 1996 Flood

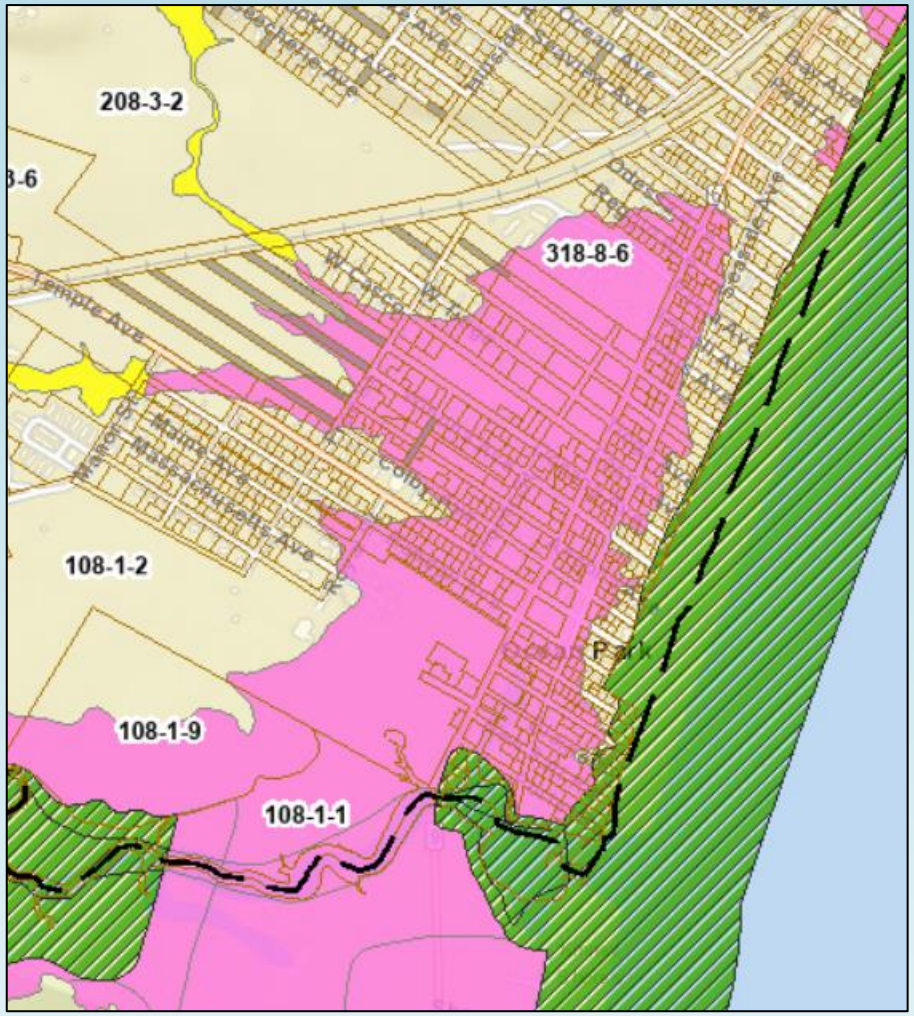
Figure 6. Flooding at Winona Avenue in the Ocean Park area of Old Orchard Beach, Maine (site 54) on October 22, 1996 *(Photograph by David A. Rodgers / The Portland Newspapers).*



Hodgkins, G. and Stewart, G.J., 1997. *Flood of October 1996 in southern Maine* (Vol. 97, No. 4189). US Department of the Interior, US Geological Survey.

Proposed FEMA Flood Map

- Quite a bit of Ocean Park is within the high risk mapped flood zone
- If your property is located in the 100 yr floodplain, then your flooding risk over a 10 yr period is 10%
- Flood frequency analysis does not consider a changing climate – analysis of historical data



What can I do About it?

- Purchase flood insurance – very expensive
- Manage your property – elevate the land, elevate the structure

Some Things to Keep in Mind

- It makes a difference how much and how rapidly the global climate continues to warm
- The effort to rebuild the primary dunes in Ocean Park has helped to diminish storm surge
- Importance of coastal marshes – store flood waters, Ocean Park Marsh, Jordan Park Marsh
- Management of the tide gate can affect flooding
- Management of stormwater runoff in the Goosefare Brook watershed will affect flooding – stormwater detention, impervious surfaces

How Warming will Likely affect Future Global Sea Level

Global Warming (deg F)	Sea Level Rise (ft)	CO2 concentration (ppm)
2.7	1.4	462
3.6	1.7	462-604
5.4	2.0	604-802
7.2	2.3	802
9.0	2.7	1017

Average change for the years 2081- 2100 relative to average climate of 1850 – 1900, sea level changes are relative to the year 2005

Current warming is 2.0 deg F, and CO2 is 417 ppm

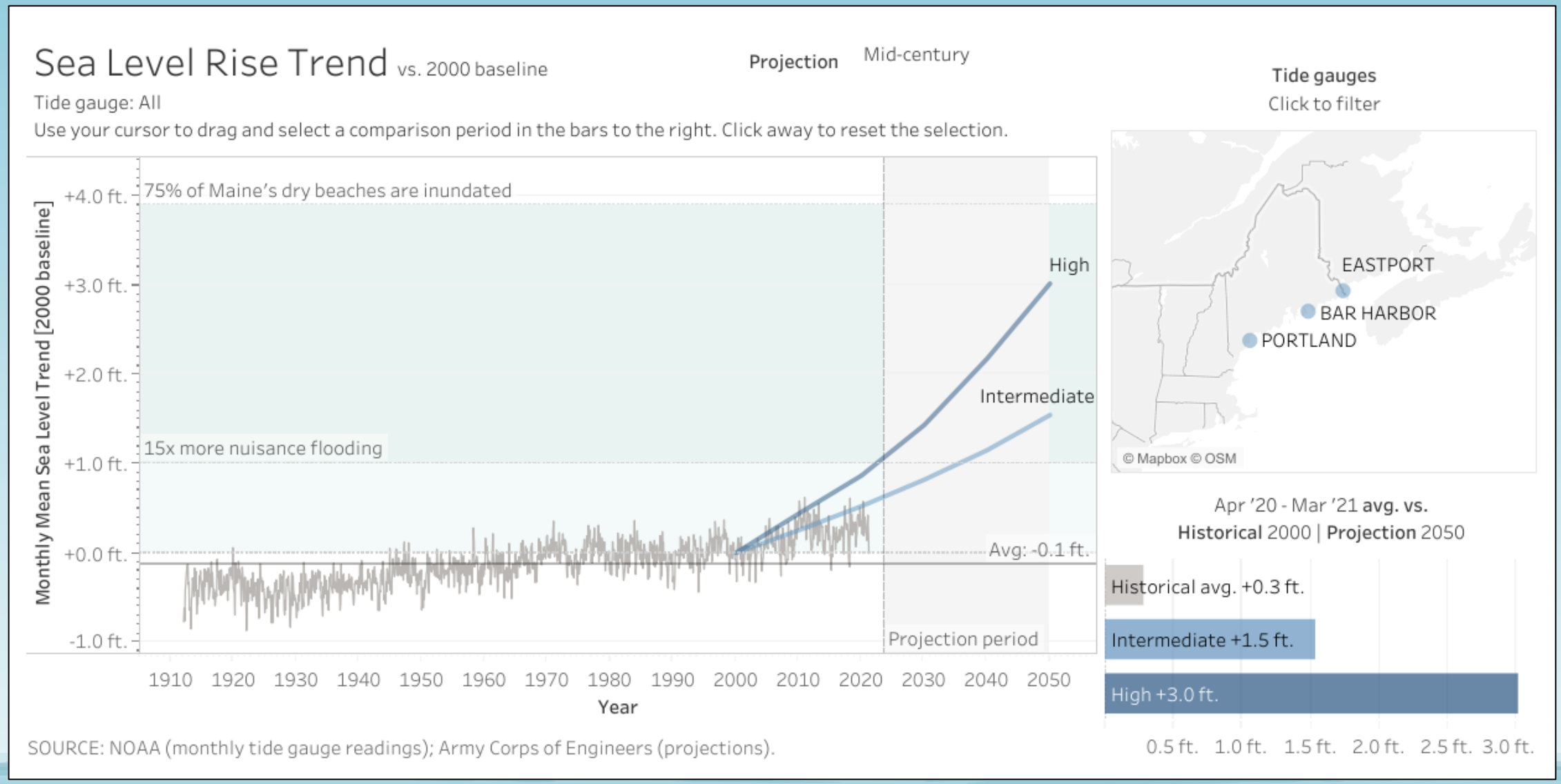
Sweet, W.V., et al., 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf

Uncertainty

- Earth is a complex system – computer model simulations, approximations of the real system
- Antarctic ice future has high uncertainty
- Natural variability – some aspects are not fully predictable
- Example – Sweet et al., 2022 report, sea level rise for northeastern US coastline for the year 2100: 4.3 ± 2.3 ft.

Resources – Maine Climate Plan

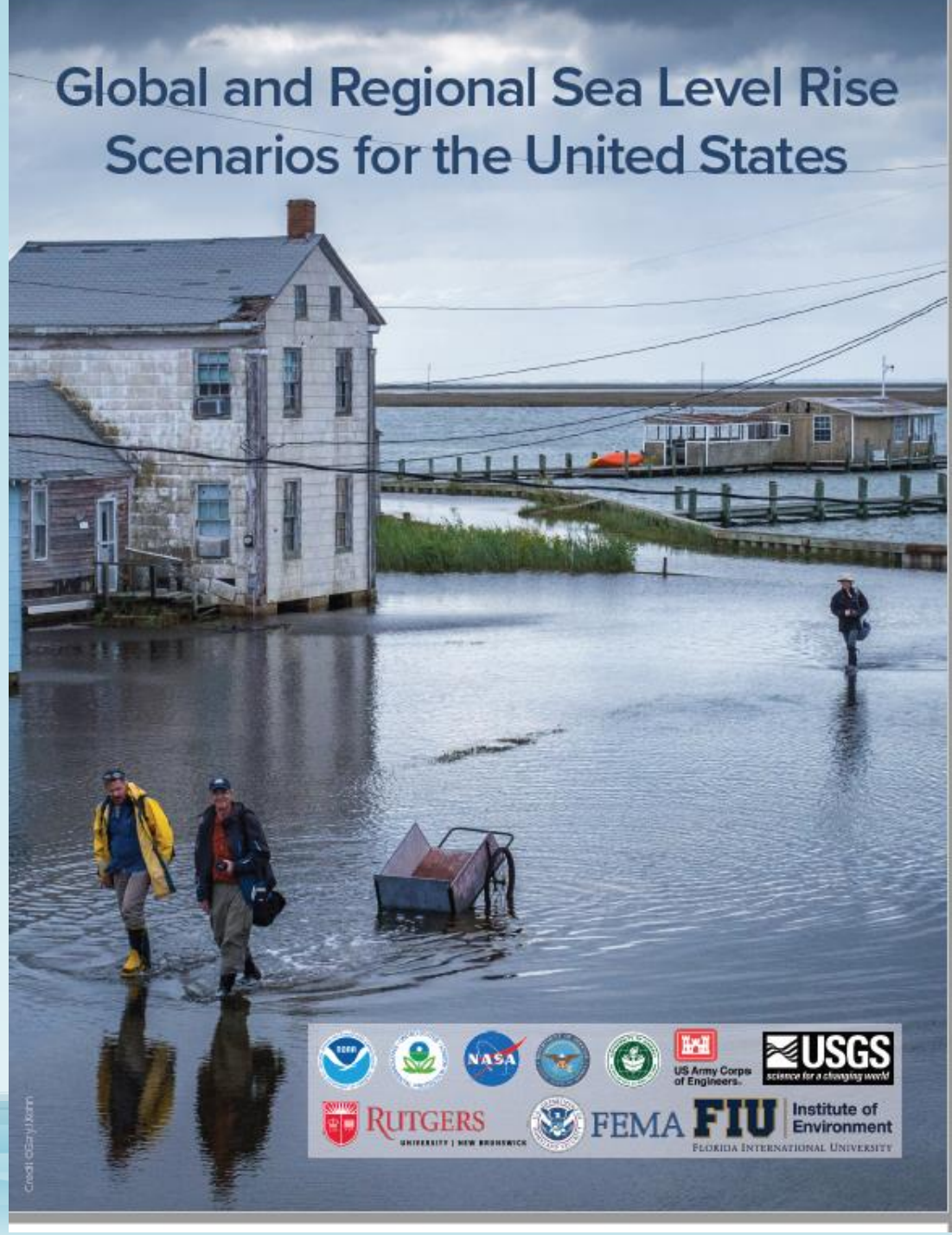
https://www.maine.gov/climateplan/



https://www.maine.gov/climateplan/climate-impacts/climate-data

Resource – Sweet et al. 2022 Report

Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf



Summary

- Sea level varies naturally over geologic time by hundreds of feet
- Sea level change is affected by many factors – solar radiation, ocean basins, position of land relative to the sea, others
- Technically we are still in the most recent ice age – but anthropogenic-driven climate change expected to delay the next glacial advance by tens of thousands of years
- Human activities have increased the concentrations of greenhouse gases in the atmosphere and as a result the climate is warming, and sea level is rising
- Current sea level rise is mainly driven by thermal expansion and the melting of ice in Greenland and Antarctica
- Sea level is highly likely to rise in the foreseeable future by about 4 ft ± 2 ft by the year 2100. Future sea level rise will be dependent on our future emissions of greenhouse gases.

What to do

- Continue to track this issue – new scientific information emerges
- Adaptation and resilience – use the best scientific information available to plan your future
- Get involved when you see an opportunity – education, outreach, management decisions, advisory committees
- Consider actions that will help to minimize future risk not just for ourselves but at a global scale
- Fortunate in the US because we are wealthy nation and can afford to invest in engineered solutions that those in poor nations cannot afford