Coastal Flood Risk Management Problems

BEE 6940 Lecture 4

February 13, 2023

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Coastal Flood Risk Overview

Coastal Flood Risk

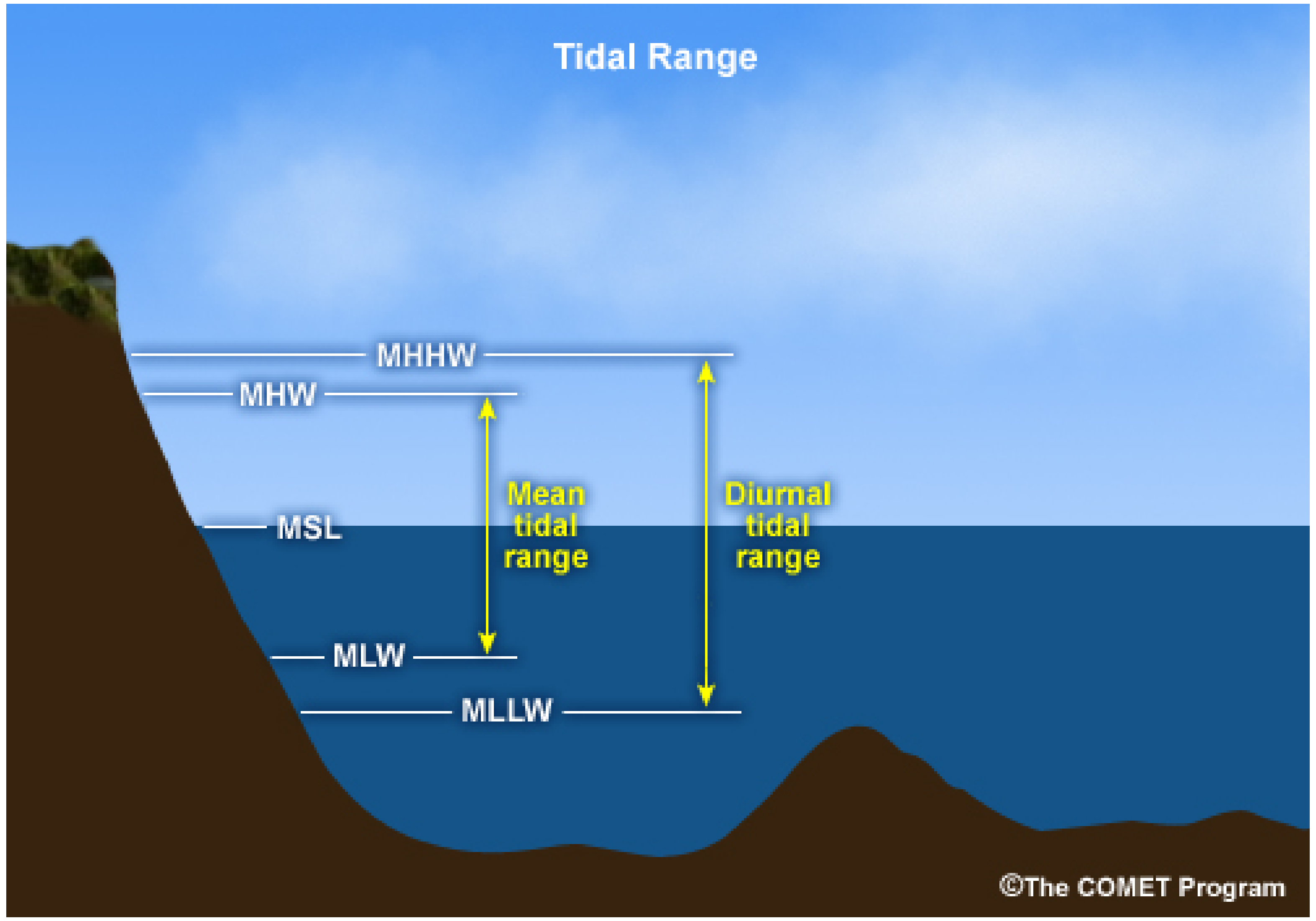
Coastal flooding: this is our motivating problem in this course.

Let's think about this through our hazard-exposure-vulnerability-response risk model.

How Are Local High Water Levels Measured?

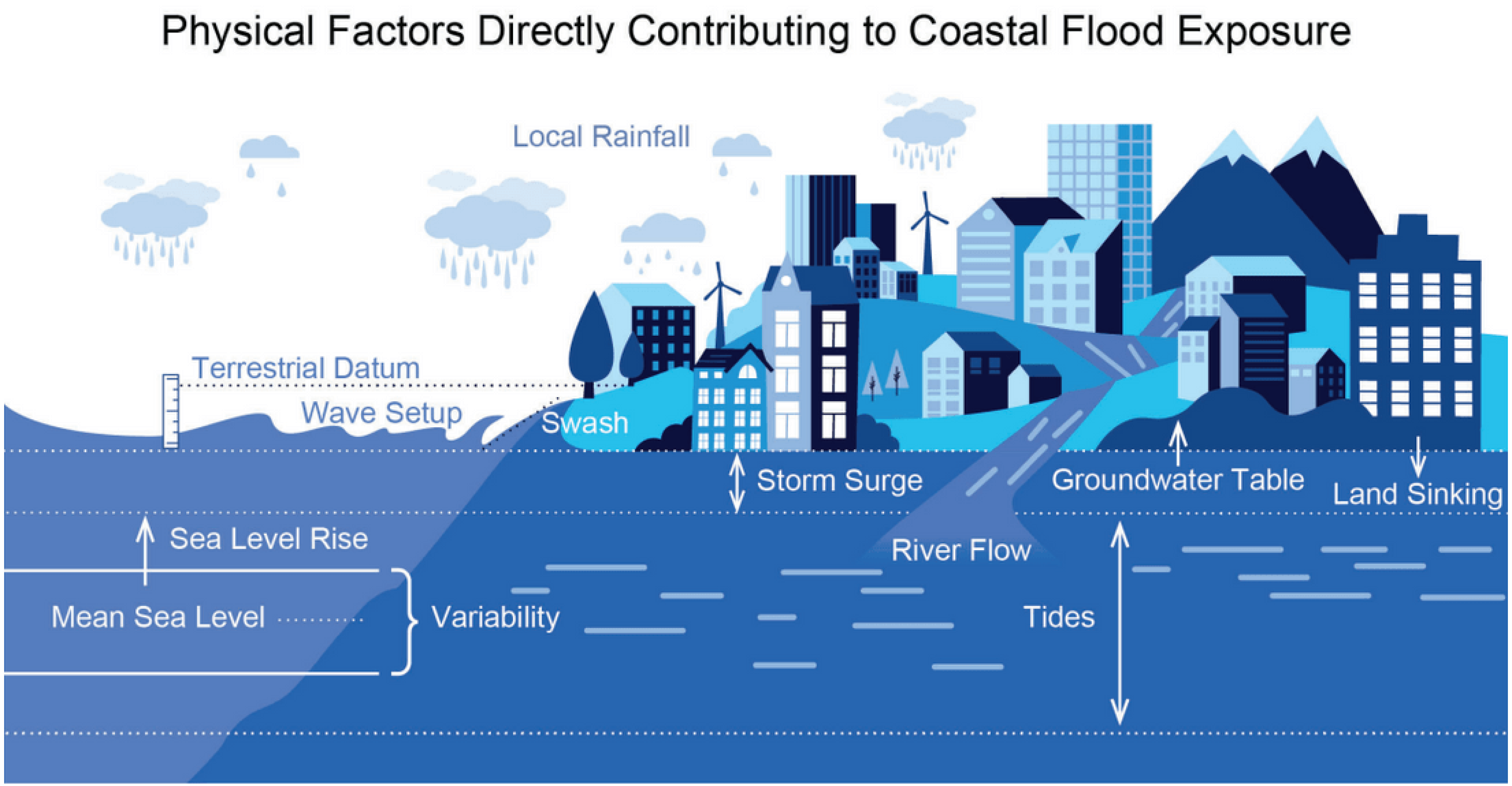
Tide gauge data comes in many "flavors", based on local tidal and diurnal cycles.

Mean Highest High Water (MHHW) is the typical "extreme" sea level datum.



Source: *Inside the Eye Blog, National Hurricane Center, 01-29-2016*

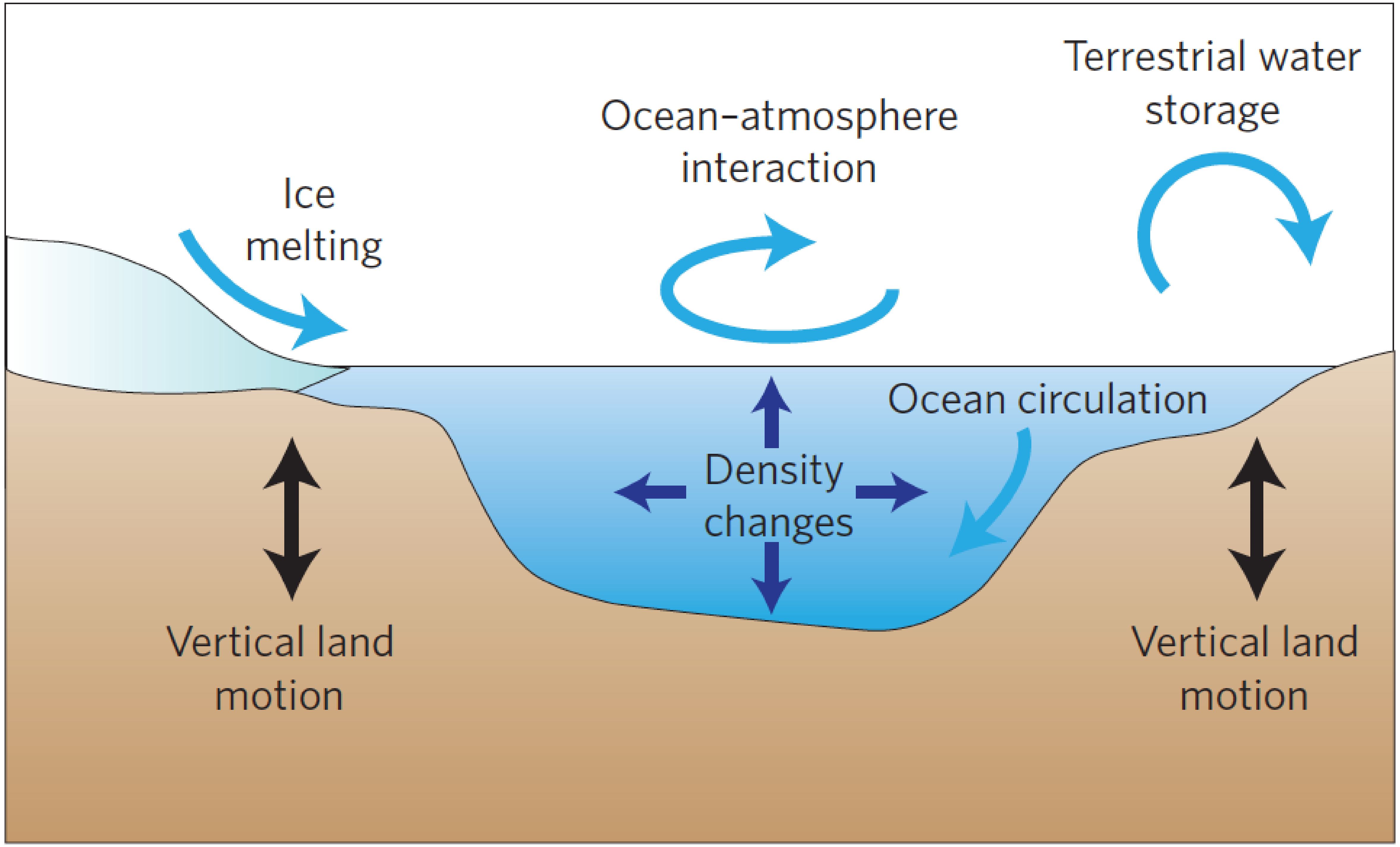
Contributors to Extreme Sea Levels



Source: NOAA 2022 Sea Level Rise Technical Report

Sea Level Rise

Contributors to Global Mean SLR



Source: Milne et al (2009)

Local Sea Levels Have Been Increasing

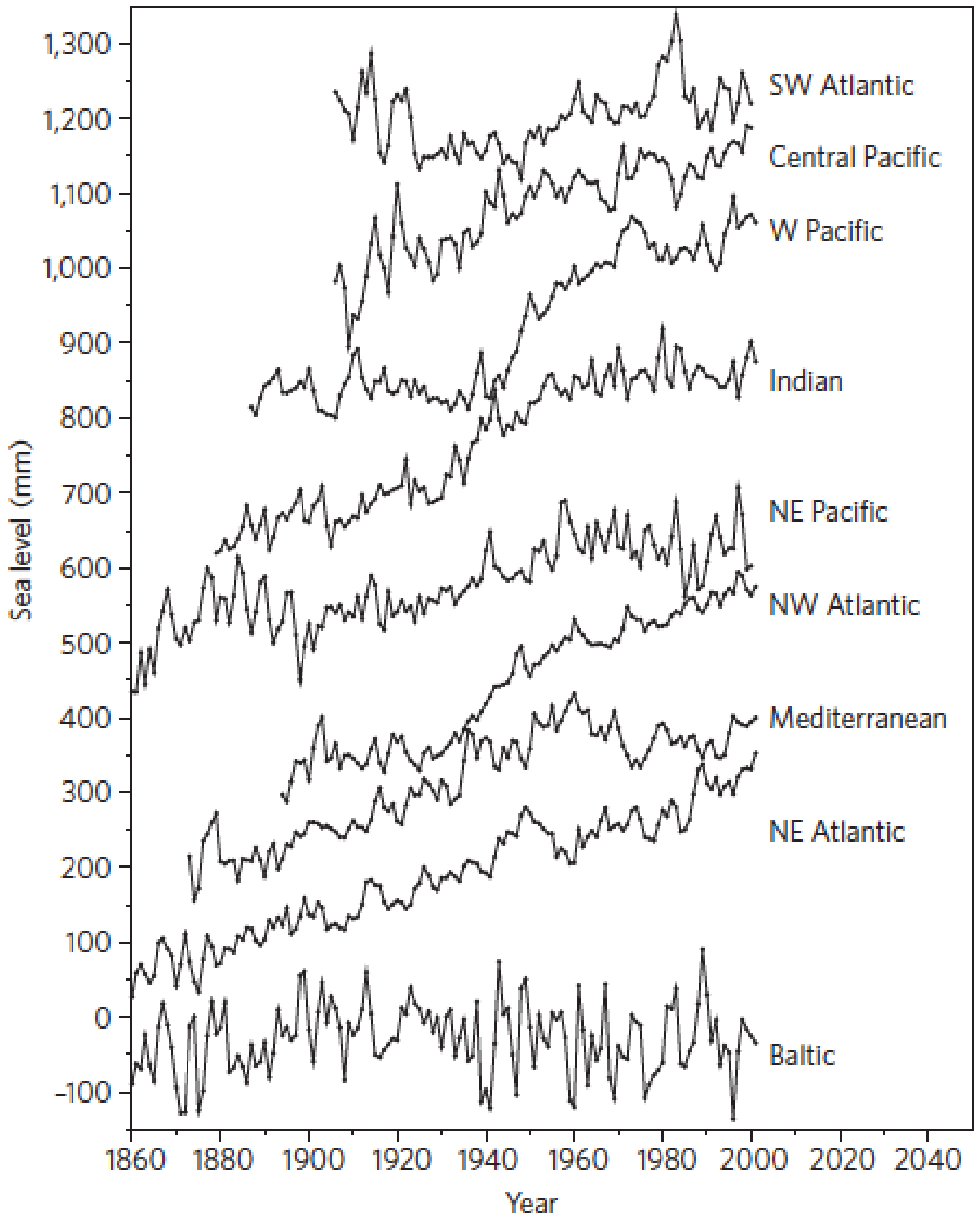


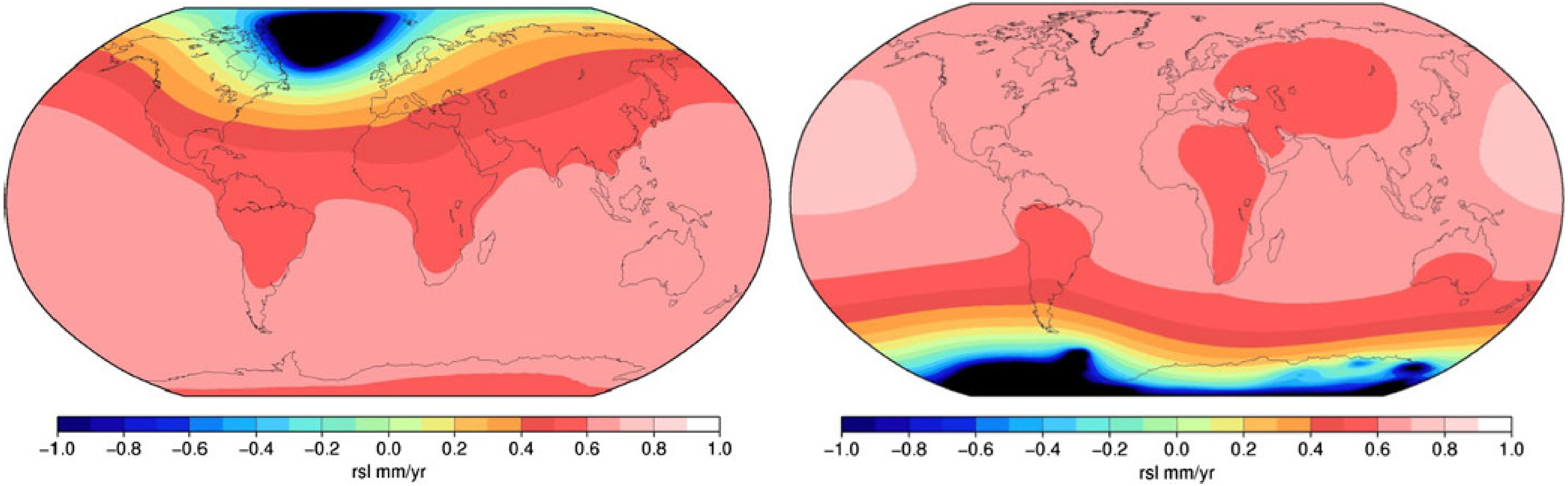
Figure is from a 2009 paper, but these trends have only accelerated since then.

Why is the Baltic stagnant?

Source: Milne et al (2009)

Spatial SLR Impact of Ice Sheet Melt

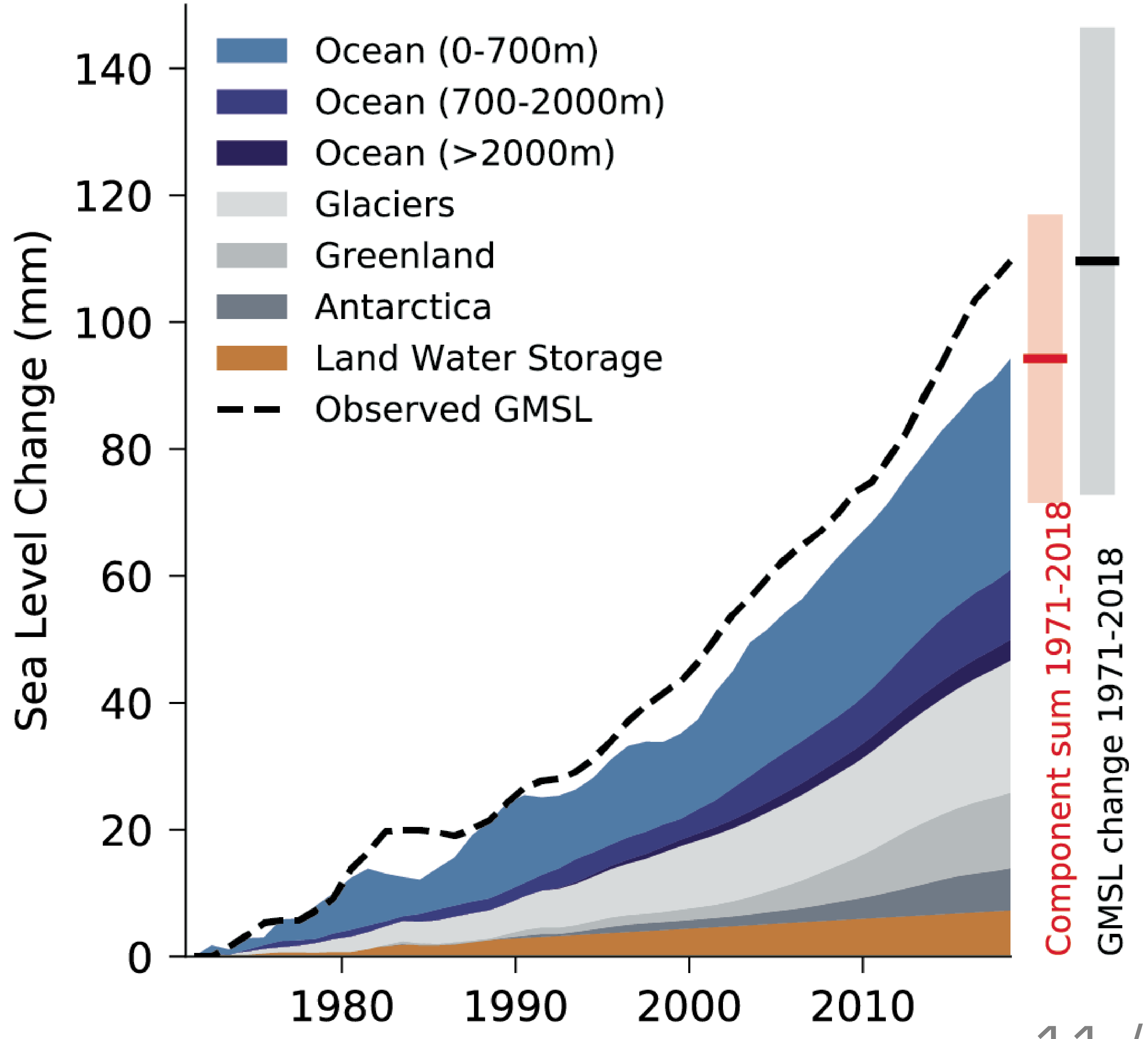
Ice sheet impact on SLR depends on gravitational effect of the ice.



Incomplete Accounting of Past SLR

We can't actually account for the entirety of observed SLR.

Source: [IPCC AR6 Working Group 1, Chapter 9 (2021)]



Other Contributors to Relative Sea Level Rise

- Glacial Isostatic Adjustment (GIA)
- Subsidence

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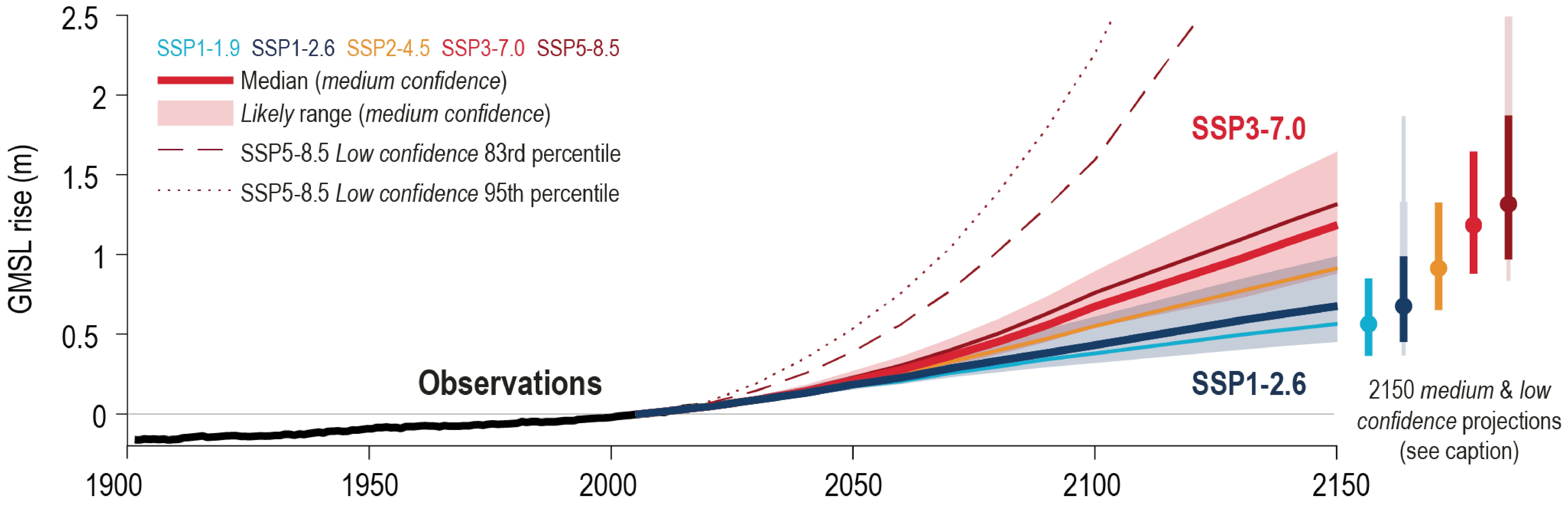
These effects can be very large depending on the location.

For example, Norfolk (VA)'s relative SLR is primarily driven by subsidence due to aquifier depletion.

IPCC Projections of Future SLR

Projections of future SLR to and past 2100 depend strongly on the associated level of future warming.

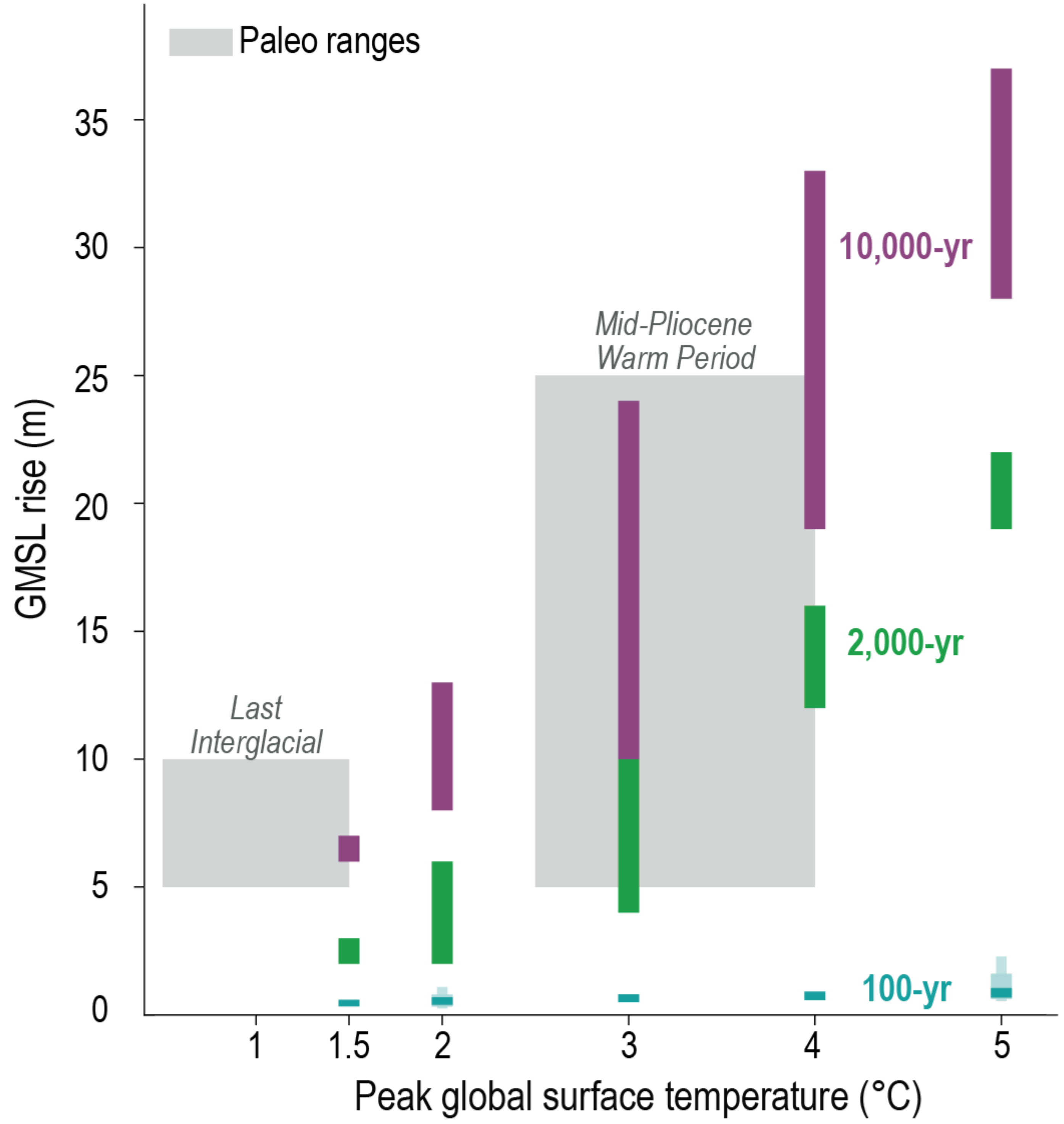


Source: *IPCC AR6 Working Group 1, Technical Summary (2021)*

Sea Level Rise After Peak Warming

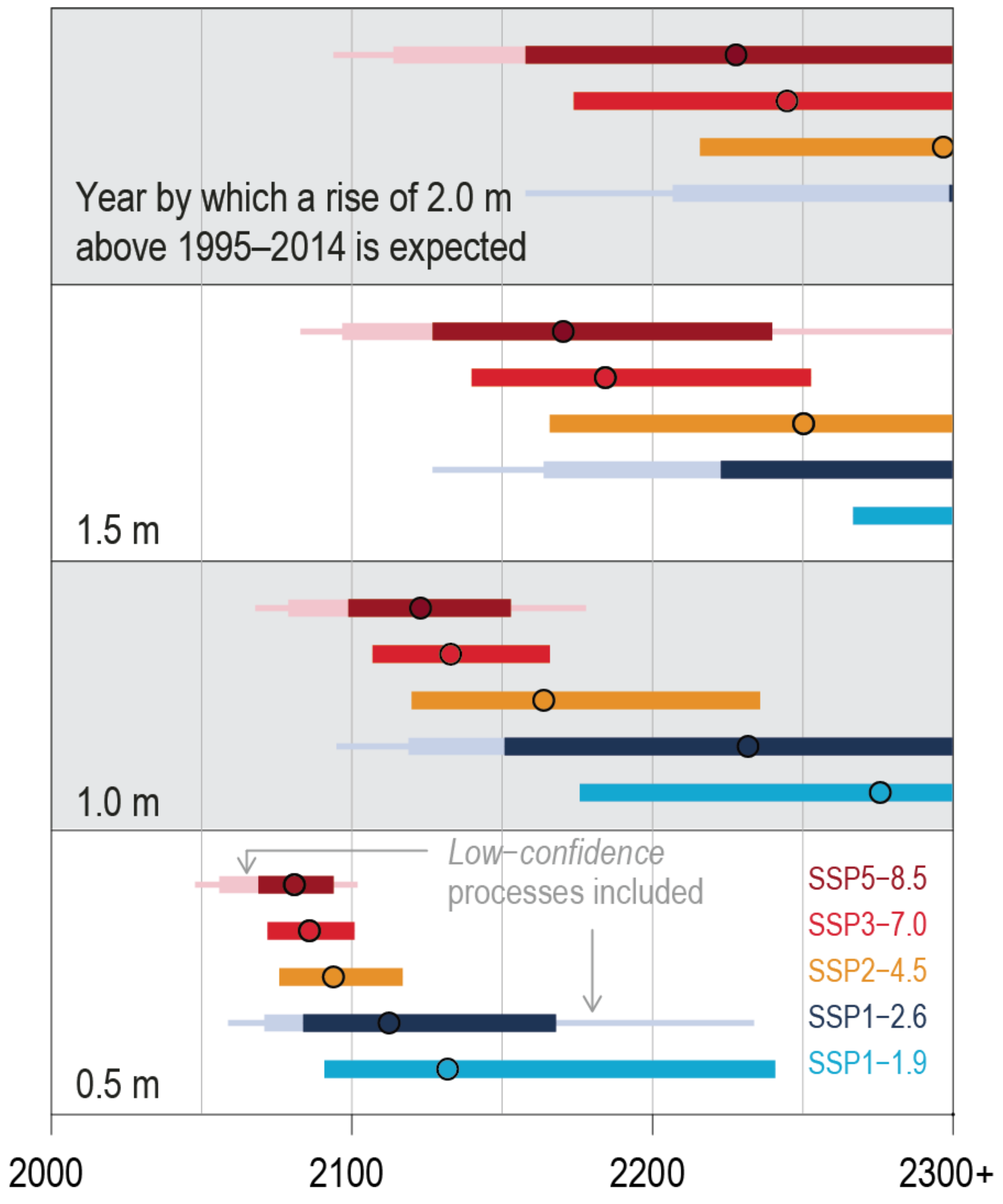
Due to ocean heat uptake and circulation and cumulative warming of ice sheets, sea levels will continue to rise after warming ceases.

Source: IPCC AR6 Working Group 1, Technical Summary (2021)



Sensitivity of Future SL to Emissions Pathway

When we are likely to hit a certain level of GMSL is strongly dependent on the emissions trajectory, but there is considerable uncertainty.

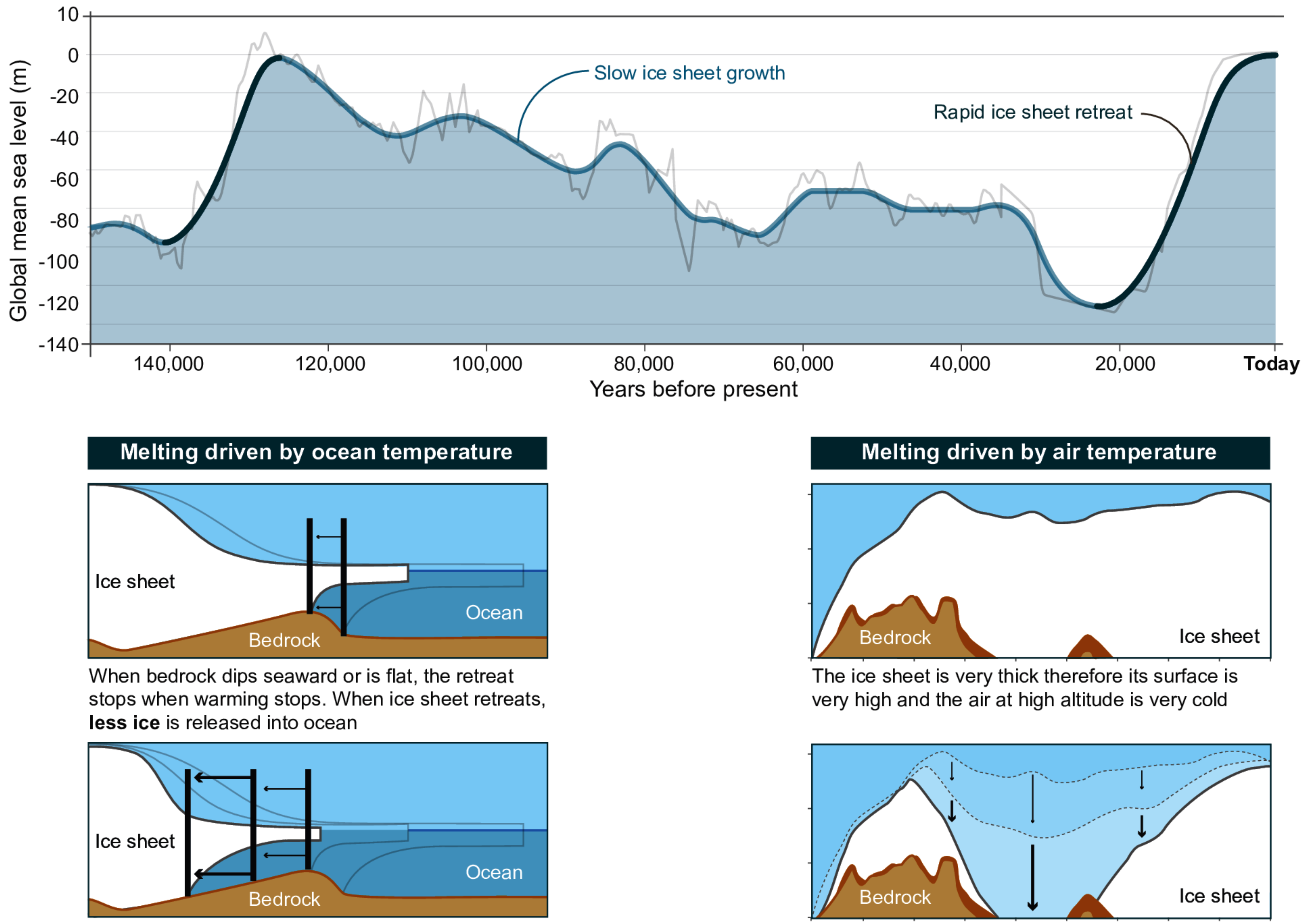


Source: IPCC AR6 Working Group 1, Technical Summary (2021)

Additional Uncertain Processes

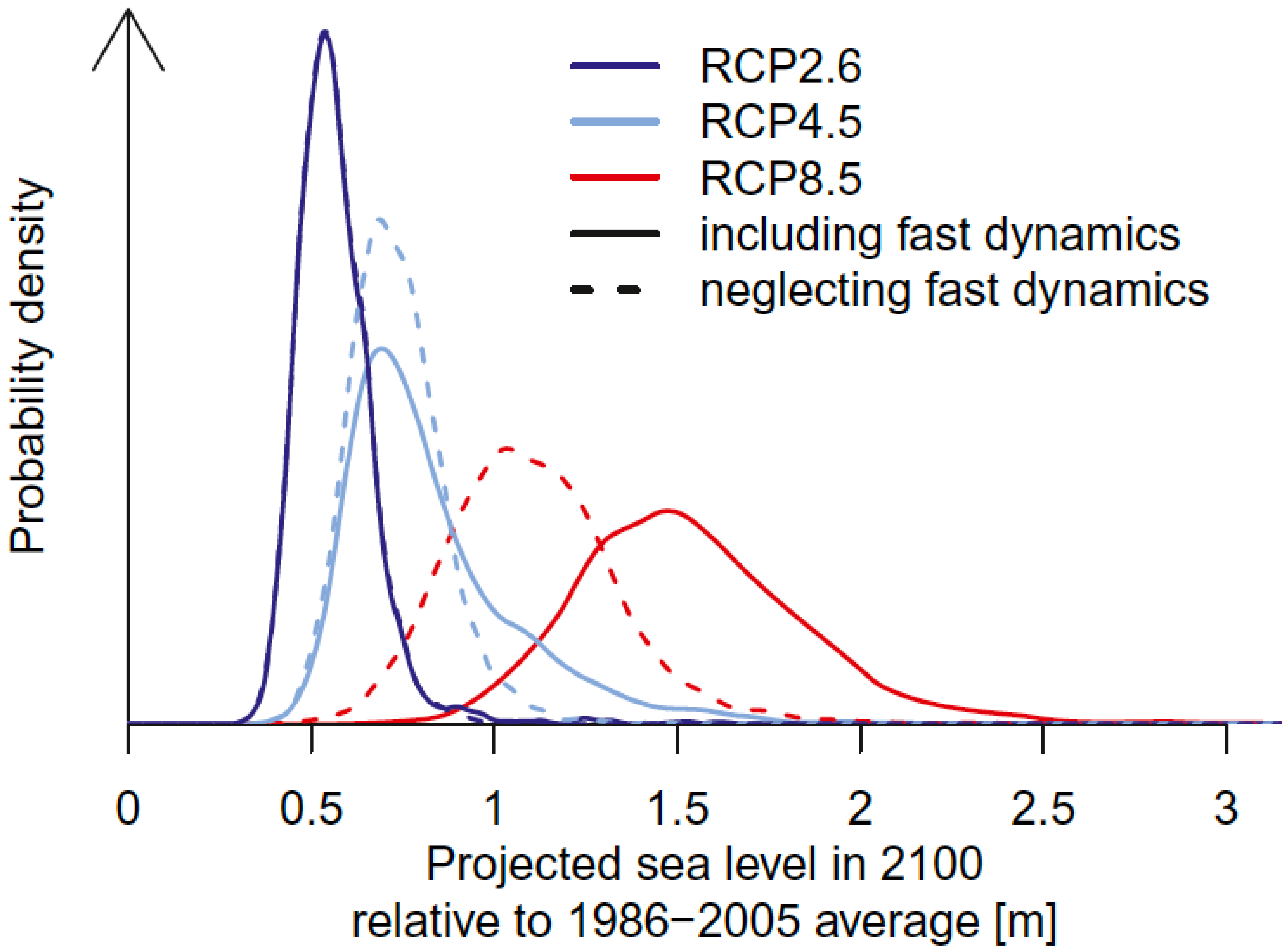
These projections may underestimate some additional processes or uncertainties — remember, we can't fully explain recent SLR by adding up our estimates of contributions from individual processes!

Unstable Ice Sheet Melting Dynamics



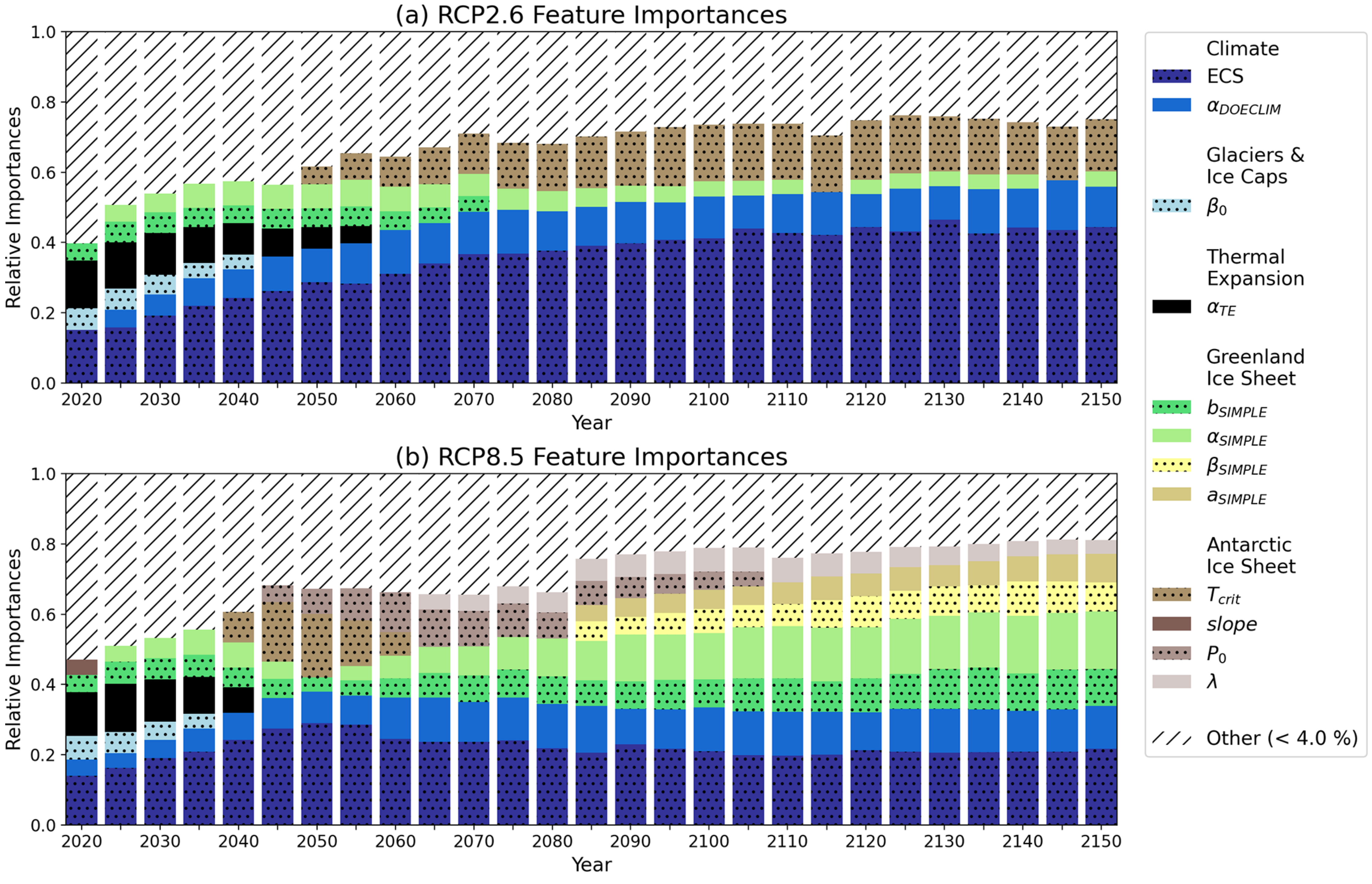
Source: *IPCC AR6 Working Group 1, Technical Summary (2021)*

Ice Sheet Dynamics Can Accelerate SLR



Source: Wong, Bakker & Keller (2017)

Key Drivers of Future SLR Variability



Source: Hough & Wong (2022)

Storm Surge

Extreme Sea Levels

Extreme sea levels are a combination of tidal extremes and (often) storm surge, or "storm tides".

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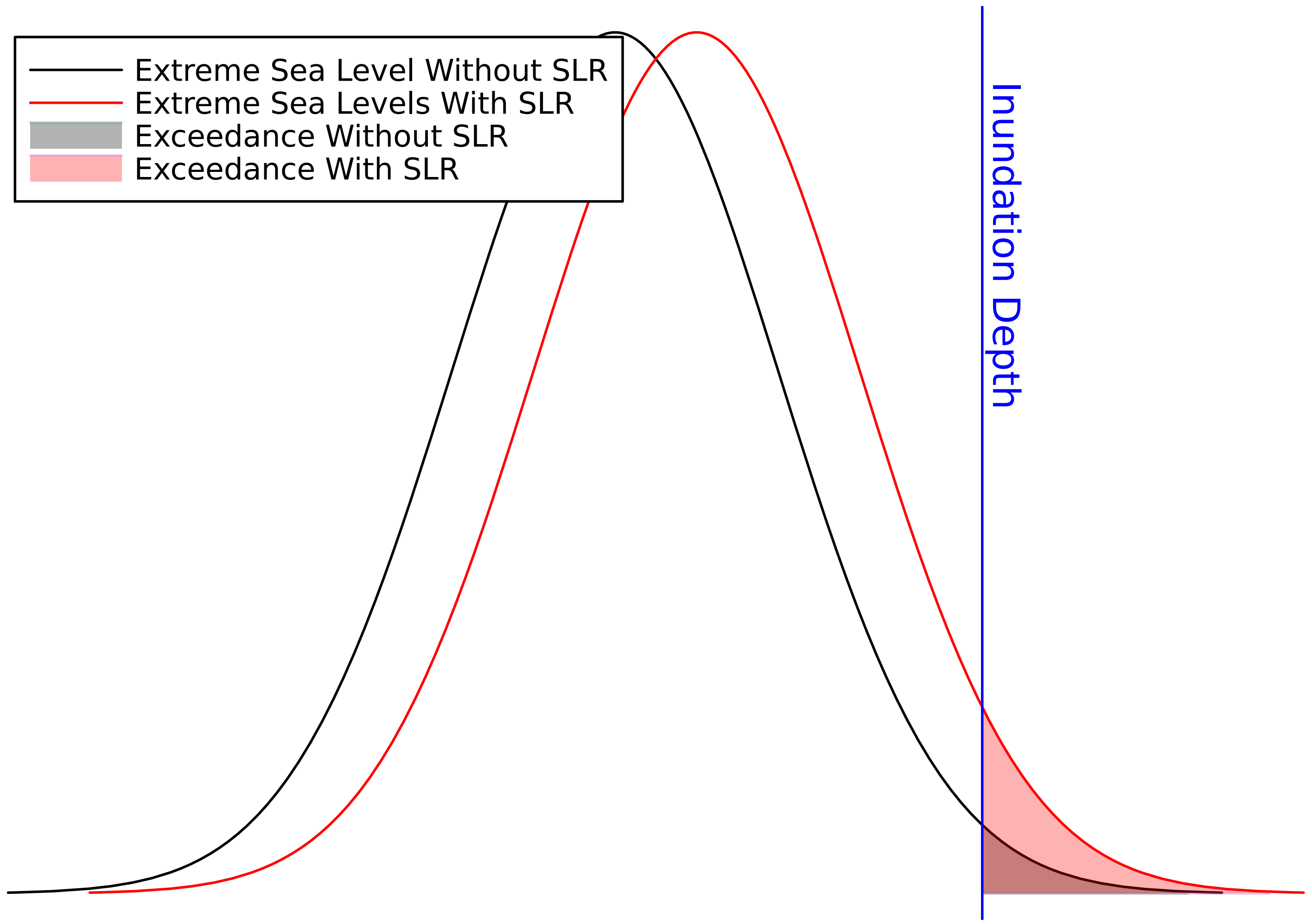
Storm surge is the result of winds pushing water against the shore. Physical modeling of surges is complex — topography, storm intensity, size of cyclone, angle of approach, continental shelf slope, all matter!

However, we can (and will!) model storm tides using extreme value statistics.

Impact of SLR on Inundation Probabilities

The shift in storm tide level needed for inundation with SLR changes exceedance probabilities nonlinearly.



For the cartoon on the left:

- Probability w/o SLR: 1%
- Probability w/SLR: 4%

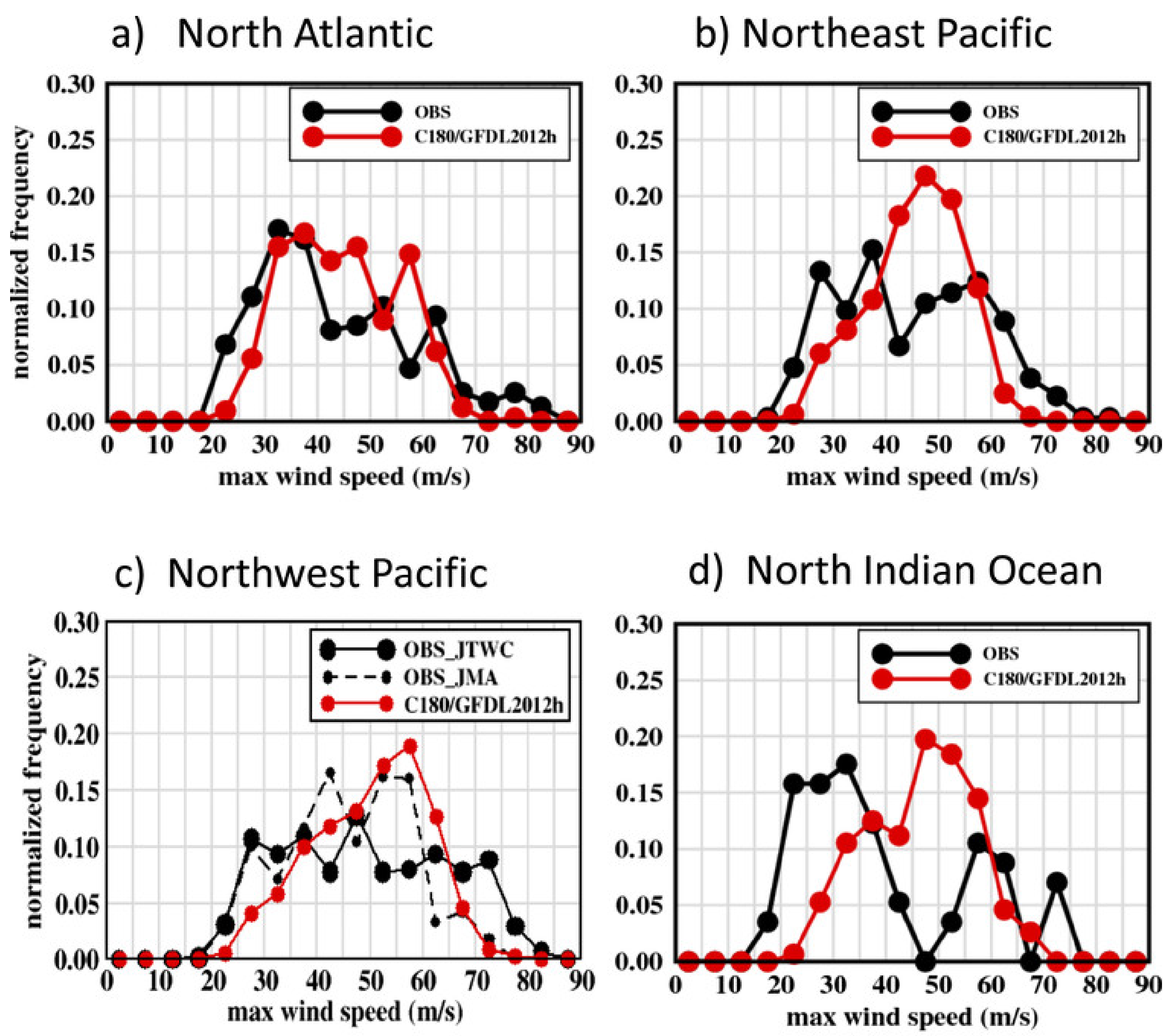
Key Question: Are Storm Surges Stationary?

Common practice is to assume *stationarity* in future storm surge levels.

However:

- SLR means more water to surge against the coast;
- Considerable uncertainty about impact of climate change on tropical cyclone intensity.

Some Evidence Tropical Cyclone Intensity Is Increasing



An increase is consistent with the energetic model from Emanuel (1986), which models TC energetics as a Carnot engine.

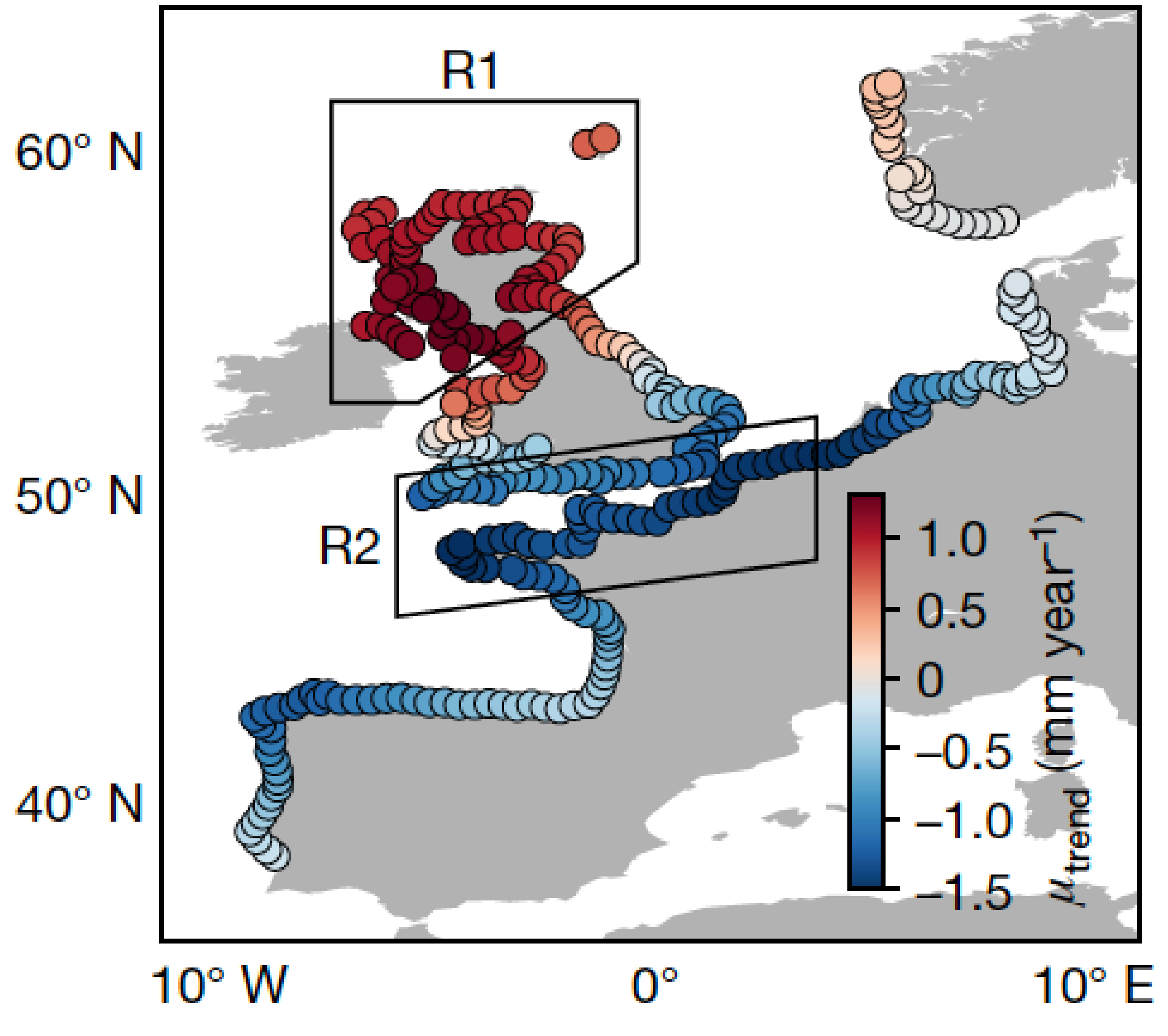
Source: Knutson et al (2015)

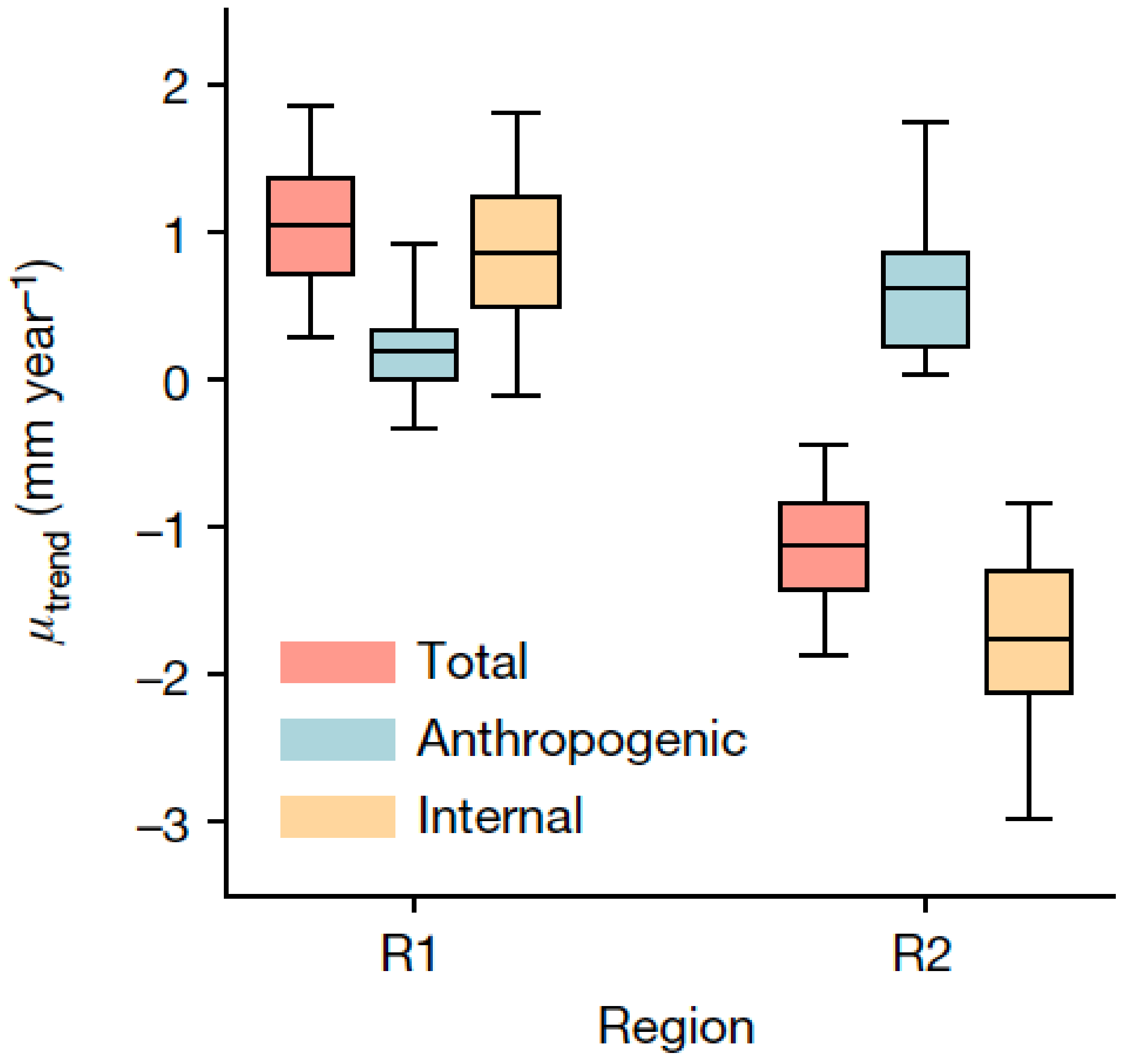
Potential Covariates for Storm Surge Intensity Changes

Actually very difficult (as we will discuss later) to decide between:

- Temperature (global mean temperature or sea-surface)
- Climate indices (NAO, ENSO)
- Sea level anomalies
- Stationary!

Difficult to Identify Climate Change Influence On Storm Surge

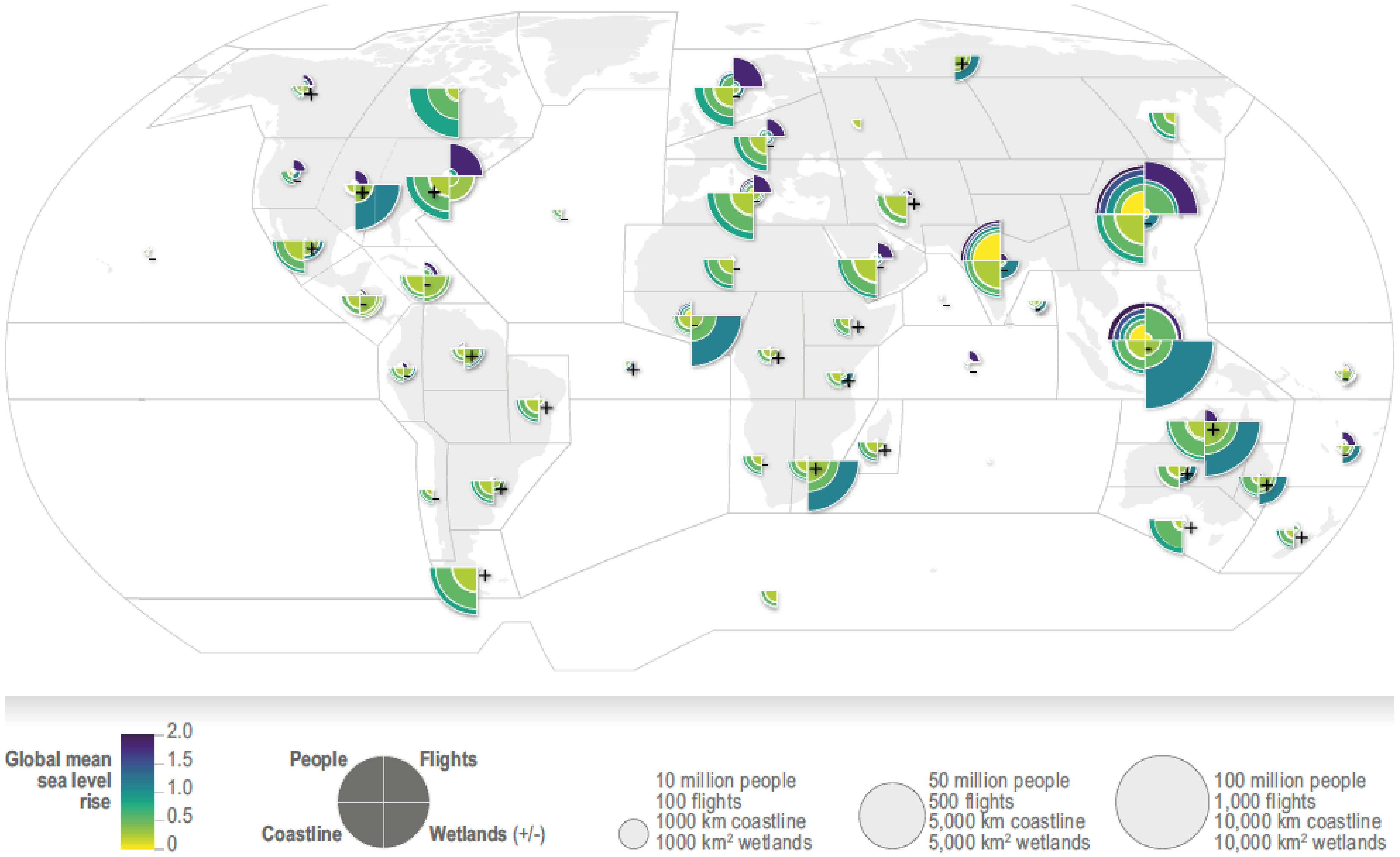




Source: Calafat et al (2022)

Exposure, Vulnerability, & Response

Impacts from Coastal Flooding



Source: *IPCC AR6 WG2 Cross-Chapter Paper 2, Cities and Settlements By The Sea (2022)*

Local Dynamics Impacting Exposure and Vulnerability

Characterizing exposure and vulnerability is highly local and reflective of many socioeconomic, infrastructure, and topographical factors:

- drainage and permeability;
- location of critical infrastructure;
- housing stock & location;
- economic and social inequities.

Local Dynamics Impacting Exposure and Vulnerability

As a result, it's hard to speak in general terms about potential impacts and their trends.

But:

- Migration and urbanization are key drivers;
- Coastal amenities seem to (presently) outweigh perceptions of risk in population patterns and housing markets.

Human-System Responses

Responses are also hard to fully characterize, but some relevant factors:

- Levee effect (back to White (1945));
- Transportation networks and evacuation;
- Increasing discussion of retreat from high-risk coastal cities.

Some Important Considerations

- Human-system dynamics are difficult to model well!
  - Precriptive vs. Descriptive modeling
  - Many theories of behavior
  - How do you account for heterogeneity and distributional outcomes?
- Uncertainties everywhere!
  - Several different building inventory models (*e.g.* HAZUS): these are often incomplete or rely on statistical interpolations.
  - Choice of digital elevation model also can make a big

Flood Risk Management

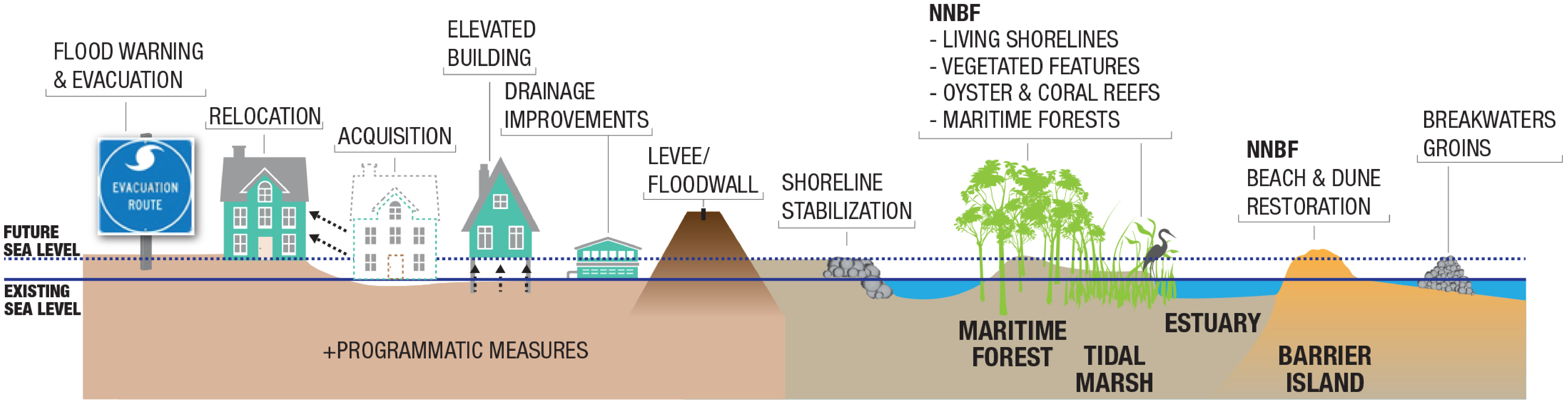
Coastal Flood Risk Management As a Decision Problem

Some common objectives:

- Net costs/benefits;
- Reliability (minimizing flood probability)
- Expected loss of life.

These all raise additional questions about equity and ethics!

Many Different Coastal Flood Risk Management Levers



Source: *Layers of Protection, US Army Corps of Engineers*

Time Preference of Money

Would you rather have $\$100$ today or $\$1000$ ten years from now?

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Many economic reasons to value money/costs/benefits today more than in the future:

- Inflation;
- Technological innovation;
- Compounding value of alternative investments.

Discount Rates

These preferences are captured with the *discount rate*. Let I be the investment level, r the interest rate, then the return $R(t)$ is

$$R(t) = I(1+r)^t \Rightarrow I = R(t) \times d(t),$$

and where the **discount factor** $d(t)$ is:

$$d(t) = \frac{1}{(1+r)^t}.$$

In this case, we interpret r as the **discount rate**.

Impact of Discount Rates

The choice of discount rate plays a major role in any cost-benefit analysis. Consider an initial investment of $\$1000$:

Years	1%	4%	7%
1	990.05	960.79	932.39
10	904.84	670.32	496.59
50	606.53	135.34	30.20
100	367.88	18.32	0.91
200	135.34	0.34	0.00

Relevant Considerations

So, to set up the decision problem, need to decide:

- SLR model/included processes;
- How to model storm surge (*e.g.* stationary or not);
- How to treat changes in exposure/vulnerability;
- If endogenous responses will be considered;
- Key objective(s);
- Levers which will be included;
- Discount rates for future costs and/or impacts.

What Will We Focus On?

Going forward, in this class we will focus more on uncertainty quantification for the flood hazard:

- Calibrating SLR models and capturing uncertainties;
- Model selection and hypothesis testing for storm surge stationarity.

The main reason for this is that these are the most universal considerations given the local character and difficulties of the human-system elements of risk. But many of the techniques we discuss can be brought to bear on these components.

Upcoming Schedule

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Wednesday: Discuss Van Dantzig (1956) and lab on sensitivity analysis for the Van Dantzig coastal flood risk management problem.

Next Monday: The bootstrap and sea-level rise models.