Class 18: Projections III – Short vs. Long Term

- Most projections go to 2100, what about after that?
- What happens when runaway feedbacks run their course?

Learning Objectives

1. Understand why climate projections to 2100 might not capture every expected climate impact from human carbon emissions
2. Identify and describe a predicted slow climate response to human carbon emissions
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4. Explain how a predicted long-term climate response will affect human societies

Climate in the News

The Washington Post

Democracy Dies in Darkness

Climate and Environment

More than 11,000 scientists from around the world declare a ‘climate emergency’

Study outlines six major steps that ‘must’ be taken to address the situation.

A new report by 11,258 scientists in 153 countries from a broad range of disciplines warns that the planet “clearly and unequivocally faces a climate emergency,” and provides six broad policy goals that must be met to address it.

Climate in the News

Science & Health

As Trump Resists Climate Action, Many States Take Matters Into Their Own Hands

By Steve Baragona
November 6, 2019 04:02 PM

Governors from 24 states and Puerto Rico have pledged to cut their states' greenhouse gases in line with what President Barack Obama pledged in the 2015 Paris agreement.

Known as the United States Climate Alliance, the states include more than half the U.S. population. If they were their own country, it would be the world's third-largest economy.

Climate in the News

The New York Times

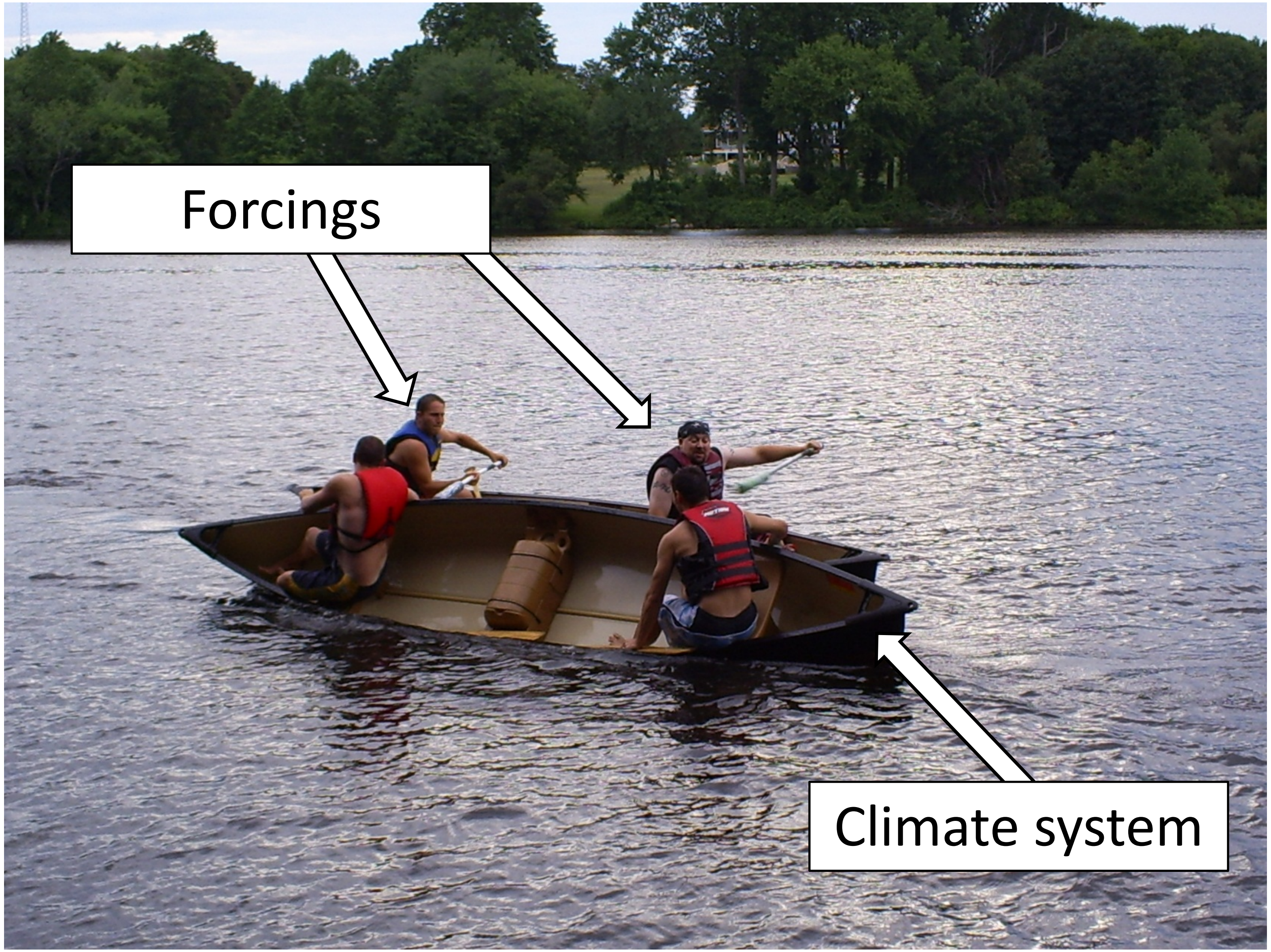
Italy's Students Will Get a Lesson in Climate Change. Many Lessons, in Fact.

Public schools will require children in every grade to study sustainability. That could put Italy at the forefront of environmental education.

Merely studying place names and locations in geography class? "Forget that," Education Minister Lorenzo Fioramonti said Tuesday. Remo Casilli/Reuters

Review: Tipping Points

- Two stable states
  - "Upright"
  - "Flipped"
- A threshold between these states
- Once threshold is crossed, transition to the other state



Review: Tipping Points

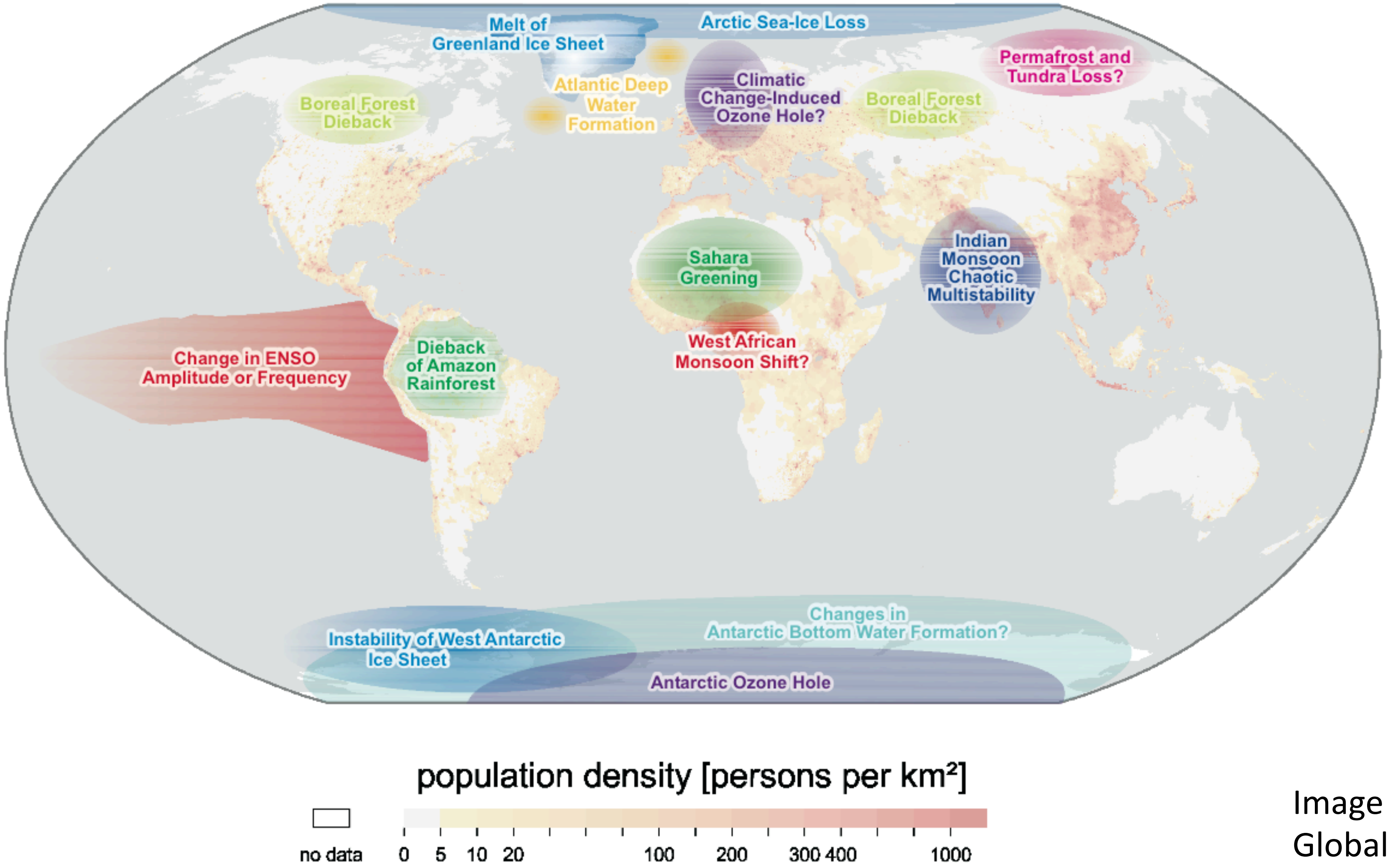
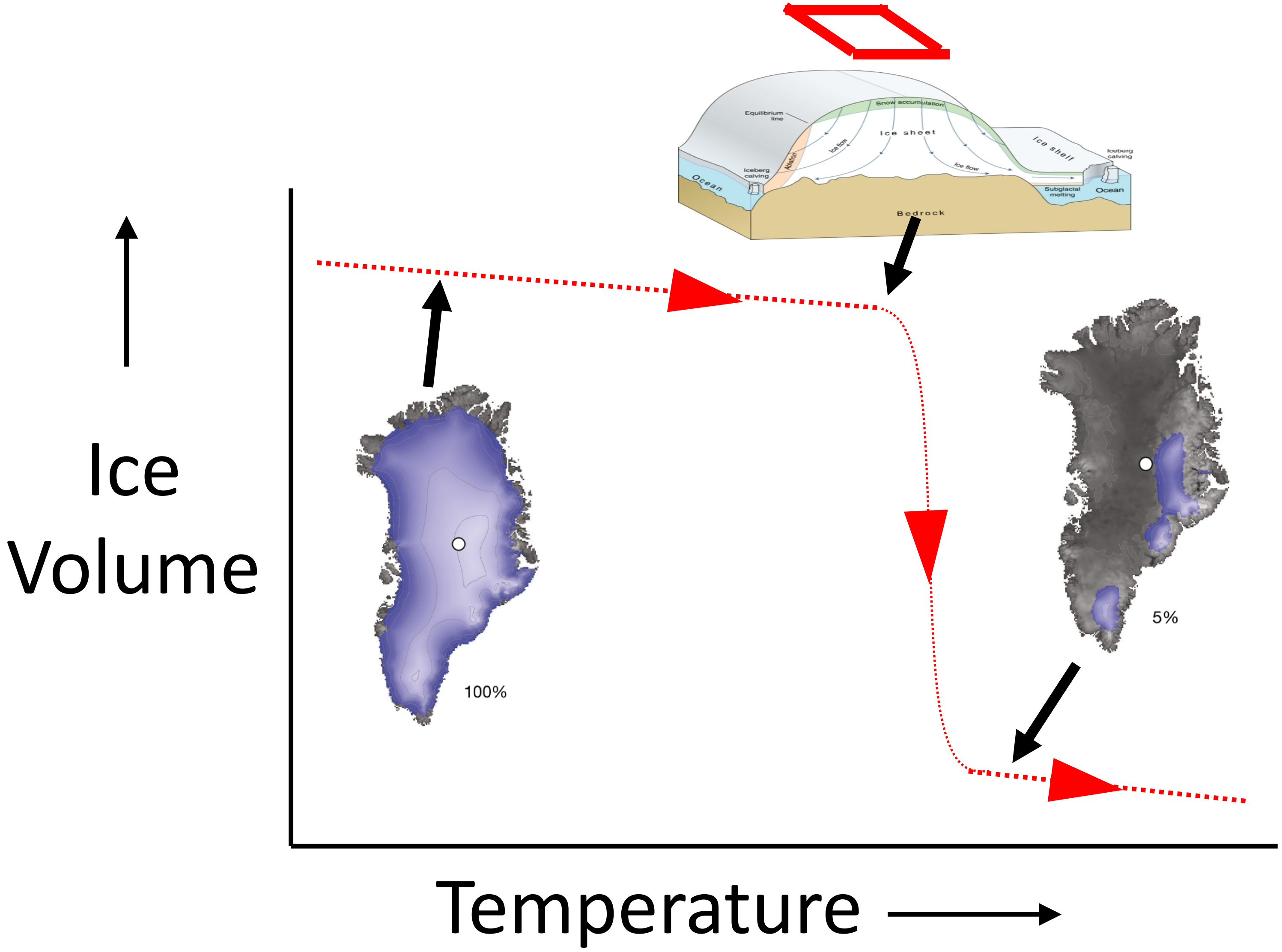


Image from GlobalChange.gov

Review: Tipping Points

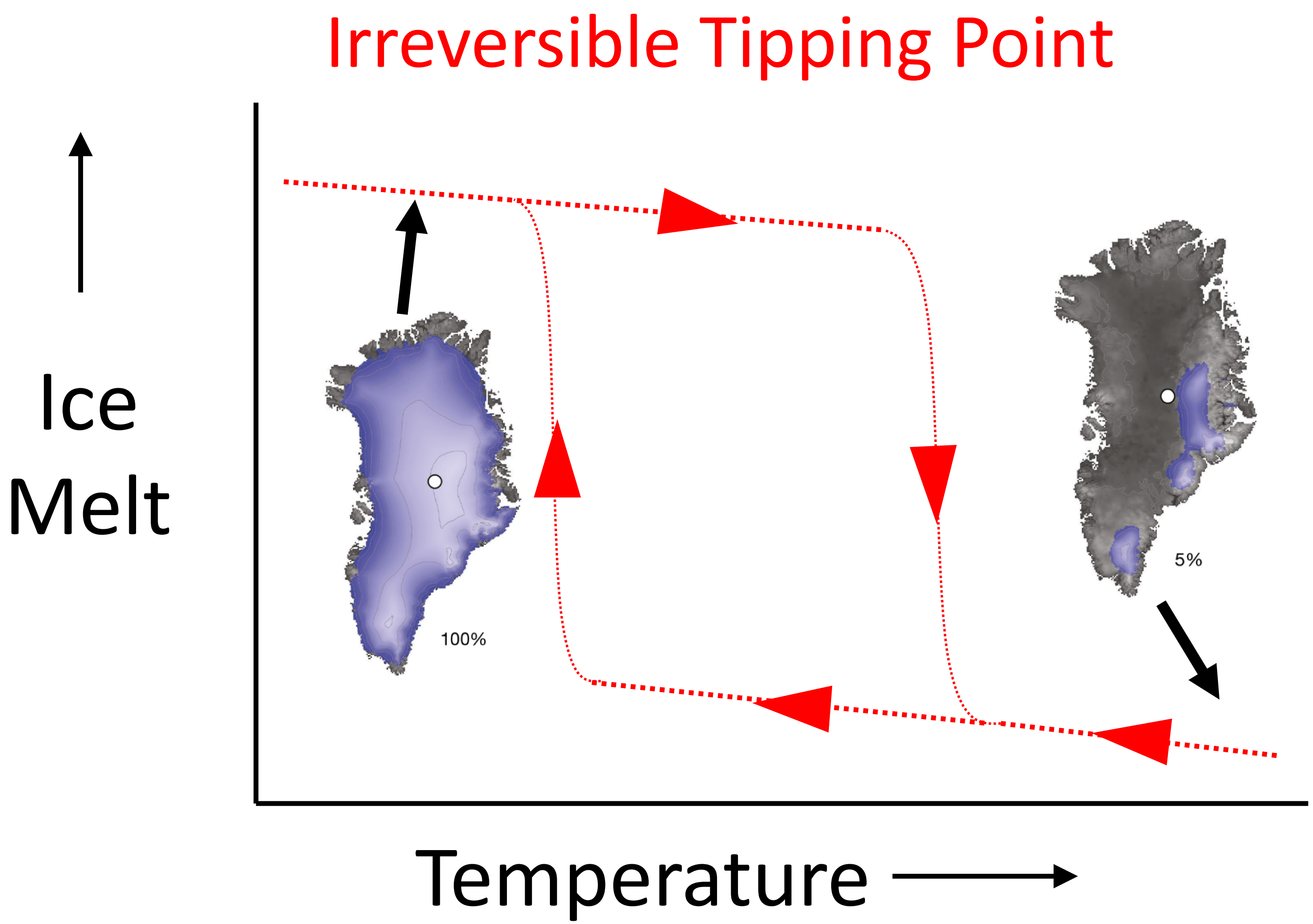
Runaway Positive Feedbacks:

- Once past a ‘threshold’, no more forcing is needed for the system to keep changing
- Eventually a new ‘stable’ state will be reached
- In this case: Greenland mostly melted



Review: Tipping Points

- This is an **irreversible** tipping point system
- There is a different threshold to flip the system back
- This dynamic in a system is called **hysteresis**



Review: Tipping Points

- Modeling systems with feedbacks is *very* difficult
- Strength and speed of feedbacks are hard to predict
- Models of systems almost always *underpredict* the strength and speed of system response

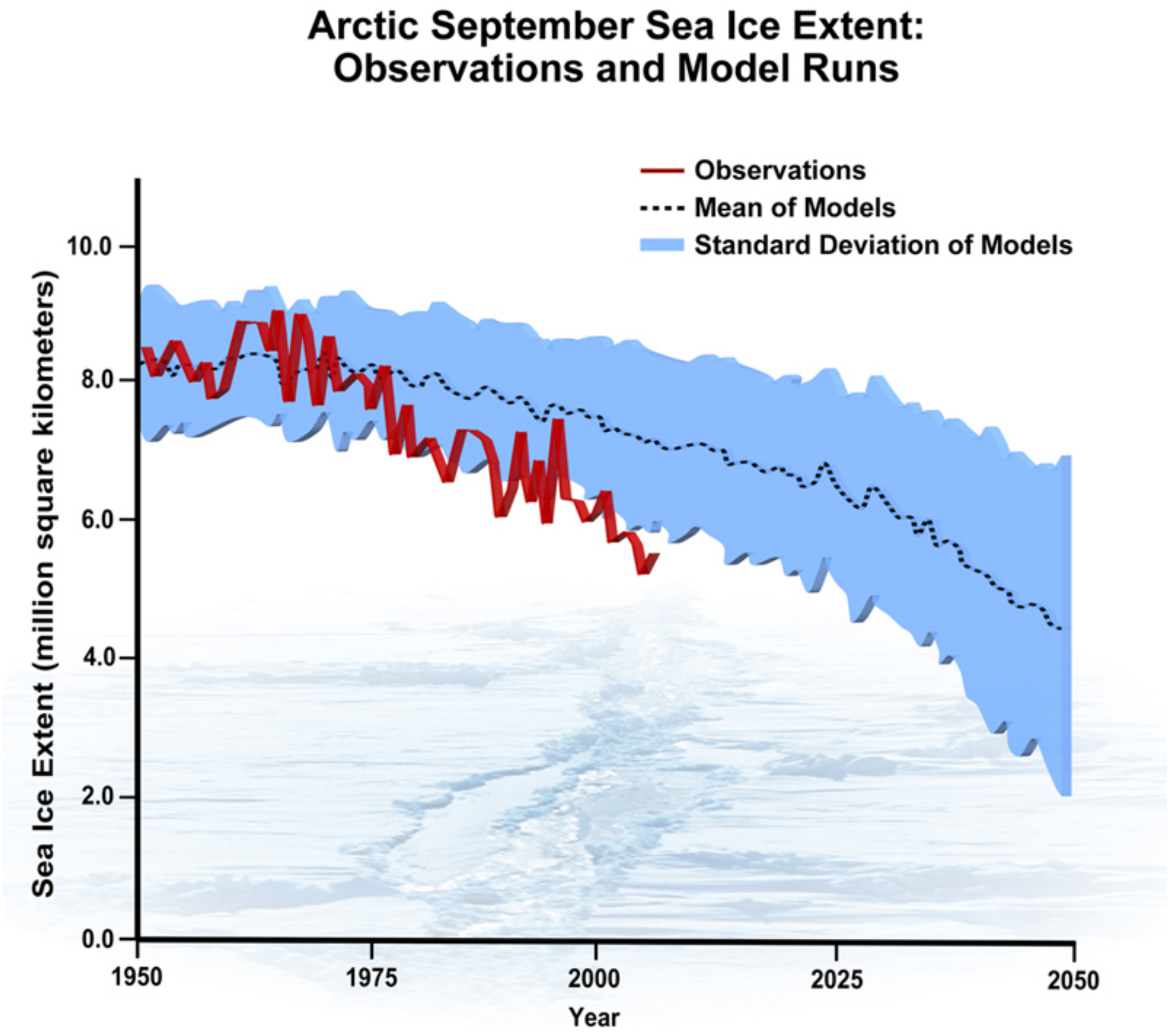


Image from UCAR.edu

Today’s Class: Projections III – Long Term

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Why take the long view? → Slow Responses and Feedbacks → The *really* long view → Societal Impacts

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Why take the long view?

Fast Climate Responses

- Some climate systems respond quickly (decades) to a forcing
- See big response by 2100
- Examples:
  - **Permafrost**
  - Sea ice
  - Coral deaths
  - Surface ocean heating

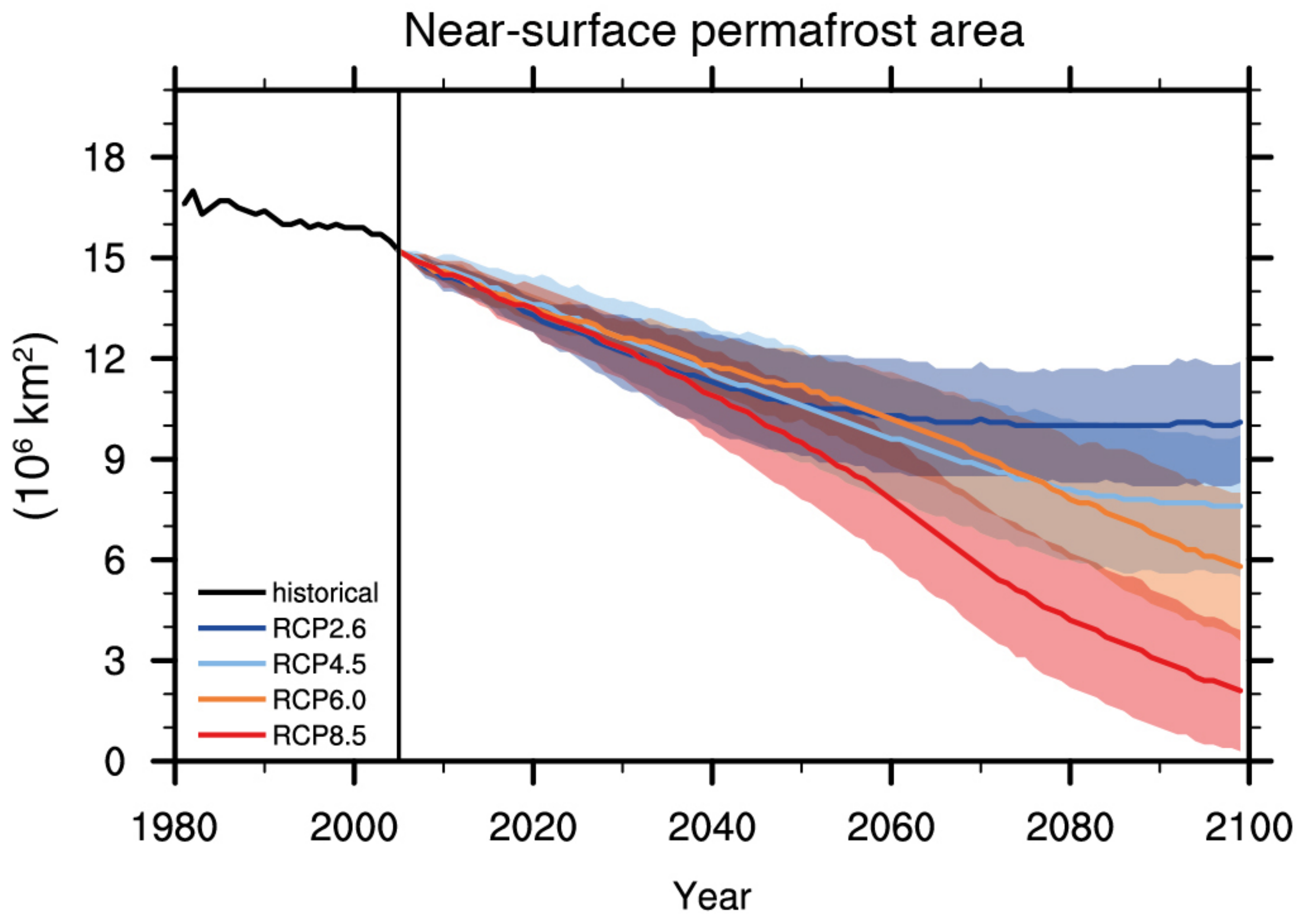

Figure from the IPCC

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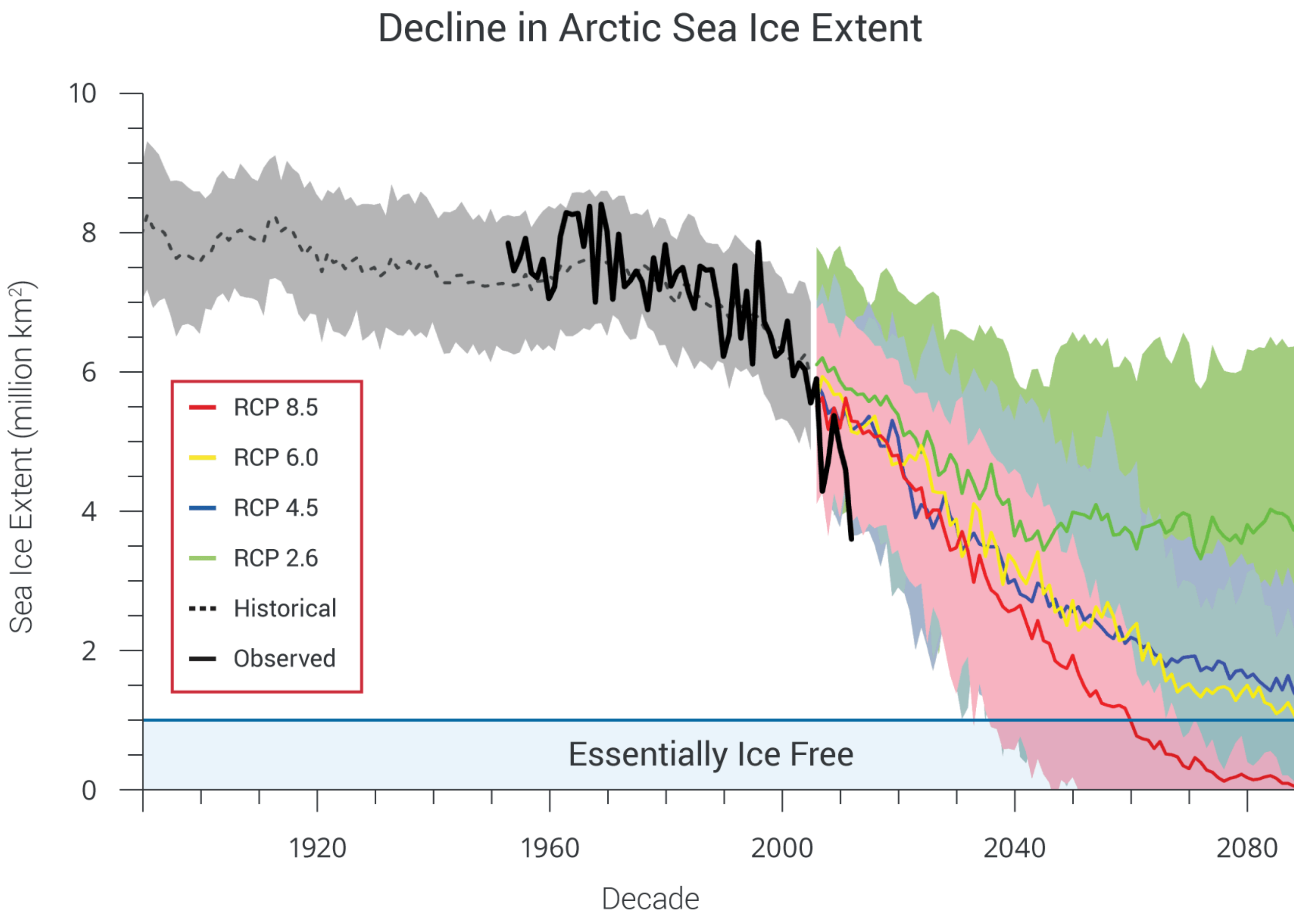

Figure from the National Climate Assessment

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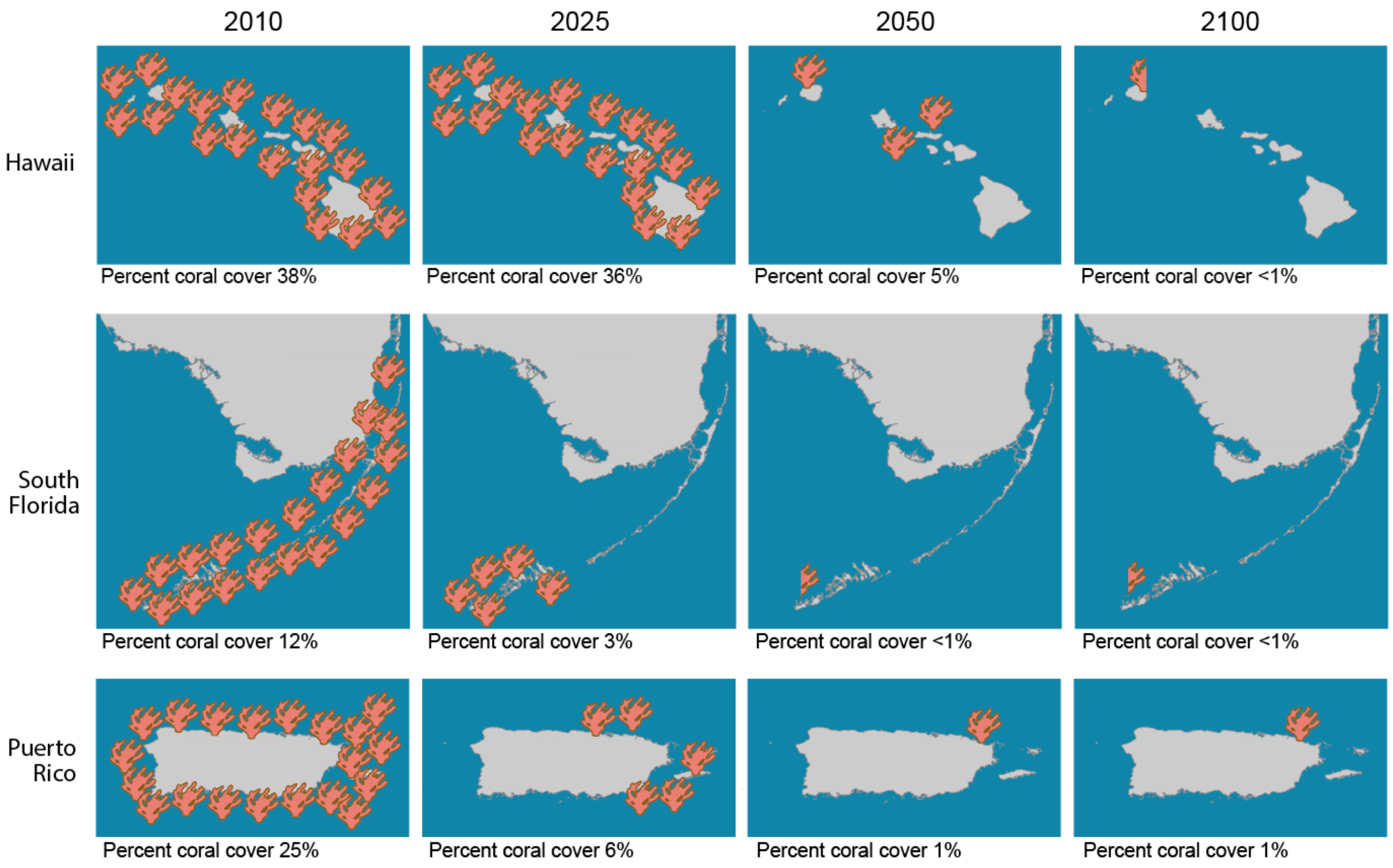

Figure from the EPA

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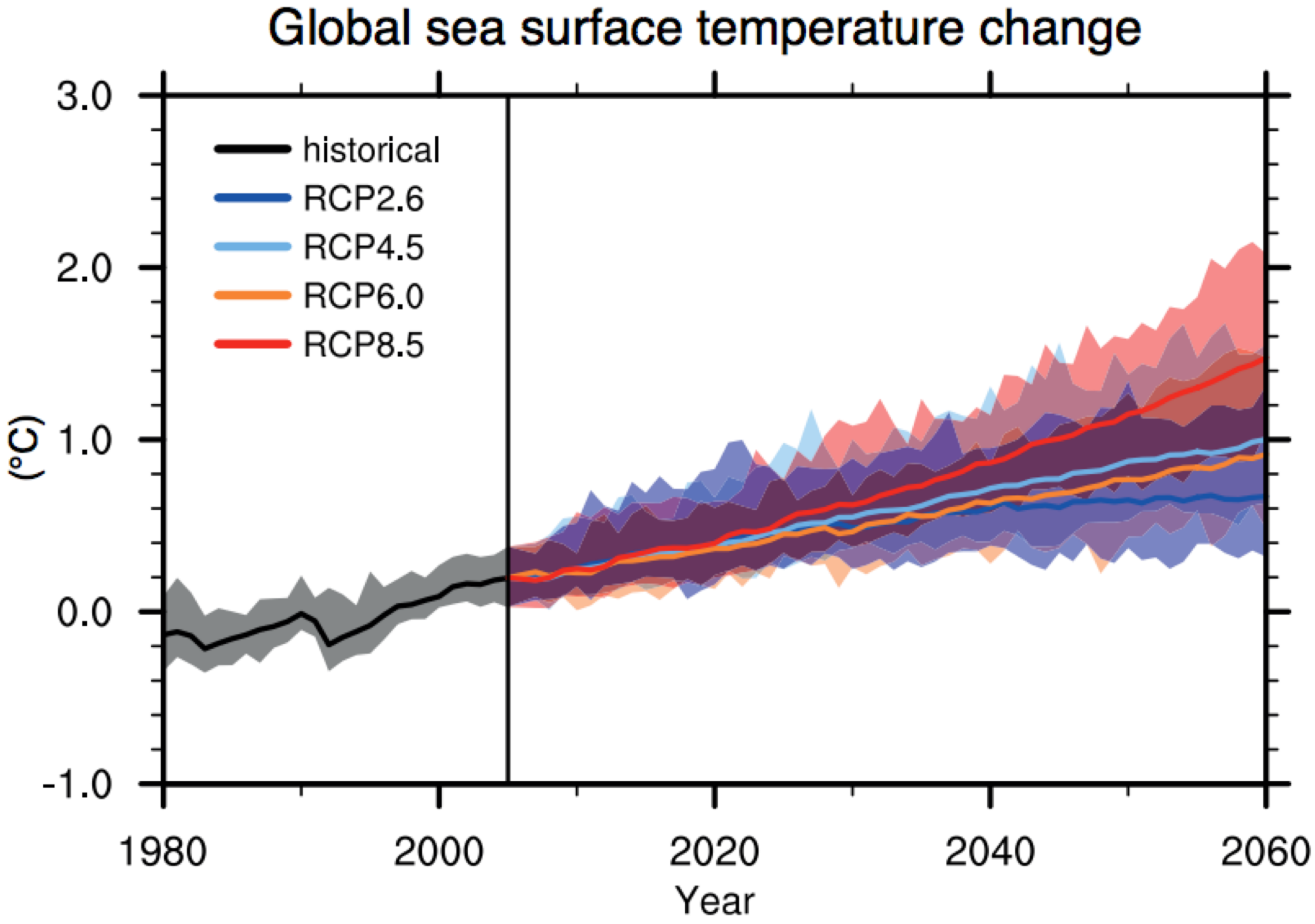


Figure from the IPCC

Think, Pair, Share

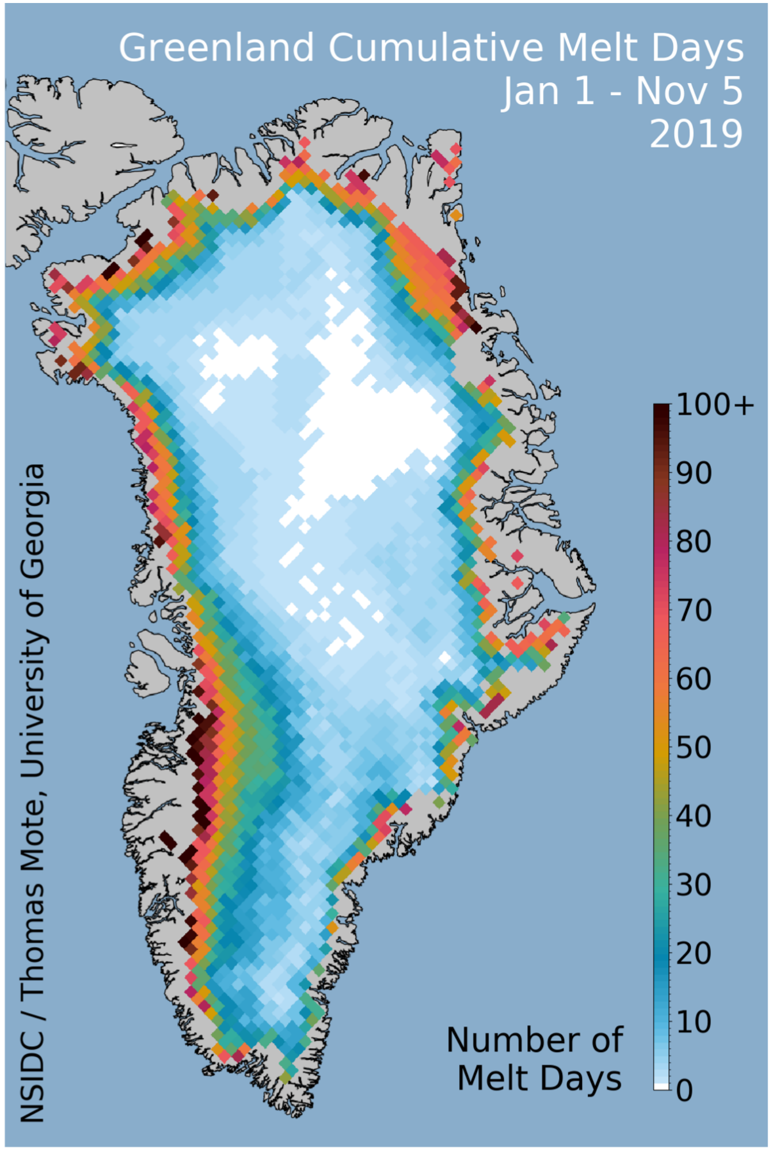
Think back on the climate systems and feedbacks we’ve discussed in class.

What are some slow-responding climate systems (century or longer)?

Slow Responses & Feedbacks

Slow Climate Responses

- Some systems respond slowly (centuries to millennia) to a forcing
- Will not see the *full* response by 2100
- Examples:
  - **Ice sheet melt**
  - Ocean circulation change
  - Deep ocean heat sequestration



Slow Responses & Feedbacks

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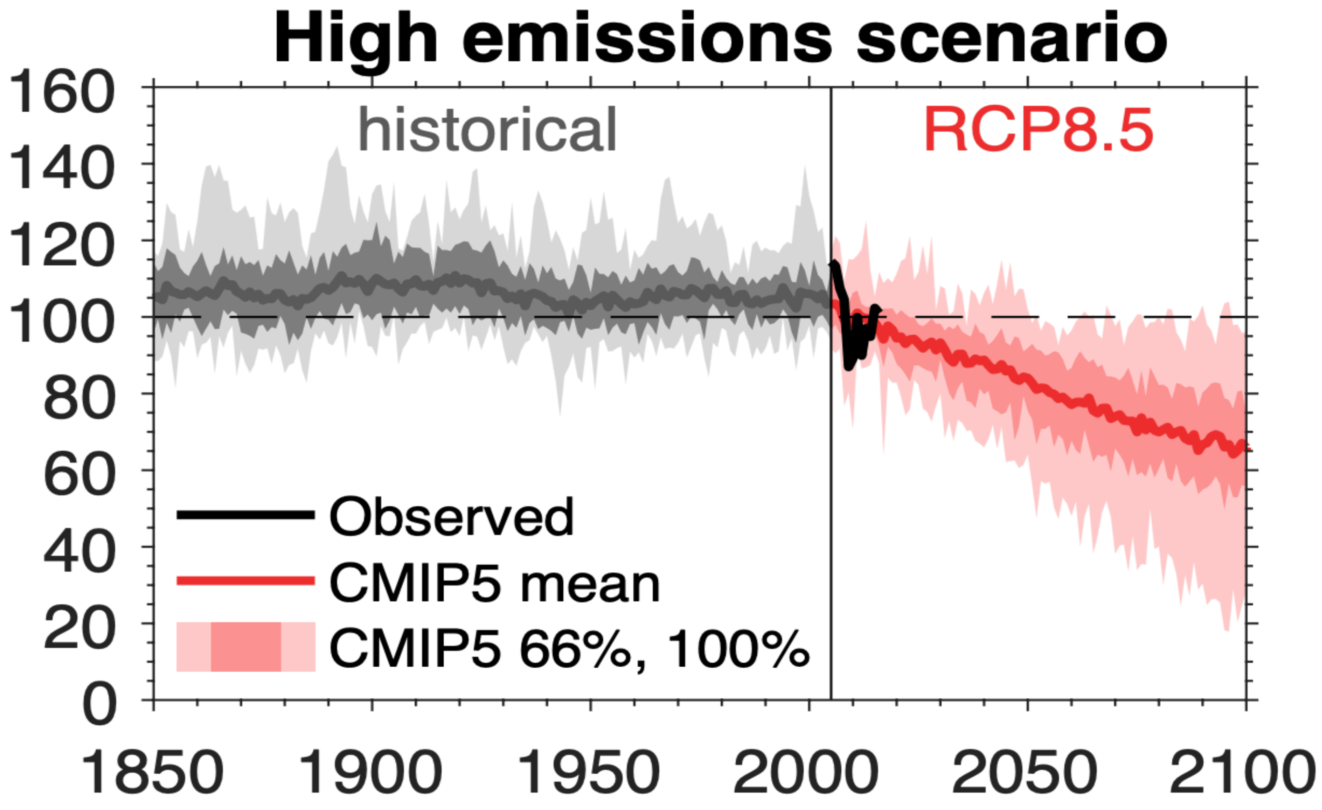
AMOC Strength (% Relative to Today)



Slow Responses & Feedbacks

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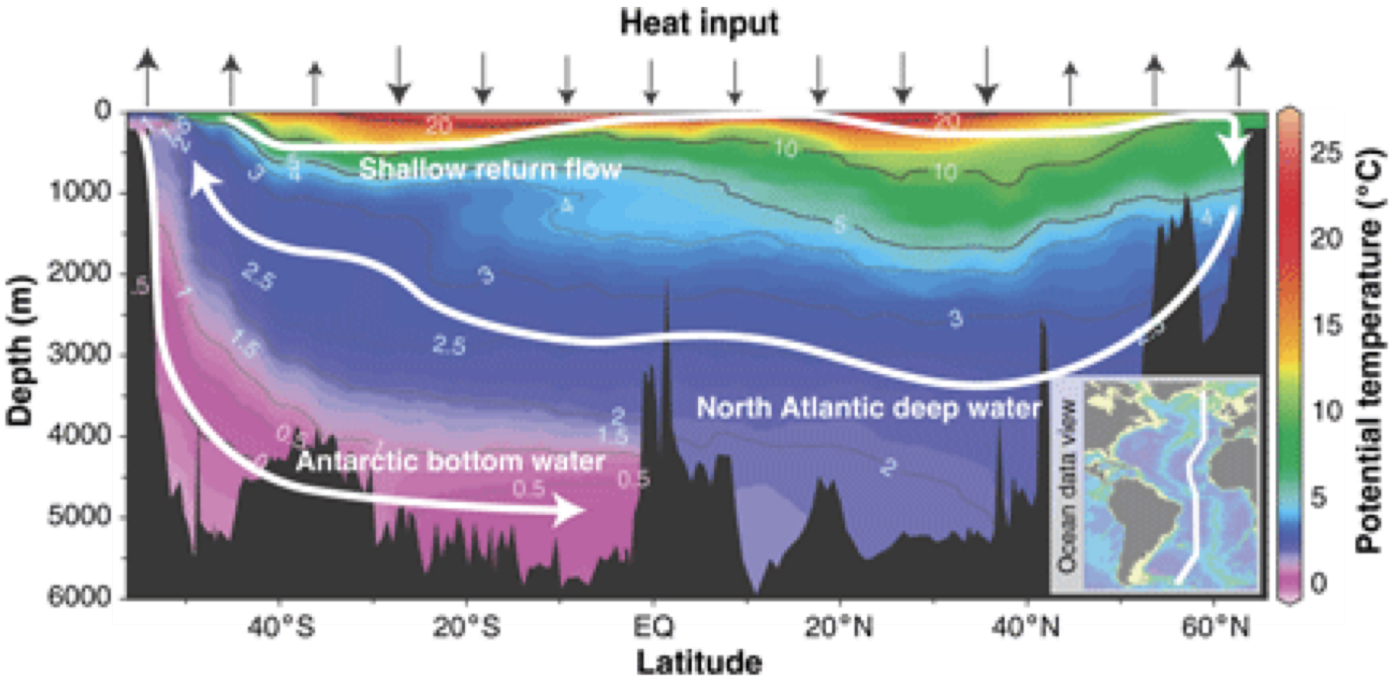
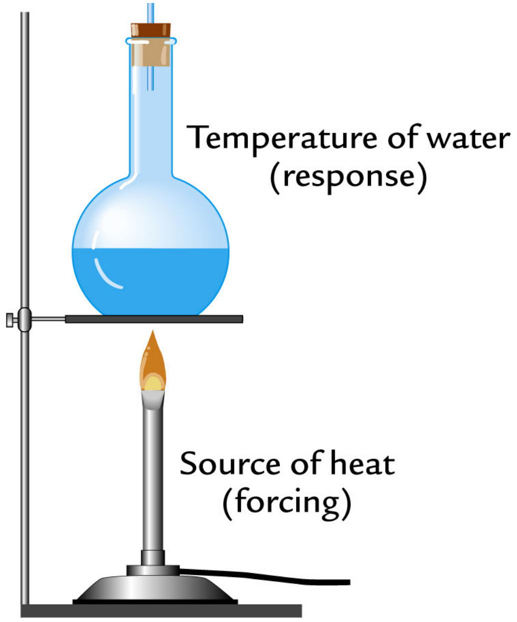
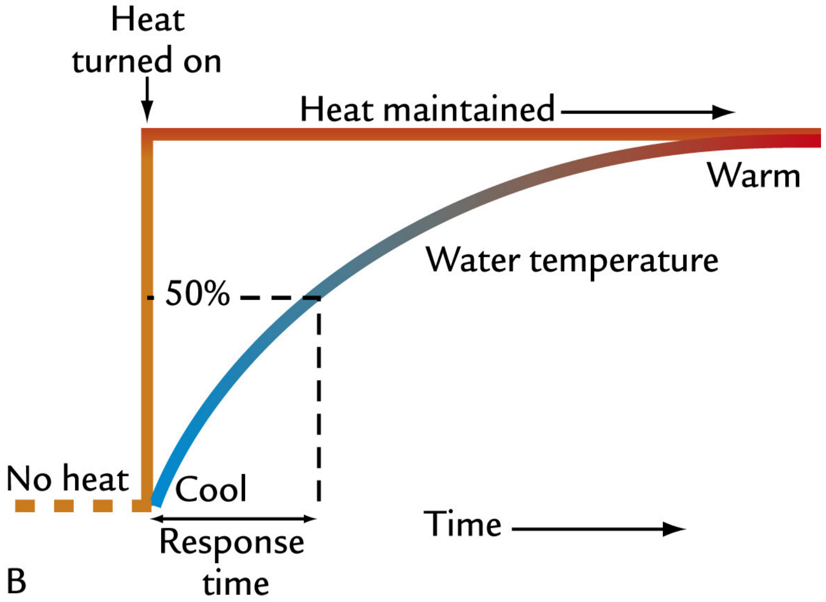


Slow Responses & Feedbacks

Important point about slow responses:

- If a slow-response system (like ice sheets) has not changed drastically by 2100, it does not mean that it is not changing
- These systems will still be 'catching up' to warming by 2100

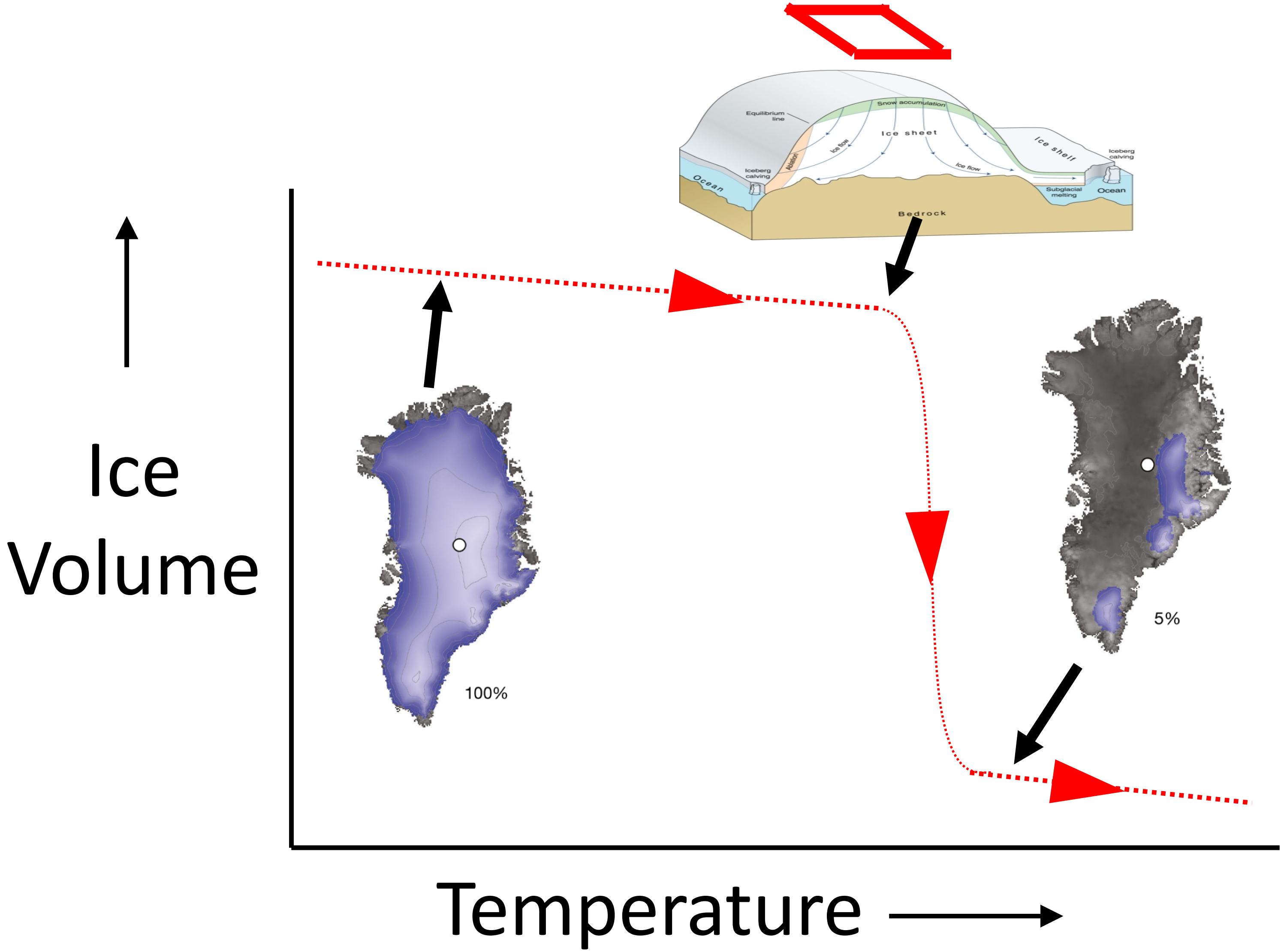




Slow Responses & Feedbacks

And, of course, don't forget about tipping points

- If threshold is passed, no more forcing needed for big change to occur
- If threshold passed before 2100, might not see full impact until later



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The *Really* Long View – 2300 CE

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- How much will temperature increase by 2300?
  - Depends on emissions!

- With drastic emission cuts (RCP2.6), 1°C or less

- 'Business as usual' (RCP8.5), 4 - 12°C

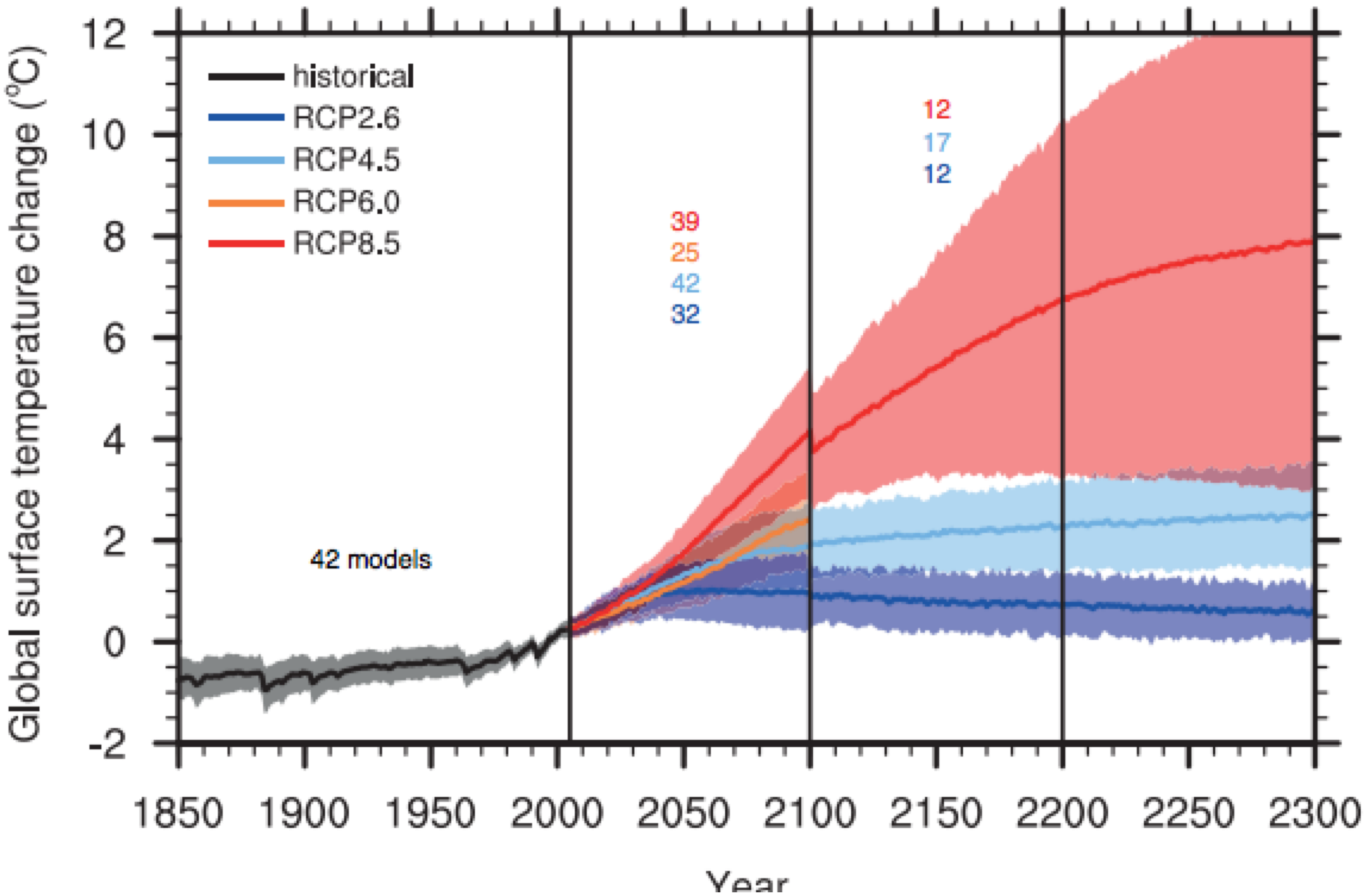

Figure from the IPCC

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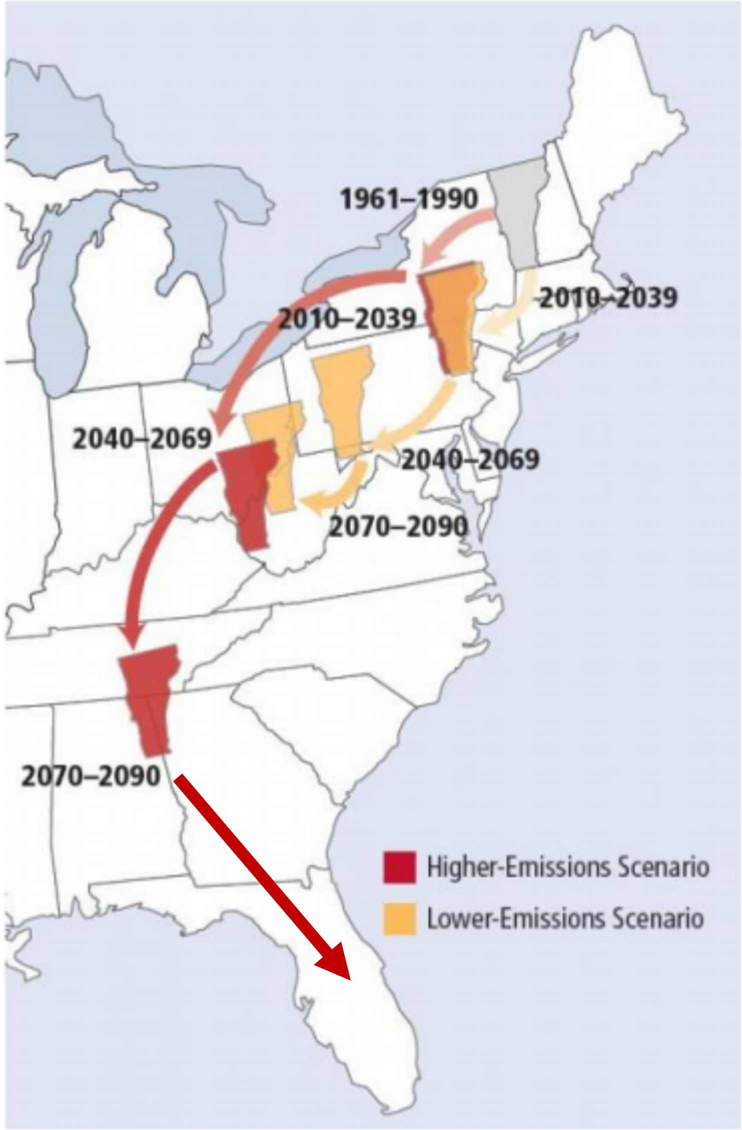

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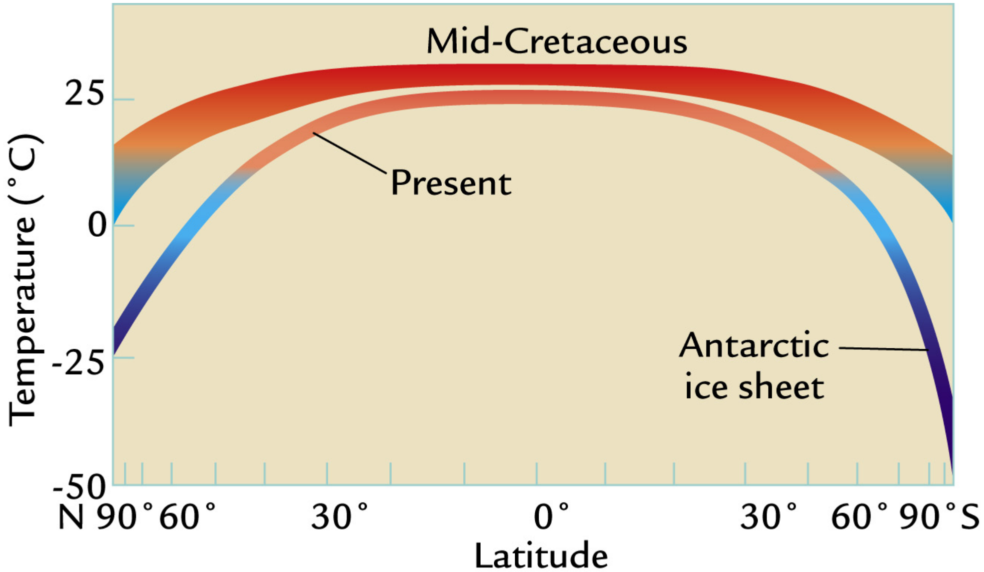
- How much will temperature increase by 2300?
  - Depends on emissions!
- With drastic emission cuts (RCP2.6), 1°C or less
- 'Business as usual' (RCP8.5), 4 - 12°C
- CO_2 concentration at or above Cretaceous levels



The *Really* Long View – 2300 CE

Important point:

- Fewer models running projections the farther out you go
- Bigger uncertainties

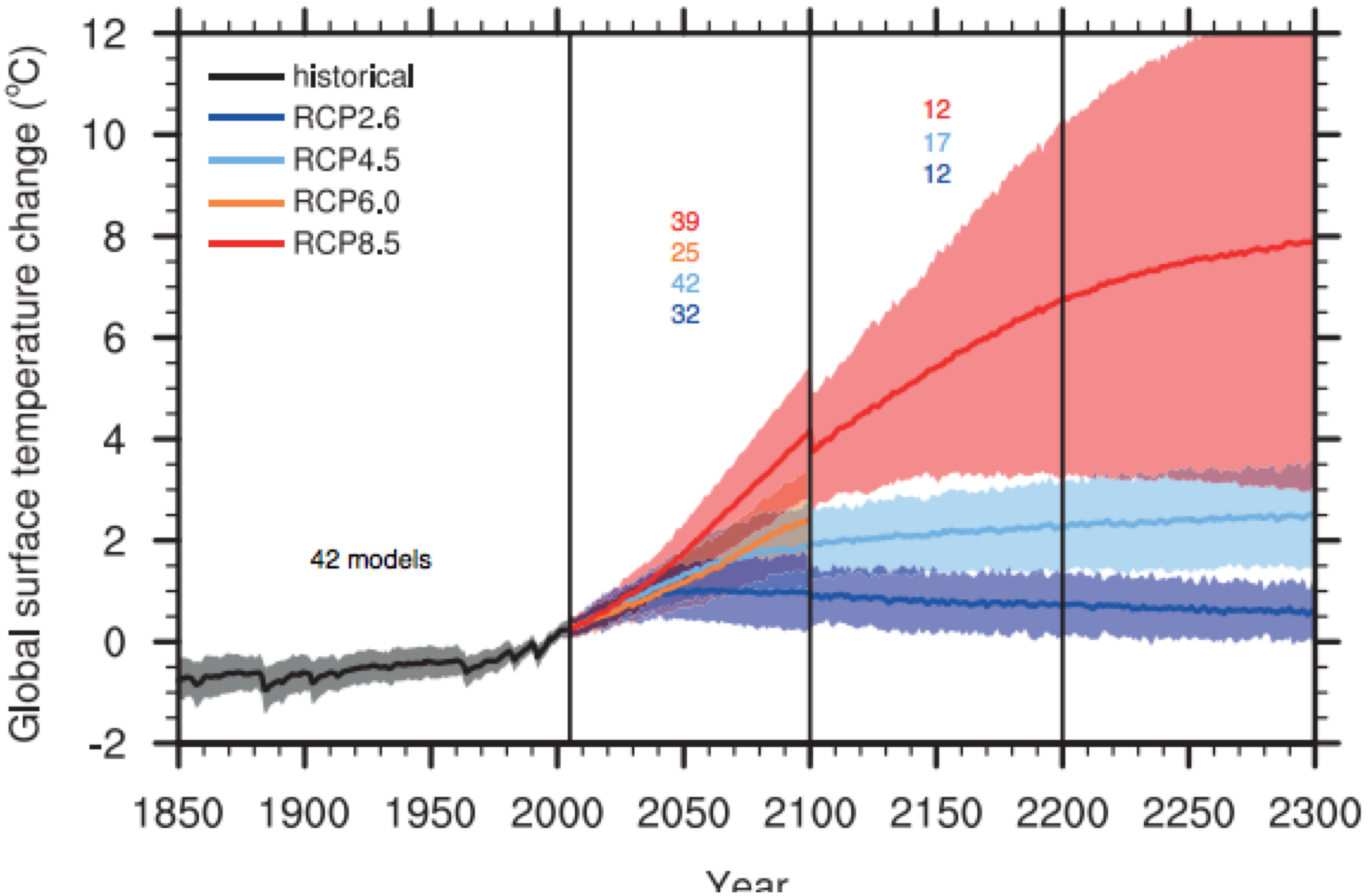


Figure from the IPCC

The *Really* Long View – 2300 CE (Greenland)

RCP 8.5 (red) - Greenland contributing 1 - 3 meters of sea level rise

RCP 2.6 (dark blue) – Greenland contributing 0.2 – 0.5 meters of sea level rise

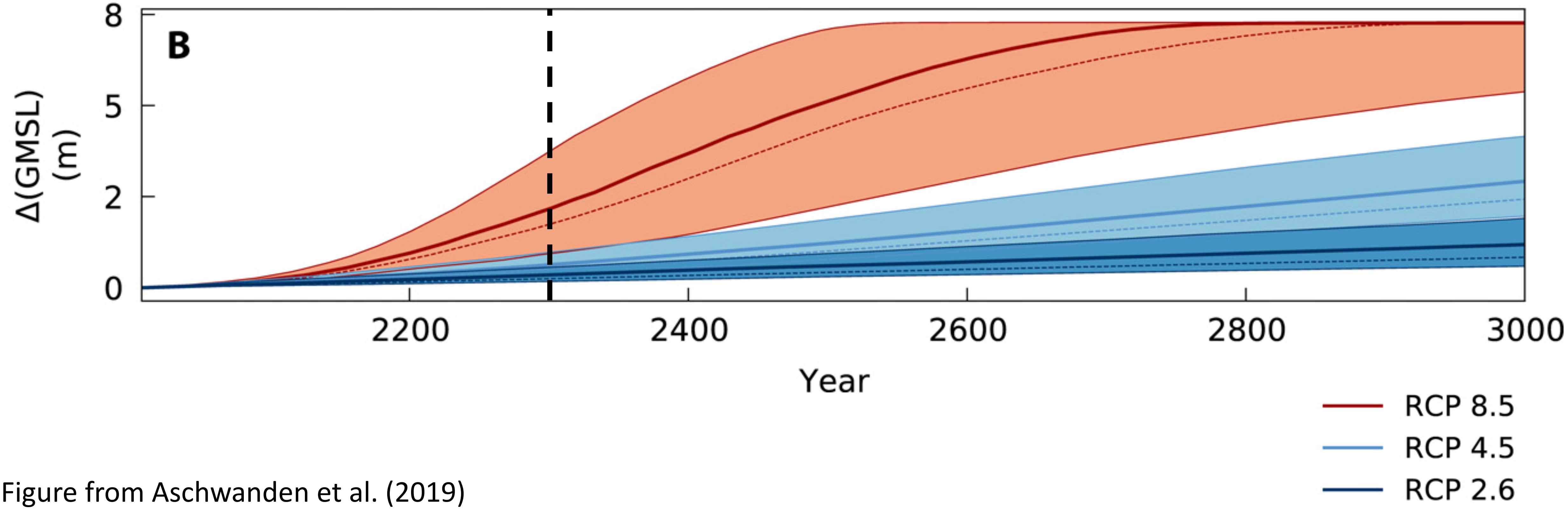
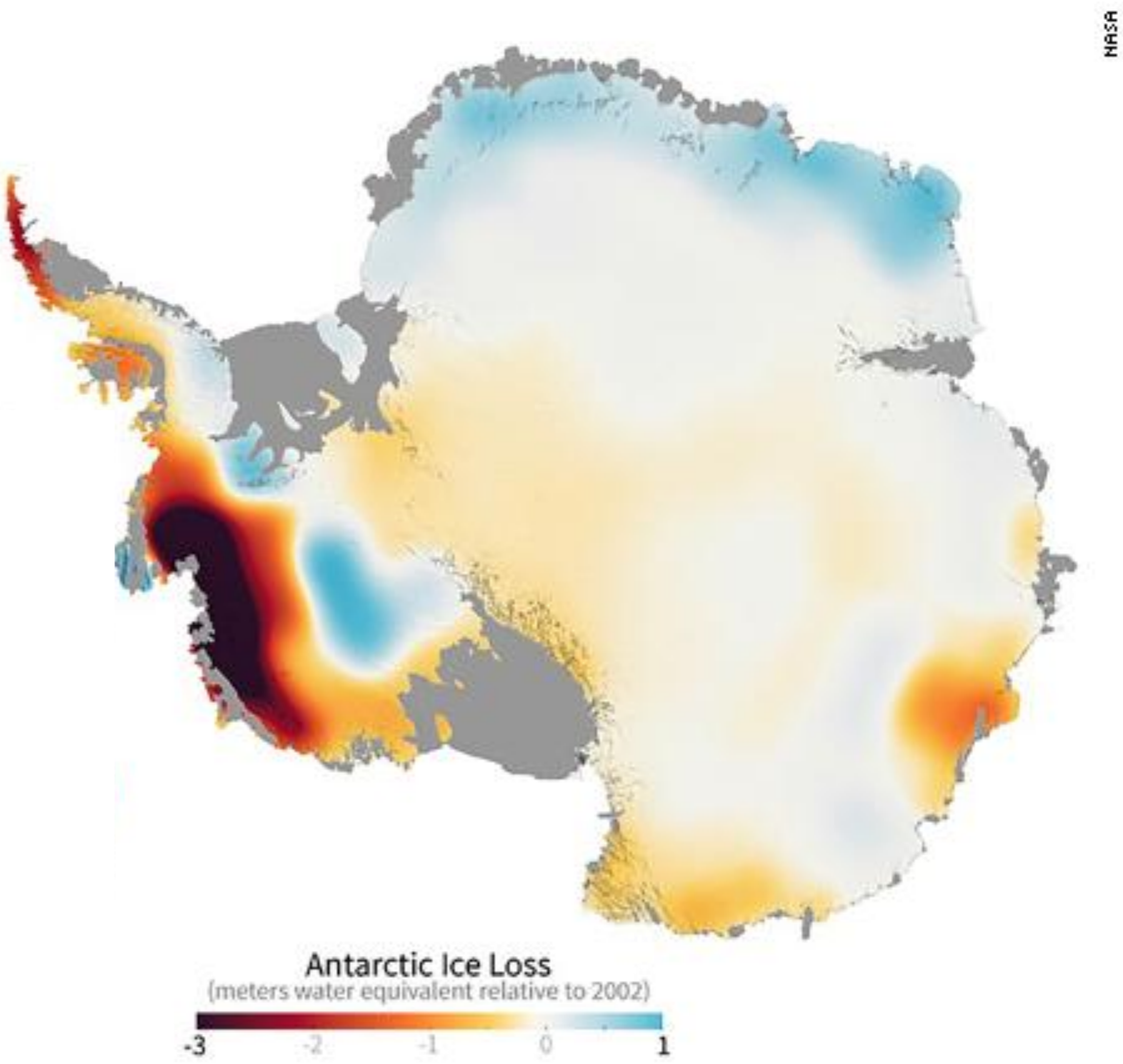


Figure from Aschwanden et al. (2019)

The *Really* Long View – 2300 CE (Antarctica)

Some uncertainty about Antarctica, depends on emission scenario

- Some areas losing mass, some gaining
  - Satellites show net loss right now
- 500 – 700 ppm CO_2 may lead to slight mass gain on Antarctica
- >700 ppm CO_2 will likely lead to mass loss (melting > precipitation)



The *Really* Long View – 2300 CE (AMOC)

RCP 8.5 (red) - AMOC drastically weakened

RCP 2.6 (dark blue) - AMOC could recover fully

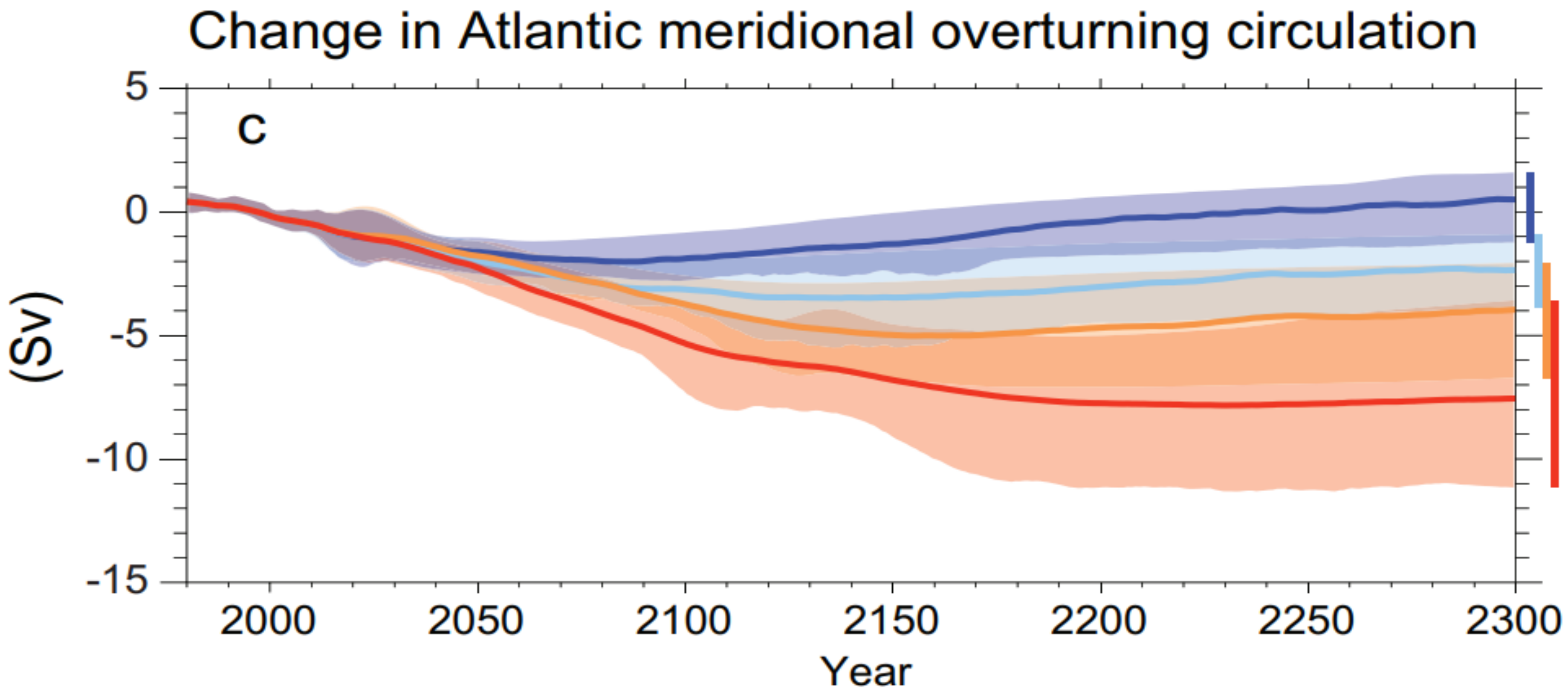


Figure from the IPCC

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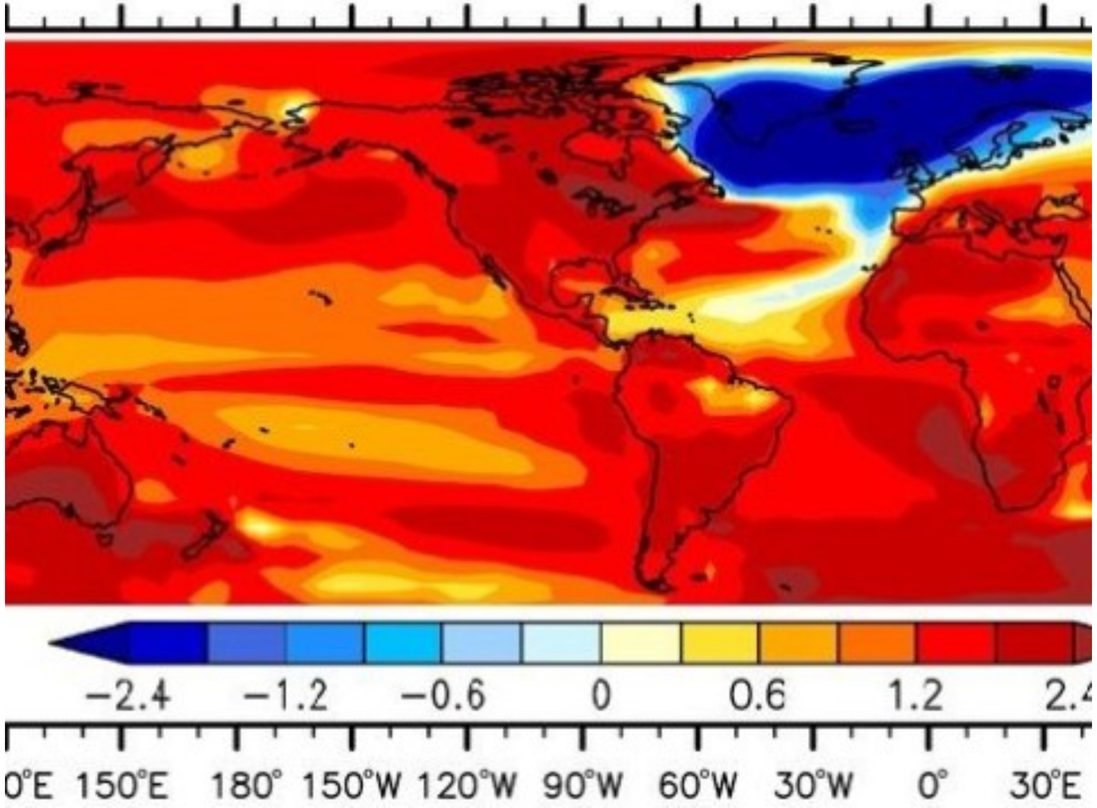


The *Really* Long View – 2300 CE (Deep Ocean Heat)

Often predicted in terms of ocean thermal expansion (more heat in ocean = more expansion)

- **RCP 8.5 -** Lots of heat in deep ocean
- **RCP 2.6 -** Slowed deep ocean heating

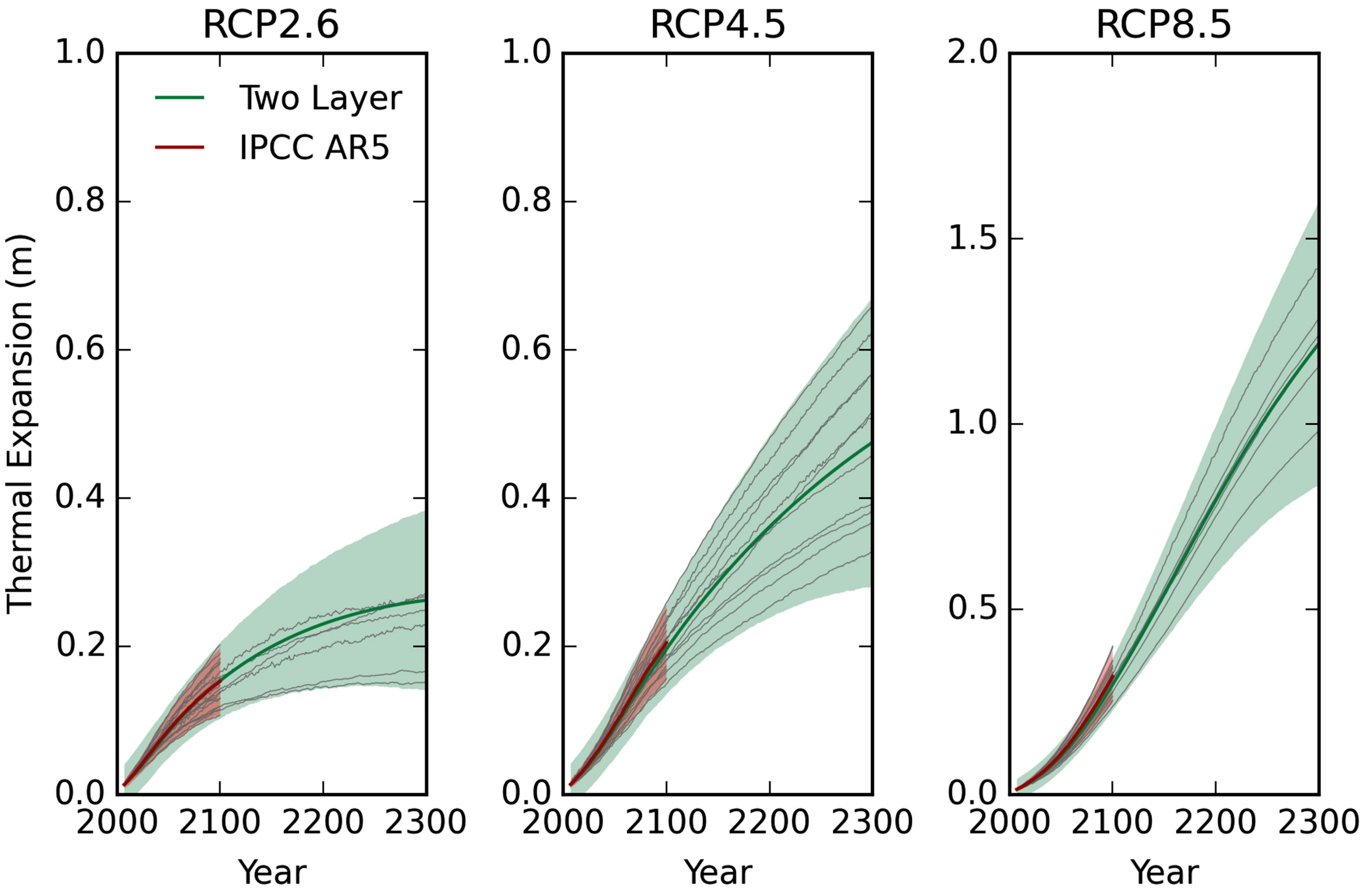


Figure from Palmer et al. (2018)

The *Really* Long View – 2300 CE (Deep Ocean Heat)

RCP 8.5 – Up to 1.5 m of sea level rise from thermal expansion alone!

The *Really* Long View – 3000 CE

Think, Pair, Share: The *Really* Long View – 3000 CE

What do you think is the biggest uncertainty when predicting climate change out to the year 3000?

The *Really* Long View – 3000 CE

What are humans going to do?

- Few models for projections this far out
- One example (used in IPCC) has emissions reducing at some point between now and 2150
- Emissions reach zero by 2300

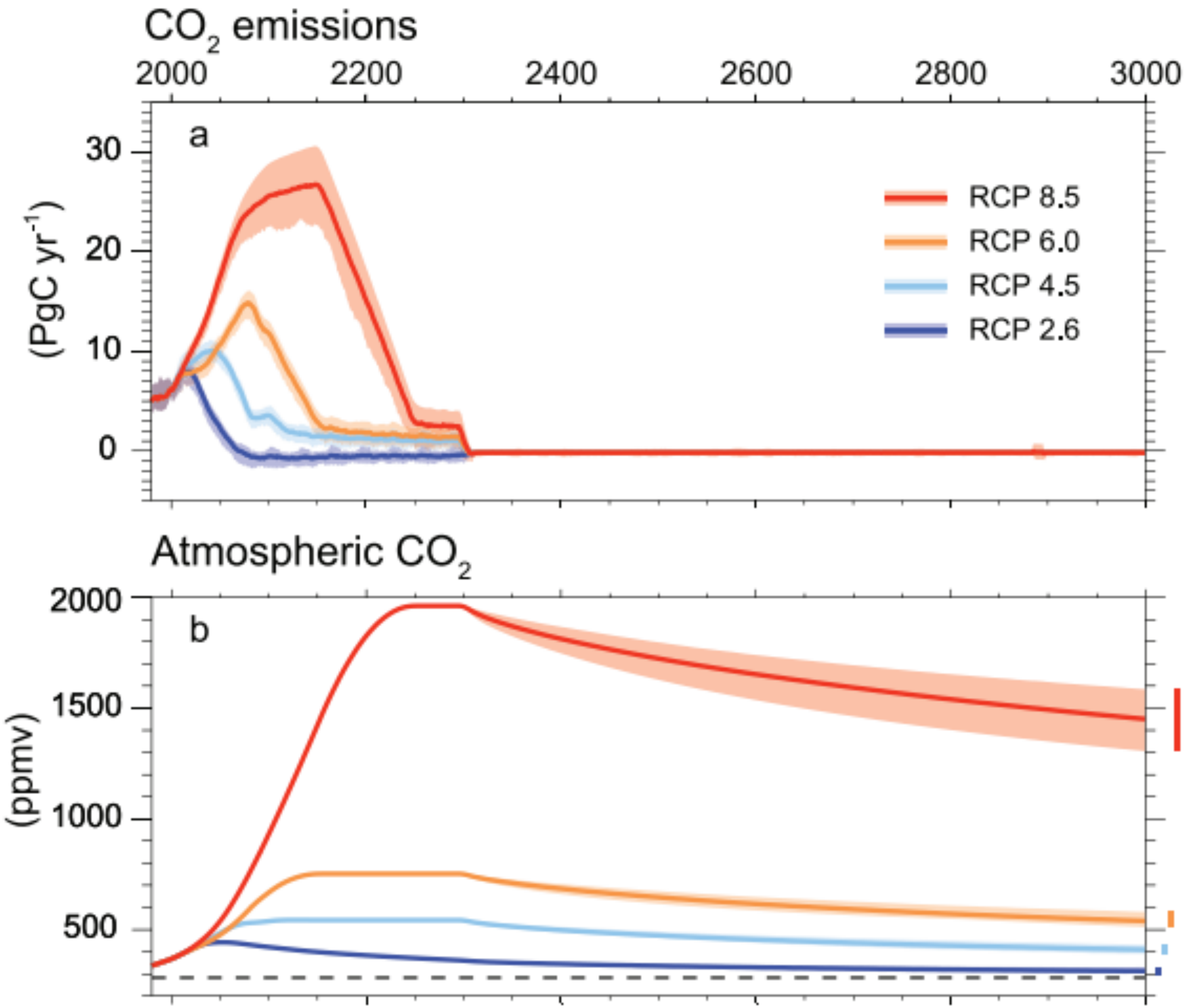


Figure from the IPCC

The *Really* Long View – 3000 CE (Temperature)

What are humans going to do?

- Atmospheric CO_2 reduction is slow
- Surface temperature reduction is even slower
- **RCP 8.5 -** 5.5 to 7.5°C warmer
- **RCP 2.6** – Maybe cooler?

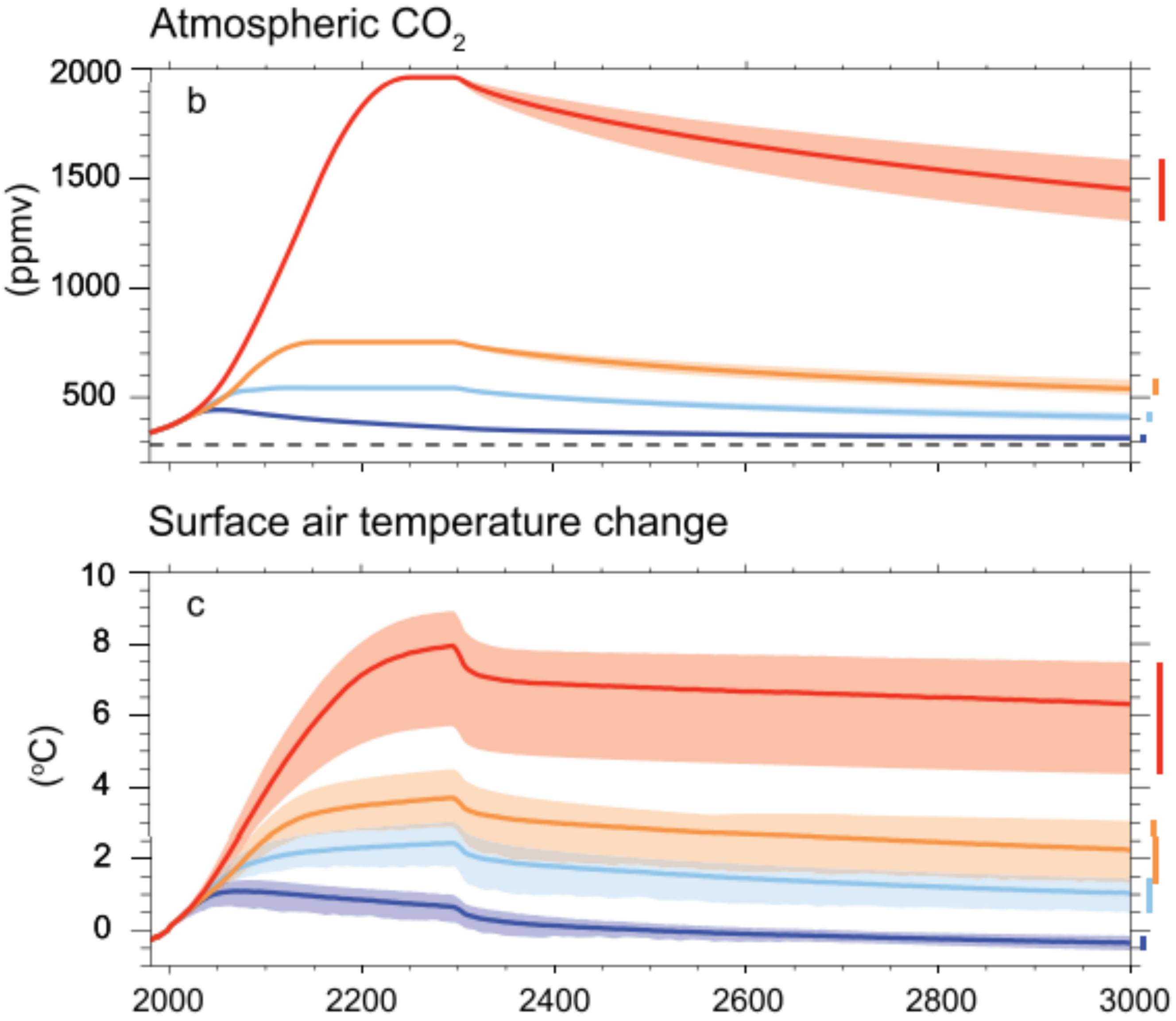


Figure from the IPCC

The *Really* Long View – 3000 CE (Greenland)

RCP 8.5 (red) - Greenland almost fully melted

RCP 2.6 (dark blue) – Greenland contributing 0.6 – 1.8 meters of sea level rise

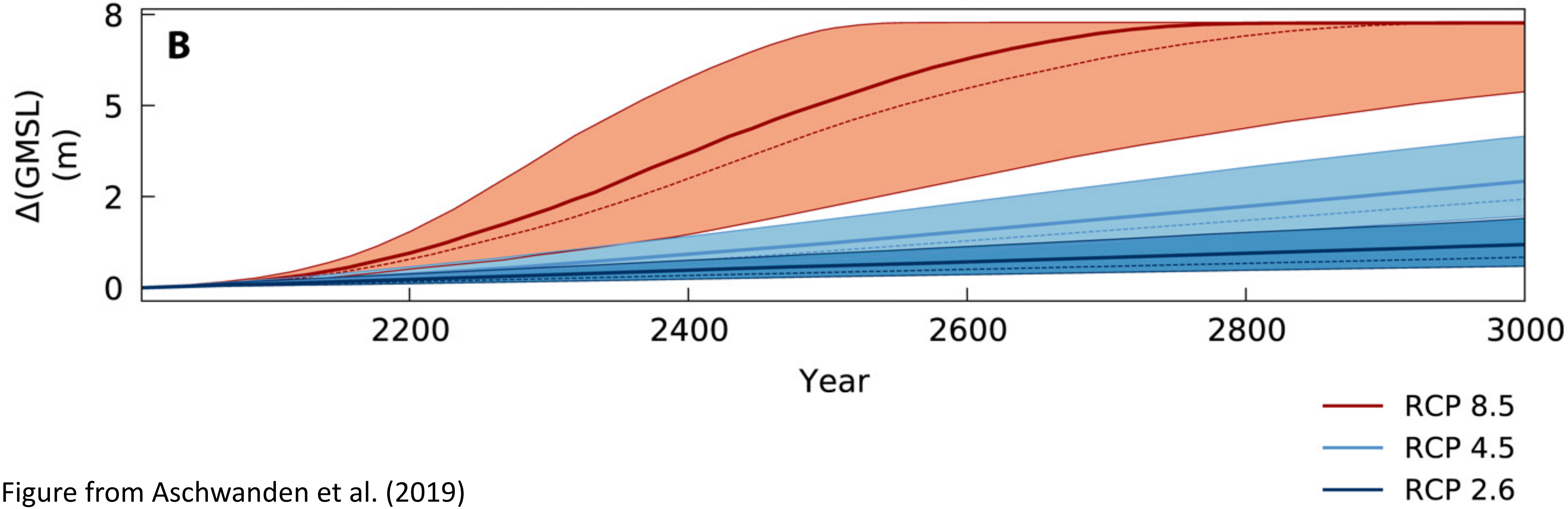


Figure from Aschwanden et al. (2019)

The *Really* Long View – 3000 CE

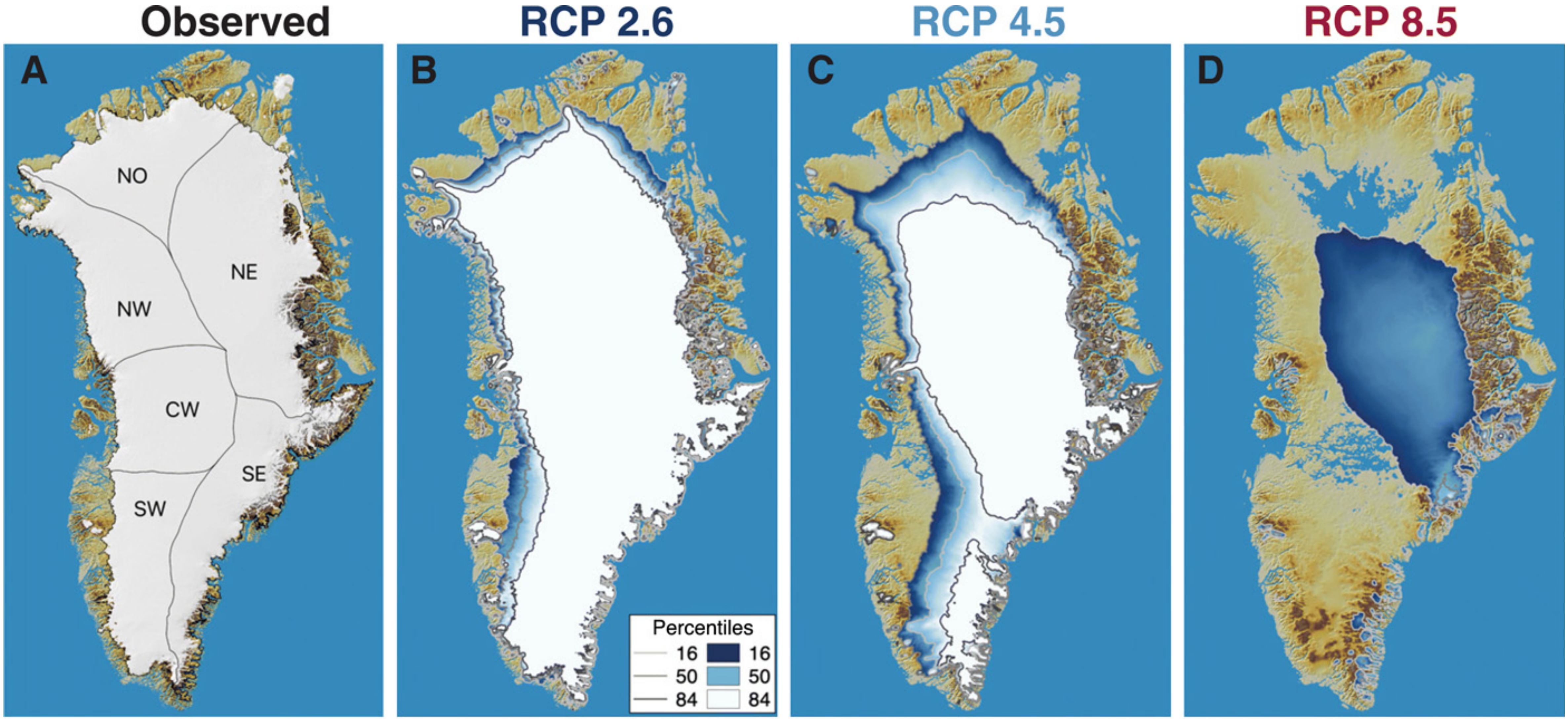
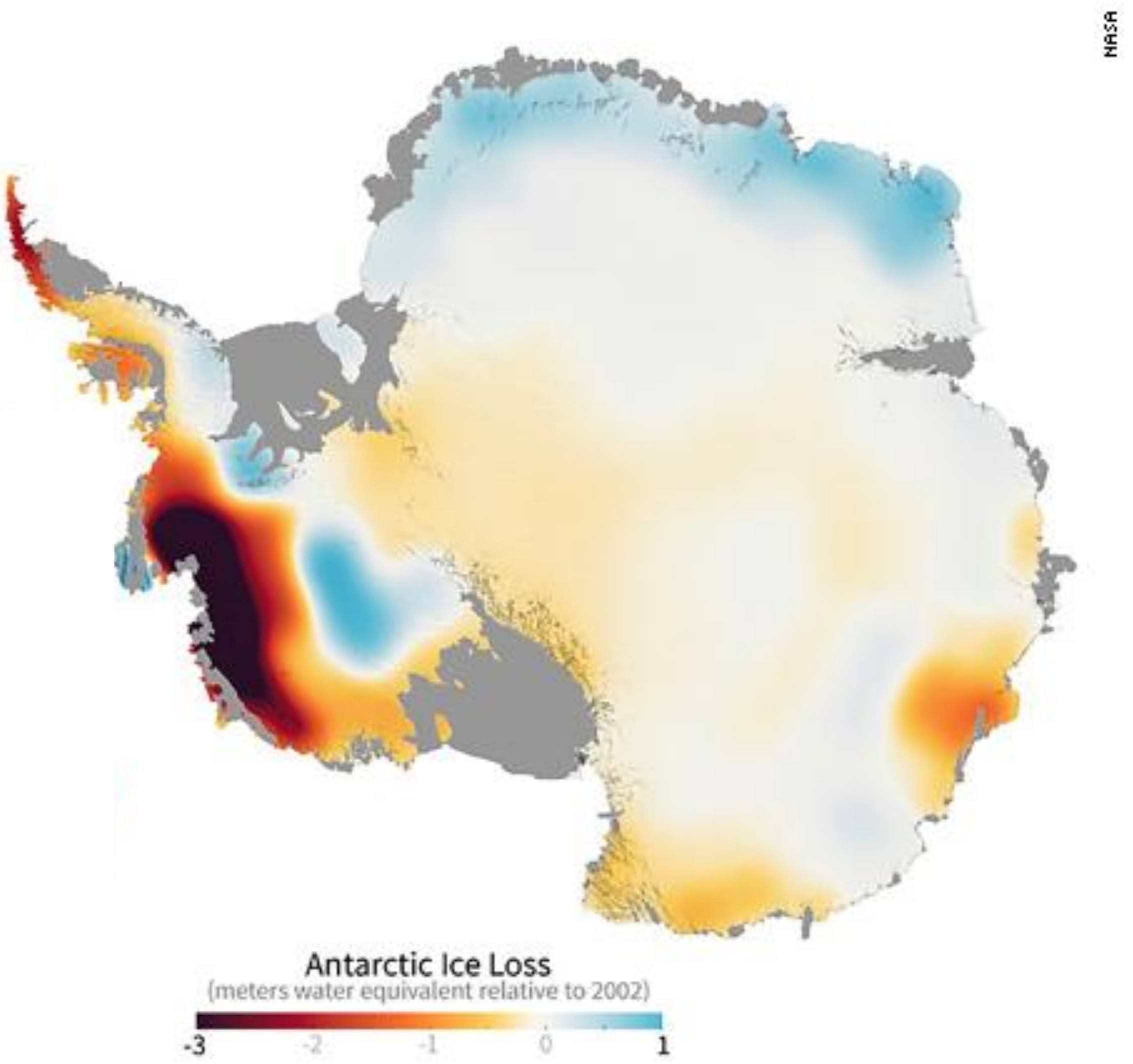


Figure from Aschwanden et al. (2019)

The *Really* Long View – 3000 CE (Antarctica)

Again, some uncertainty here

- Under high emissions scenario, likely that West Antarctic tipping point threshold has been passed
- Rate of ice melt is uncertain
- **RCP 8.5** – 2 to 4 meters of sea level
- **RCP 2.6** – 0 to 0.5 meters of sea level



The *Really* Long View – 3000 CE (AMOC)

No AMOC projections out this far! Likely that AMOC follows Greenland trend

- **RCP 8.5 – Reduced AMOC**
- **RCP 2.6 – Recovered AMOC**

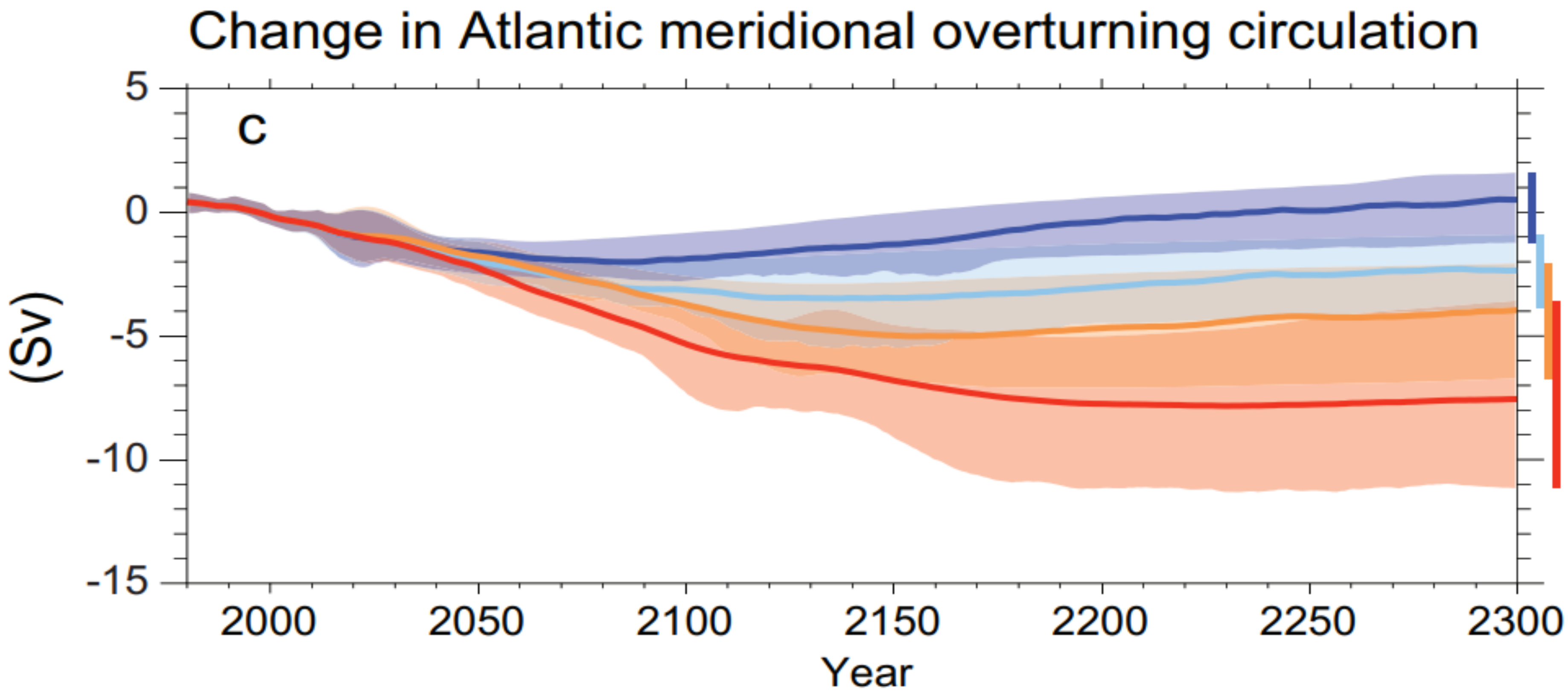


Figure from the IPCC

The *Really* Long View – 3000 CE (Deep Ocean Heat)

Ocean will continue taking up heat through 3000 AD

- **RCP 8.5 –** Potentially huge amounts of heat now in deep ocean (1 – 3.3 m of expansion)
- **RCP 2.6 –** Some, but very little heat in deep ocean (0.1 – 0.4 m of expansion)

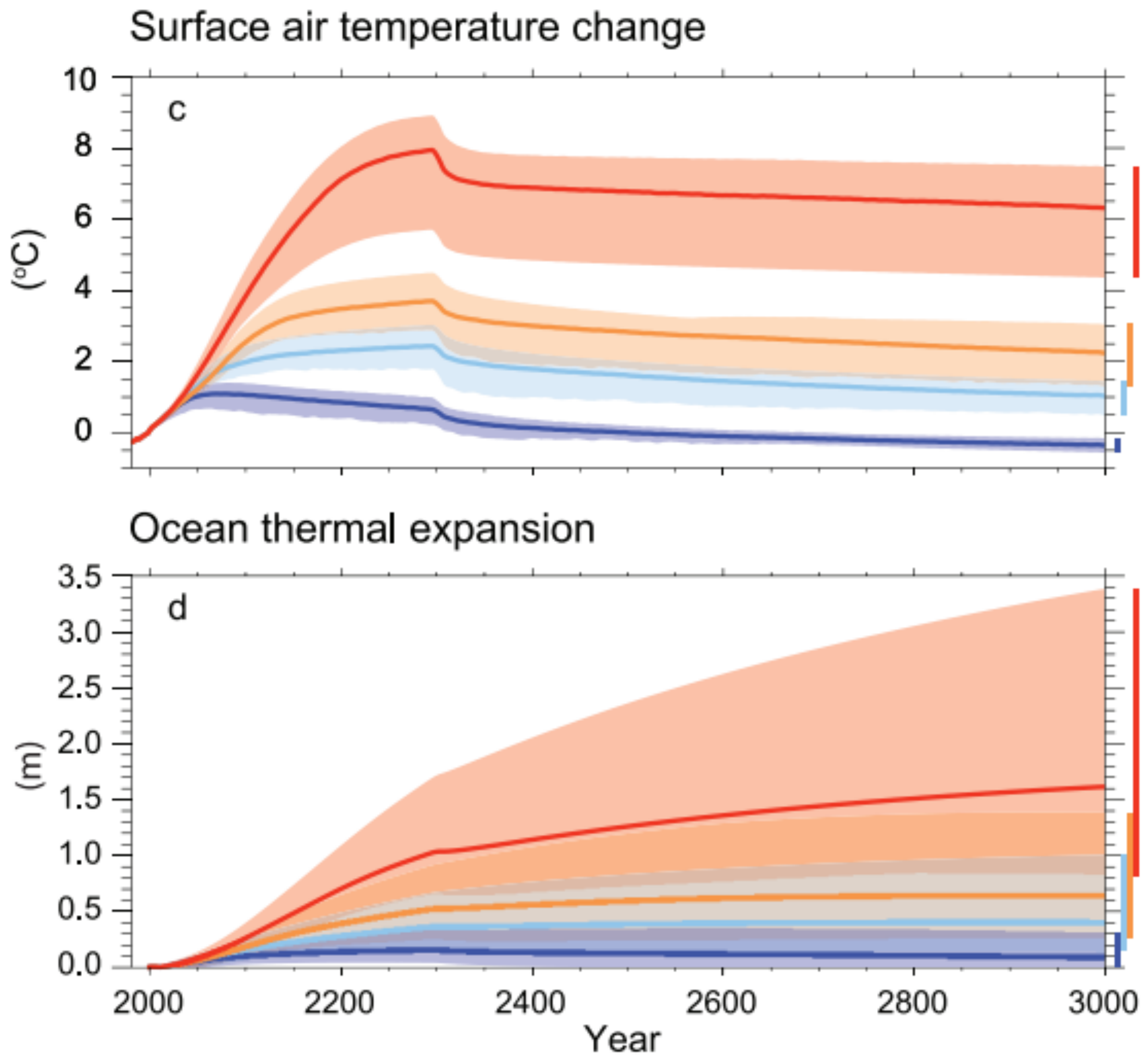


Figure from the IPCC

The *Really* Long View – 12,000 CE

The *Really* Long View – 12,000 CE

Only one team has ever projected climate out this far

nature climate change

Consequences of twenty-first-century policy for multi-millennial climate and sea-level change

Peter U. Clark[1*], Jeremy D. Shakun[2], Shaun A. Marcott[3], Alan C. Mix[1], Michael Eby[4,5], Scott Kulp[6], Anders Levermann[7,8,9], Glenn A. Milne[10], Patrik L. Pfister[11], Benjamin D. Santer[12], Daniel P. Schrag[13], Susan Solomon[14], Thomas F. Stocker[11,15], Benjamin H. Strauss[6], Andrew J. Weaver[4], Ricarda Winkelmann[7], David Archer[16], Edouard Bard[17], Aaron Goldner[18], Kurt Lambeck[19,20], Raymond T. Pierrehumbert[21] and Gian-Kasper Plattner[11]

(2016)

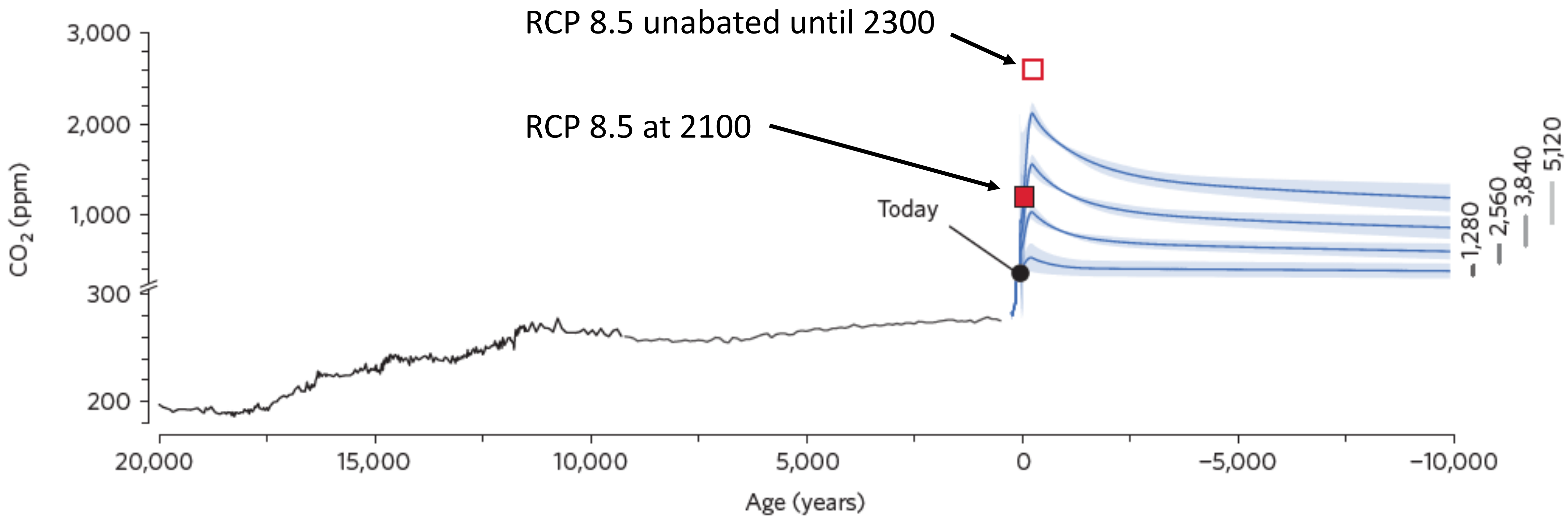
Scientist Profile: Professor Peter Clark

Dr. Peter Clark is a Distinguished Professor of Earth, Ocean, and Atmospheric Sciences at Oregon State University. His research is focused on cryosphere change in the past and future. He was the lead author of the Sea Level Change chapter in the Fifth Assessment Report from the IPCC. His climate projection to 10,000 years in the future remains the longest published projection to date.

The *Really* Long View – 12,000 CE

As before, biggest uncertainty is humans

Clark et al. followed IPCC scenarios to 3000 (emissions to 0 in all cases by 2300)

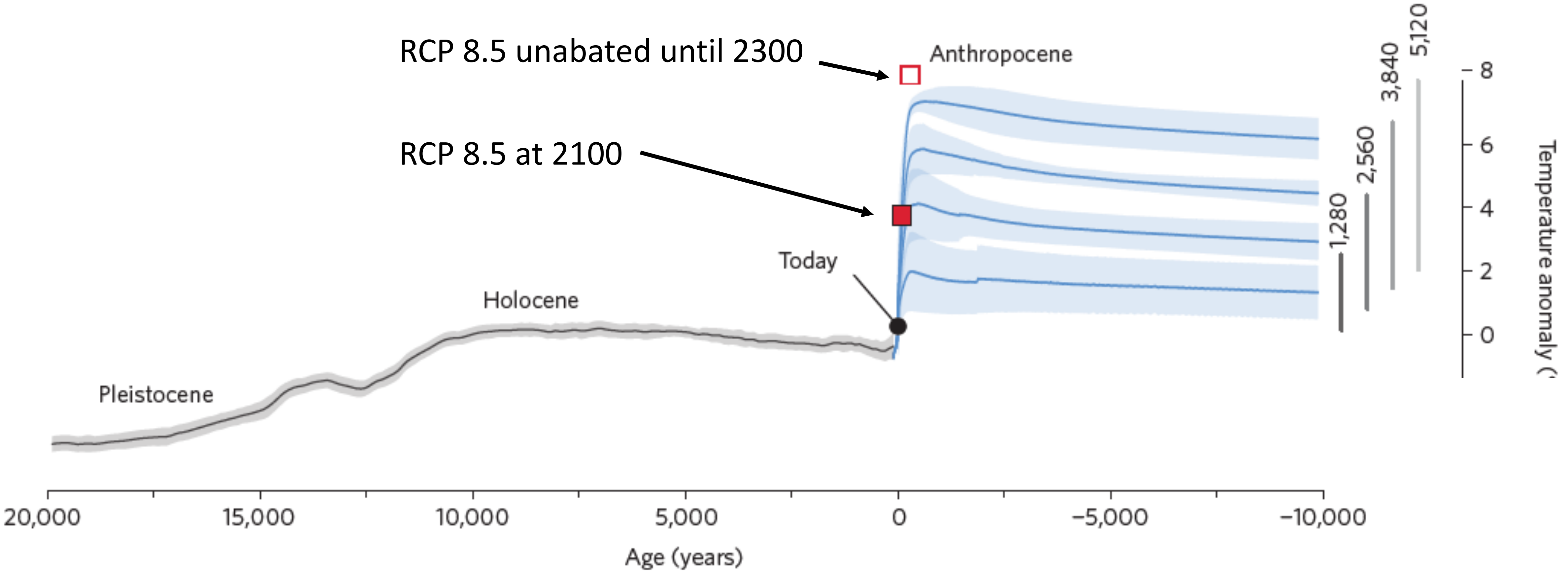


The *Really* Long View – 12,000 CE

Temperatures continue their slow decline (as seen in the 3000 AD projections)

RCP 8.5 – Still 5 to 6.5°C warmer

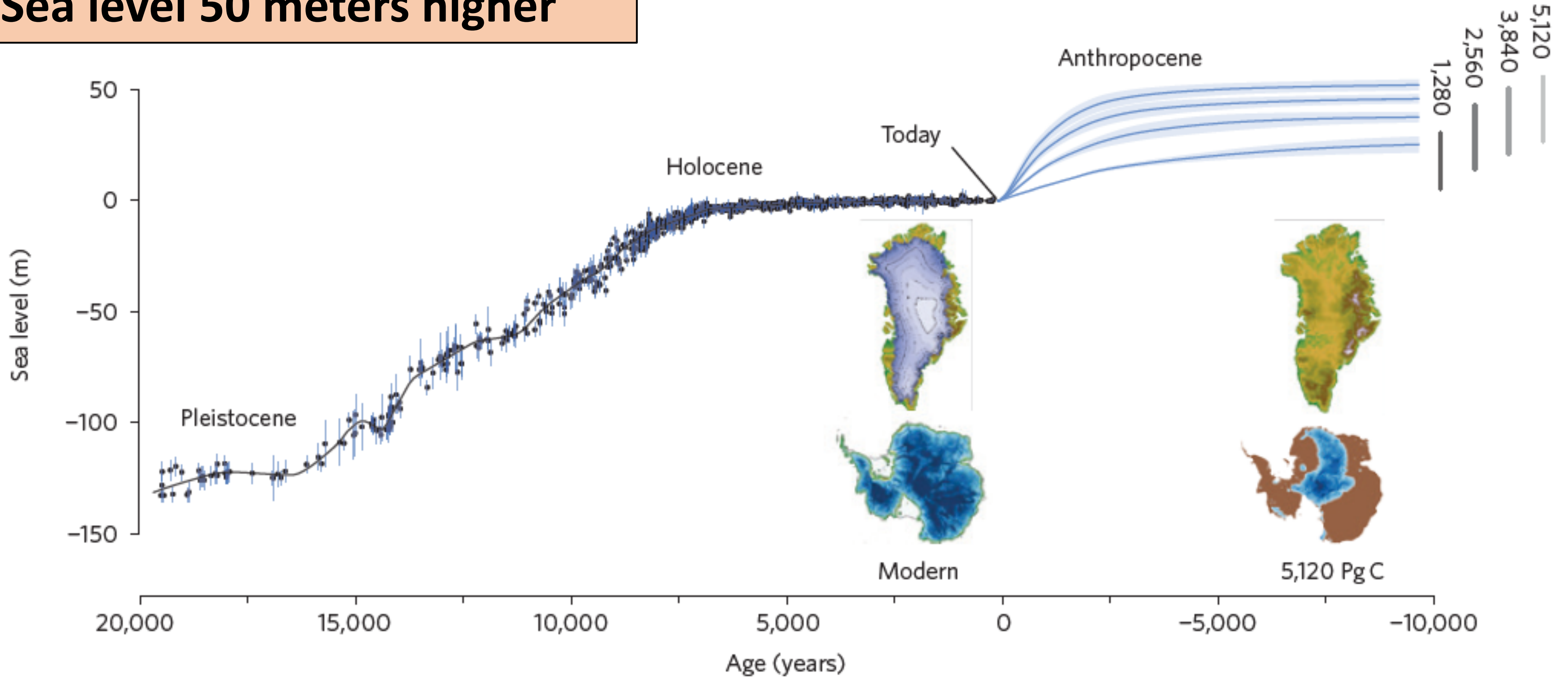
RCP 4.5 (lowest here) – 0.5 to 2°C warmer



The *Really* Long View – 12,000 CE

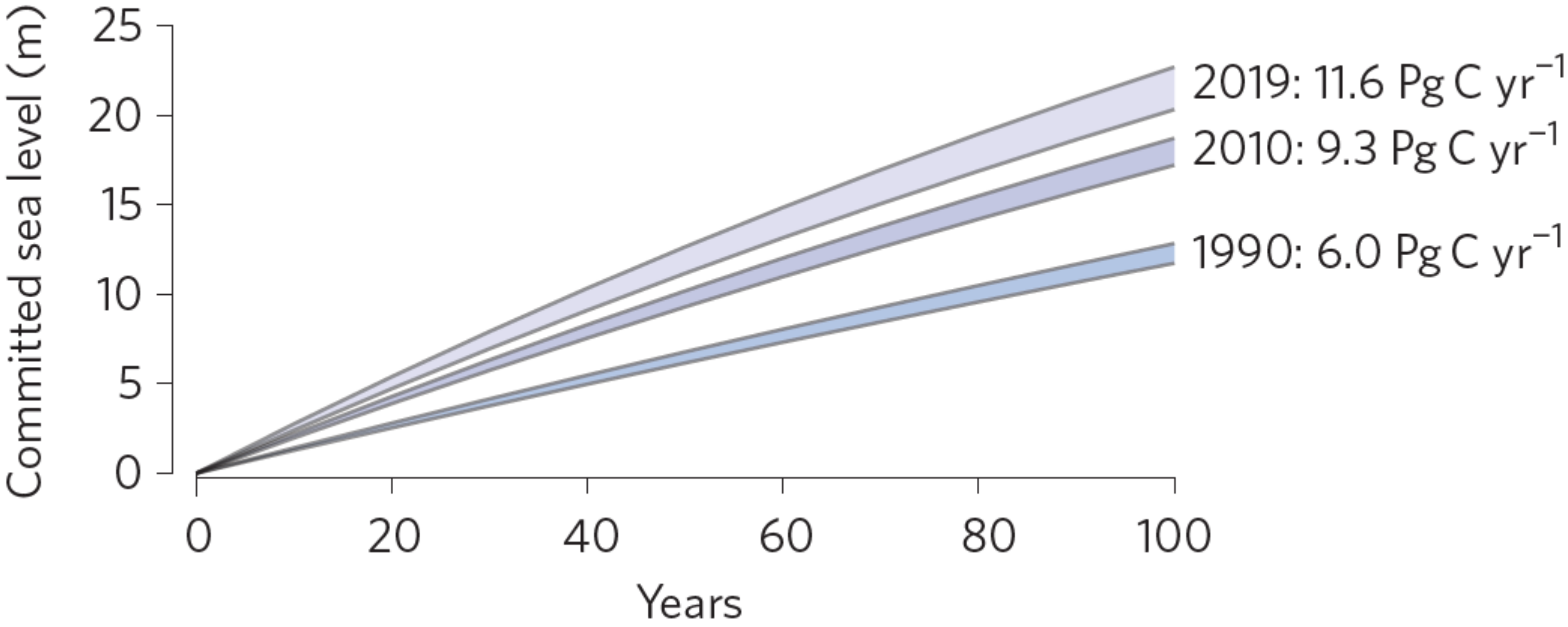
Under the highest emission scenario, Greenland gone, Antarctica smaller

Sea level 50 meters higher



The *Really* Long View – 12,000 CE

Our emissions this century will directly effect these long-term predictions



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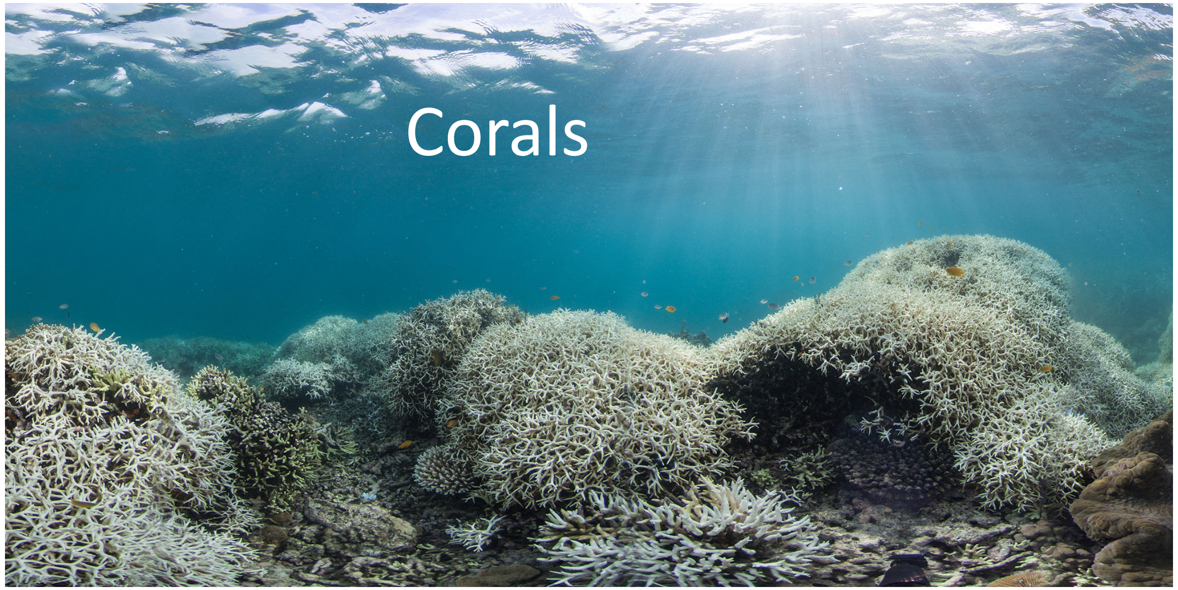
Think, Pair, Share

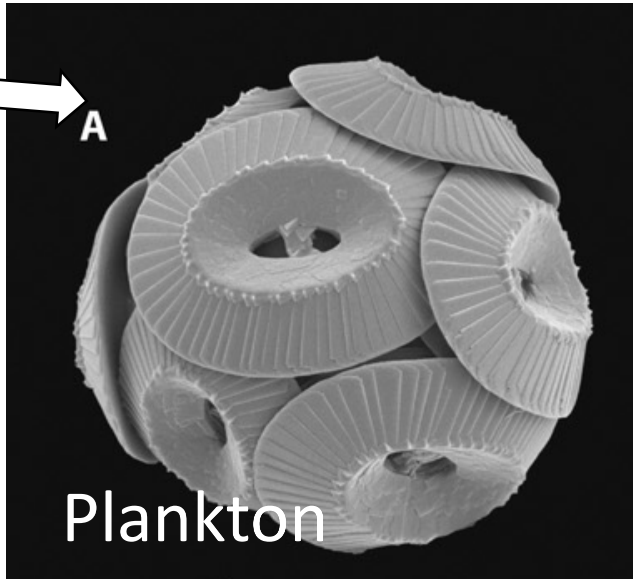
What are some societal impacts that these slow climate responses could have?

Societal Impacts

Increased ocean heat and carbon uptake leads to:

- Warmer waters
- Ocean acidification
- Will affect marine ecosystems drastically

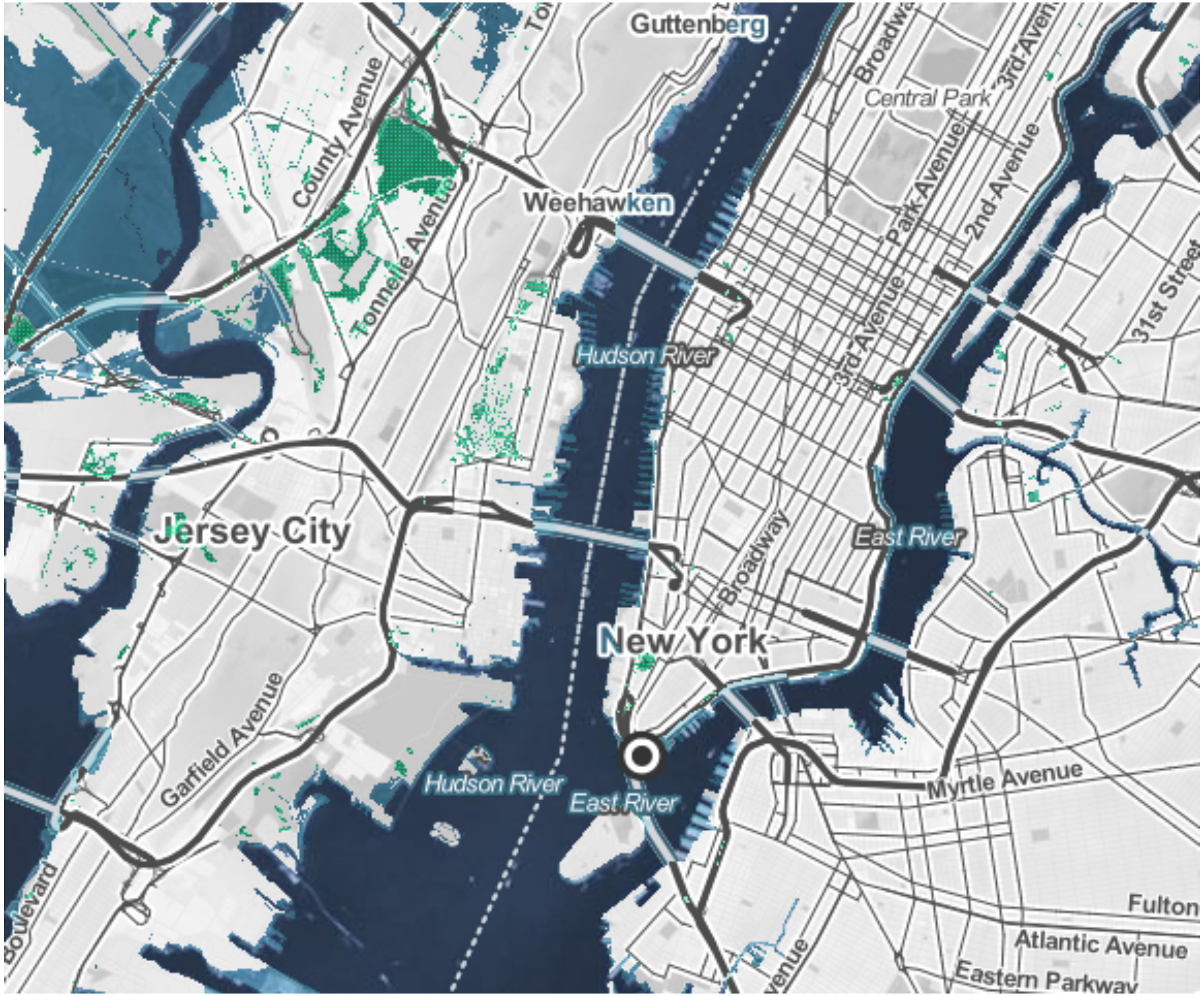




Societal Impacts

3000 CE Sea Level Rise

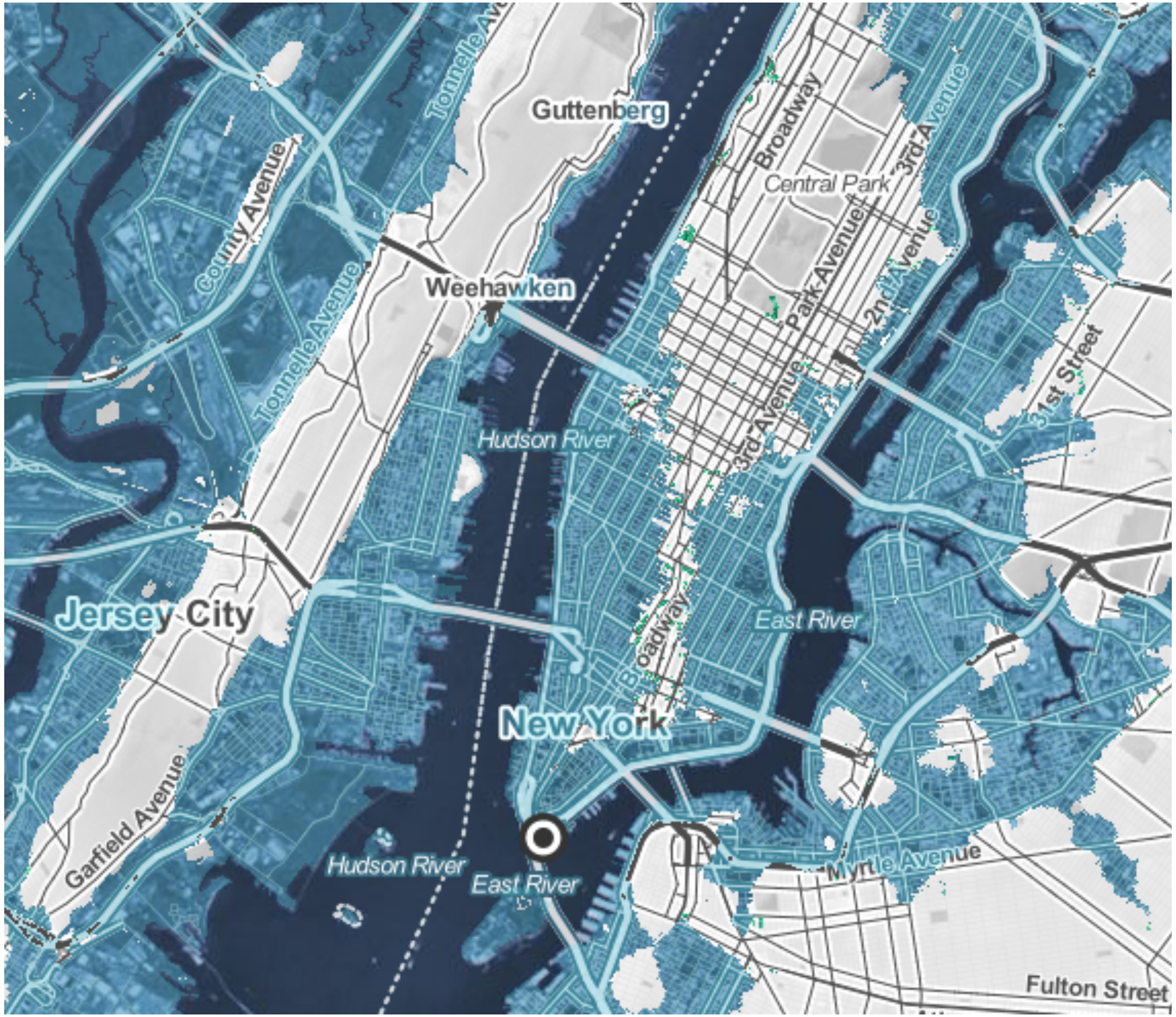
- **RCP 8.5 –** 8 to 14 meters
- **RCP 2.6** – 0.7 to 2.7 meters
- **Map showing 0.5 m sea level rise**



Societal Impacts

3000 CE Sea Level Rise

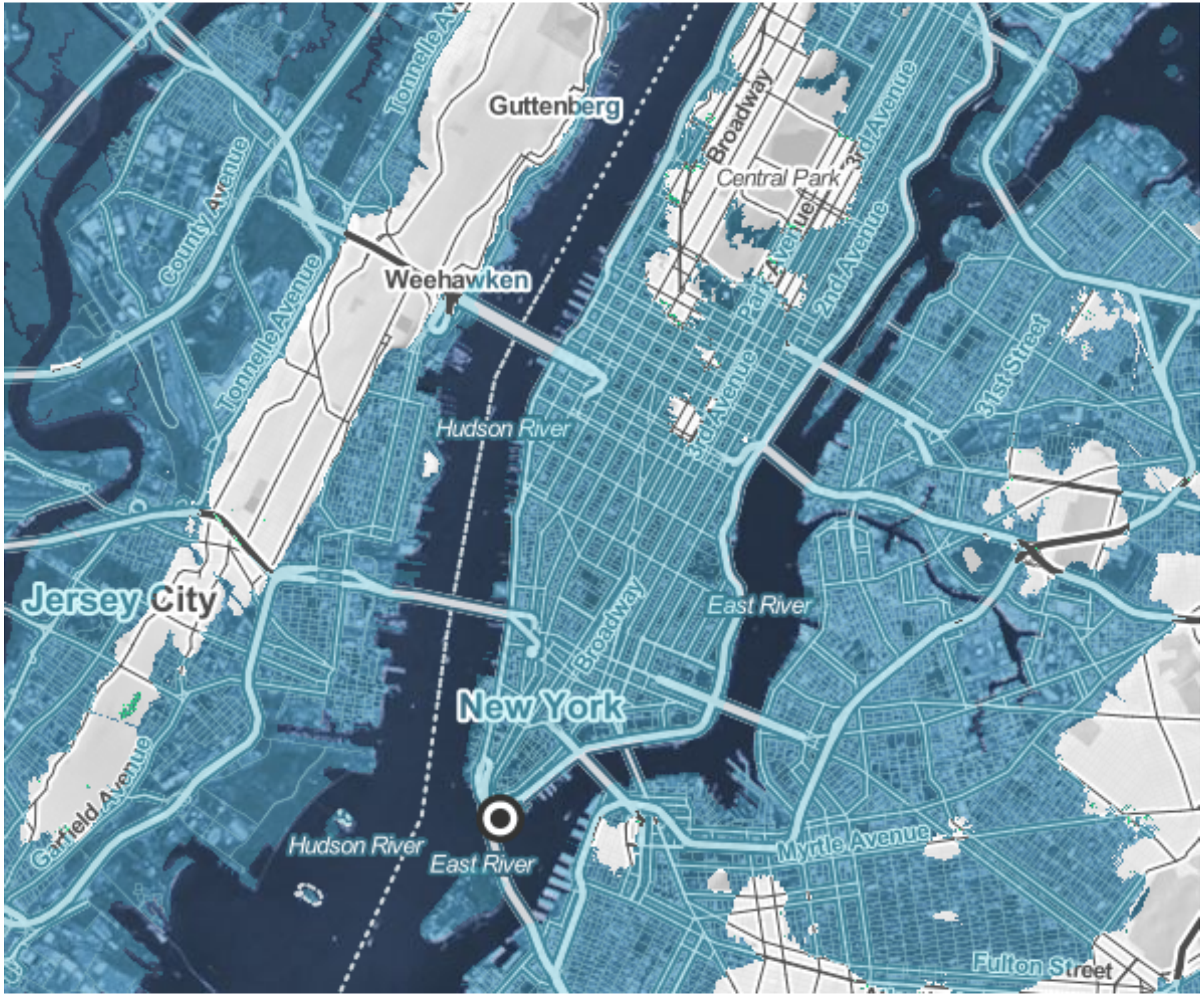
- **RCP 8.5 –** 8 to 14 meters
- **RCP 2.6** – 0.7 to 2.7 meters
- **Map showing 10 m sea level rise**



Societal Impacts

12,000 CE Sea Level Rise

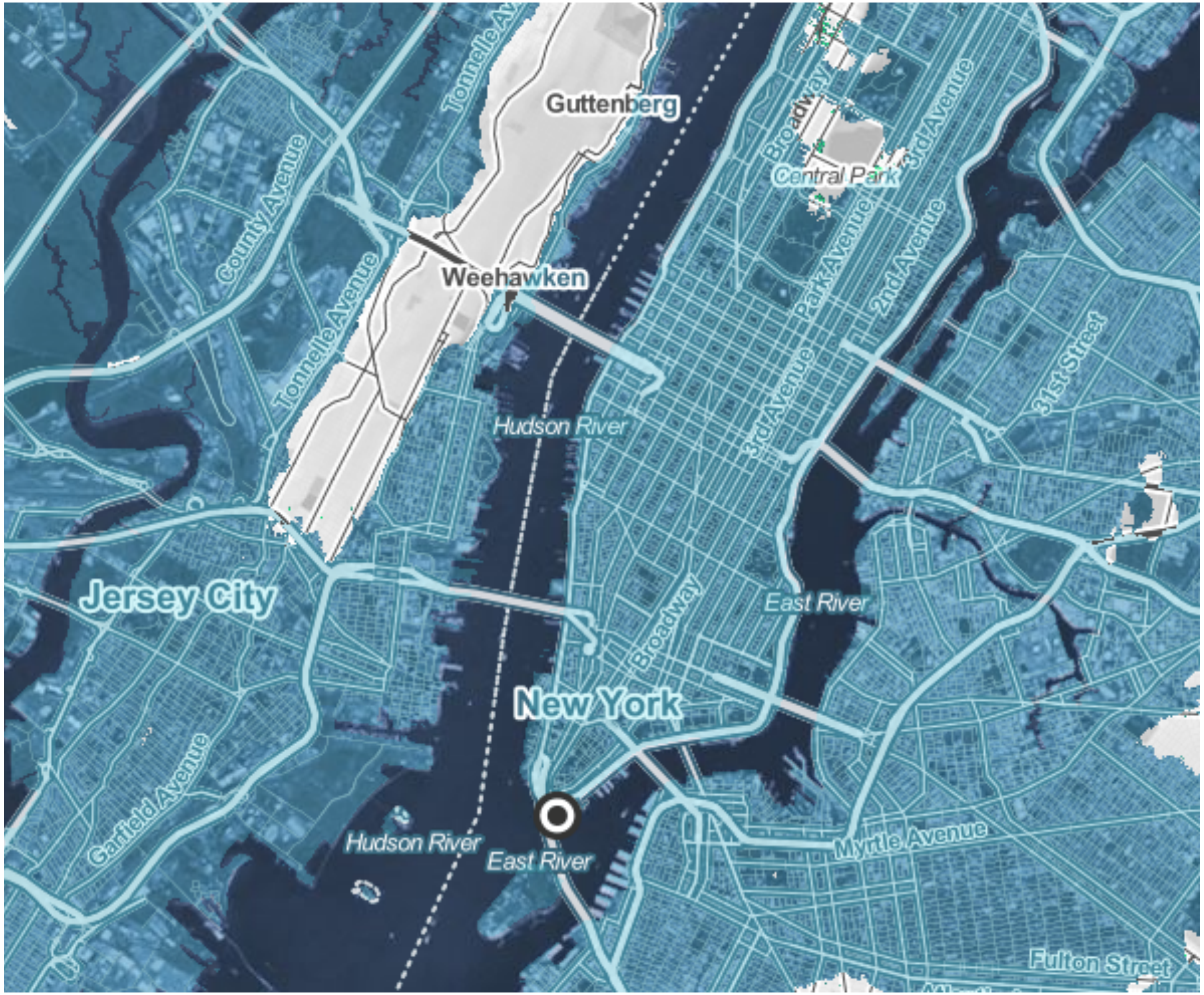
- **RCP 8.5 –** 50 meters
- **RCP 4.5** – 18 to 21 meters
- **Map showing 20 m sea level rise**



Societal Impacts

12,000 CE Sea Level Rise

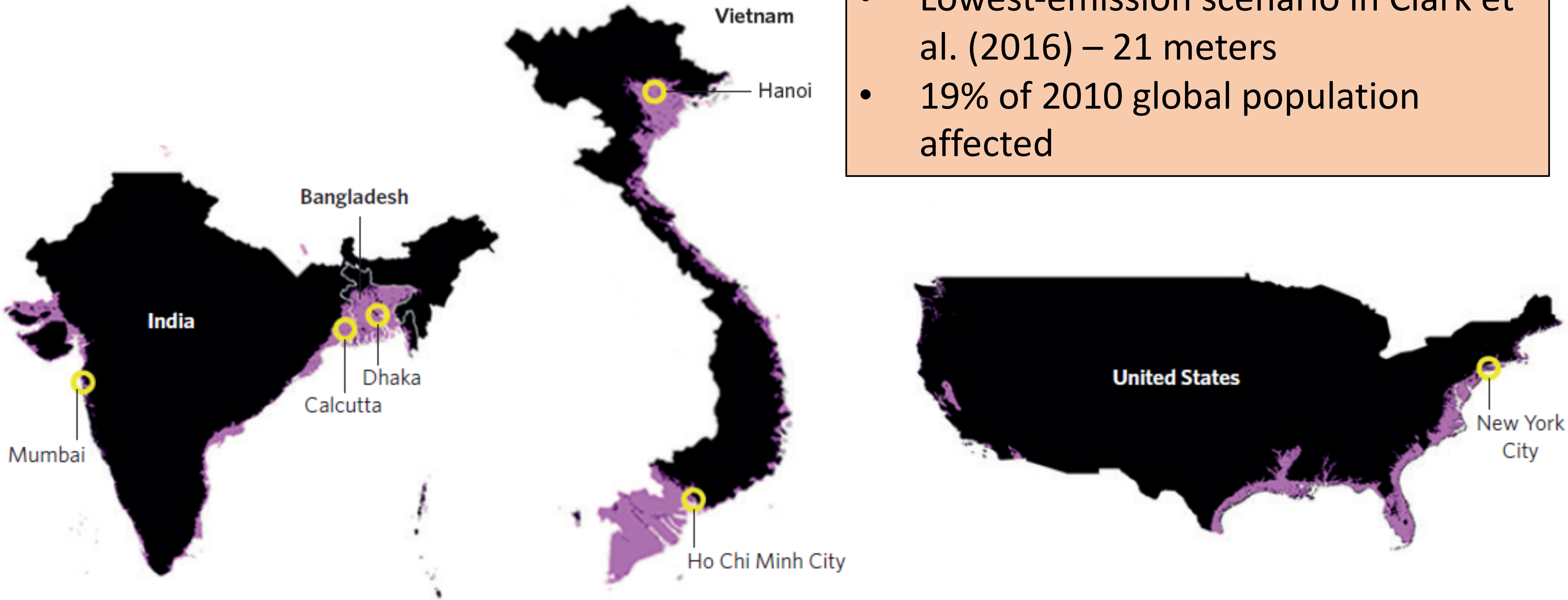
- **RCP 8.5 –** 50 meters
- **RCP 4.5** – 18 to 21 meters
- **Map showing 30 m sea level rise**



Societal Impacts

Long-term sea level rise

- Lowest-emission scenario in Clark et al. (2016) – 21 meters
- 19% of 2010 global population affected



Societal Impacts