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
3. Explain expected climate impacts by 2300, 3000, and 12,000 CE
4. Explain how a predicted long-term climate response will affect human societies
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.
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.
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
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
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.
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
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

![Near-surface permafrost area](image)

Figure from the IPCC
Why take the long view?

**Fast Climate Responses**

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Figure from the National Climate Assessment
Why take the long view?

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Figure from the EPA
Why take the long view?

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Figure from the IPCC
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

Greenland Cumulative Melt Days
Jan 1 - Nov 5 2019

NSIDC / Thomas Mote, University of Georgia
Slow Climate Responses

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• Examples:
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Slow Climate Responses

• Some systems respond slowly (centuries to millennia) to a forcing
• Will *not* see a big response by 2100
• Examples:
  • Ice sheet melt
  • Ocean circulation change
  • Deep ocean heat sequestration
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.
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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Why take the long view? – Slow Responses and Feedbacks – The really long view – Societal Impacts
The *Really* Long View – 2300 CE
The Really Long View – 2300 CE

- 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
The Really Long View – 2300 CE

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

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

CO₂ 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)
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
The Really Long View – 2300 CE (AMOC)

- **RCP 8.5** - AMOC drastically weakened
- **RCP 2.6** - AMOC could recover fully
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?
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
No AMOC projections out this far! Likely that AMOC follows Greenland trend
- RCP 8.5 – Reduced AMOC
- RCP 2.6 – Recovered AMOC
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

Only one team has ever projected climate out this far

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

Peter U. Clark¹*, Jeremy D. Shakun², Shaun A. Marcott³, Alan C. Mix¹, Michael Eby⁴,⁵, Scott Kulp⁶, Anders Levermann⁷,⁸,⁹, Glenn A. Milne¹⁰, Patrik L. Pfister¹¹, Benjamin D. Santer¹², Daniel P. Schrag¹³, Susan Solomon¹⁴, Thomas F. Stocker¹¹,¹⁵, Benjamin H. Strauss⁶, Andrew J. Weaver⁴, Ricarda Winkelmann⁷, David Archer¹⁶, Edouard Bard¹⁷, Aaron Goldner¹⁸, Kurt Lambeck¹⁹,²⁰, Raymond T. Pierrehumbert²¹ and Gian-Kasper Plattner¹¹

(2016)
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)

RCP 8.5 unabated until 2300

RCP 8.5 at 2100

Today

CO₂ (ppm)

Age (years)
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

RCP 8.5 unabated until 2300

RCP 8.5 at 2100

Anthropocene

Today

Holocene

Pleistocene

Age (years)
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

2019: 11.6 Pg C yr\(^{-1}\)
2010: 9.3 Pg C yr\(^{-1}\)
1990: 6.0 Pg C yr\(^{-1}\)
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Responses & Feedbacks vs. Time
The really long view
Societal Impacts
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Why take the long view?

Responses & Feedbacks vs. Time

The really long view

Societal Impacts
Think, Pair, Share

What are some societal impacts that these slow climate responses could have?
Increased ocean heat and carbon uptake leads to:

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