Climates of the Future

EES 3310/5310

Global Climate Change

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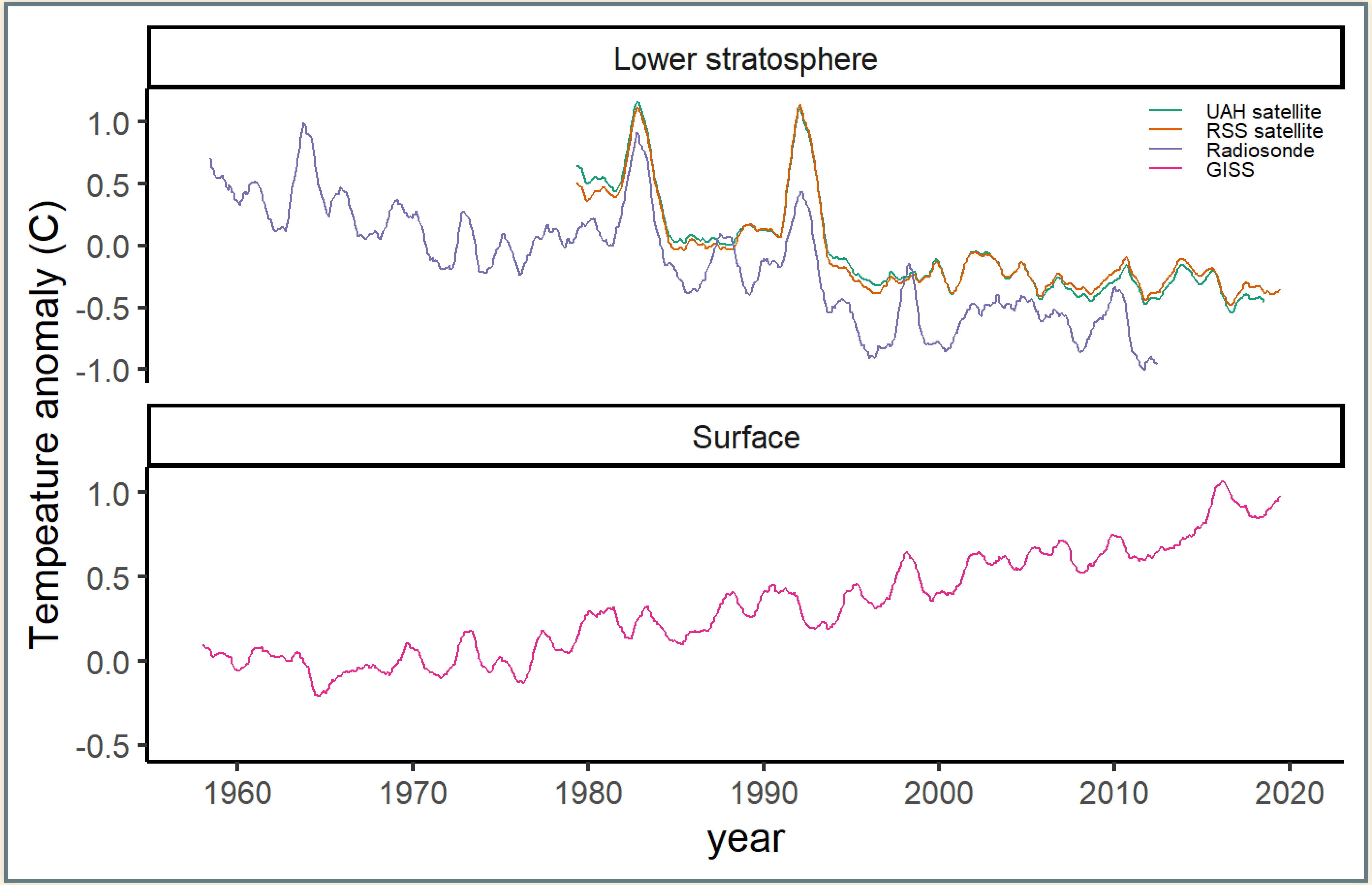
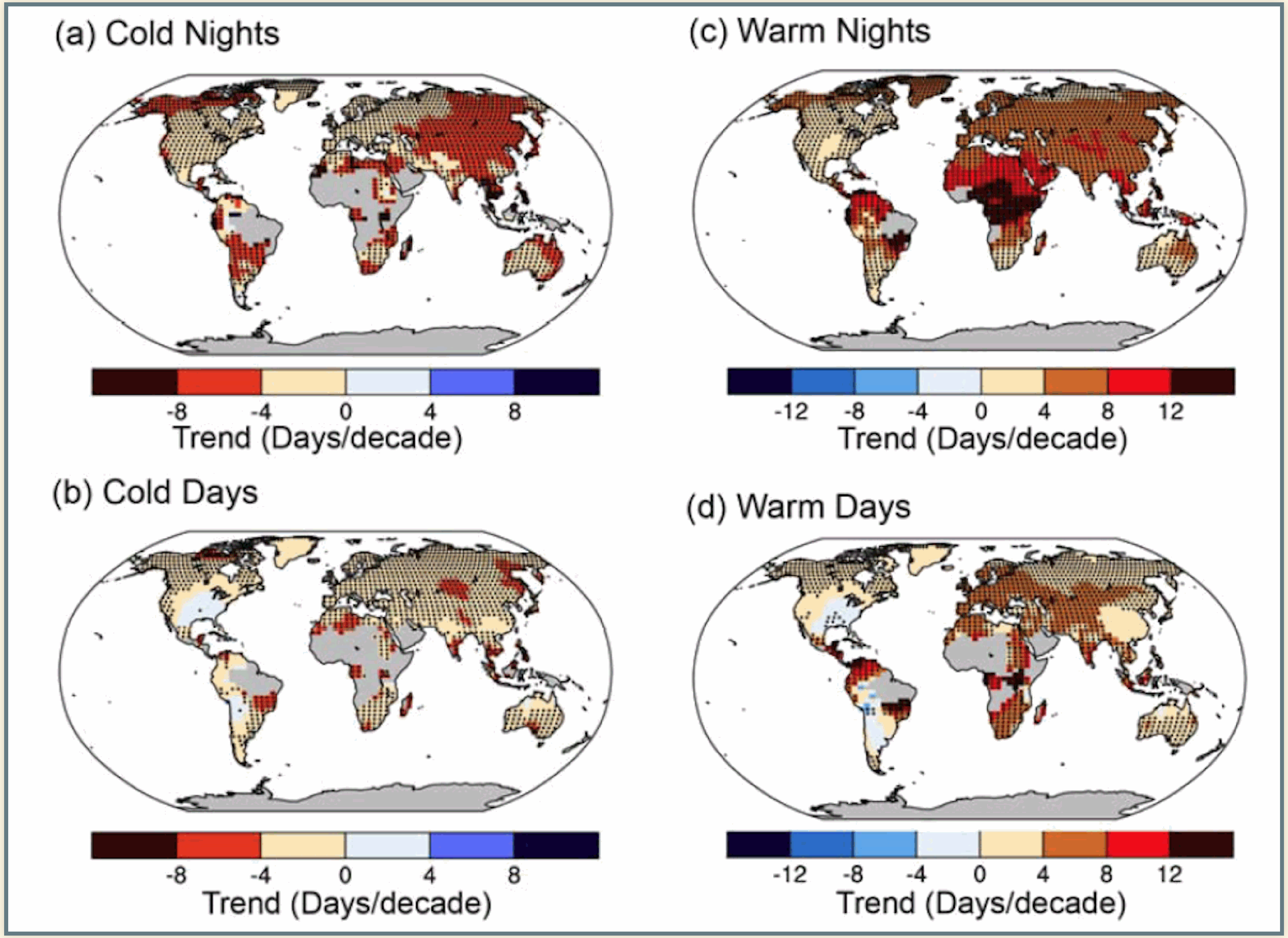
Class #17: Friday, February 14 2020

Using Models to Test Theories about the Cause of Global Warming

Stratosphere vs. Troposphere:



Day vs. Night



(a) Cold Nights
-8 -4 0 4 8
Trend (Days/decade)
(c) Warm Nights
-12 -8 -4 0 4 8 12
Trend (Days/decade)
(b) Cold Days
-8 -4 0 4 8
Trend (Days/decade)
(d) Warm Days
-12 -8 -4 0 4 8 12
Trend (Days/decade)

Modeling for Science vs. Policy

Modeling for Science vs. Policy

Integrated Assessment Models (IAMS)

- Combine climate system and world economy
  - Emissions as a consequence of economic activity
    - Energy use for production (factories, etc.)
    - Energy use for consumption (households, etc.)
    - Farming: fertilizers, livestock, paddy fields, etc.
  - Climatic impacts on economy
    - Cost of severe weather
    - Sea level rise
    - Droughts & heat waves
    - …
- **Optimize for greatest net economic output**

Predictions & Projections

- Predictions are hard:
- Biggest uncertainty in predicting future climates is GHG emissions
  - We can predict consequences of emissions
  - We can't predict what emissions will be
- Projections:
  - Conditional predictions:
    - "**If** emissions do this, **then** climate will do that."
  - Scenarios and Pathways of future emissions:
    - **Scenario**:
      - Start with a story of economic & political development
      - Calculate resulting emissions
    - **Pathway**:
      - Start with possible emissions trajectory
      - Develop a plausible story that could produce it

Projections for future emissions in US:

	2010	**2050**	**Growth rate**
g (\$/person)	42,300	83,495	1.7%
ef (tons/\$million)	432	228	-1.6%
P (millions)	309	393	0.6%
Total Emissions *F* (million tons CO_2)	**5,647**	**7,471**	1.7 - 1.6 + 0.6 = **0.7%**

Projections for future world emissions:

	2010	**2050**	**Growth rate**
g ($/person)	9,780	22,654	2.1%
ef (tons/$million)	522	275	-1.6%
P (millions)	6,410	9,188	0.9%
Total Emissions F (million tons CO_2)	**32,724**	**57,289**	2.1 - 1.6 + 0.9 = **1.4%**

Uncertainties in Projections

Projections for future world emissions:

	2010	**2050**	**2100**	**Growth rate**
g ($/person)	9,780	22,654	64,737	2.1%
ef (tons/$million)	522	275	124	-1.6%
P (millions)	6,410	9,188	14,409	0.9%
Total Emissions F (million tons CO_2)	**32,724**	**57,289**	**115,366**	**1.4%**

Uncertainties in Projections

Projections for future world emissions with slightly different growth rates:

	2010	2050	2100	Growth rate
g ($/person)	9,780	24,541	77,505	2.3%
ef (tons/$million)	522	298	148	-1.4%
P (millions)	6,410	9,563	15,766	1.0%
Total Emissions F (million tons CO_2)	**32,724**	**69,973**	**180,930**	**1.9%**
Difference		**12,684**	**65,564**	**0.5%**
Difference (%)		**22%**	**57%**	

Decisions Under Uncertainty

- **Global Climate change:**
  - Great Certainty:
    - People are warming the planet.
    - Warming will continue long after CO_2 stops rising.
    - Changes will persist for thousands of years.
  - Uncertain:
    - How much will planet warm (factor of ~2).
- **Impacts of Global Climate Change:**
  - Fairly Certain:
    - Severe heat waves will get worse.
    - Drought will get worse for much of the planet.
    - Intense rain & floods will get worse.
  - Very Uncertain:
    - Hurricanes & tornadoes.
- **Local/Regional Climate Change**
  - Fairly certain about some detailed local impacts.
  - Enormously uncertain about others.

Consequences of Climate Change

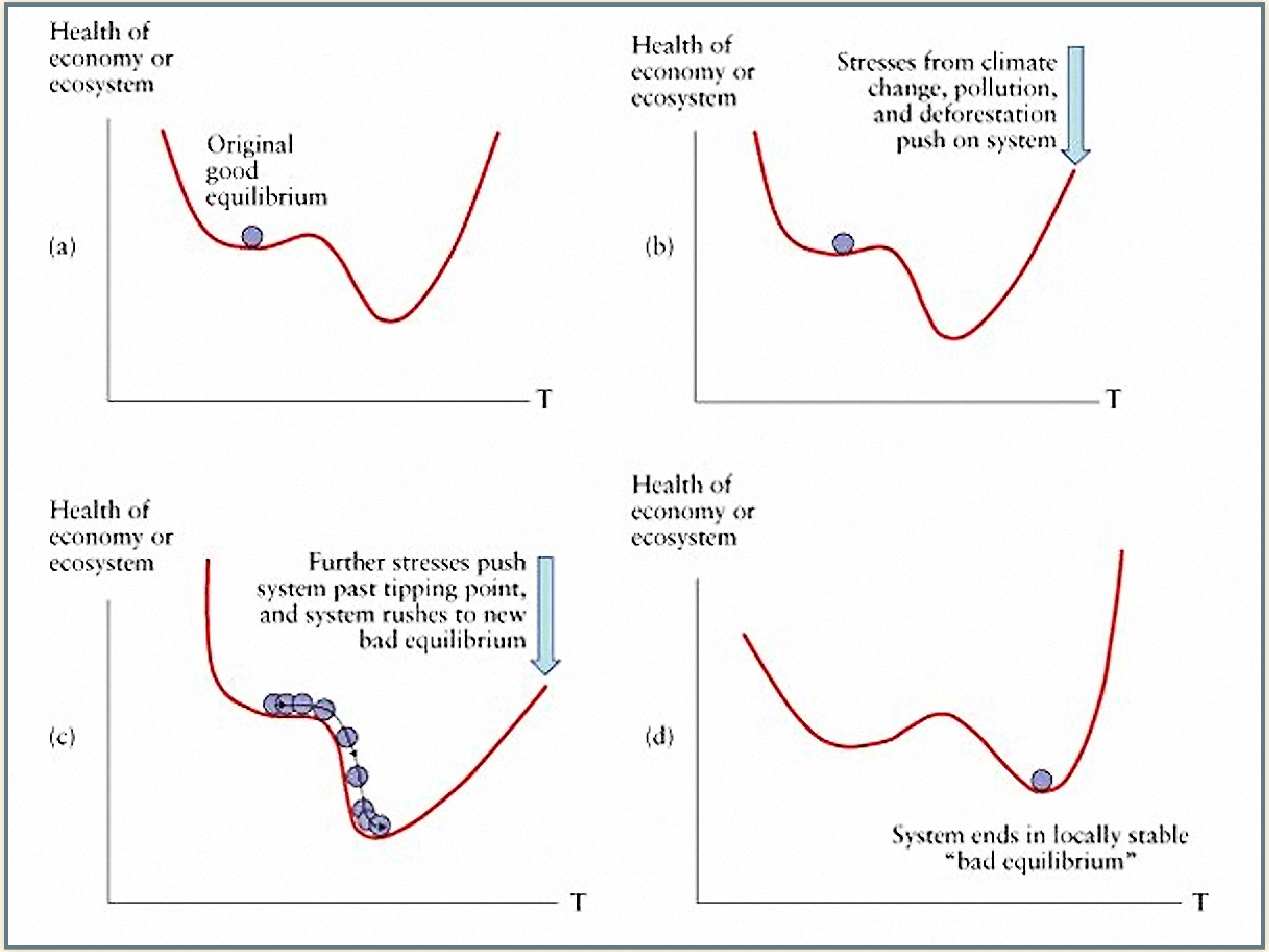
- **Economic effects:**
  - Costs of acting
  - Costs of inaction
  - Uncertainties
- **Policy issues:**
  - Markets vs. Regulation
    - Externalities
    - Kaya Identity: $F = P \times g \times e \times f$.

Tipping points

What we know about tipping points

- Very hard to predict them.
- *Climate Casino*: important tipping points:
  - Ice sheet melting
  - Coral reefs
  - Tropical rain Forests
  - Runaway greenhouse gas release
  - Slowdown of ocean conveyor belt circulation
  - ...

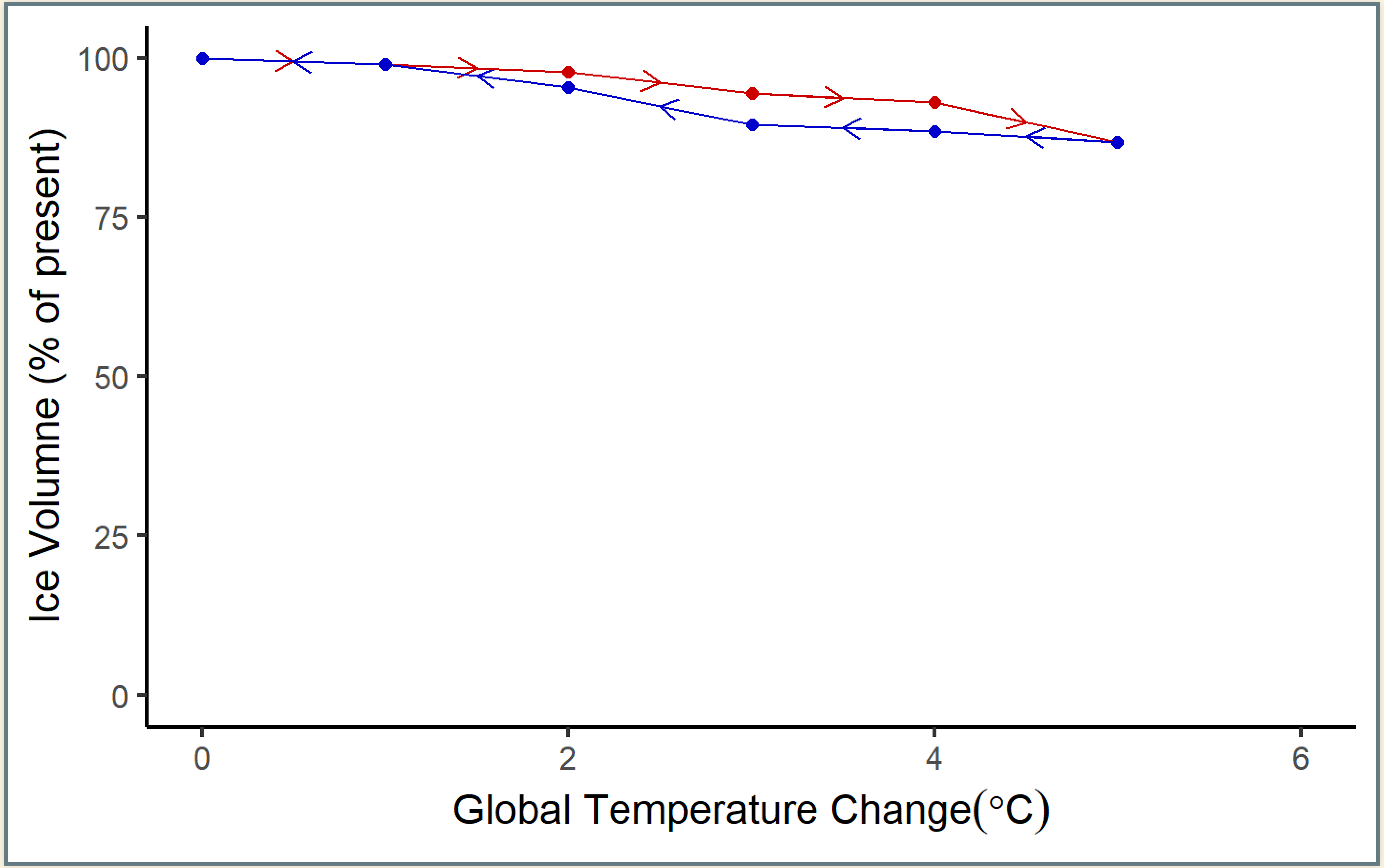
Bistability & Tipping Points



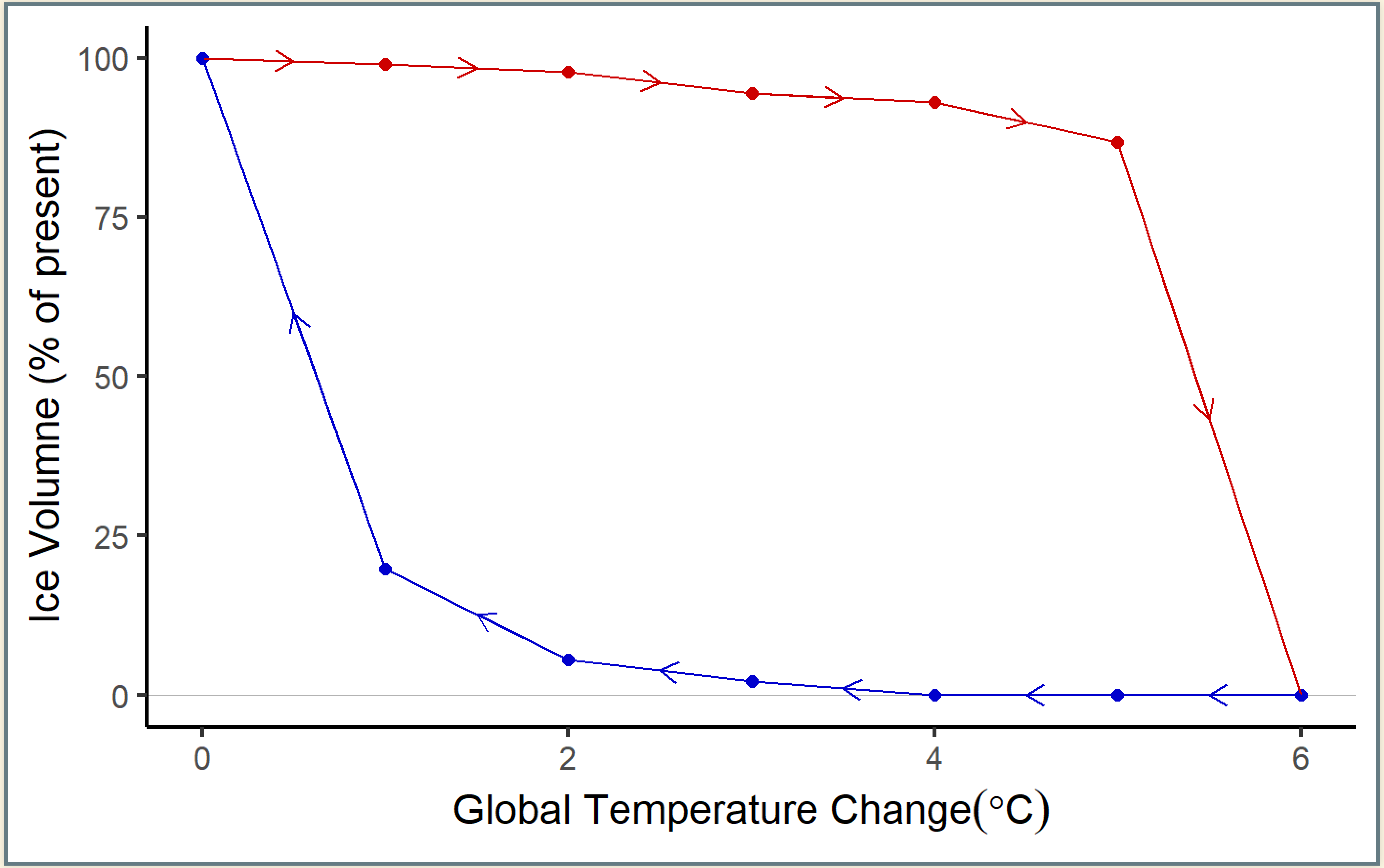
Hysteresis and Tipping Points

GRANTISM Model

Hysteresis:
Temperature and Ice Sheets



Hysteresis:
Crossing Tipping Point



Principles of Tipping Points

- Ordinary positive feedbacks amplify changes (hot → hotter, cold → colder).
  - Small positive feedbacks amplify but the *system remains stable*.
- If positive feedbacks are too strong they become *self-perpetuating*.
  - Secondary forcing from feedback creates *unstoppable change*.
- If feedback *strengthens with warming*:
  - Tipping point: feedback becomes strong enough to continue warming independent of external forcing.
- **Not all positive feedbacks have tipping points.**
- **Hard to predict** when a positive feedback might go from *amplifying* to *runaway* (tipping point).

Where are they?

- *Climate Casino*: No big danger of fast tipping points if warming stays less than 3°C
- But, recent research finds that West Antarctic Ice Sheet has already crossed irreversible tipping point.

New Scientific Paper

Climate tipping points — too risky to bet against

Timothy M. Lenton, Johan Rockström, Owen Gaffney, Stefan Rahmstorf, Katherine Richardson, Will Steffen & Hans Joachim Schellnhuber

The growing threat of abrupt and irreversible climate changes must compel political and economic action on emissions.

Politicians, economists and even some natural scientists have tended to assume that tipping points[1] in the Earth system — such as the loss of the Amazon rainforest or the West Antarctic ice sheet — are of low probability and little understood. Yet evidence is mounting that these events could be more likely than was thought, have high impacts and are interconnected across different biophysical systems, potentially committing the world to long-term irreversible changes.

Here we summarize evidence on the threat of exceeding tipping points, identify knowledge gaps and suggest how these should be plugged. We explore the effects of such large-scale changes, how quickly they might unfold and whether we still have any control over them.

In our view, the consideration of tipping points helps to define that we are in a climate emergency and strengthens this year's chorus of calls for urgent climate action — from schoolchildren to scientists, cities and countries.

The Intergovernmental Panel on Climate Change (IPCC) introduced the idea of tipping points two decades ago. At that time, these 'large-scale discontinuities' in the climate system were considered likely only if global warming exceeded 5 °C above pre-industrial levels. Information summarized in the two most recent IPCC Special Reports (published in 2018 and in September this year)[2,3] suggests that tipping points could be exceeded even between 1 and 2 °C of warming (see 'Too close for comfort').

If current national pledges to reduce greenhouse-gas emissions are implemented — and that's a big 'if' — they are likely to result in at least 3 °C of global warming. This is despite the goal of the 2015 Paris agreement to limit warming to well below 2 °C. Some economists, assuming that climate tipping points are of very low probability (even if they would be catastrophic), have suggested that 3 °C warming is optimal from a cost–benefit perspective. However, if tipping points are looking more likely, then the 'optimal policy' recommendation of simple cost–benefit climate-economy models[4] aligns with those of the recent IPCC report[2]. In other words, warming must be limited to 1.5 °C. This requires an emergency response.

Ice collapse

We think that several cryosphere tipping points are dangerously close, but mitigating greenhouse-gas emissions could still slow down the inevitable accumulation of impacts and help us to adapt.

Research in the past decade has shown that the Amundsen Sea embayment of West Antarctica might have passed a tipping point[3]: the 'grounding line' where ice, ocean and bedrock meet is retreating irreversibly. A model study shows[5] that when this sector collapses, it could destabilize the rest of the West Antarctic ice sheet like toppling dominoes — leading to about 3 metres of sea-level rise on a timescale of centuries to millennia. Palaeo-evidence shows that such widespread collapse of the West Antarctic ice sheet has occurred repeatedly in the past.

The latest data show that part of the East Antarctic ice sheet — the Wilkes Basin — might be similarly unstable[3]. Modelling work suggests that it could add another 3–4 m to sea level on timescales beyond a century.

The Greenland ice sheet is melting at an accelerating rate[3]. It could add a further 7 m to sea level over thousands of years if it passes a particular threshold. Beyond that, as the elevation of the ice sheet lowers, it melts further, exposing the surface to ever-warmer air. Models suggest that the Greenland ice sheet could be doomed at 1.5 °C of warming[3], which could happen as soon as 2030.

Thus, we might already have committed future generations to living with sea-level rises of around 10 m over thousands of years[3]. But that timescale is still under our control. The rate of melting depends on the magnitude of warming above the tipping point. At 1.5 °C, it could take 10,000 years to unfold[3]; above 2 °C it could take less than 1,000 years[6].

An aeroplane flies over a glacier in the Wrangell St Elias National Park in Alaska.

FRANS LANTING/NAT. GEO. IMAGE COLLECTION

Researchers need more observational data to establish whether ice sheets are reaching a tipping point, and require better models constrained by past and present data to resolve how soon and how fast the ice sheets could collapse.

Whatever those data show, action must be taken to slow sea-level rise. This will aid adaptation, including the eventual resettling of large, low-lying population centres.

A further key impetus to limit warming to 1.5 °C is that other tipping points could be triggered at low levels of global warming. The latest IPCC models projected a cluster of abrupt shifts[7] between 1.5 °C and 2 °C, several of which involve sea ice. This ice is already shrinking rapidly in the Arctic, indicating that, at 2 °C of warming, the region has a 10–35% chance[3] of becoming largely ice-free in summer.

"The clearest emergency would be if we were approaching a global cascade of tipping points."

Biosphere boundaries

Climate change and other human activities risk triggering biosphere tipping points across a range of ecosystems and scales (see 'Raising the alarm').

Ocean heatwaves have led to mass coral bleaching and to the loss of half of the shallow-water corals on Australia's Great Barrier Reef. A staggering 99% of tropical corals are projected[2] to be lost if global average temperature rises by 2 °C, owing to interactions between warming, ocean acidification and pollution. This would represent a profound loss of marine biodiversity and human livelihoods.

As well as undermining our life-support system, biosphere tipping points can trigger abrupt carbon release back to the atmosphere. This can amplify climate change and reduce remaining emission budgets.

Deforestation and climate change are destabilizing the Amazon — the world's largest rainforest, which is home to one in ten known species. Estimates of where an Amazon tipping point could lie range from 40% deforestation to just 20% forest-cover loss[8]. About 17% has been lost since 1970. The rate of deforestation varies with changes in policy. Finding the tipping point requires models that include deforestation and climate change as interacting drivers, and that incorporate fire and climate feedbacks as interacting tipping mechanisms across scales.

With the Arctic warming at least twice as quickly as the global average, the boreal forest in the subarctic is increasingly vulnerable. Already, warming has triggered large-scale insect disturbances and an increase

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T. Lenton *et al.*, Nature **575**, 592 (2019).

But Can We Trust the Experts?

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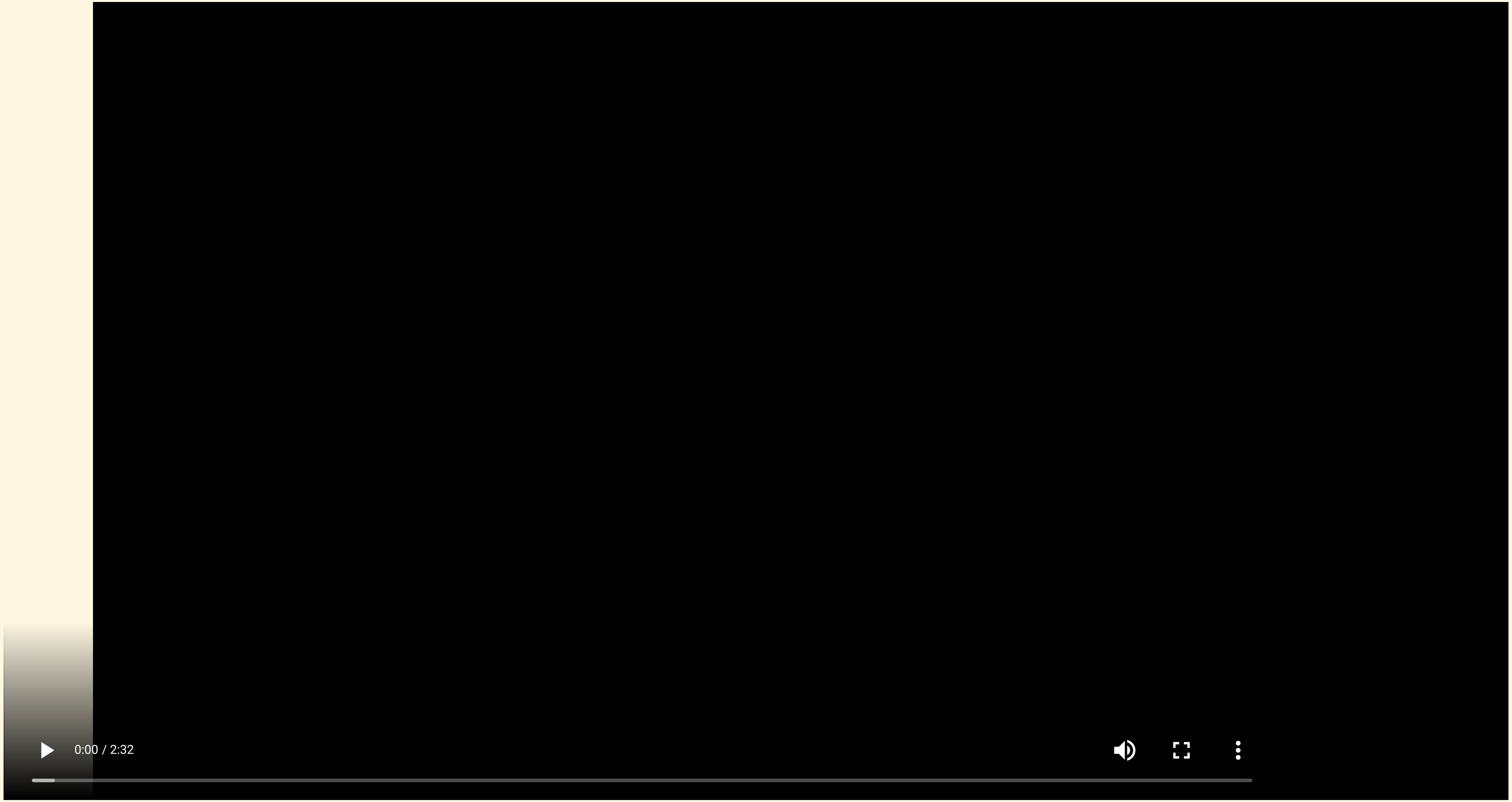
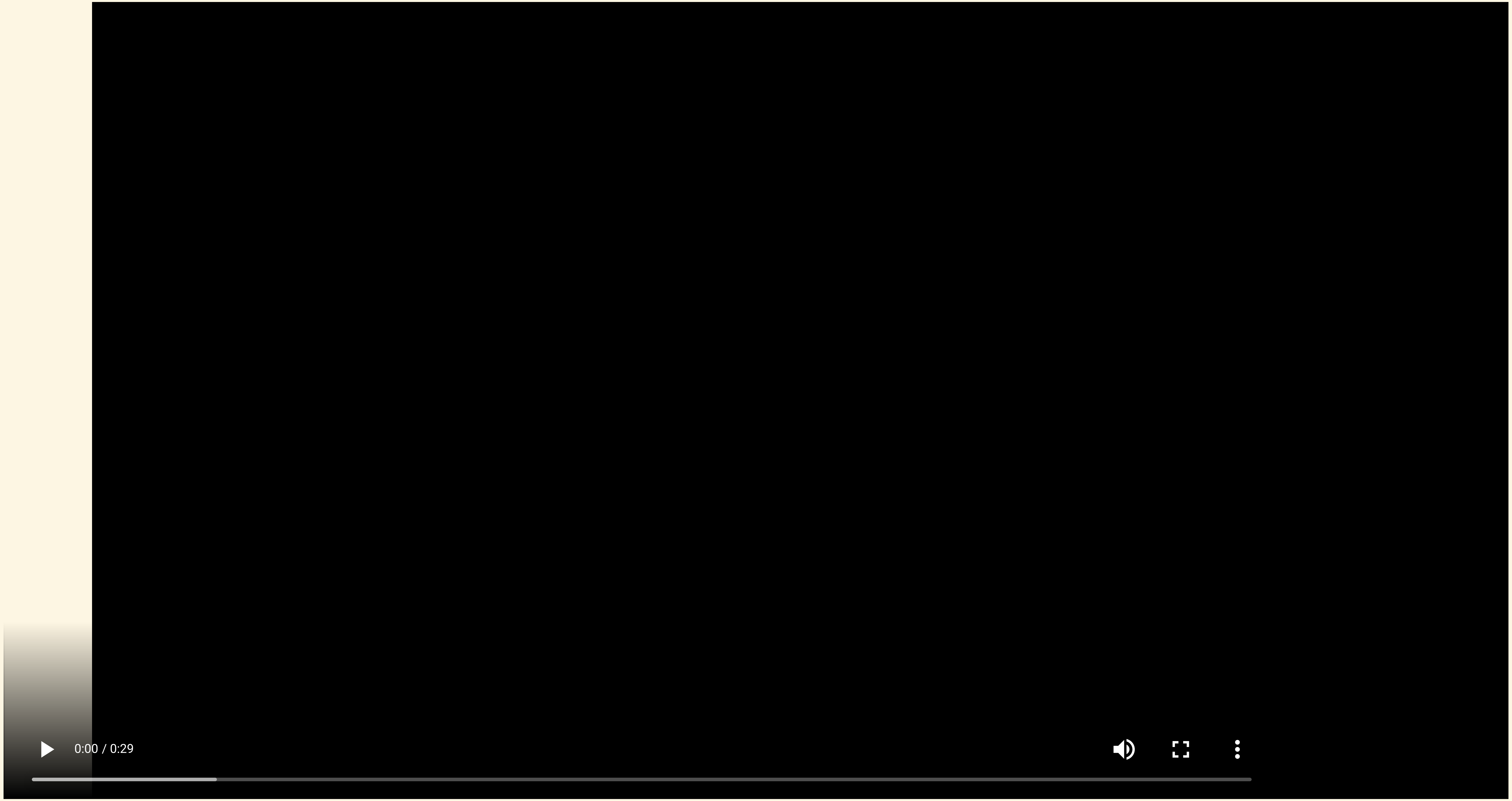
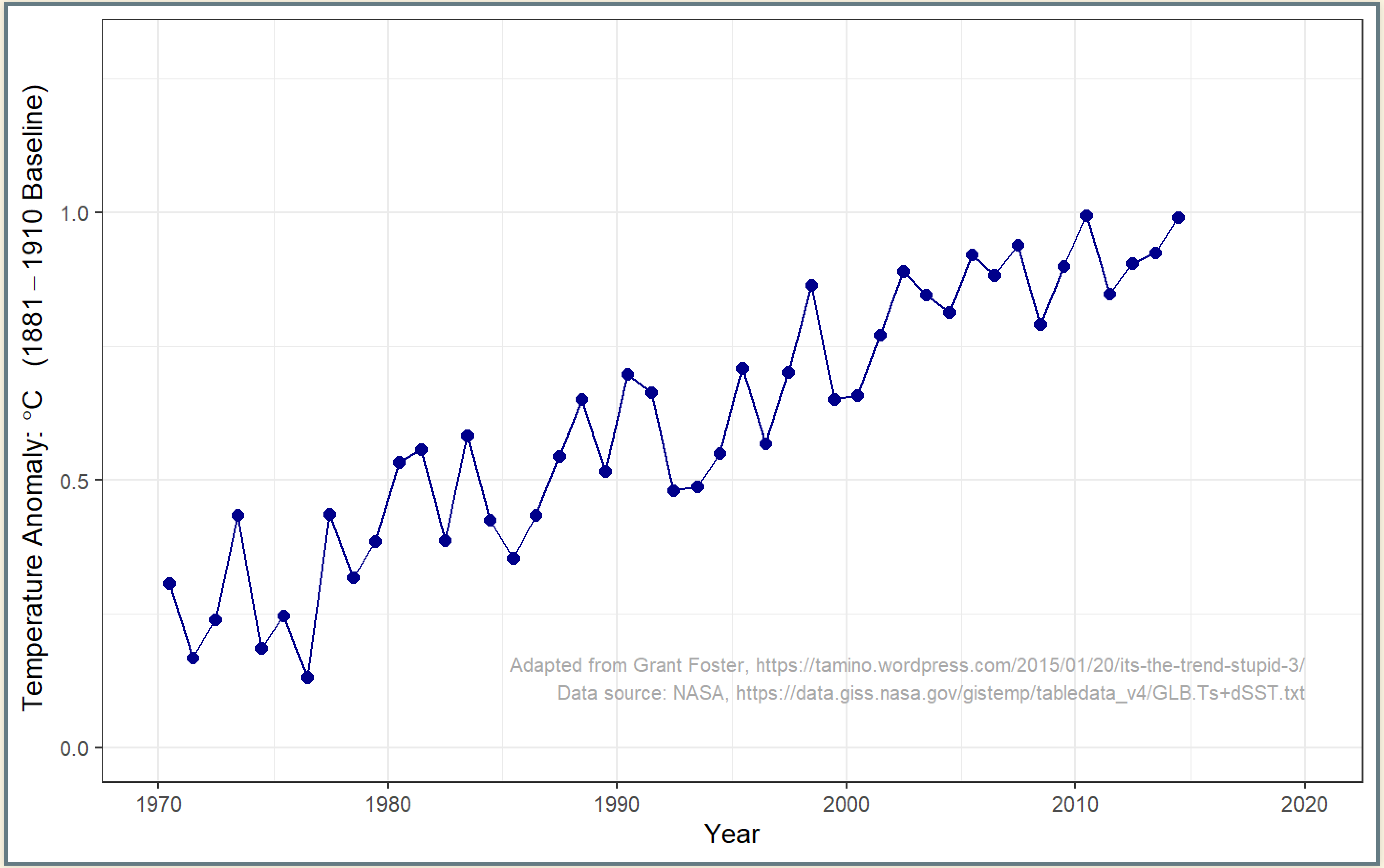


Marsha Blackburn

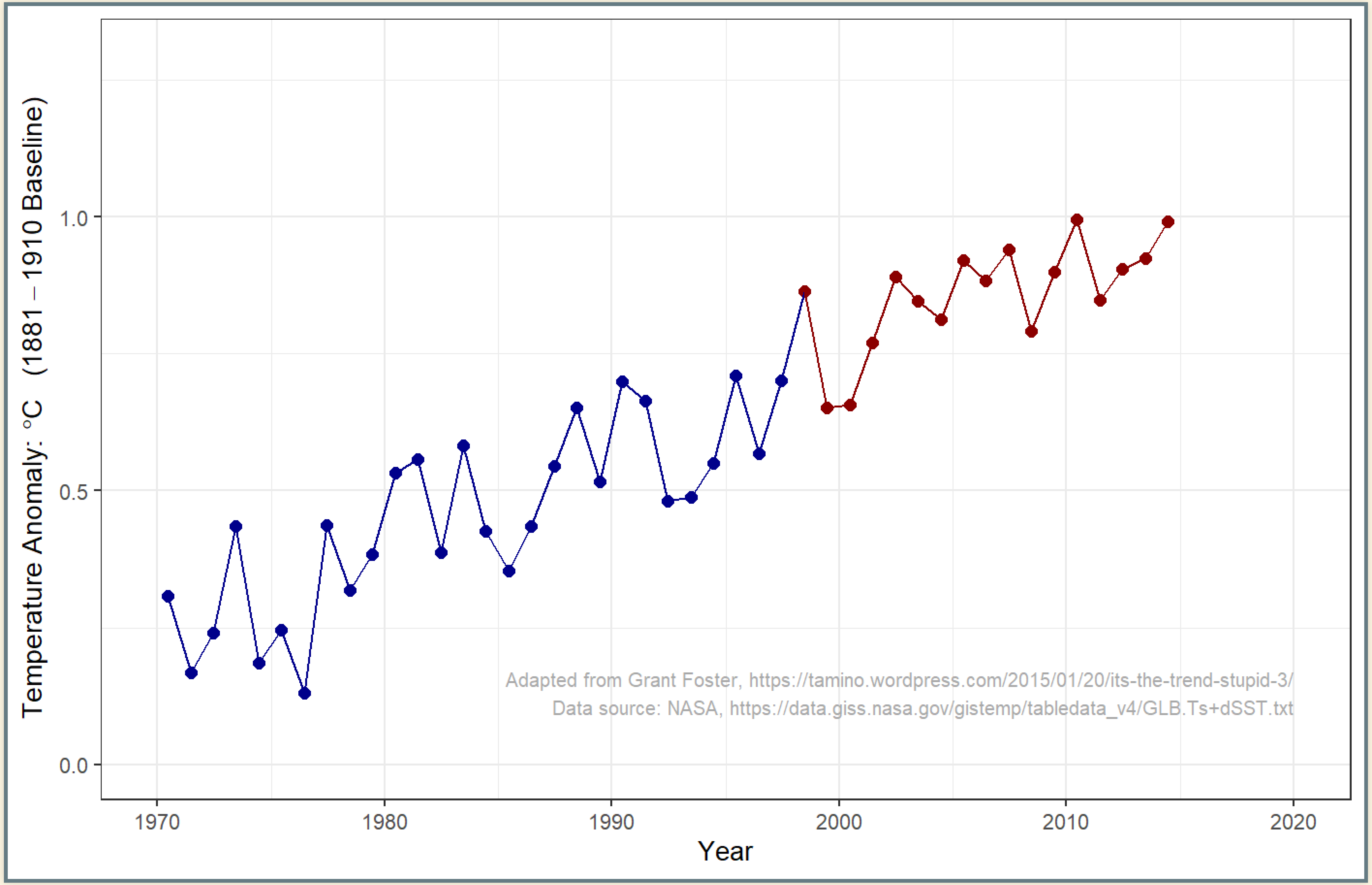


Did temperatures stop rising 18 years ago?

Look at 1970–2014



Did temperatures stop rising?



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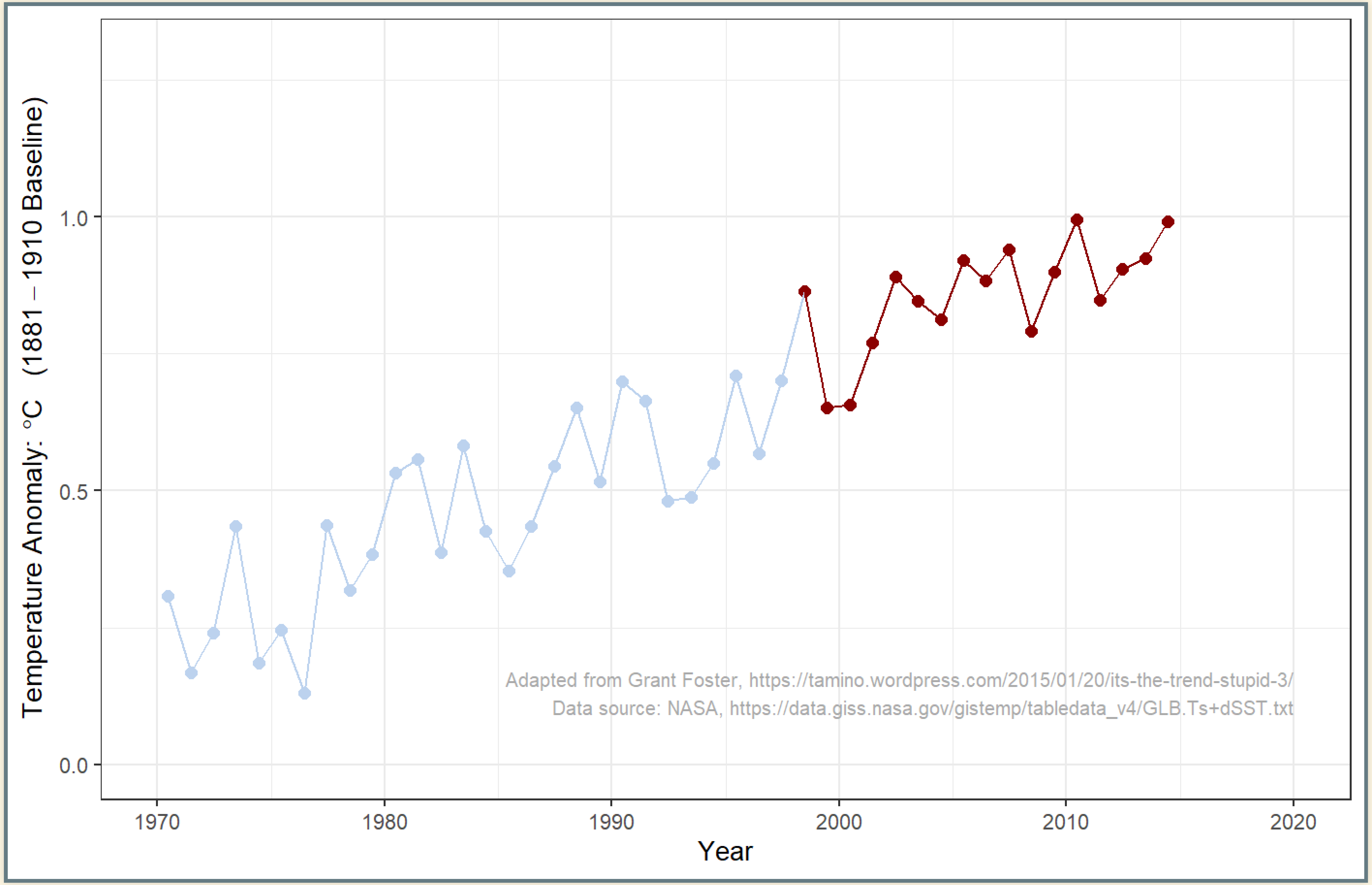

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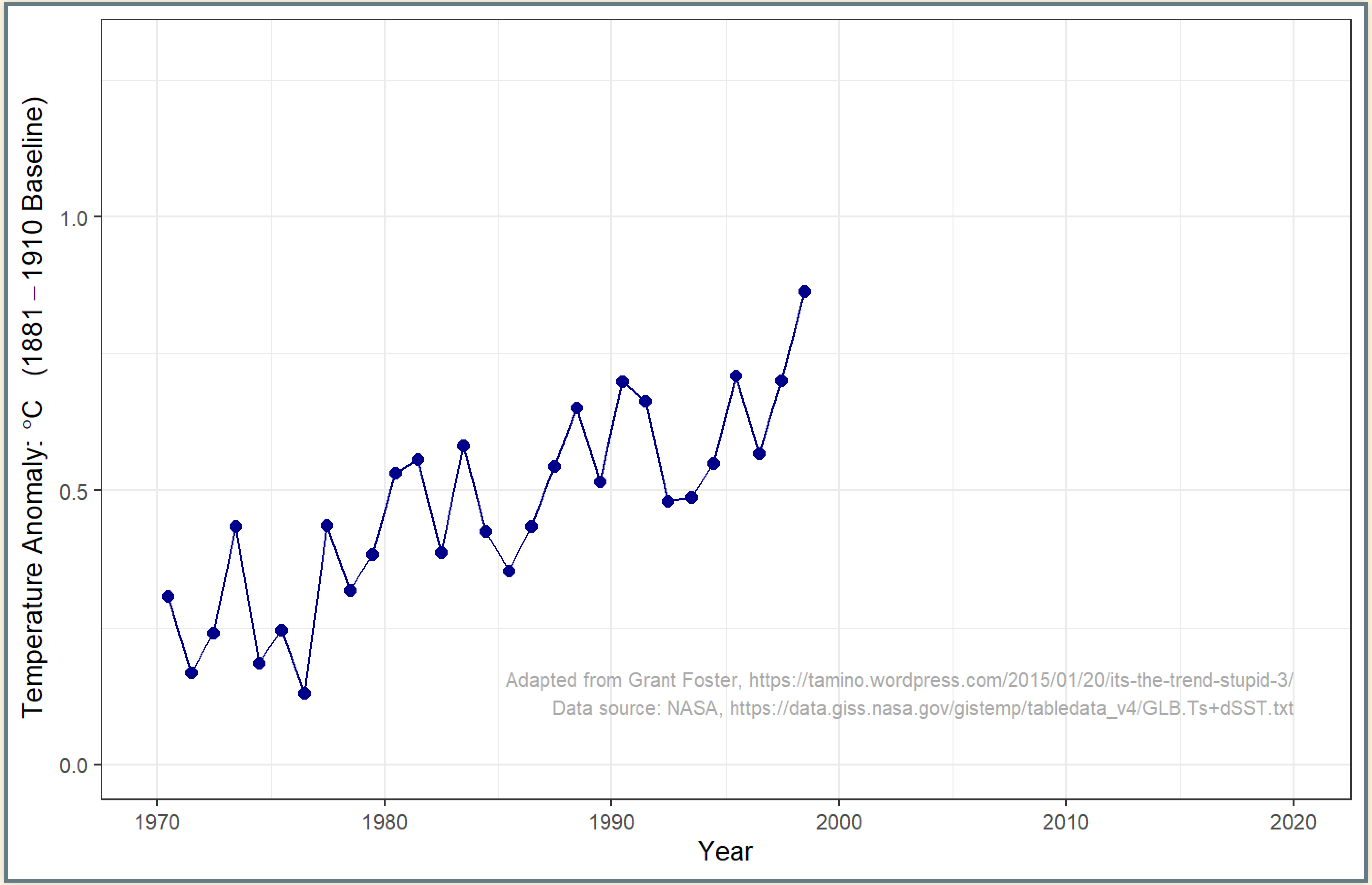

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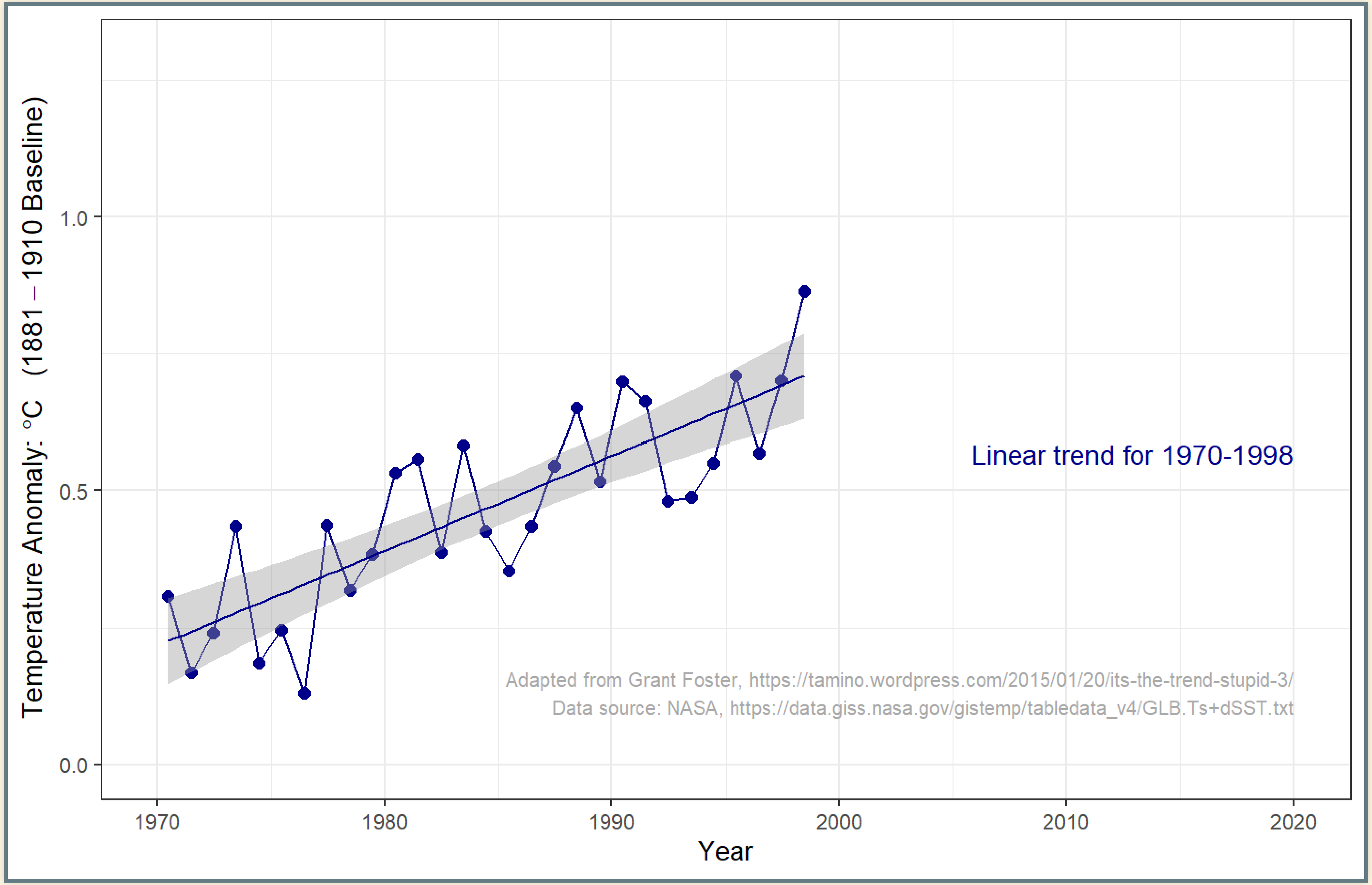

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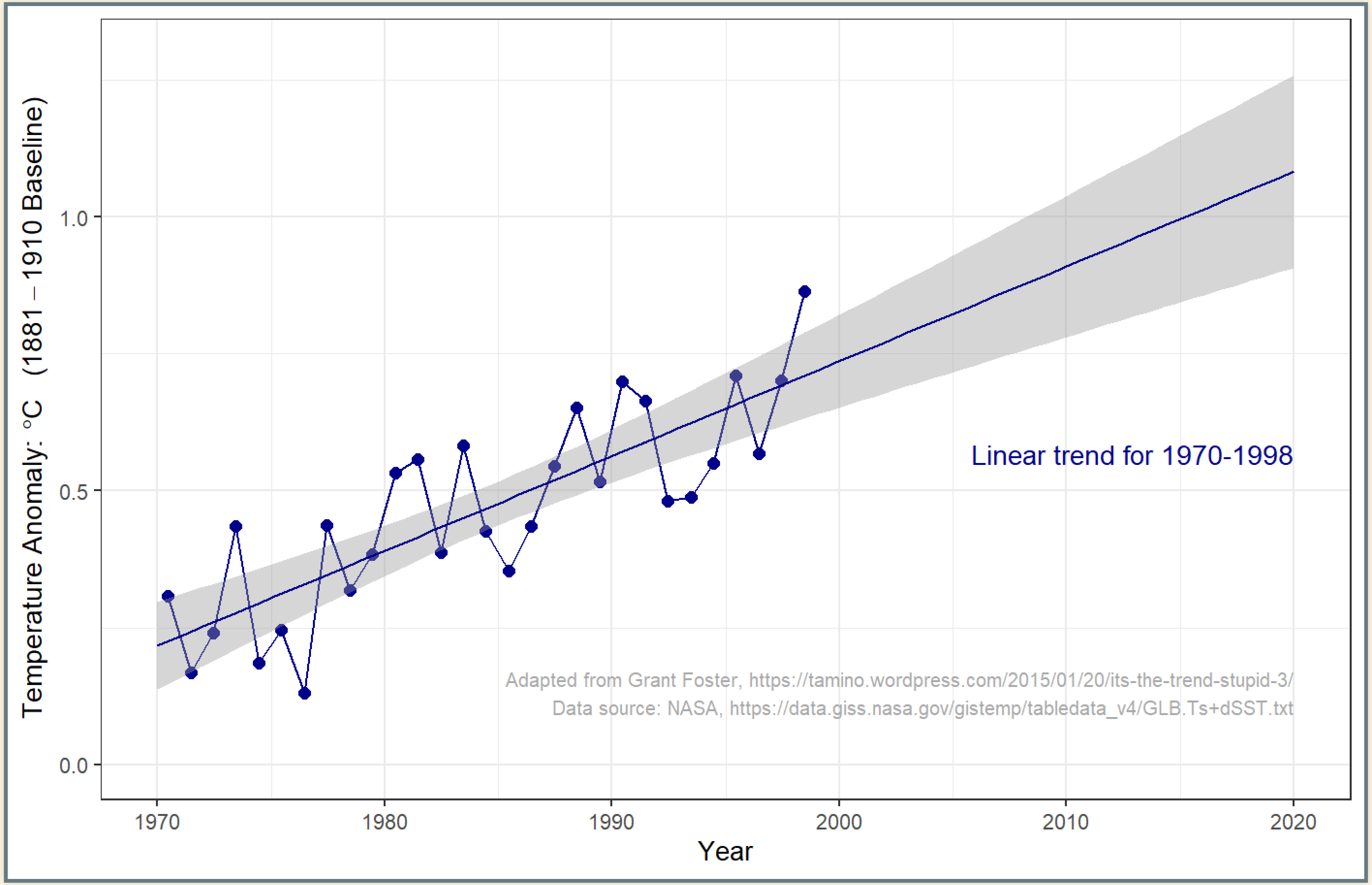

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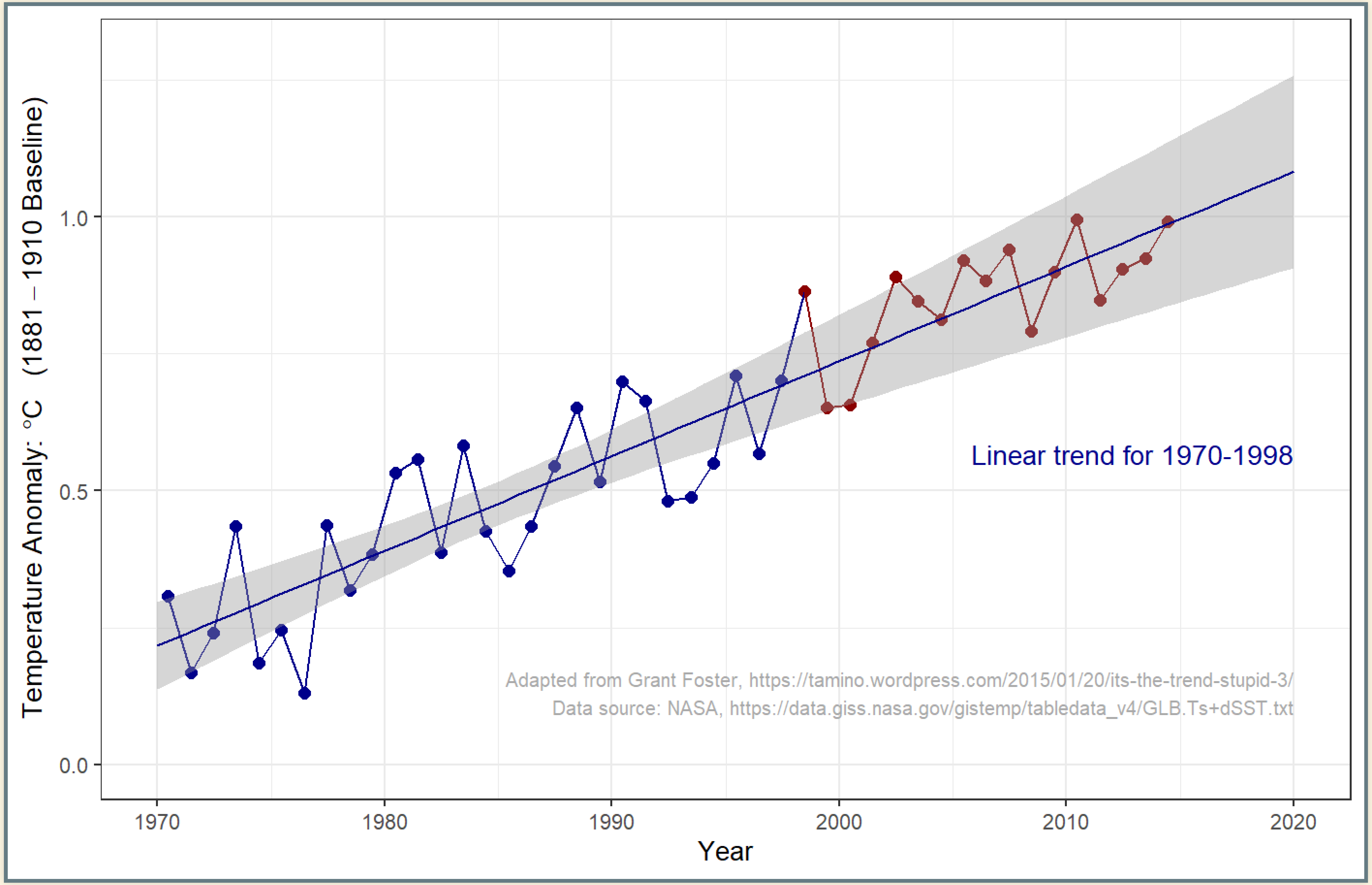

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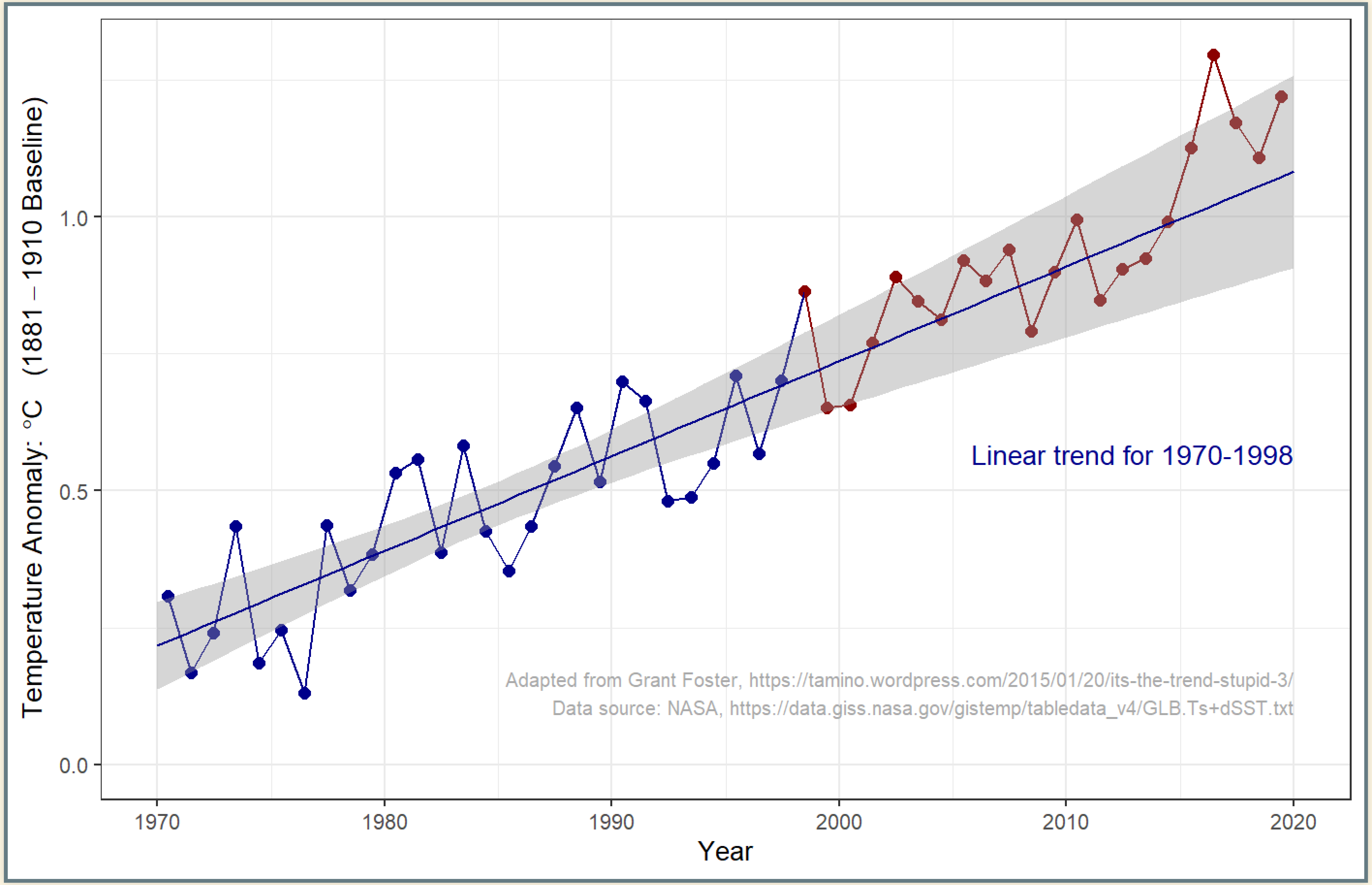


What is the Scientific Consensus?

What is the Scientific Consensus?

- Is there a consensus?
- If there is, should we trust it?

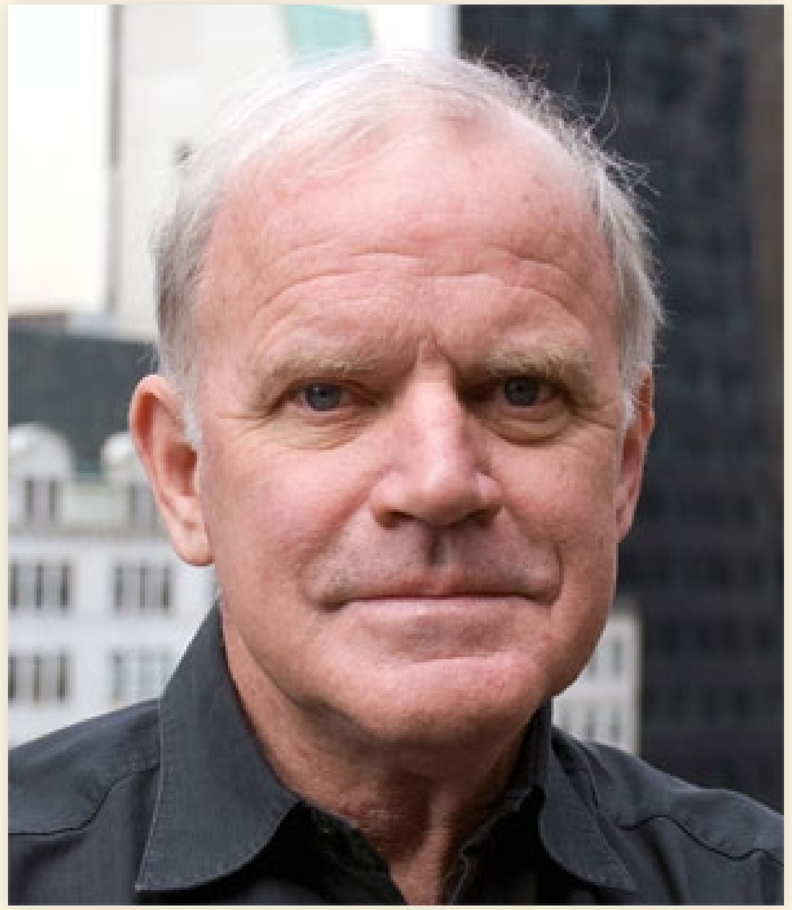
What is the Scientific Consensus?

- Is it important whether most scientists agree or not?
- What if some scientists disagree?
- Do most scientists agree?
  - Careful reviews of scientific literature find 95% of scientists publishing about climate change believe planet is warming because of human activity.

Dissident Scientists

Peter Duesberg

- Famous biology professor
- Member National Academy of Science
- Major discovery of cancer-causing virus
- Claims that HIV virus does not cause AIDS



Kary Mullis

- Nobel Prize in medicine/biology
- Invented PCR for analyzing DNA
- Endorses Duesberg’s theory of AIDS

Meaning of Consensus

- Does scientific consensus mean we can be 100% certain that people are warming the planet?
- What about the future impacts of climate change?

What Gets in the Way of Policy?

What Gets in the Way of Policy?

- Politicians don’t understand science?
- Public doesn’t understand science?
- Scientists don’t understand politics?

Issues for Policy

- What do scientists agree on?
- Should policy focus on limits to CO_2 or ΔT?
- Should policy wait for better scientific certainty?
- Uncertainty:
  - How much warming is "dangerous"?
  - How much CO_2 would produce dangerous warming?
  - Are there tipping points?
  - If so, where are they?
- Addressing uncertainty:
  - Precautionary principle
    - *Better safe than sorry*
  - No regrets policy
    - *Worth doing even if global warming turns out to be not so bad.*

1979 Report

Carbon Dioxide and Climate:
A Scientific Assessment

The conclusions of this brief but intense investigation may be comforting to scientists but disturbing to policymakers. If carbon dioxide continues to increase, the study group finds no reason to doubt that climate changes will result and no reason to believe that these changes will be negligible. … A wait-and-see policy may mean waiting until it is too late.

National Research Council, *Carbon Dioxide and Climate: A Scientific Assessment* (Nat’l. Academy Press, 1979)

Review of MODTRAN

MODTRAN:

- MODTRAN calculates *emissions* and *absorption* of longwave light in the atmosphere.
- Things that don't change during a run:
  - Heat from the sun
    - Set by "locality" of the atmosphere
  - Temperature of the ground and every layer of the atmosphere.
    - Set by "locality" of the atmosphere and "temperature offset"

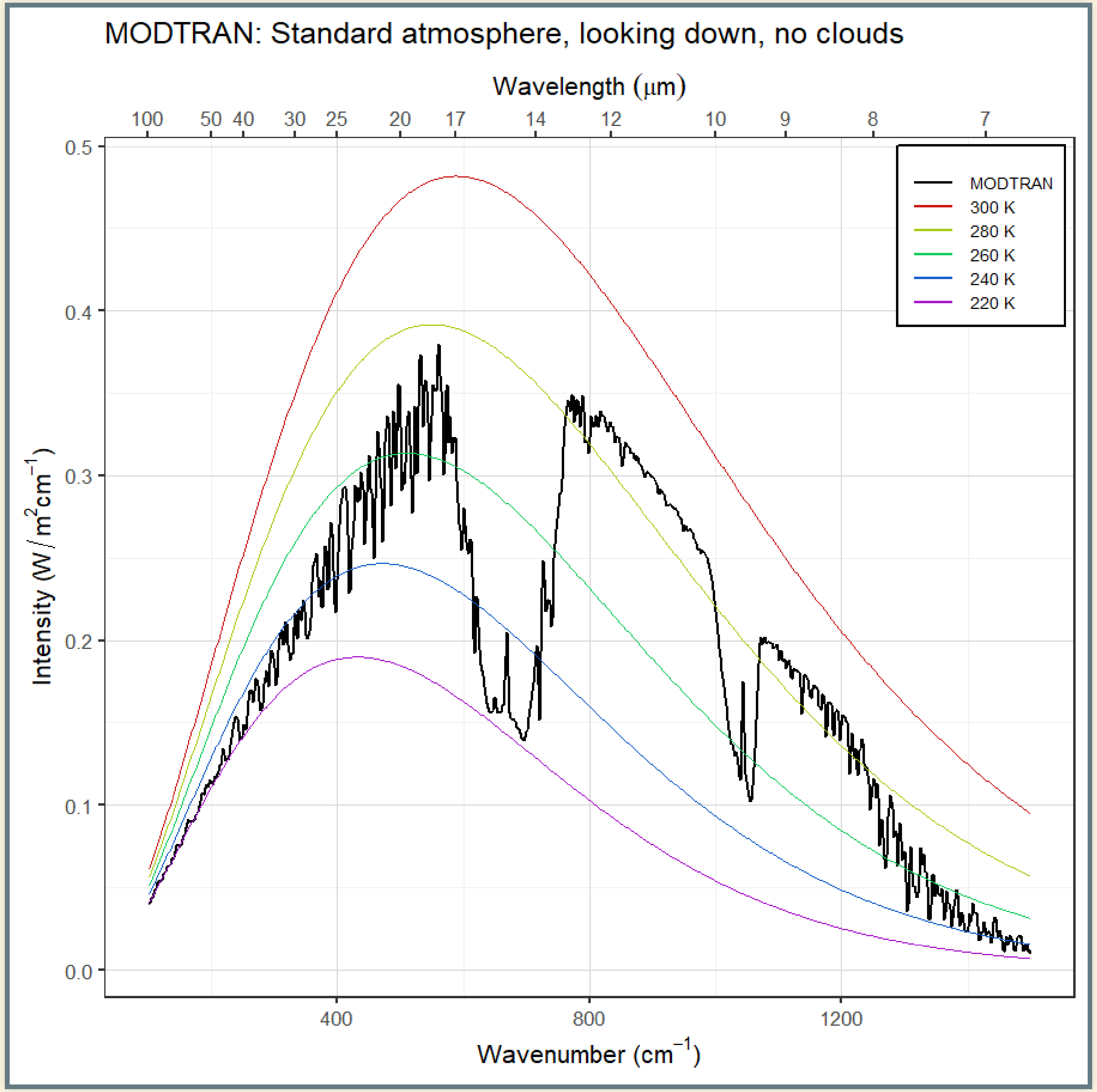
Locale	**I_{out} (W/m^2)**	**T_{ground} (K)**
U.S. Standard Atmosphere	267.98	288.2
Tropical	298.67	299.7
Midlatitude winter	235.34	272.2

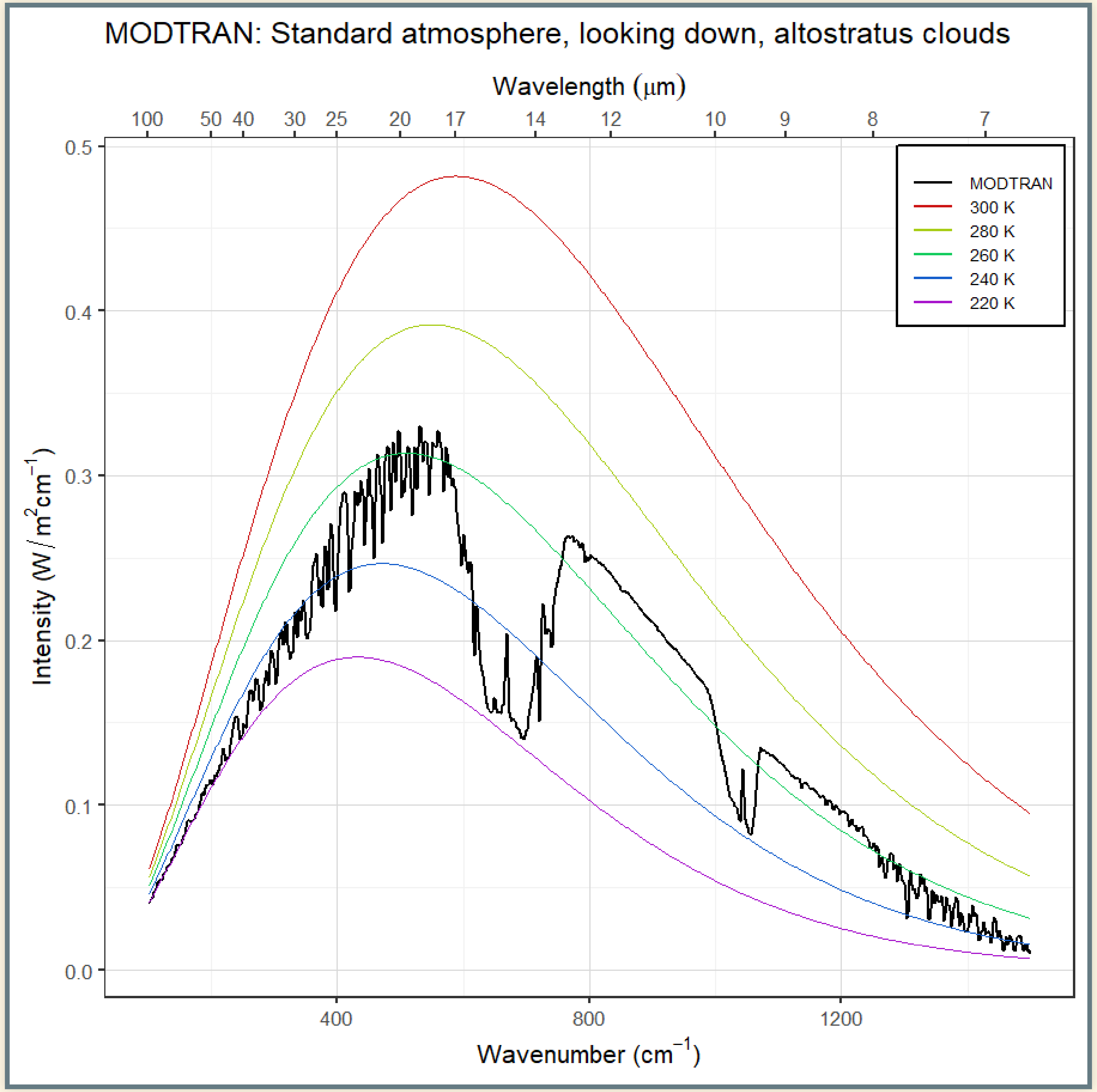
- For every wavenumber, MODTRAN calculates heat emission and absorption up and down at each layer.

MODTRAN:

- Emissivity (ε) = absorption
  - Fraction absorbed by layer $= \varepsilon$
  - Radiation emitted by layer $= \varepsilon\sigma T^4$
- ε small (near zero):
  - Little absorption or emission.
- ε large (near one):
  - Almost all incoming radiation is absorbed
  - Emission close to black body at temperature *T*.
- ε is large for wavenumbers where greenhouse gases absorb strongly.
  - Greater concentration $\rightarrow$ larger ε
- ε is small where there is little absorption
  - Atmospheric window
- Sensor sees emission at the temperature of the ***nearest layer*** with large ε:
- **Looking down from space:**
  - ***highest layer* with large ε.**
  - In atmospheric window, that layer is near the ground
  - With clouds, it's often the top of the highest cloud
- **Looking up from ground:**
  - ***lowest layer* with large ε.**
  - In atmospheric window, there's no such layer, so you see very little emission
  - With clouds, it's often the bottom of the lowest cloud

Example: Looking Down





Example: Looking Up