# Climates of the Future

EES 3310/5310

Global Climate Change

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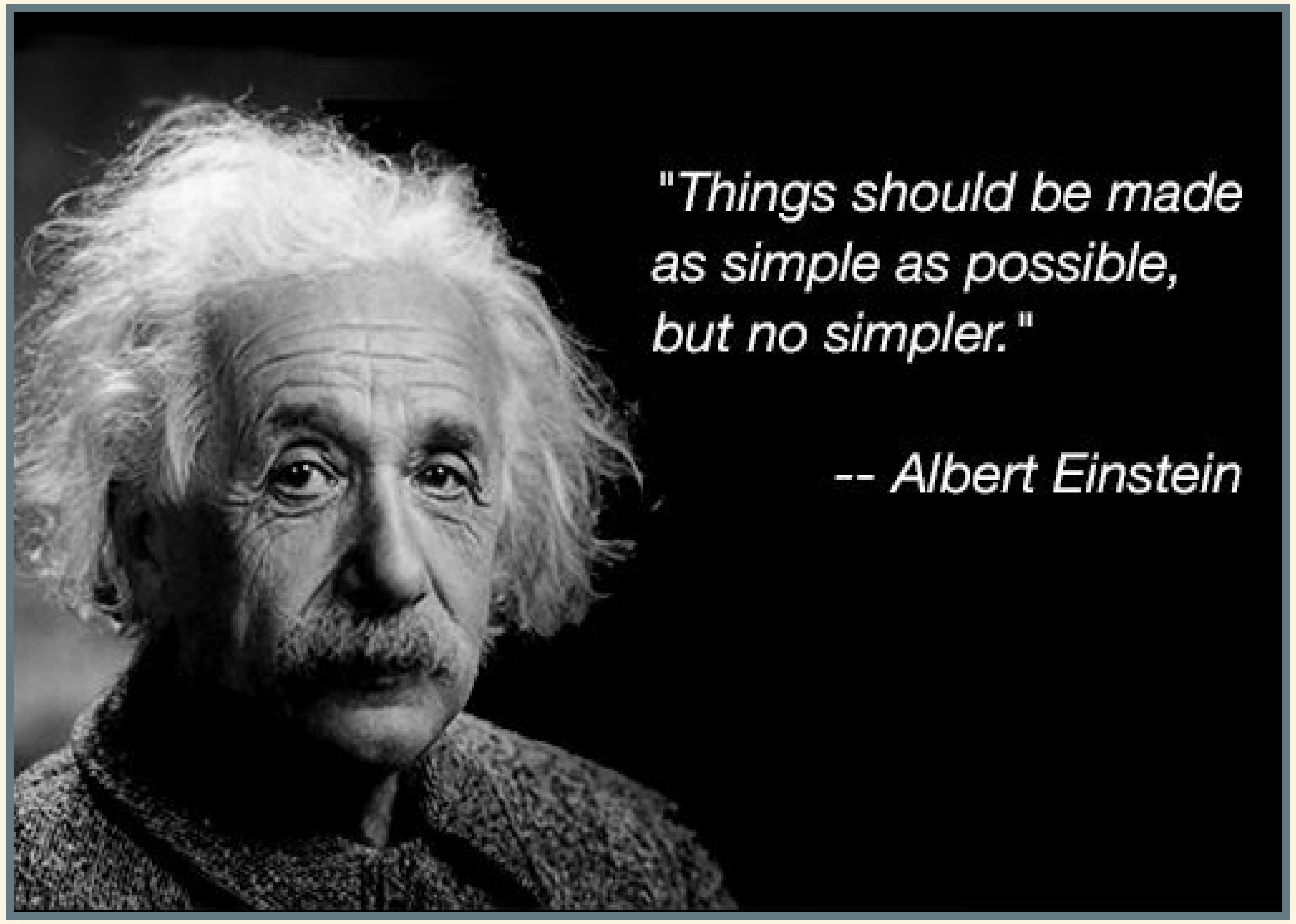
# Principles of Computer Modeling

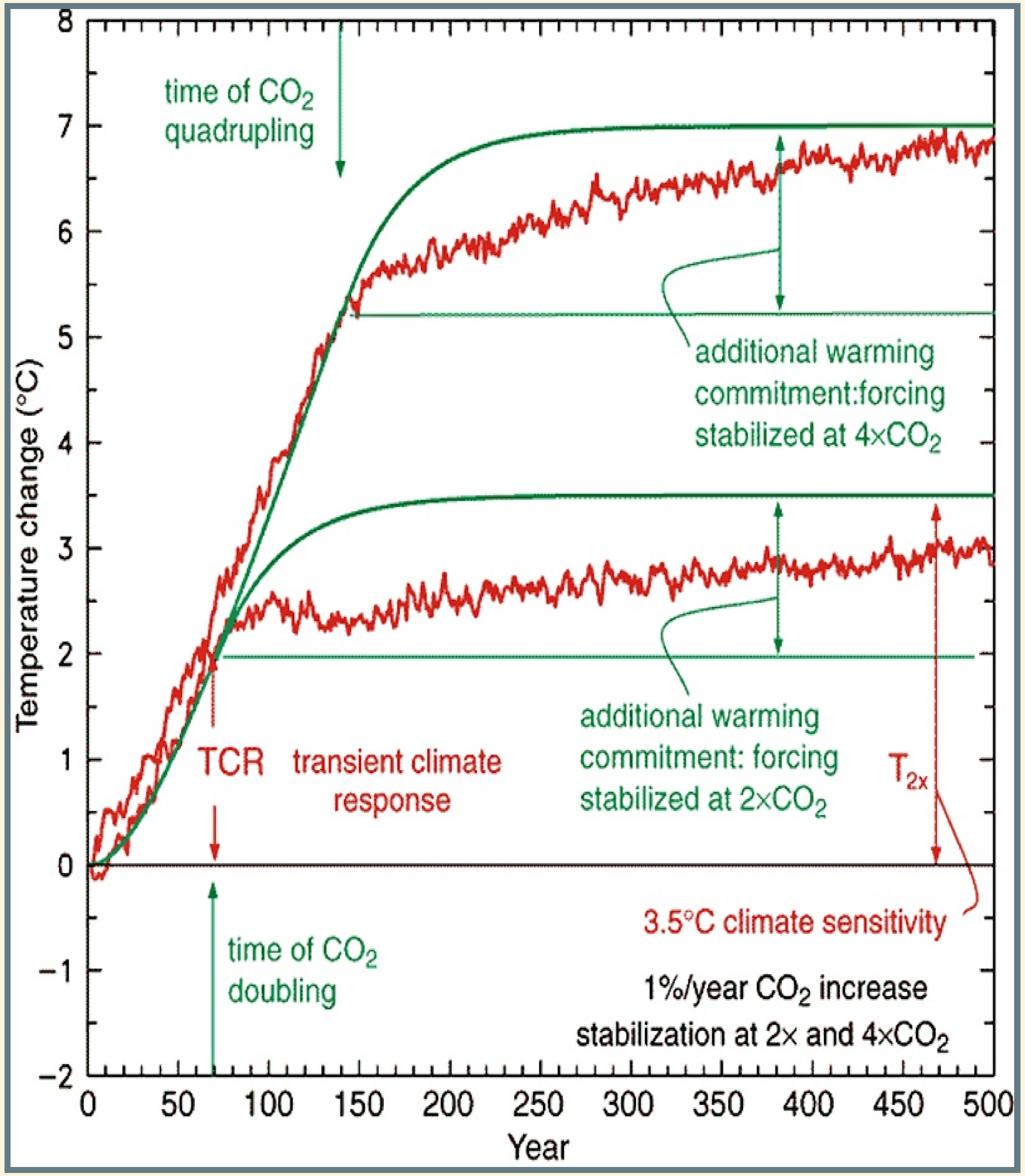
- Make models as simple as possible:
  - Start simple
  - Add complexity only as needed
    - Different models for different purposes
  - Check model against real world



# Transient vs. Equilibrium Response

# Transient vs. Equilibrium Response

- Gradually raise $CO_2$ and then stop.
- Planet takes time to heat up
  - Oceans absorb heat
  - Like pot of water on stove
- Transient response:
  $\Delta T$ when $CO_2$ stops changing
- Equilibrium response:
  Stable temperature (much later)
  - Green: Atmosphere & surface ocean
  - Red: Atmosphere, surface ocean, & deep ocean.
- Equilibrium takes many decades.



# Modeling for Science vs. Policy

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## Integrated Assessment Models (IAMS)

- Combine climate system and world economy
  - Emissions as a consequence of economic activity
    - Energy use for production
    - Energy use for consumption
    - Farming
  - Climatic impacts on economy
    - Cost of severe weather
    - Sea level rise
    - Droughts & heat waves
    - …
- **Optimize for greatest net economic output**

# Climate Projections

- Biggest uncertainty in predicting future climates is GHG emissions
  - We can predict consequences of emissions
  - We can’t predict what emissions will be
- Scenarios and Pathways:
  - **Scenario**: possible future,
    - Story of economic & political development → resulting emissions
  - **Pathway**: possible future,
    - Trajectory of emissions → economic activity that might cause them
- Projections:
  - Conditional predictions:
    - “**If** emissions do this, **then** climate will do that.”

# Projections for future emissions in US:

| | **2010** | **2050** | **Growth rate (% per year)** |
|---|---|---|---|
| *g* (\$/person) | 42,300 | 83,700 | 1.7 |
| *ef* (tons/\$million) | 432 | 226 | -1.6 |
| *P* (millions) | 309 | 399 | 0.6 |
| **Total Emissions** *F* (million tons $CO_2$) | **5,640** | **7,550** | 1.7 - 1.6 + 0.6 = **0.7** |

# Projections for future world emissions:

| | 2010 | 2050 | Growth rate (% per year) |
|---|---|---|---|
| *g* ($/person) | 9,780 | 22,400 | 2.1 |
| *ef* (tons/$million) | 522 | 278 | -1.6 |
| *P* (millions) | 6,410 | 9,170 | 0.9 |
| **Total Emissions** *F* (million tons $CO_2$) | **34,900** | **57,600** | 2.1 - 1.6 + 0.9 = **1.4** |

# Uncertainties in Projections

## Projections for future world emissions:

| | 2010 | 2050 | 2100 | Growth rate |
|---|---|---|---|---|
| *g* | 9,780 | 22,400 | 64,737 | 2.1 |
| *ef* | 522 | 278 | 123 | -1.6 |
| *P* | 6,410 | 9,170 | 14,409 | 0.9 |
| **Emissions** | **34,900** | **57,600** | **115,366** | **1.4** |
| | | | | |

# Uncertainties in Projections

## Projections for future world emissions with slightly different growth rates:

| | 2010 | 2050 | 2100 | Growth rate |
|---|---|---|---|---|
| *g* | 9,780 | 24,540 | 77,505 | 2.3 |
| *ef* | 522 | 298 | 148 | -1.4 |
| *P* | 6,410 | 9,563 | 15,766 | 1.0 |
| **Emissions** | **34,900** | **69,973** | **180,930** | **1.9** |
| **Difference (%)** | | **22%** | **57%** | |

# Decisions Under Uncertainty

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

# Consequences of Climate Change

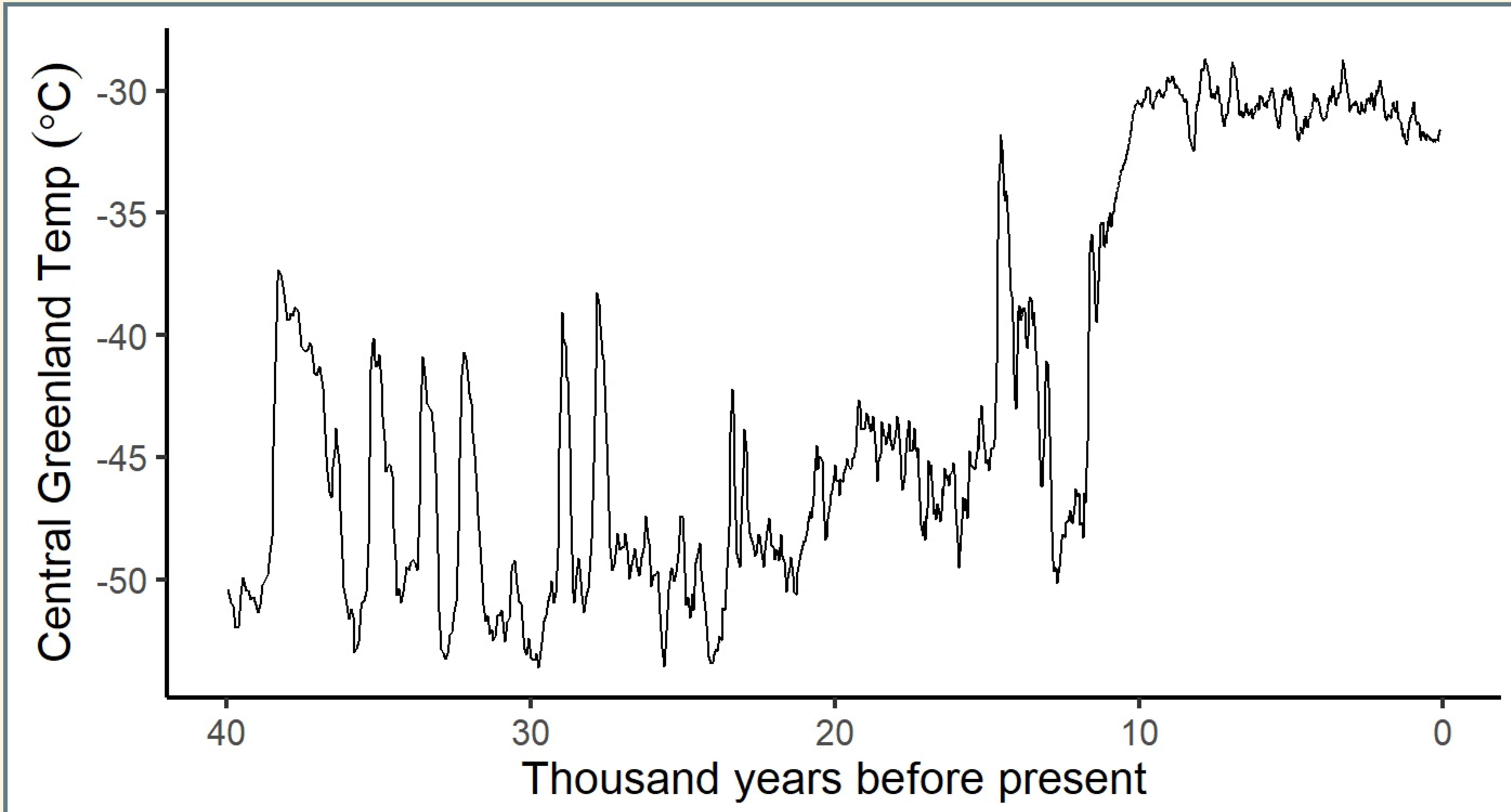
- **Economic effects:**
  - Costs of acting
  - Costs of inaction
  - Uncertainties
- **Policy issues:**
  - Markets vs. Regulation
    - Externalities
    - Kaya Identity: $F = P \times g \times e \times f$ .

# Tipping points

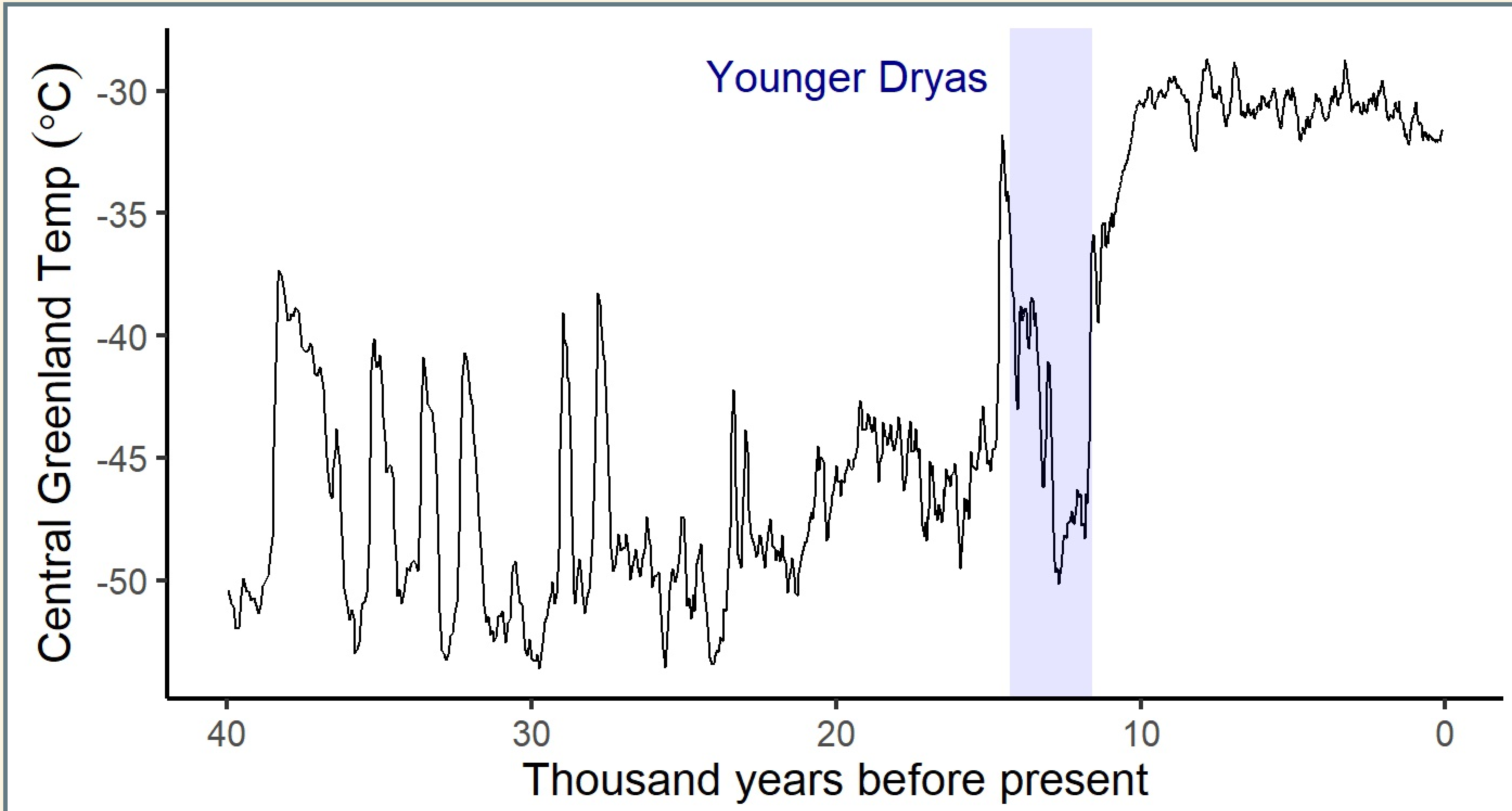
# What we know about tipping points

- 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
  - …

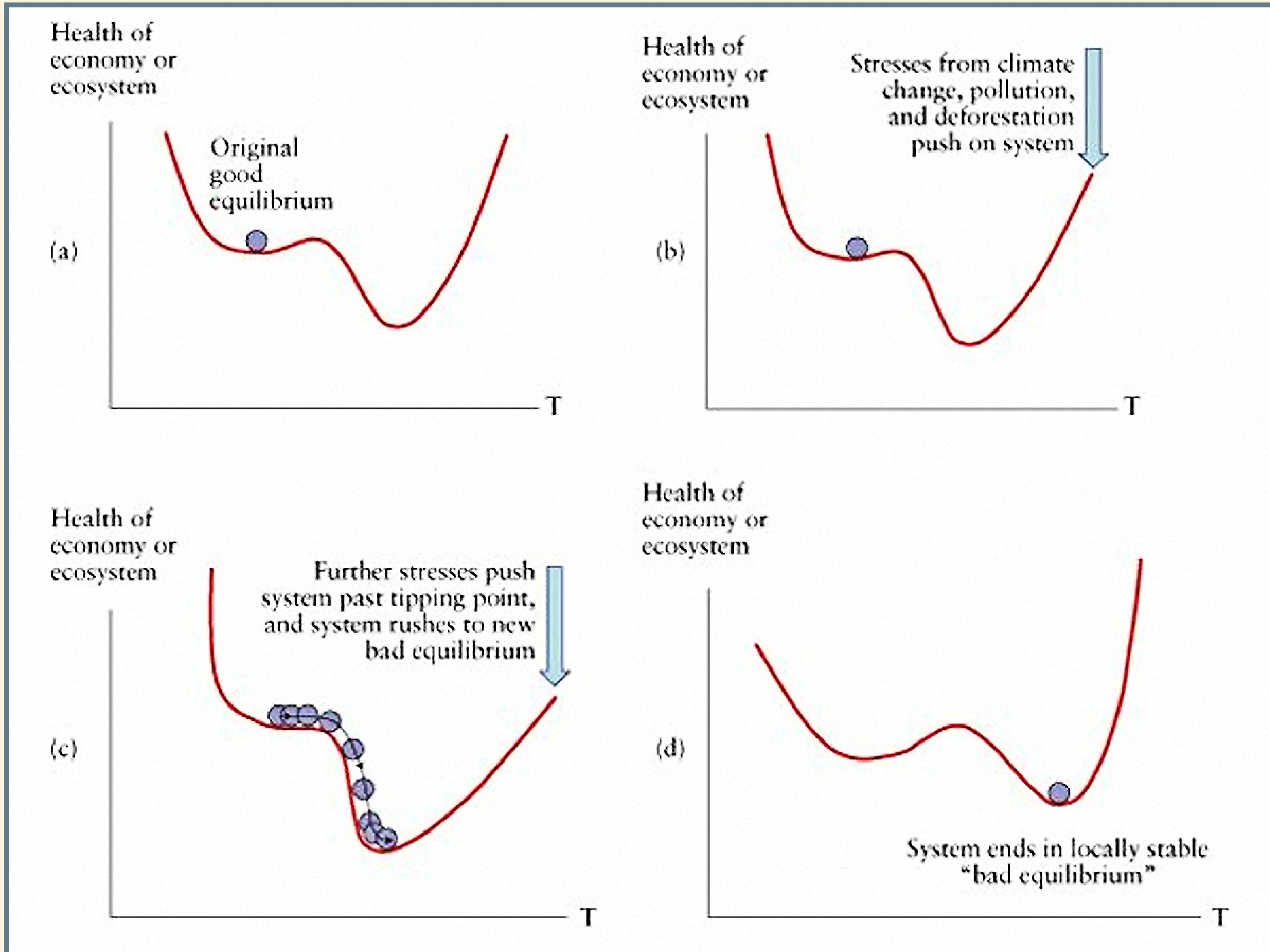
# Abrupt Climate Change



# Abrupt Climate Change



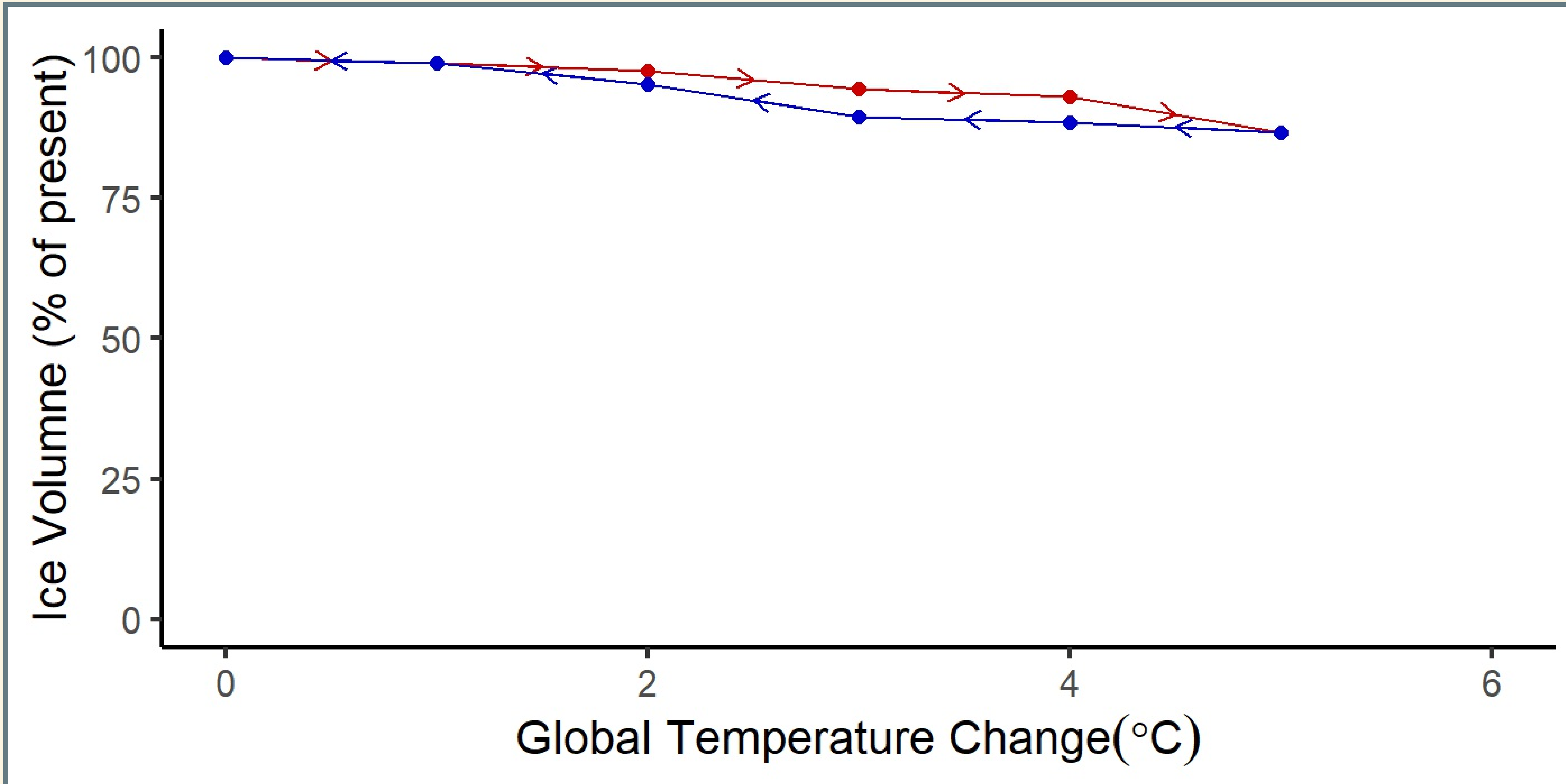
# Bistability & Tipping Points



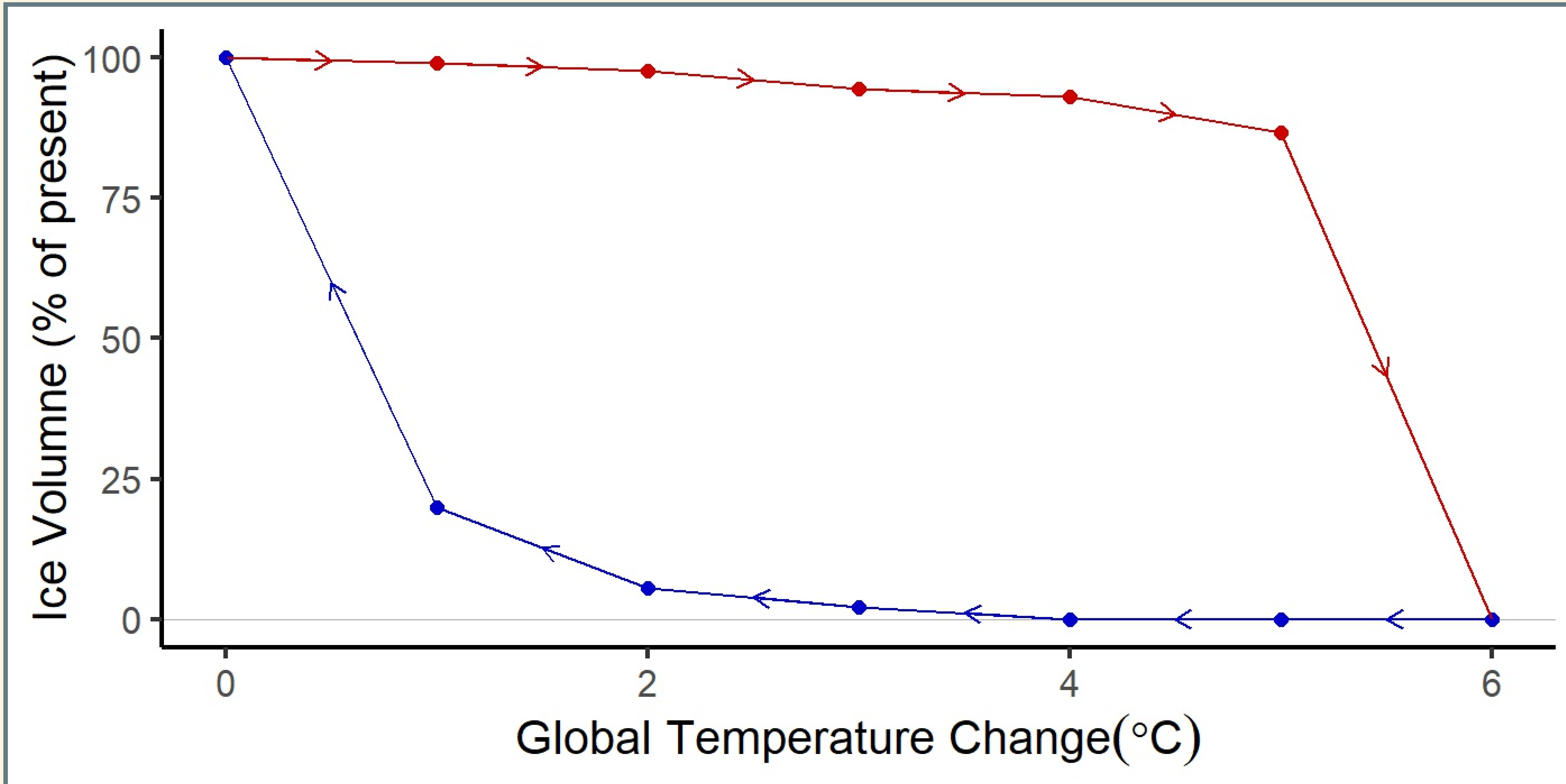
# Hysteresis and Tipping Points

# 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.

# But Can We
# Trust the Experts?

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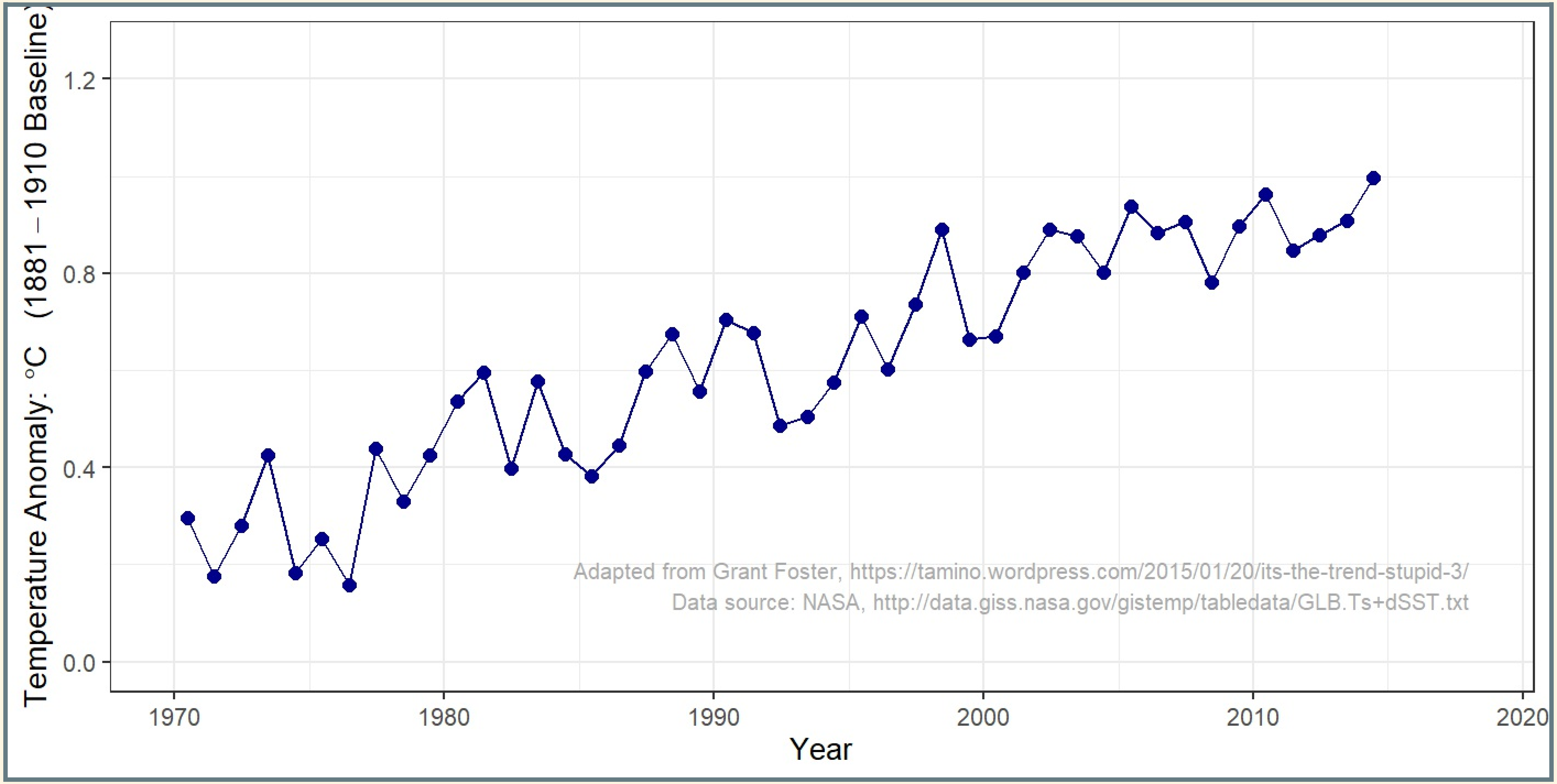
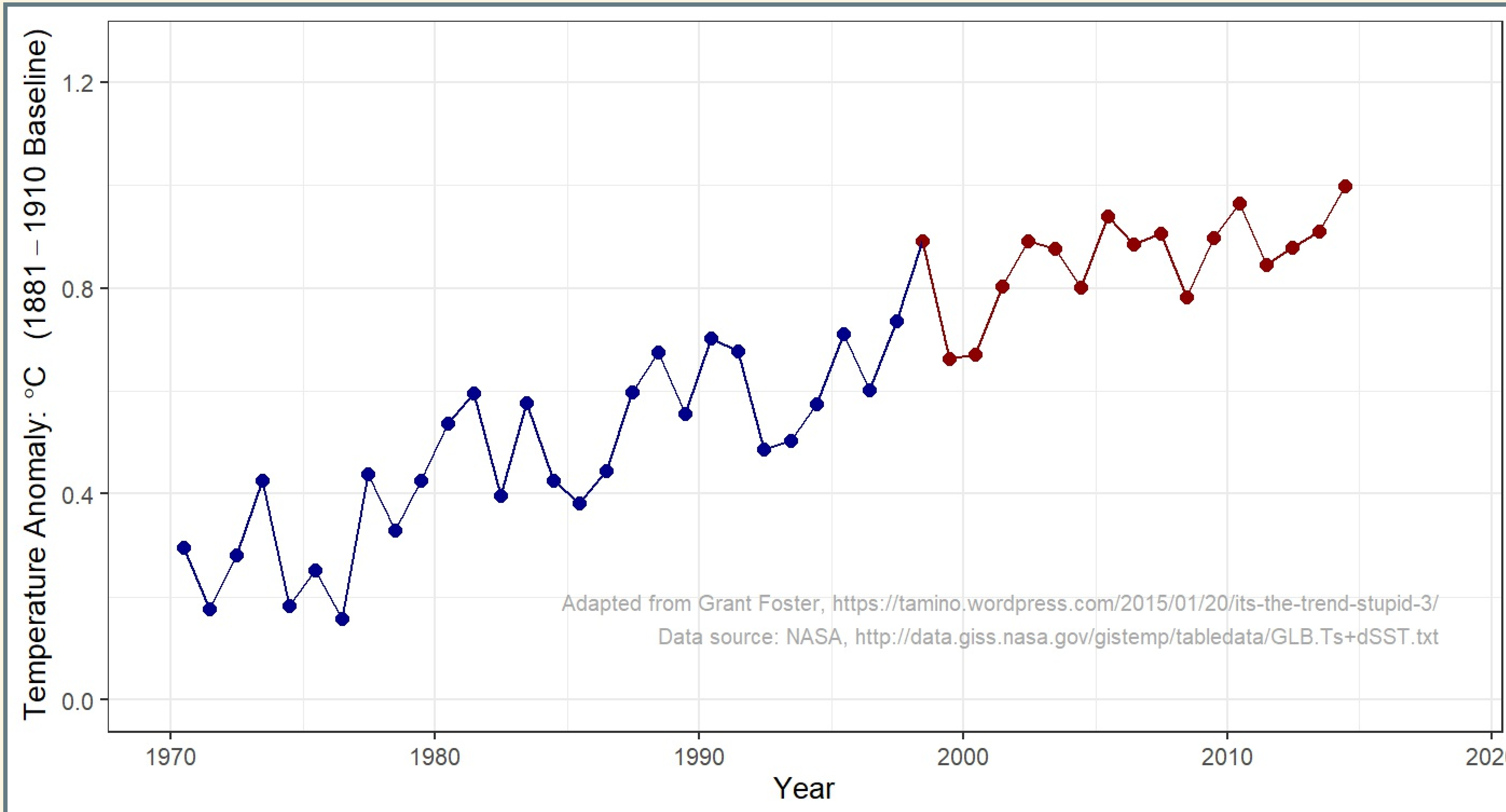
# Did temperatures stop rising 18 years ago?

## Look at 1970–2014



# Did temperatures stop rising?



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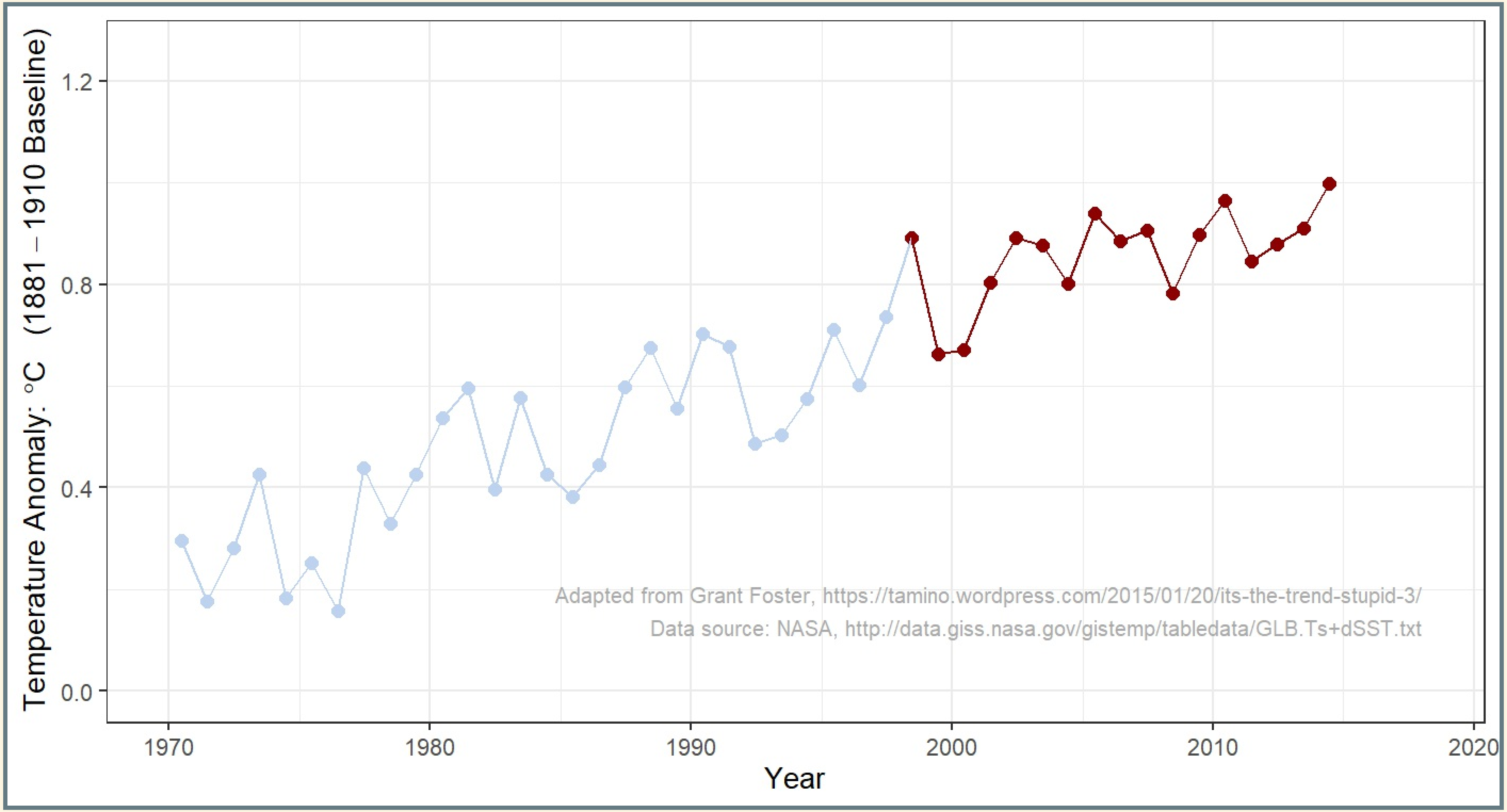

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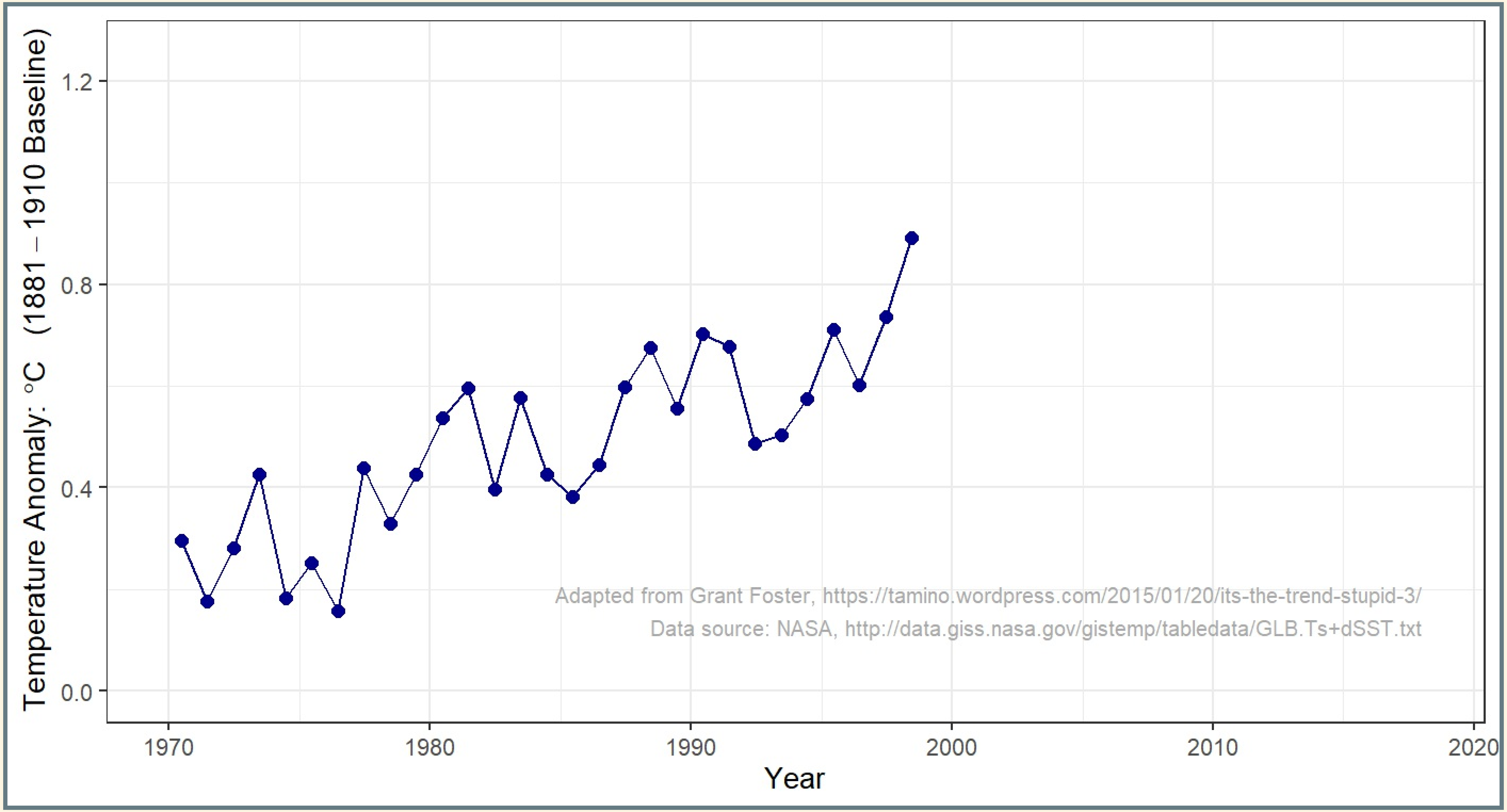

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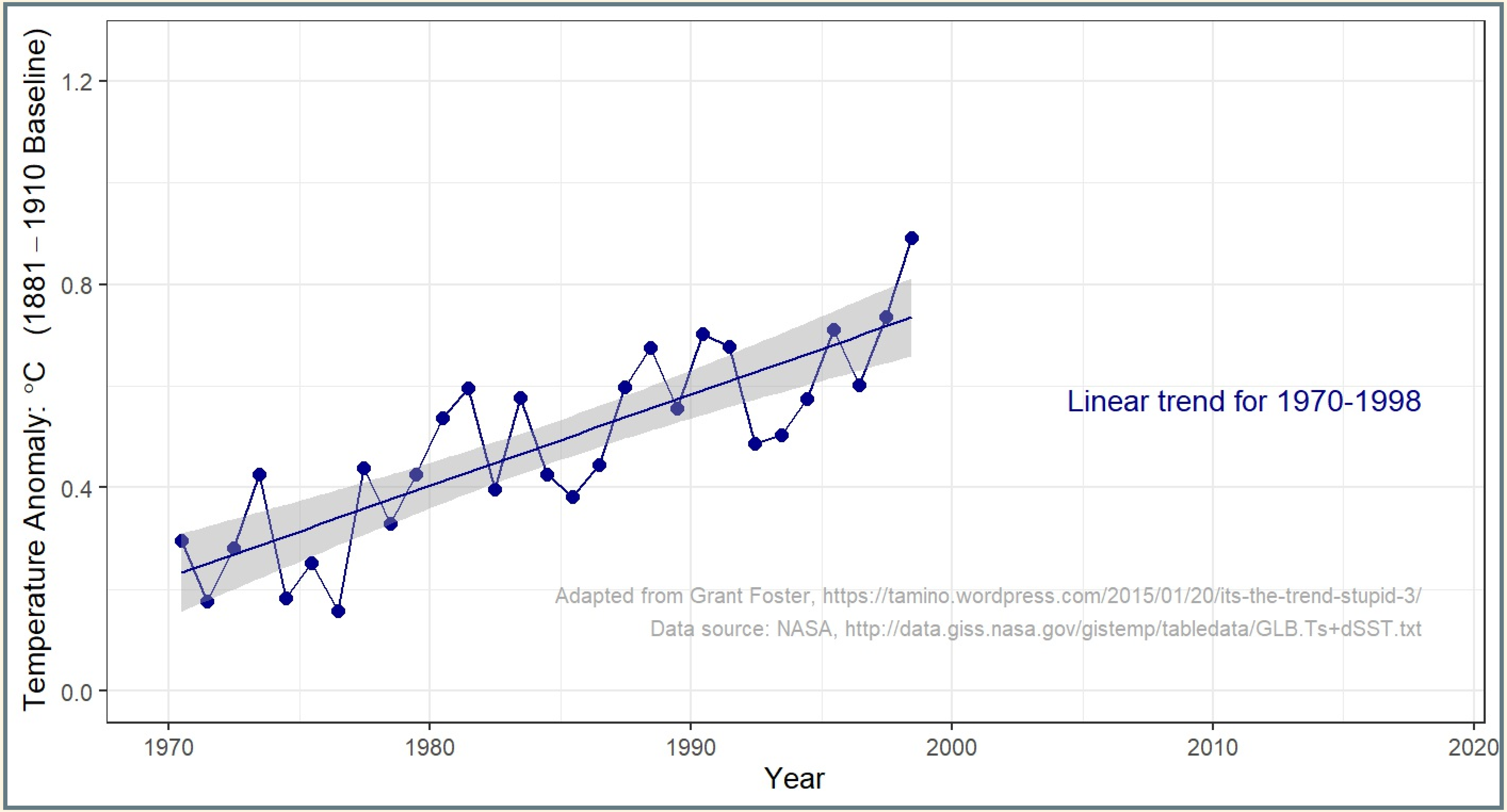

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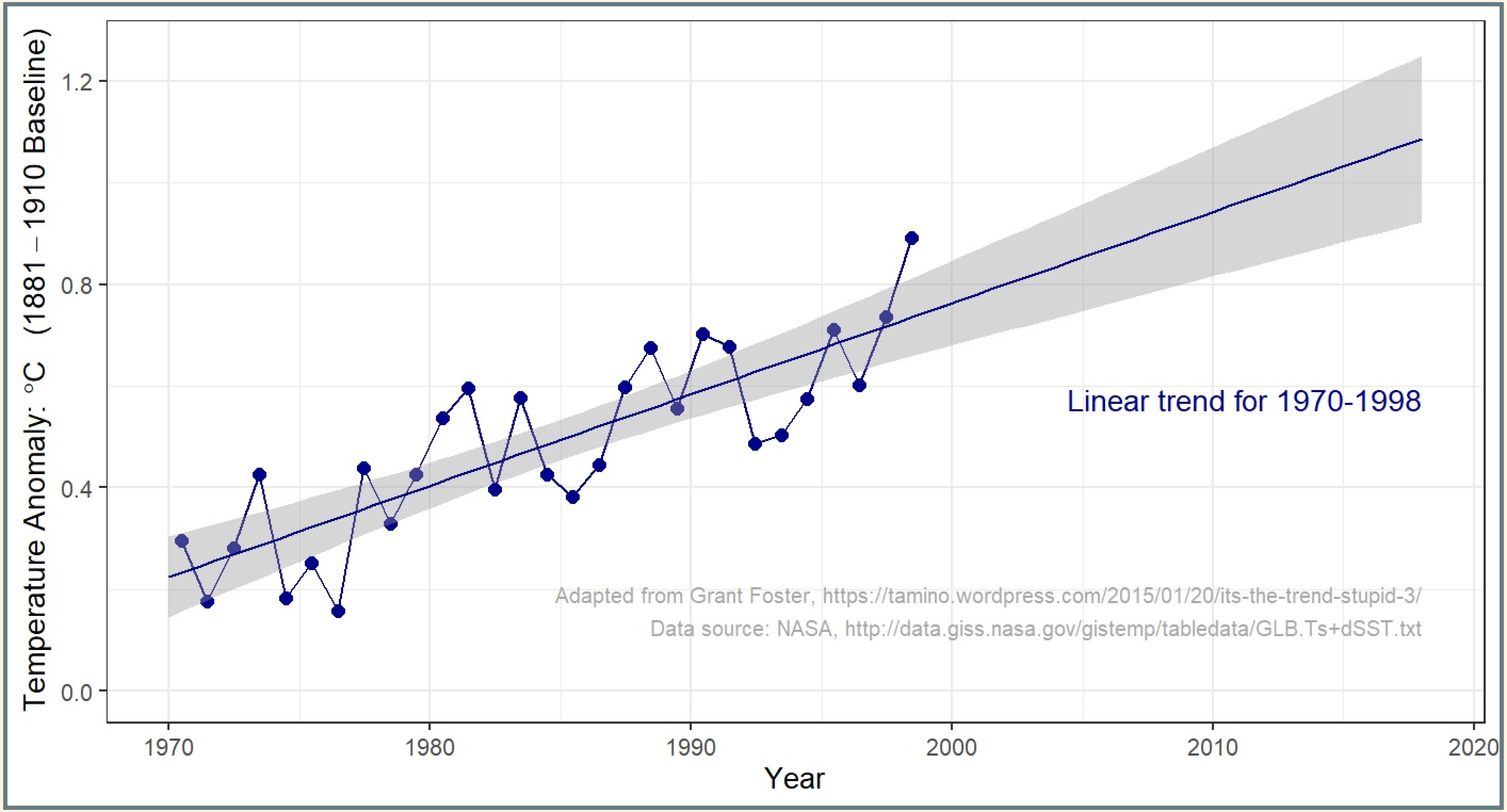

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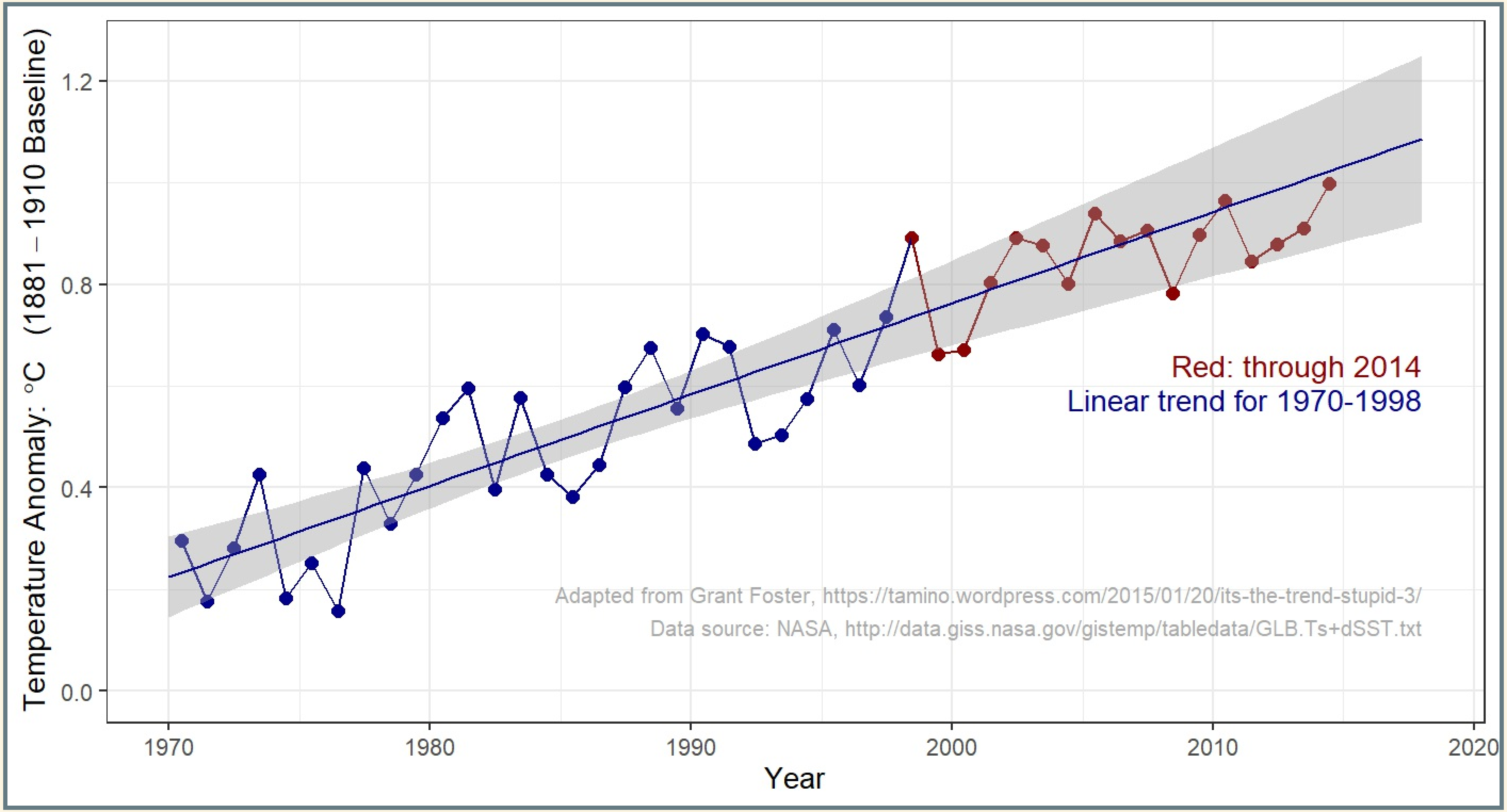

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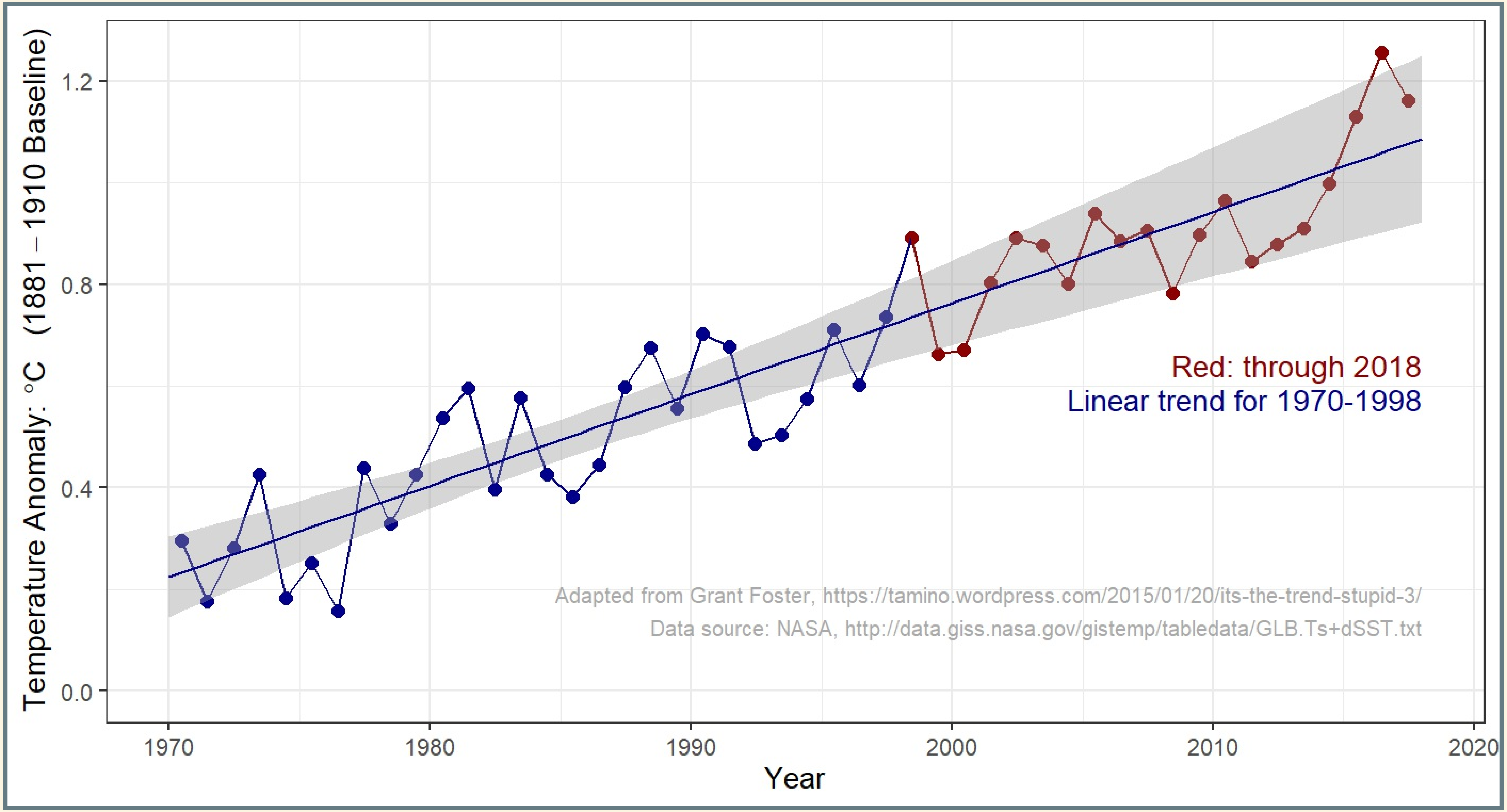


# What is the Scientific Consensus?

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

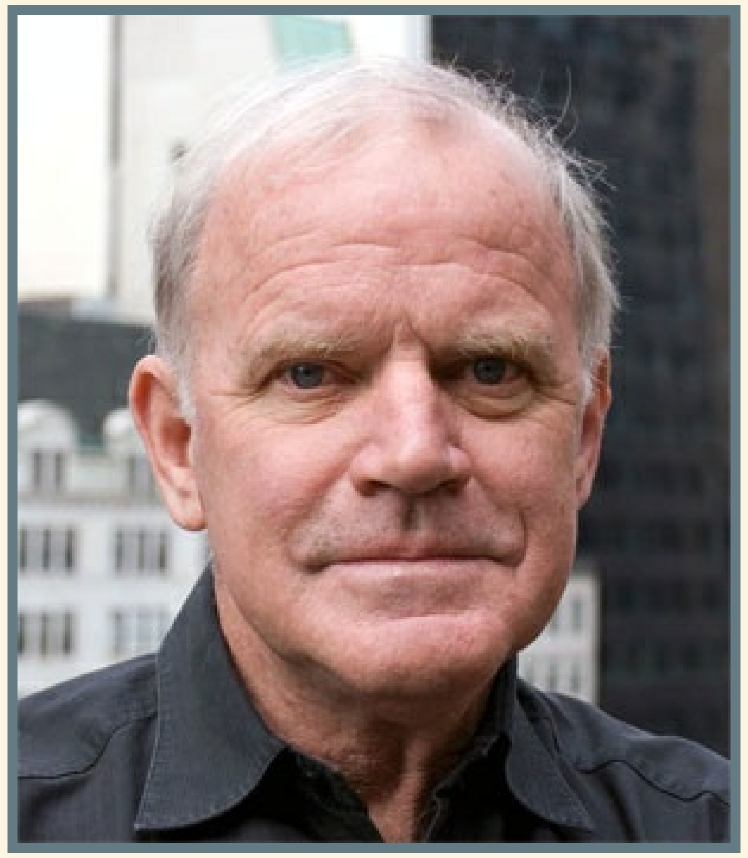
# What is the Scientific Consensus?

- 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?

- 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 $CO_2$?
- Should policy focus on limits to $CO_2$ or $\Delta T$?
- 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?

# 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)