Climates of the Past

EES 3310/5310

Global Climate Change

Jonathan Gilligan

Class #13: Wednesday, February 5 2020

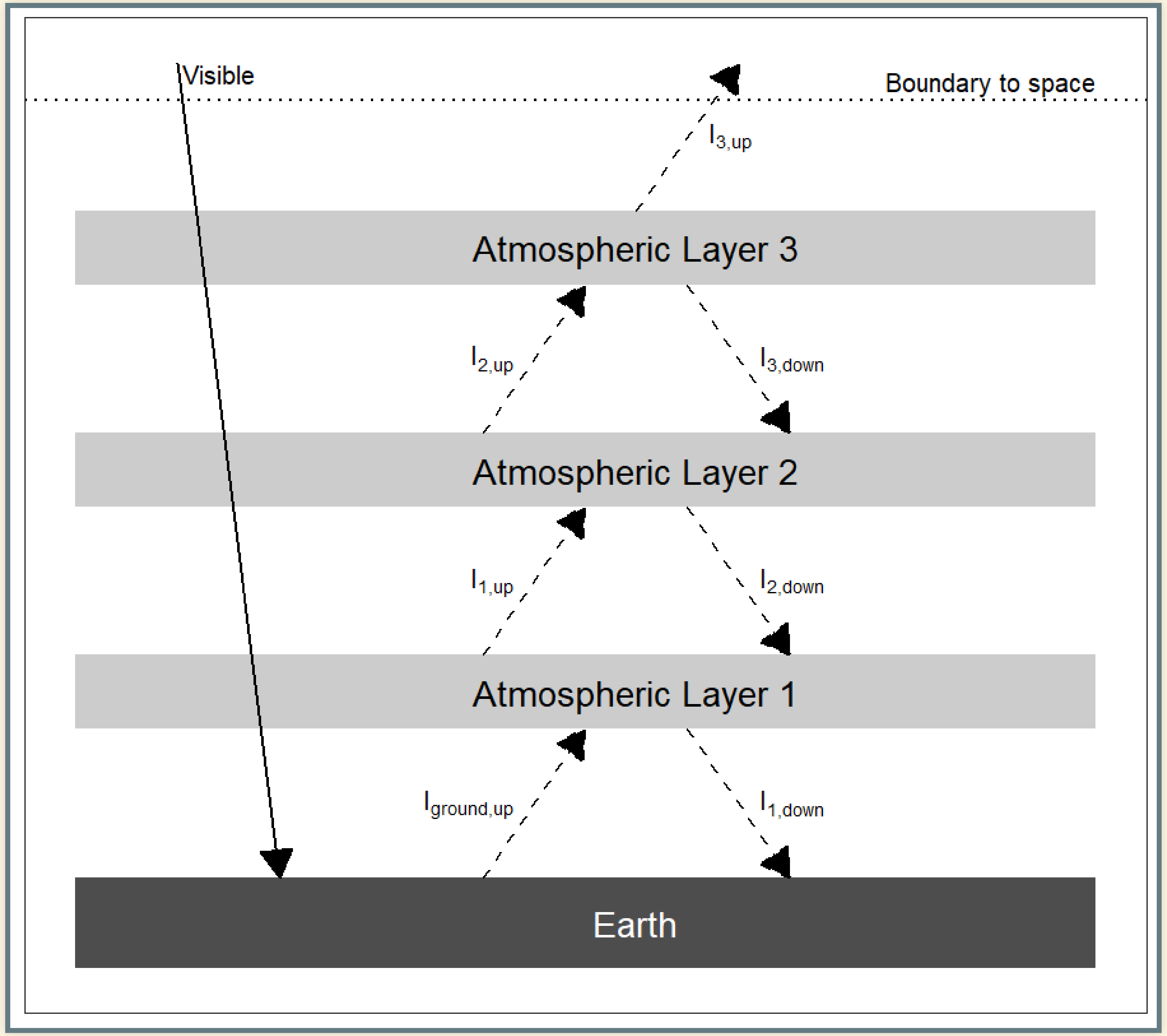
Announcements

Lab #2

- **Lab #2 has been graded**
  - Grades are posted in your GitHub repositories.
    - Comments and points in red on your `.docx` file.
    - Total score at the bottom of the last page.
  - Answers are posted on the class web page
    - Go to the lab assignment page and click on "Solutions"

Optional Extra Credit

- **Optional Extra Credit**:
  - If you are unhappy with your grade on part 1 of the homework, you can *optionally* do the following exercise for extra credit:
    - You have seen one-layer and two-layer models of the atmosphere. Solve a three-layer model of the atmosphere, as shown here.
  - Points on this will count toward making up any points you lost on part 1 of the Lab #2 assignment.



Knitting RMarkdown to `.pdf`

- **For future labs (optional):**
  - If you want to knit your documents to `.pdf` instead of `.docx`:
    - One-time preparation...
    - When you have some time to spare (this is slow):
    - At the RStudio console, type the following commands:

```
library(pacman)
p_load(tinytex)
install_tinytex()
```

    - Now your computer is ready to knit to pdf.
    - You only need to do this one time
  - **This is optional**

Carbonate vs. Silicate Weathering

Carbonate vs. Silicate Weathering

- **Carbonate Weathering:**
  - Dissolves carbonate minerals on land
  - Increases ocean carbonate
    - Adds *twice as much carbonate* to oceans as silicate weathering
    - Relieves ocean acidification
    - Increases transfer of CO_2 from atmosphere to ocean
    - Creates carbonate rocks on sea floor with carbon that originated on land
  - Does not transform atmospheric CO_2 to rocks
- **Silicate Weathering:**
  - Transforms carbon dioxide in atmosphere into rocks
    - Creates carbonate rocks on sea floor
with carbon that originated in atmosphere

Equilibrium Balances

At Equilibrium:

- Silicate weathering = Rate of CO_2 emission
  - (Before fossil fuels, CO_2 emission was just volcanic degassing)
- Total weathering (carbonate + silicate) = Rate of carbonate burial on sea-floor

Weathering as Thermostat

Weathering as Thermostat

CO_2 is balance of volcanic outgassing and chemical weathering

- **Higher temperatures:**
  - More rain, faster chemical reactions
  - Faster weathering
  - Atmospheric CO_2 falls
- **Lower temperatures**
  - Less rain, slower chemical reactions
  - Slower weathering
  - Atmospheric CO_2 rises

Temperature of Earth

- Weathering acts as thermostat.
- Earth’s temperature has been remarkably stable over time.
  - 4 billion years ago, sun was 30% dimmer…
  - But there has constantly been liquid water.
- Geologic change alters thermostat “setting”:
  - Volcanic outgassing
  - Land surface (e.g., mountain ranges)
  - Vascular plants
- In the long run, silicate thermostat will fix global warming…
  - …but it will take tens to hundreds of thousands of years.

Climates of the Past

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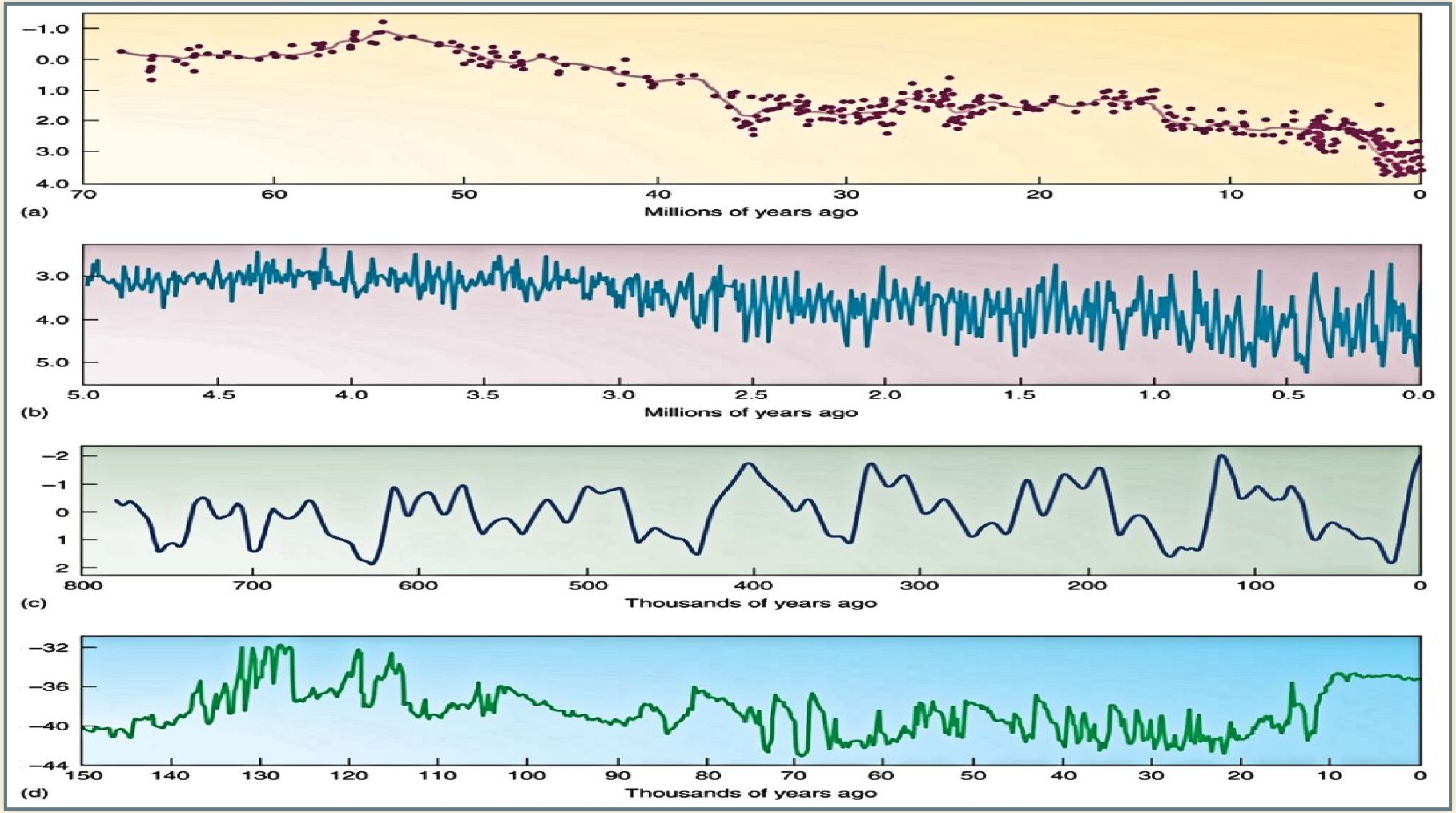
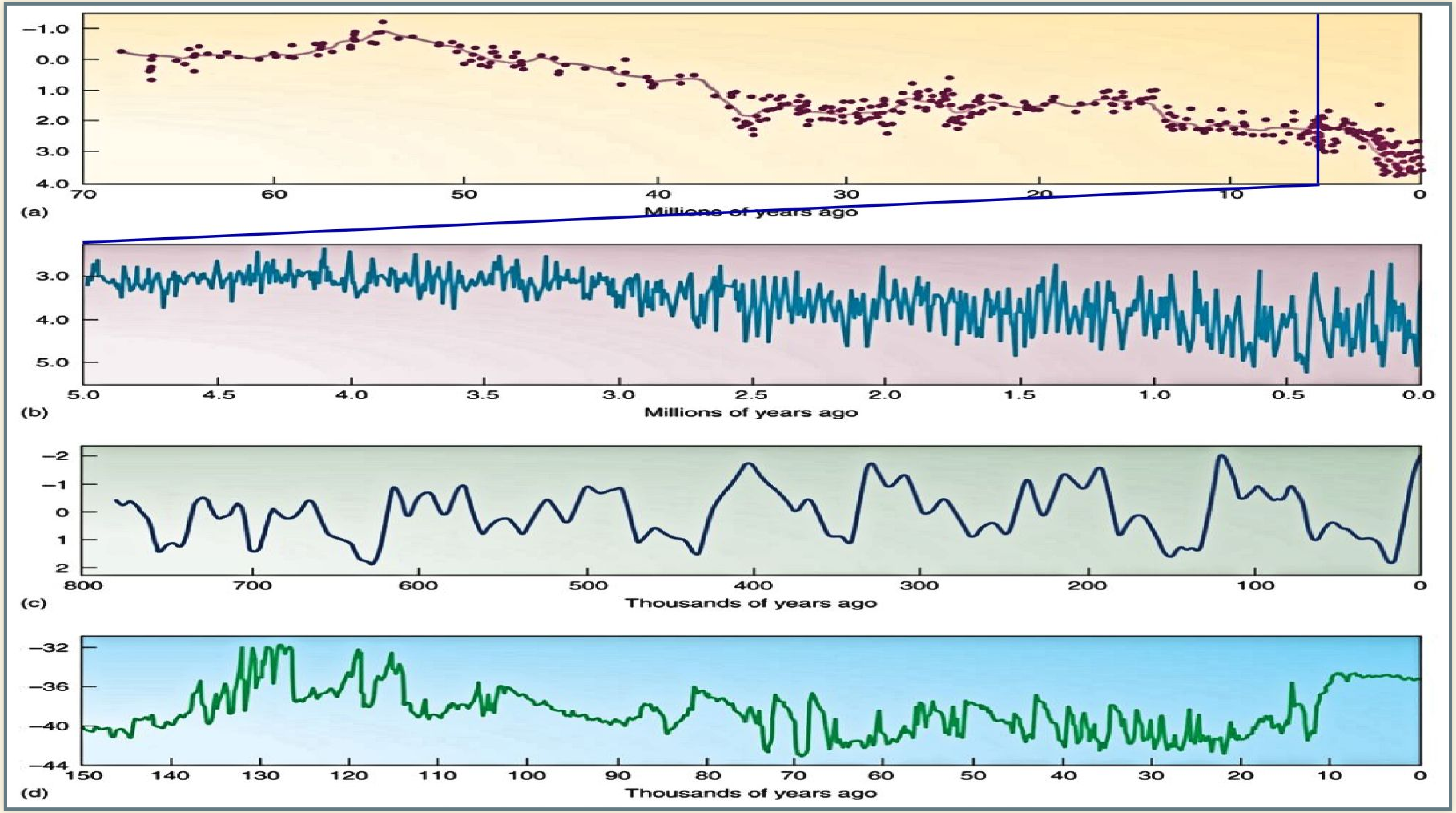
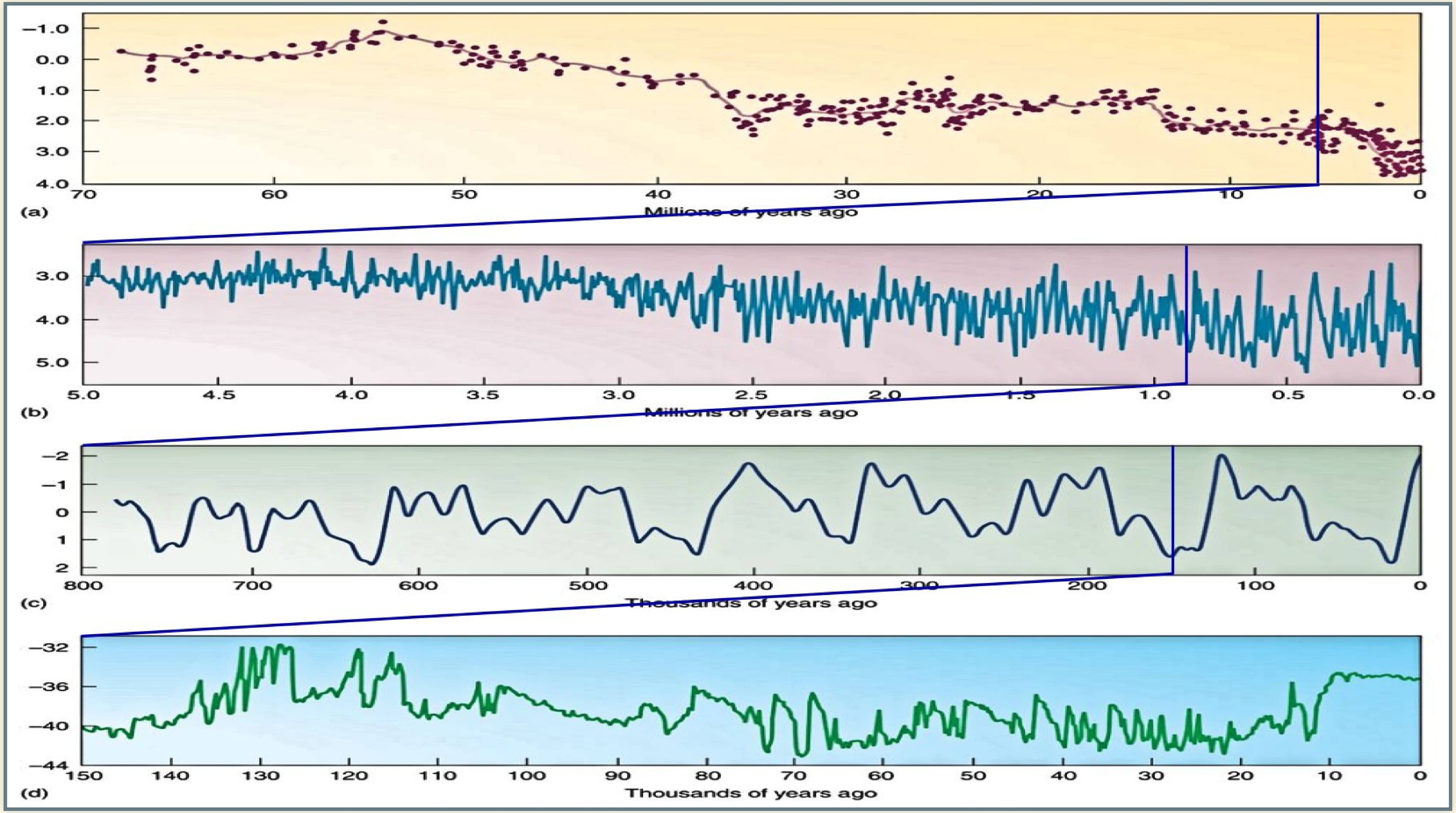


Climates of the Past



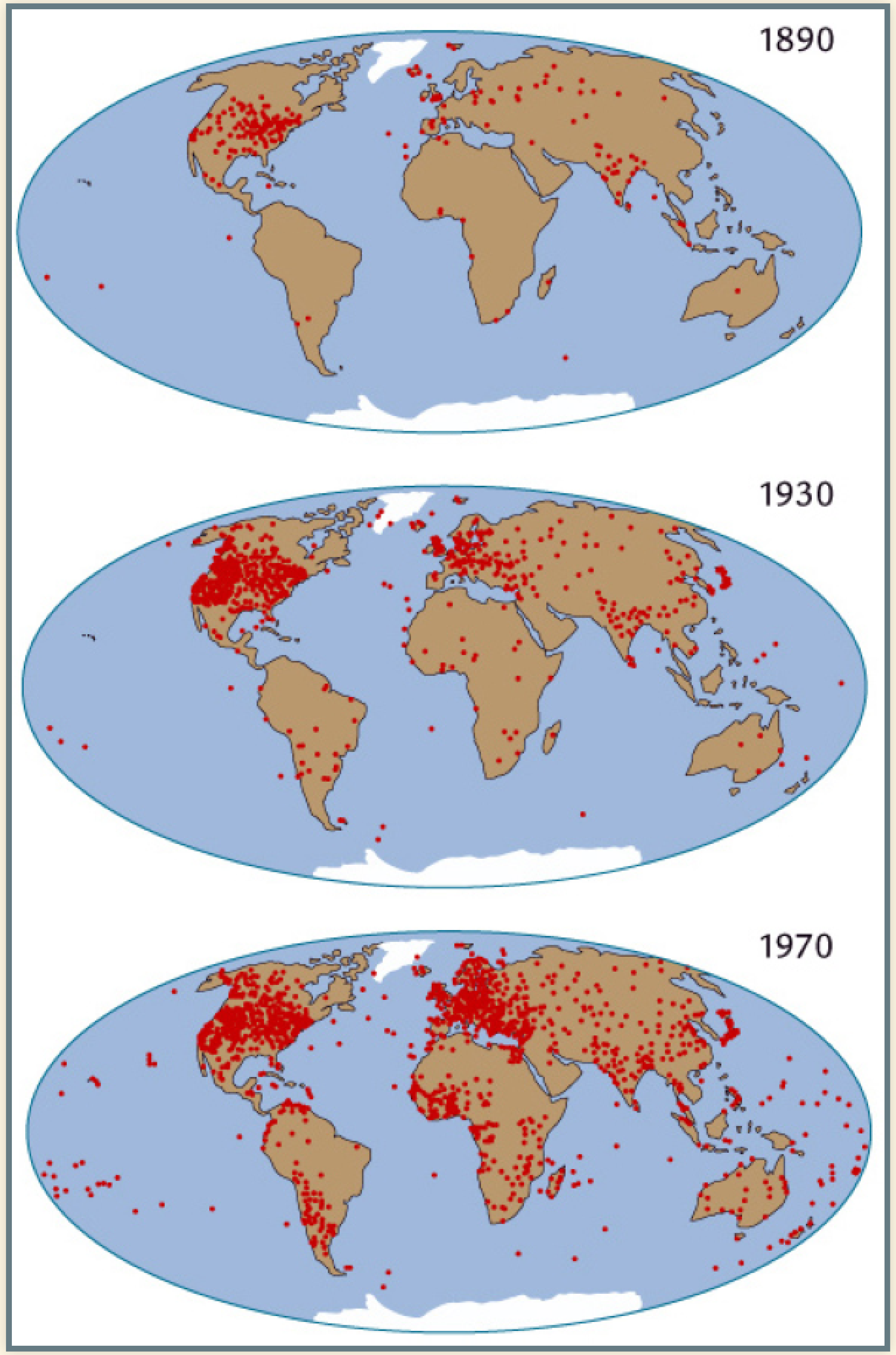
Climates of the Past



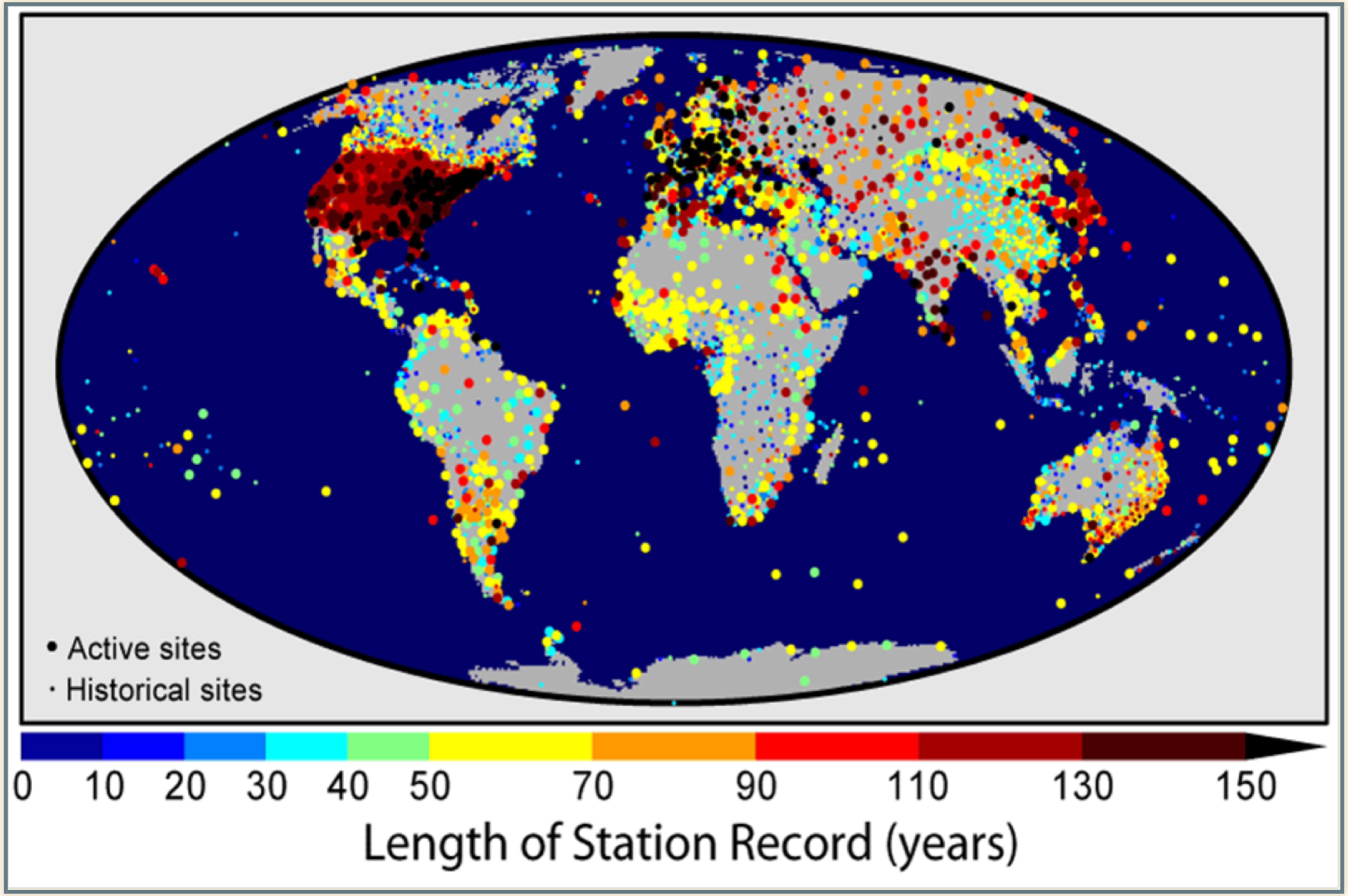
Digging into the past

Digging into the past:

The last 130 years



Surface Temperature Monitoring



- 7280 stations
- 2277 active
- 1656 > 100 years

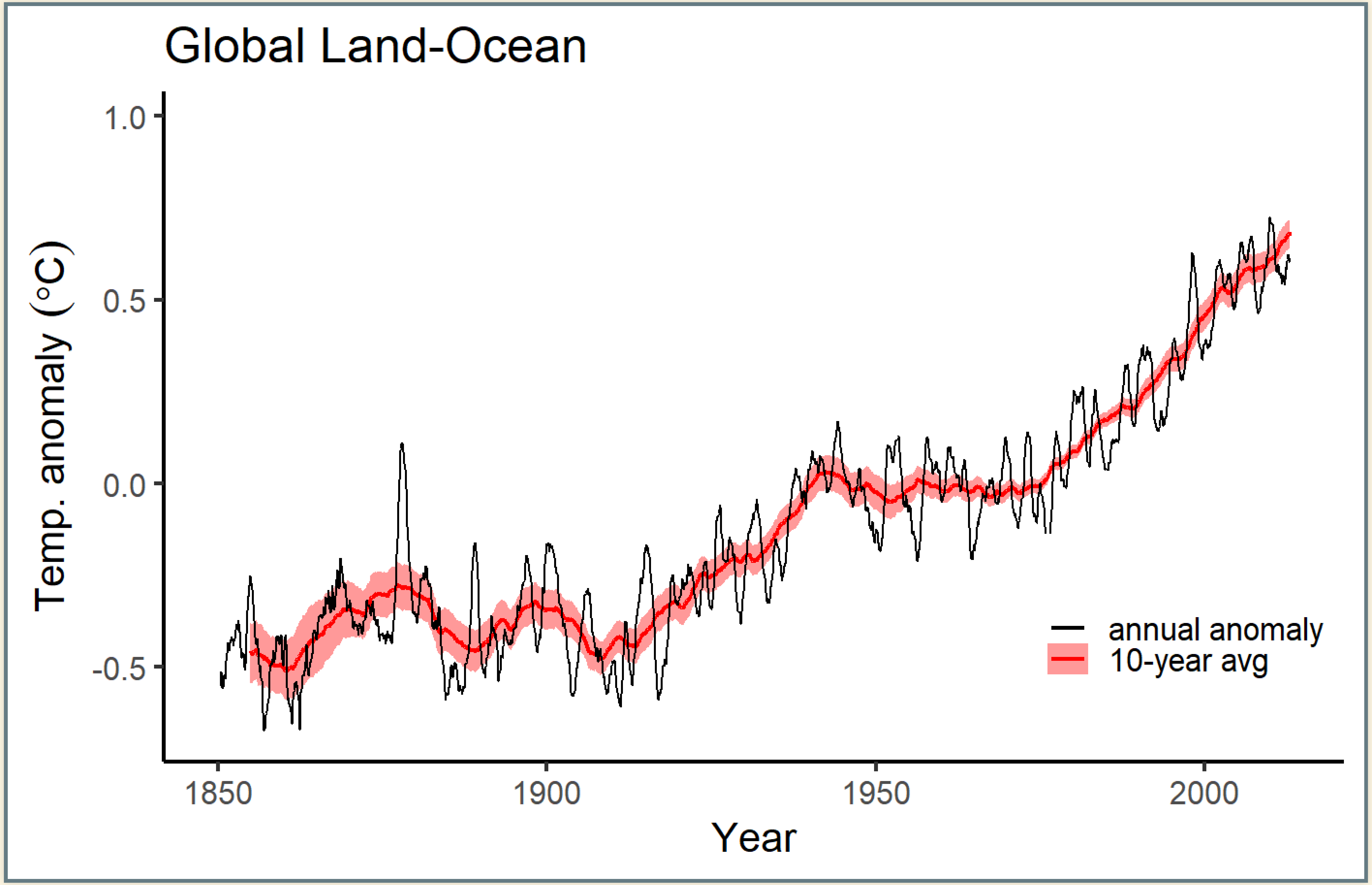
Temperature Anomaly

- **Global temperature change:**
  - Average temperatures are different at different places.
  - Temperatures change with the seasons
  - How to compare temperature change between places with different climates?
- **Temperature anomaly:**
  - Define a reference time period (several decades)
  - Anomaly = **actual temperature** at a place and time *minus* **average temperature** at that place during reference period

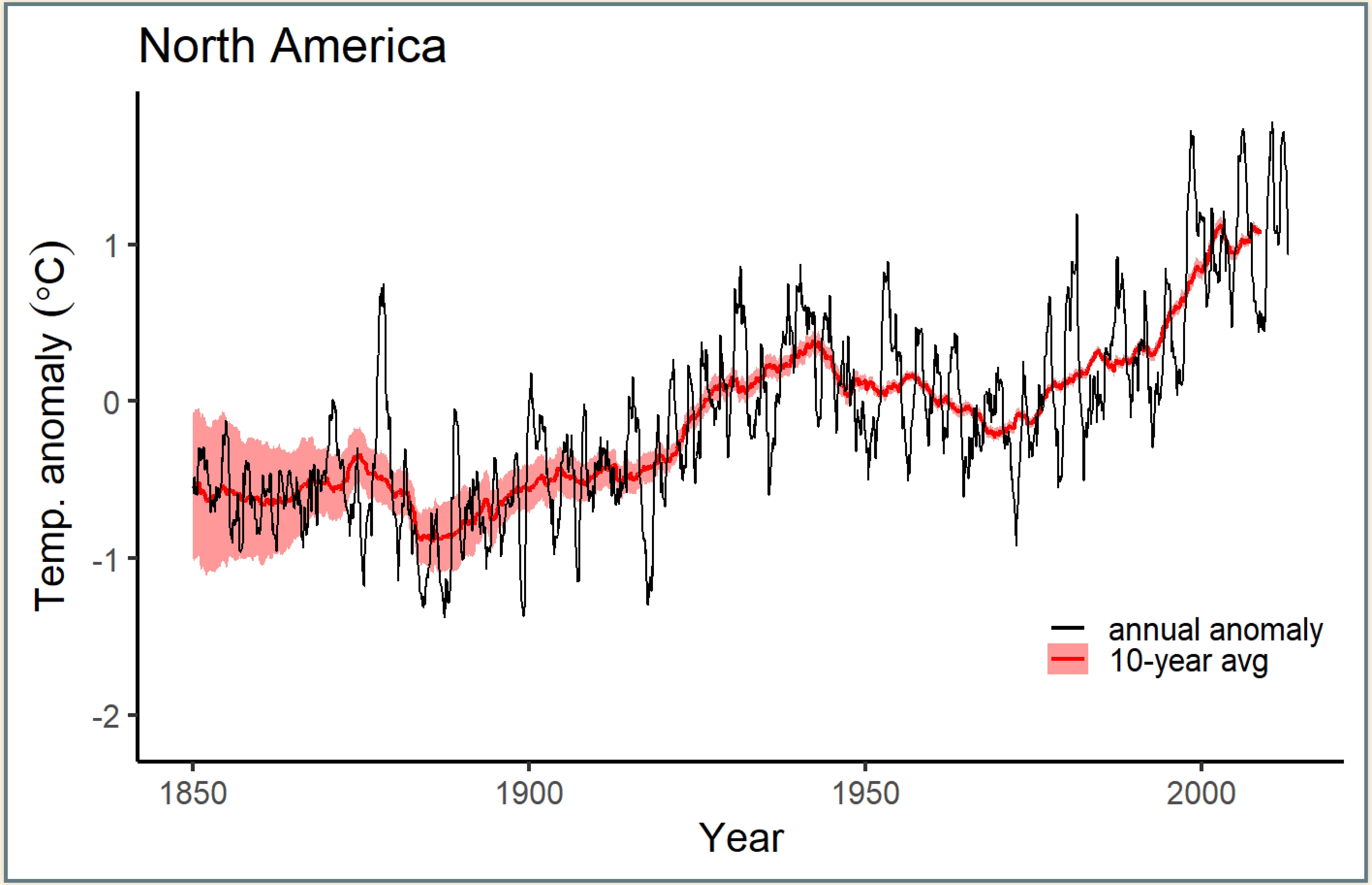
Temperature Anomaly

- Anomaly = **actual temperature** at a place and time *minus* **average temperature** at that place during reference period
- **Example: Anomaly for Nashville, January, 2020**
  - Monthly avg. temp. for January, 2020 = $7.2^{\circ}\mathrm{C}$
  - Average January temp 1950–1979 = $3.0^{\circ}\mathrm{C}$
  - Anomaly = $7.2^{\circ}\mathrm{C} - 3.0^{\circ}\mathrm{C} = 4.3^{\circ}\mathrm{C}$

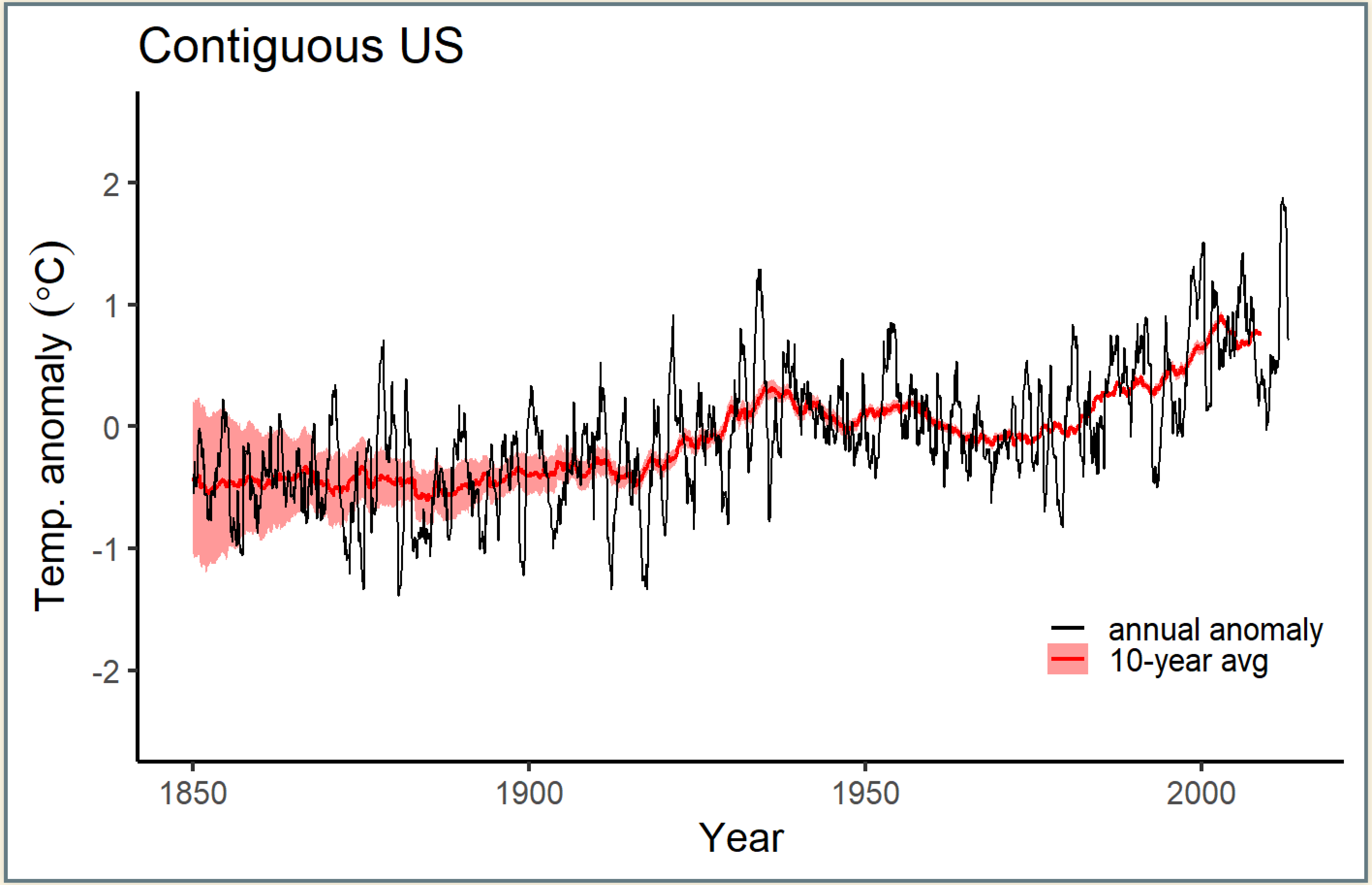
Global Anomaly
1850–2012



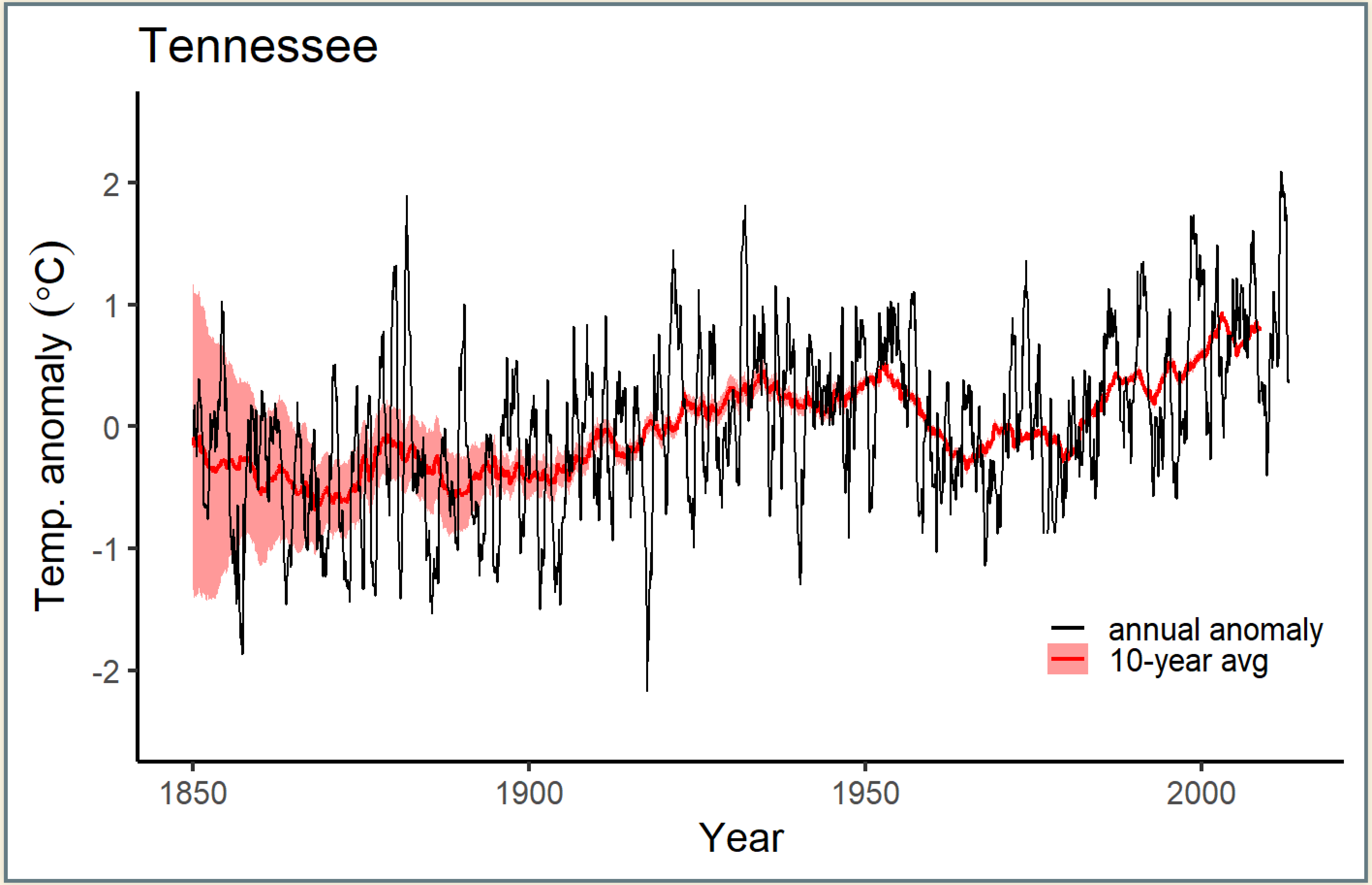
North America
1850–2012



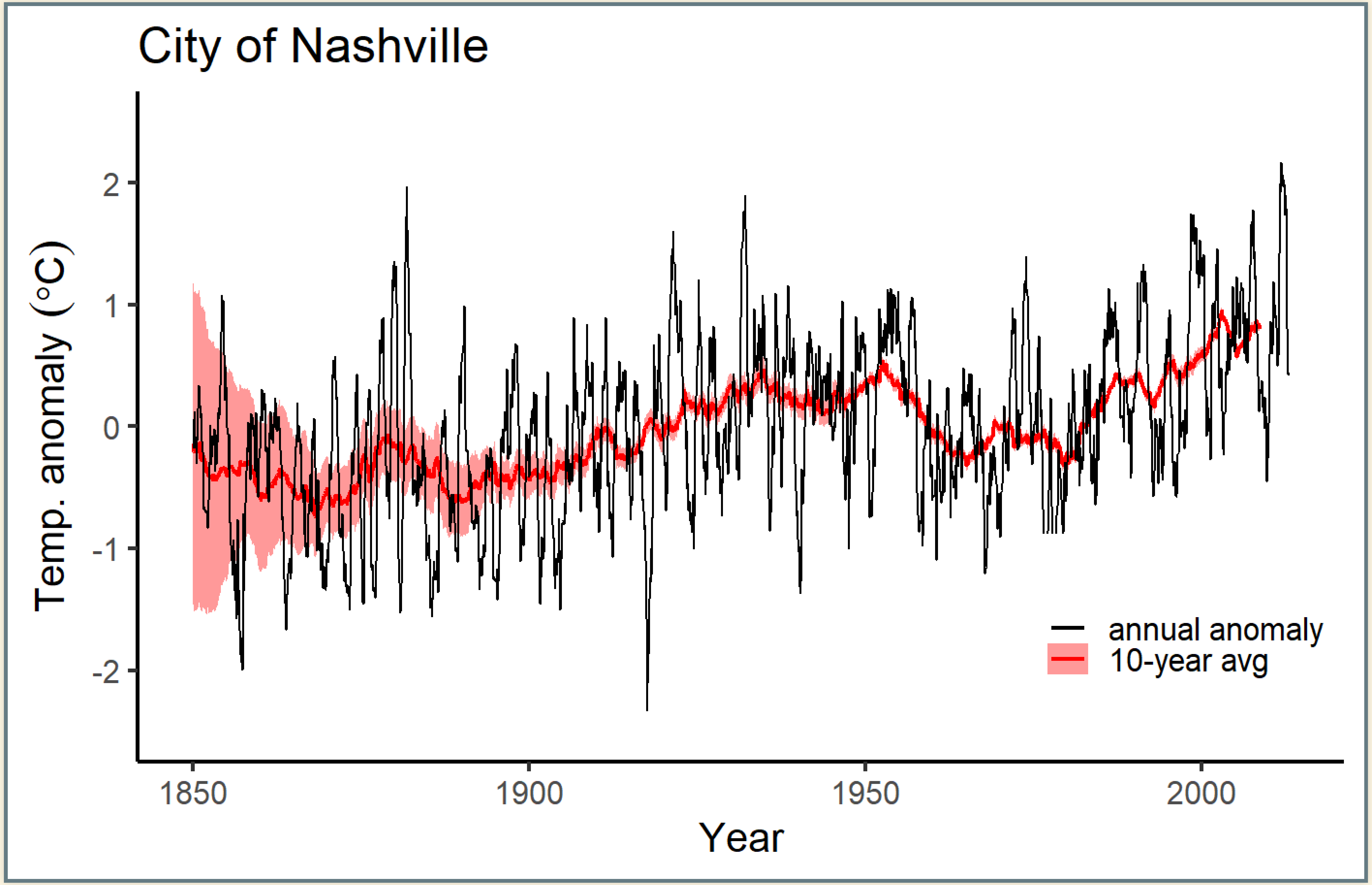
Continental US Anomaly
1850–2012



Tennessee Anomaly
1850–2012



Nashville Anomaly
1850–2012



Ocean Temperatures

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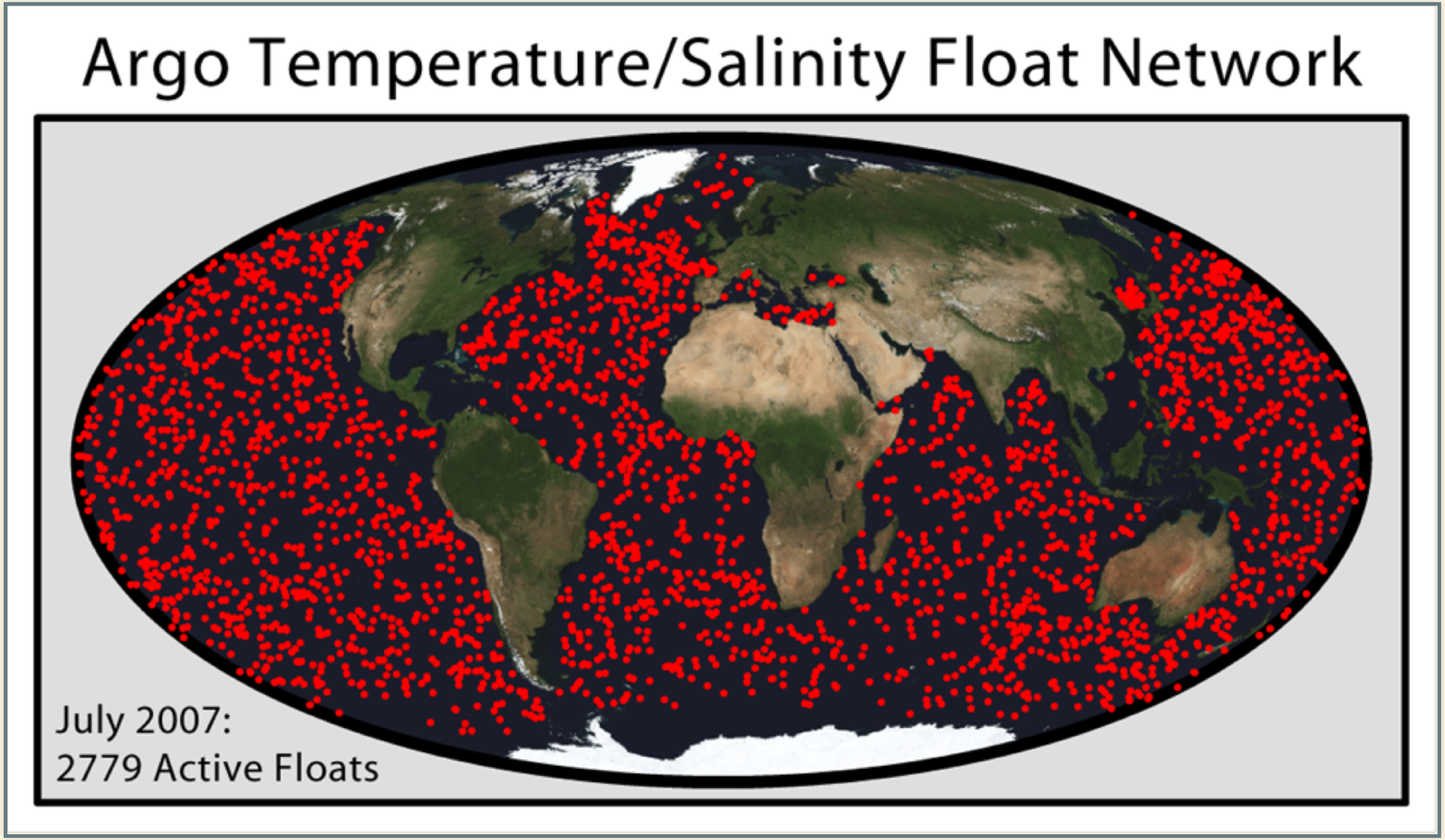
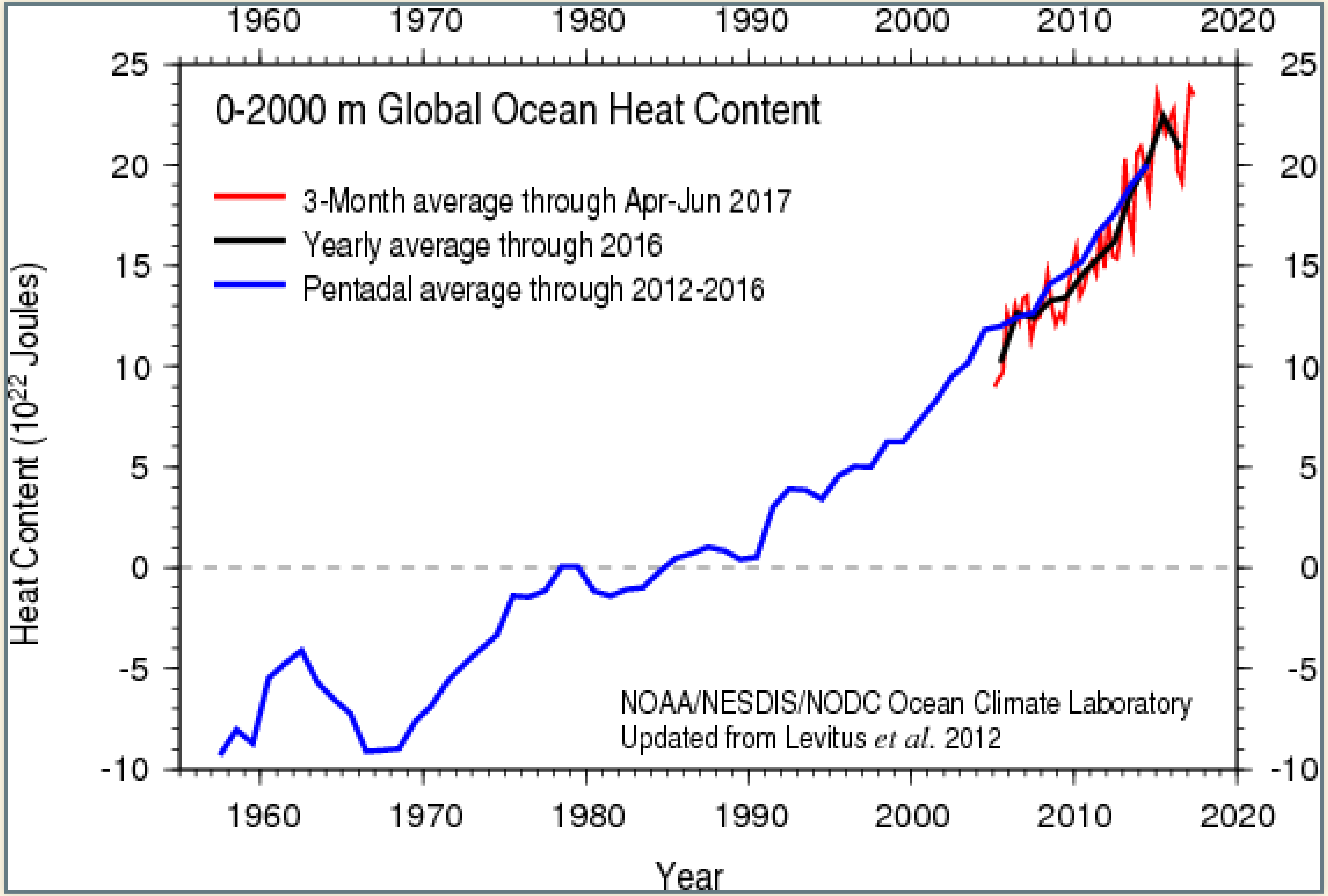


Ocean Heat Content

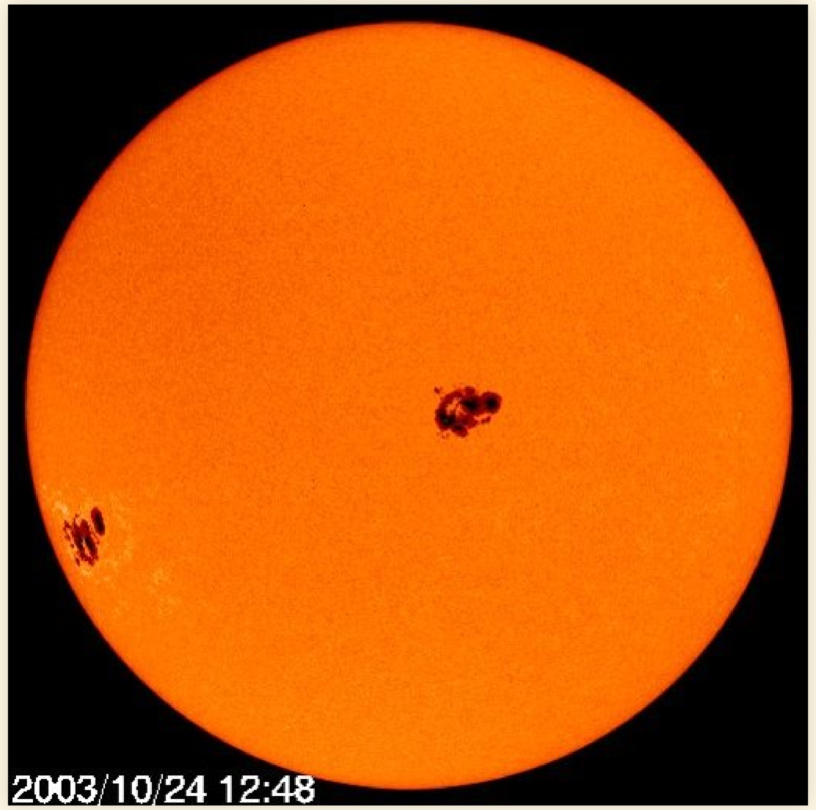


Searching for a Smoking Gun:

What caused the warming?

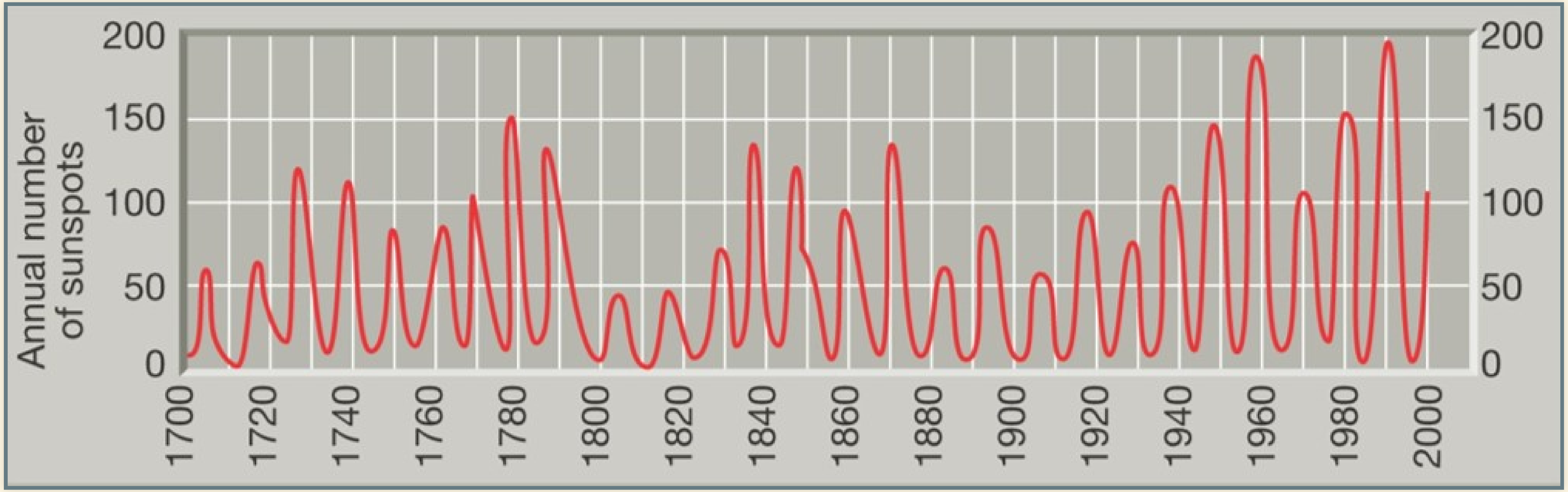
Sunspots?

Sunspots?

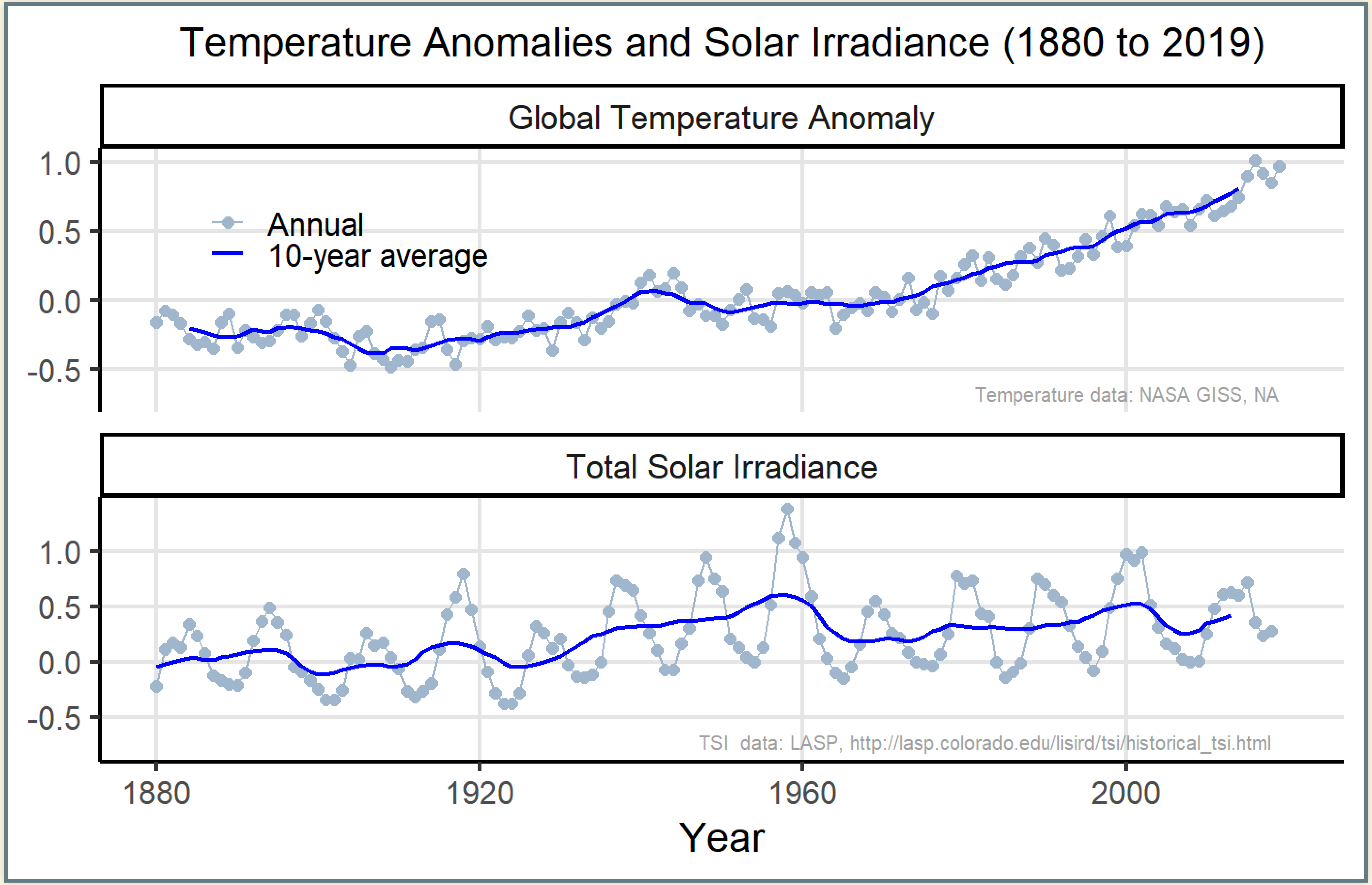


Sunspots

- More sunspots $\rightarrow$ brighter
- 11 year cycle
- Intensity changes:
  - <1% for 11-year cycle
  - <0.1% change in decadal average from little ice age to present



Sunspots didn't cause recent warming



Fingerprints:
Predictions and Patterns

Predictions: 1967

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Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory, ESSA, Washington, D. C.

(Manuscript received 2 November 1966)

ABSTRACT

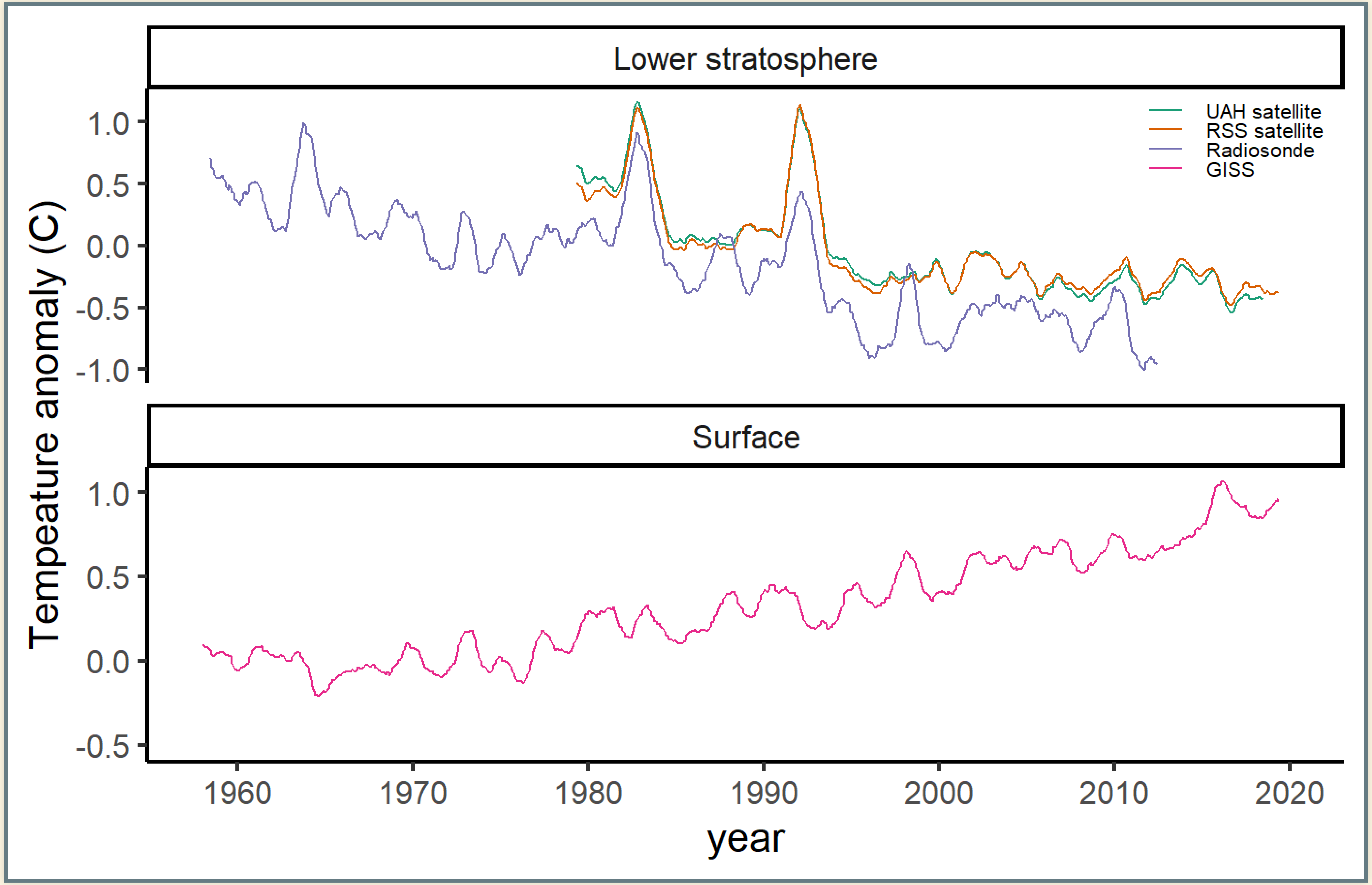
Radiative convective equilibrium of the atmosphere with a given distribution of relative humidity is computed as the asymptotic state of an initial value problem.

The results show that it takes almost twice as long to reach the state of radiative convective equilibrinm for the atmosphere with a given distribution of relative humidity than for the atmosphere with a given distribution of absolute humidity.

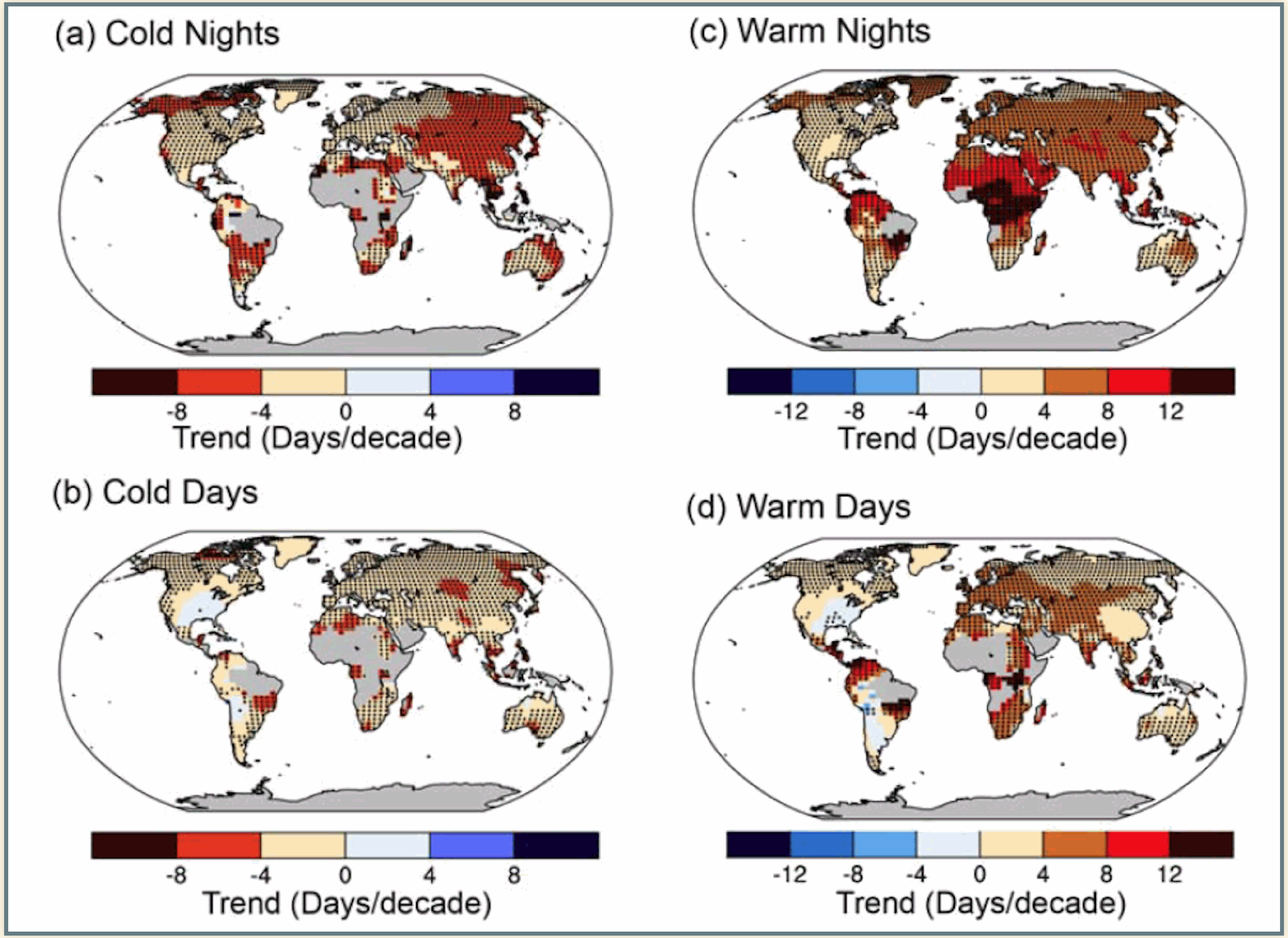
Also, the surface equilibrium temperature of the former is almost twice as sensitive to change of various factors such as solar constant, CO_2 content, O_3 content, and cloudiness, than that of the latter, due to the adjustment of water vapor content to the temperature variation of the atmosphere.

According to our estimate, a doubling of the CO_2 content in the atmosphere has the effect of raising the temperature of the atmosphere (whose relative humidity is fixed) by about 2C. Our model does not have the extreme sensitivity of atmospheric temperature to changes of CO_2 content which was adduced by Möller.

Stratosphere vs. Surface:



Day vs. Night


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