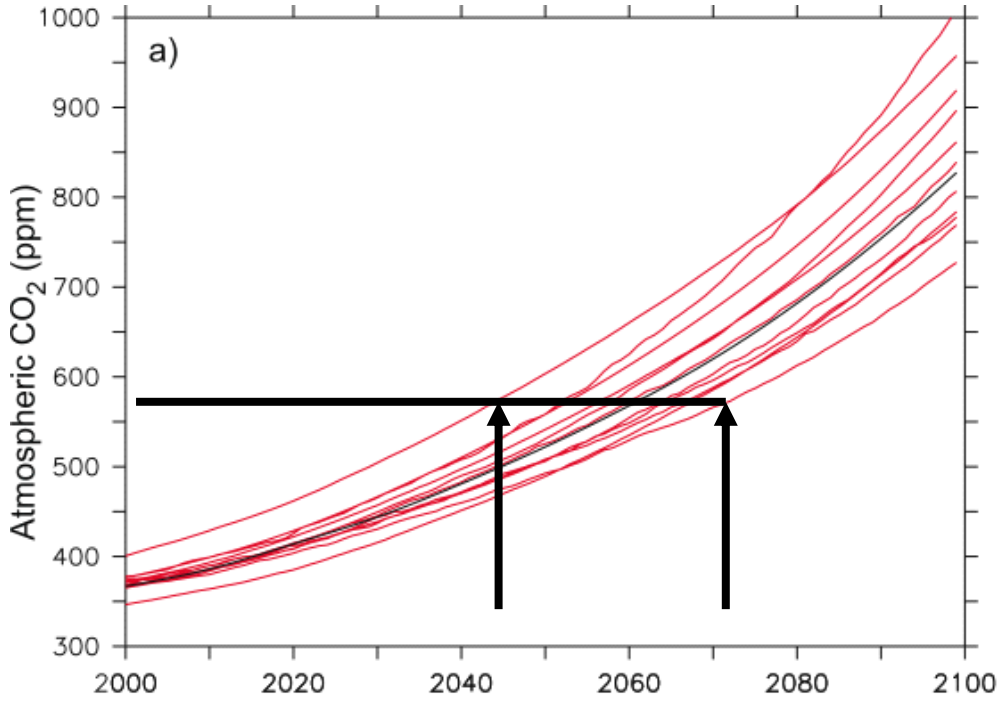
Kaya Identity Model: Predicting Future Emissions

kaya identity model

Calculate Your Carbon Footprint

Nature Conservancy Carbon Footprint Calculator

Future Atmospheric CO_2



One anthropogenic emission scenario in many different IPCC models

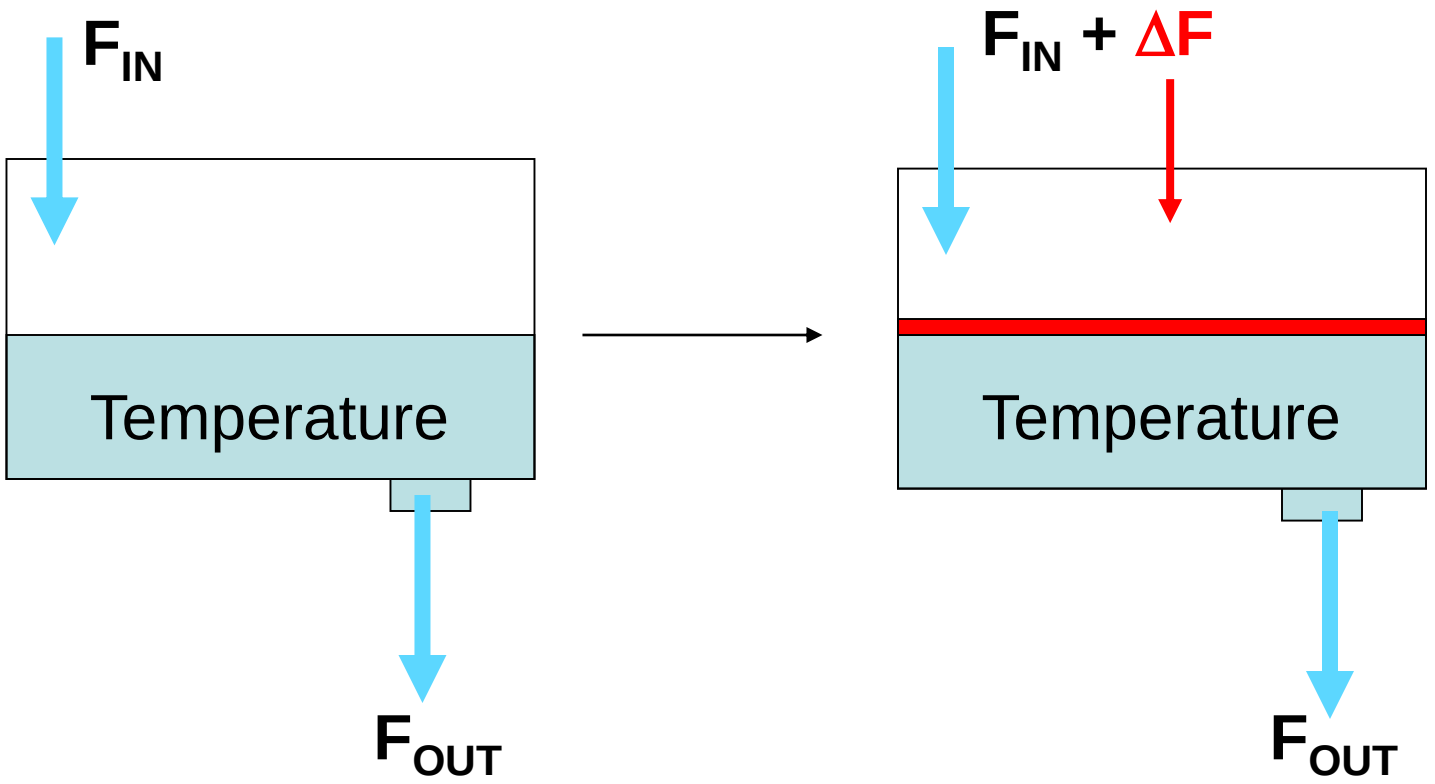
Range of model predictions suggest double pre-industrial (2 x 280 ppm) by mid-century

This Week (and next): Climate Forcings

- **Natural**
  - **Orbital (long-term)**
  - **Solar (short-term)**
  - **Volcanic (short-term)**
- **Anthropogenic**
  - **Greenhouse effect (via Carbon Cycle)**
  - **Albedo (via Aerosol Particles)**

Climate Forcings

a perturbation that directly or indirectly affects Earth's energy budget



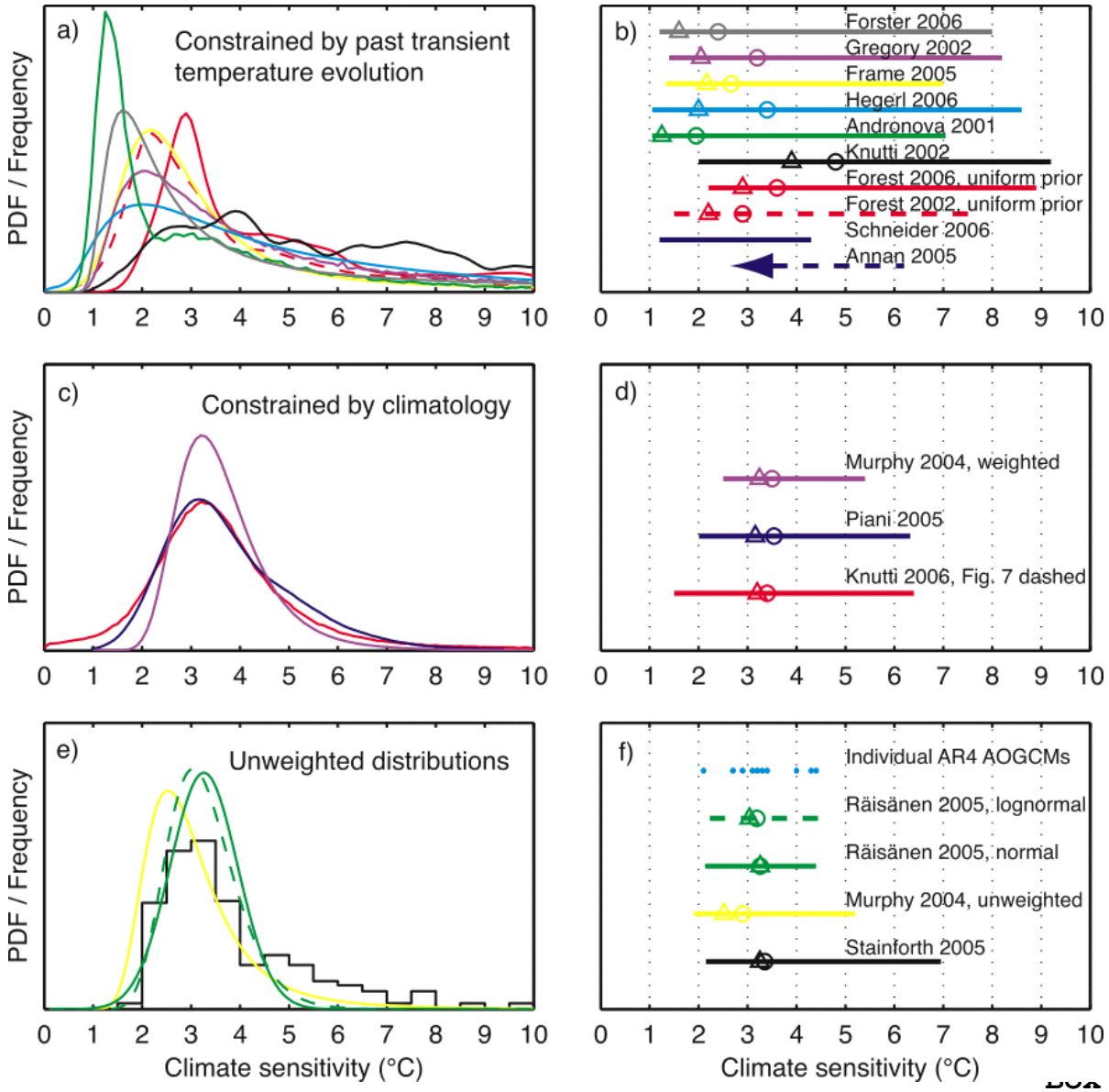
Climate Sensitivity-All about Feedbacks

$$\Delta T = \lambda \Delta F$$

λ is the ***climate sensitivity parameter***

→ ***units: K "per" W/m^2***
→ **amount of climate change for a forcing**
→ **λ determined by feedbacks!**

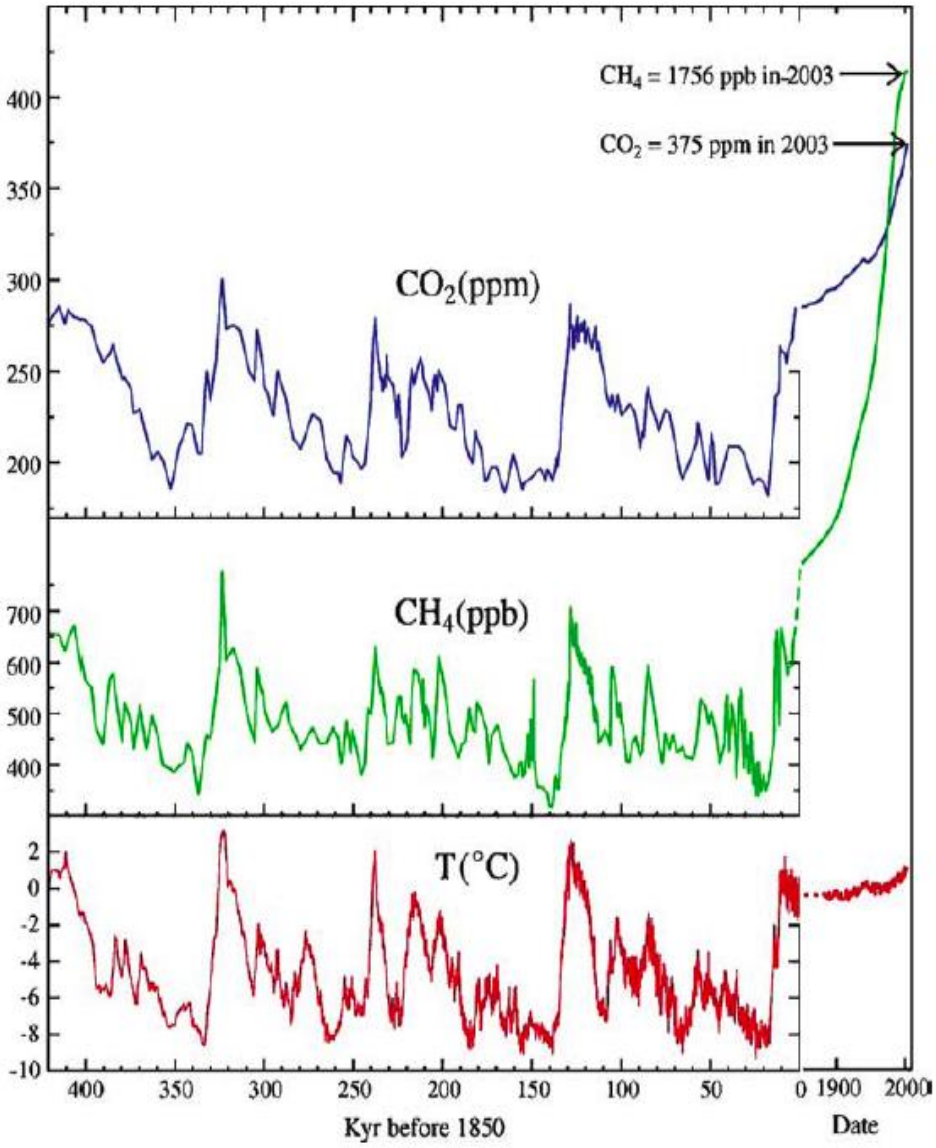
Estimates of Climate Sensitivity



T change for a 4 W/m² forcing (i.e. "double CO_2")

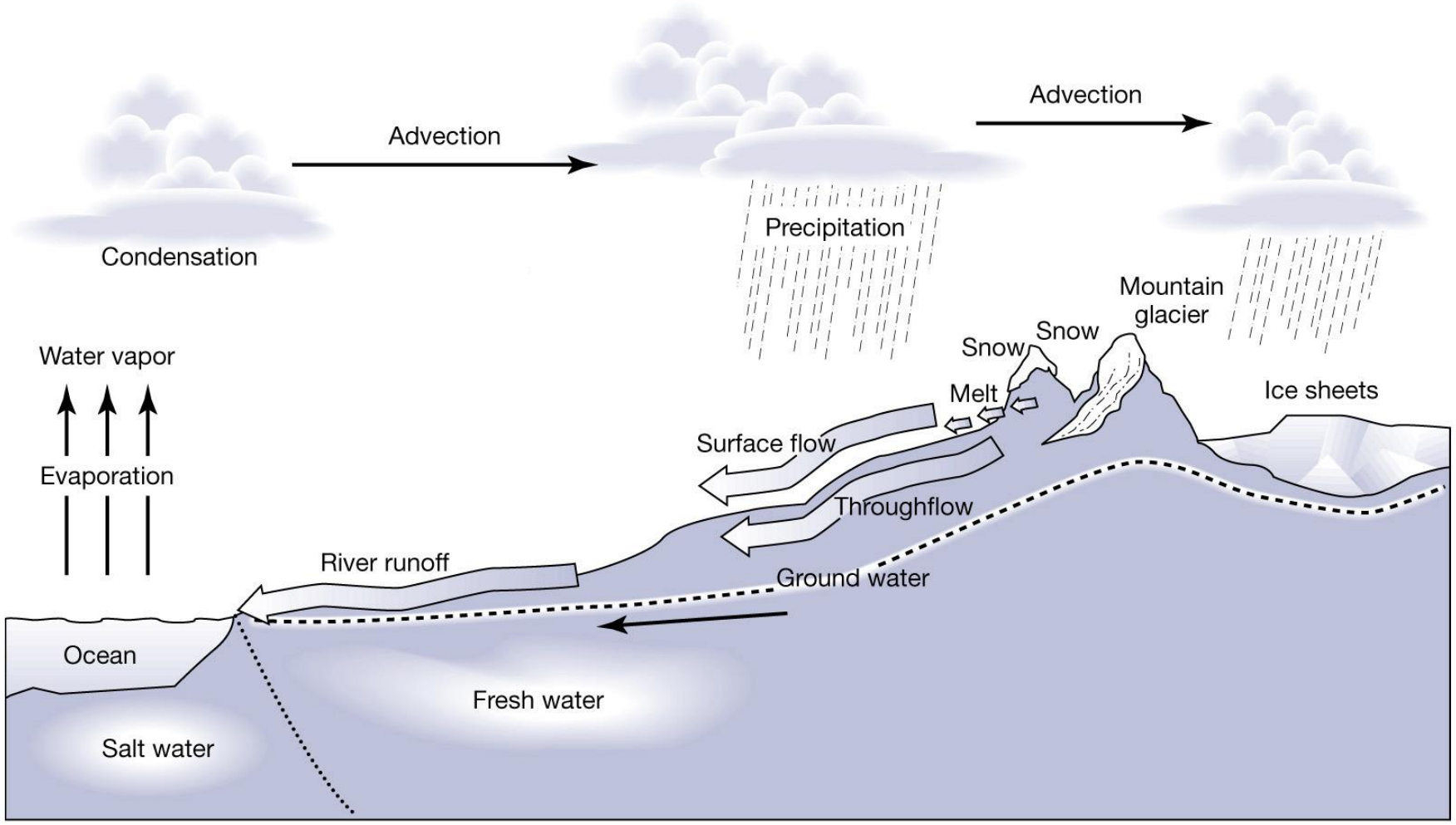
Most probable λ ~ 0.75 K/(W/m²)

Pleistocene Ice Ages



Large (but slow) natural changes in global hydrologic cycle

Water Cycle – During Glacial-Interglacial Periods



“Ice ages” – Net transfer of water from ocean to land-based ice sheets
→ Sea levels decrease

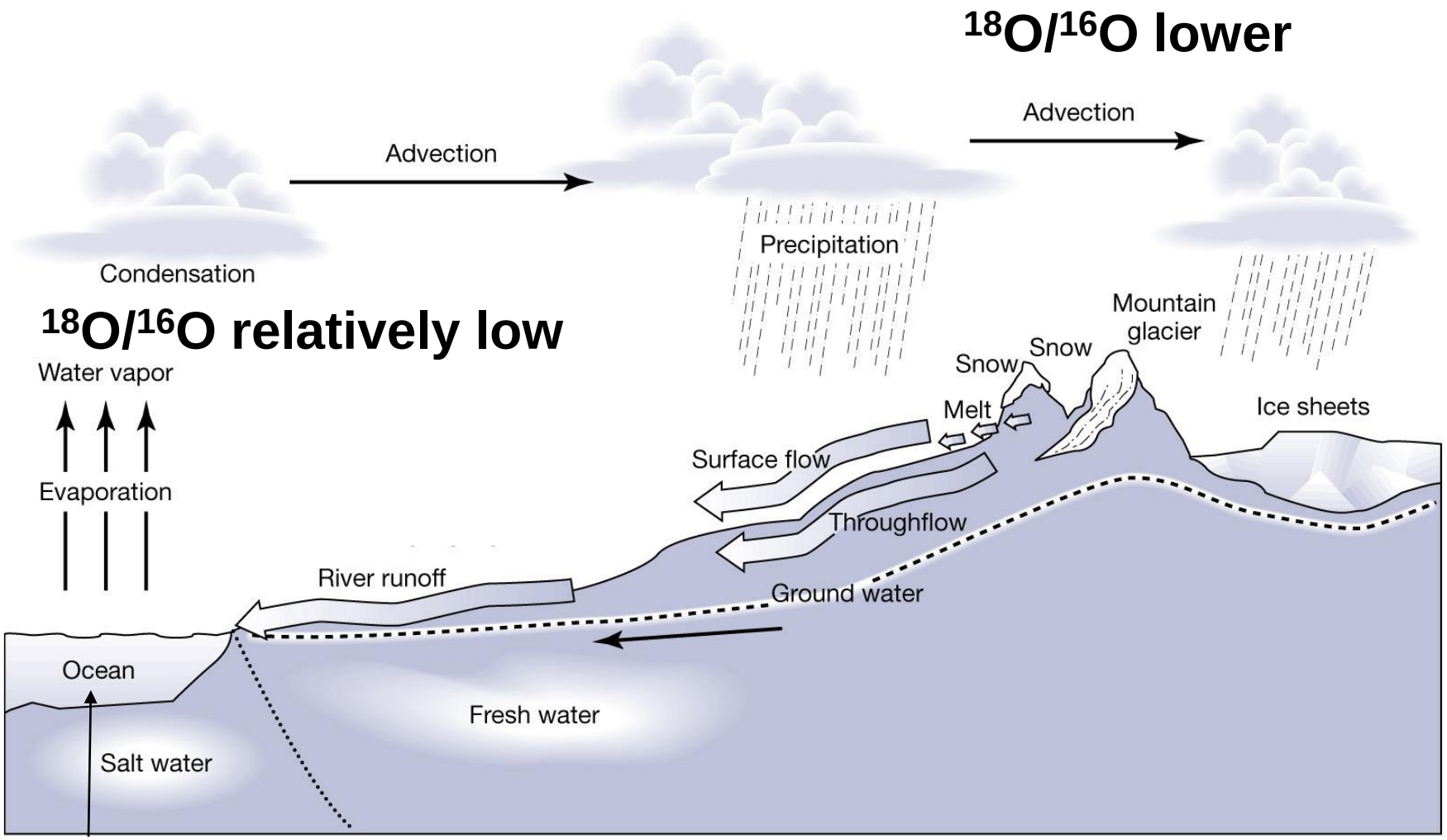
Detecting Change With Proxies

Another property/qty that is a ***function*** of (i.e. depends upon) property of interest.

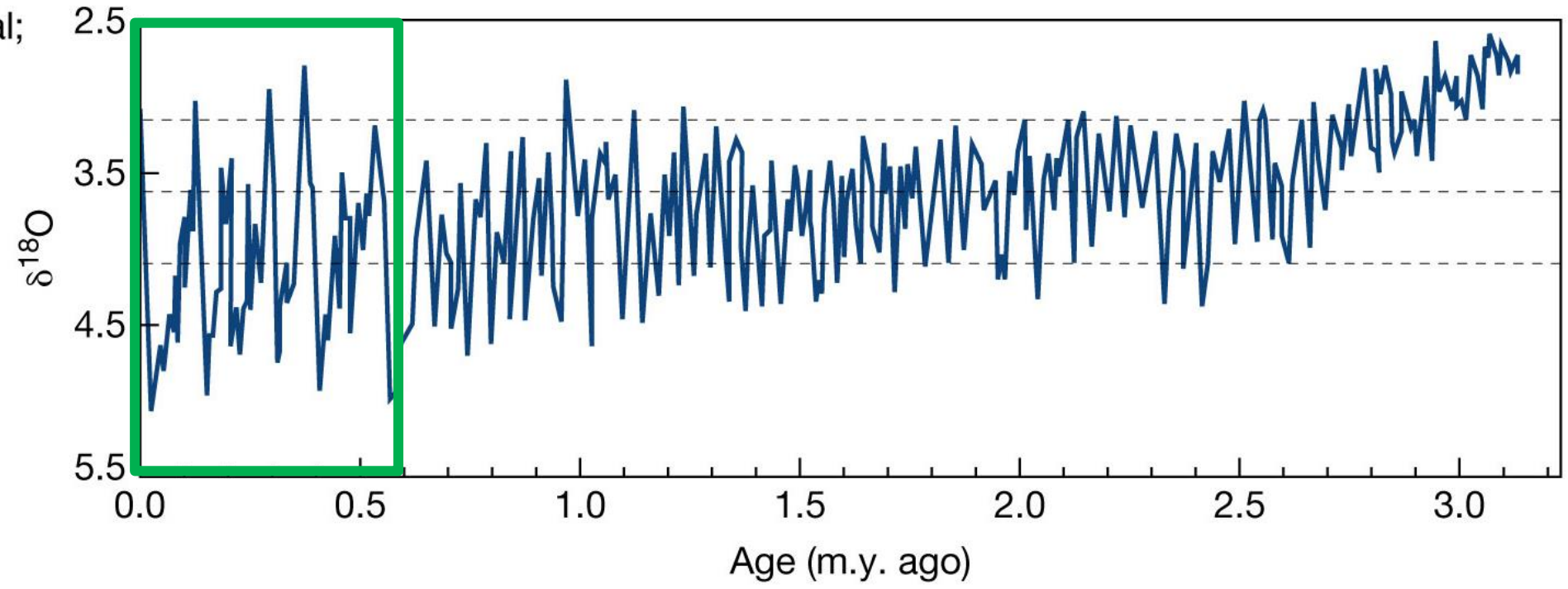
Think *ap**proxi**mate*

The measured property is a **PROXY** for the one of interest.

Water Cycle – Water Isotope Proxy

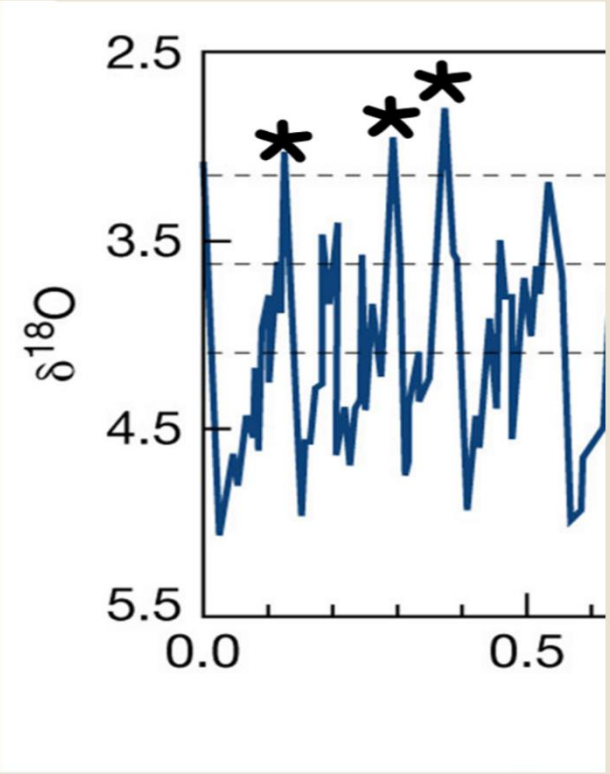


^{18}O Ratios in Sediment and Ice Core



W The times in the sediment record indicated by the '*' correspond to

Poll locked. Responses not accepted.

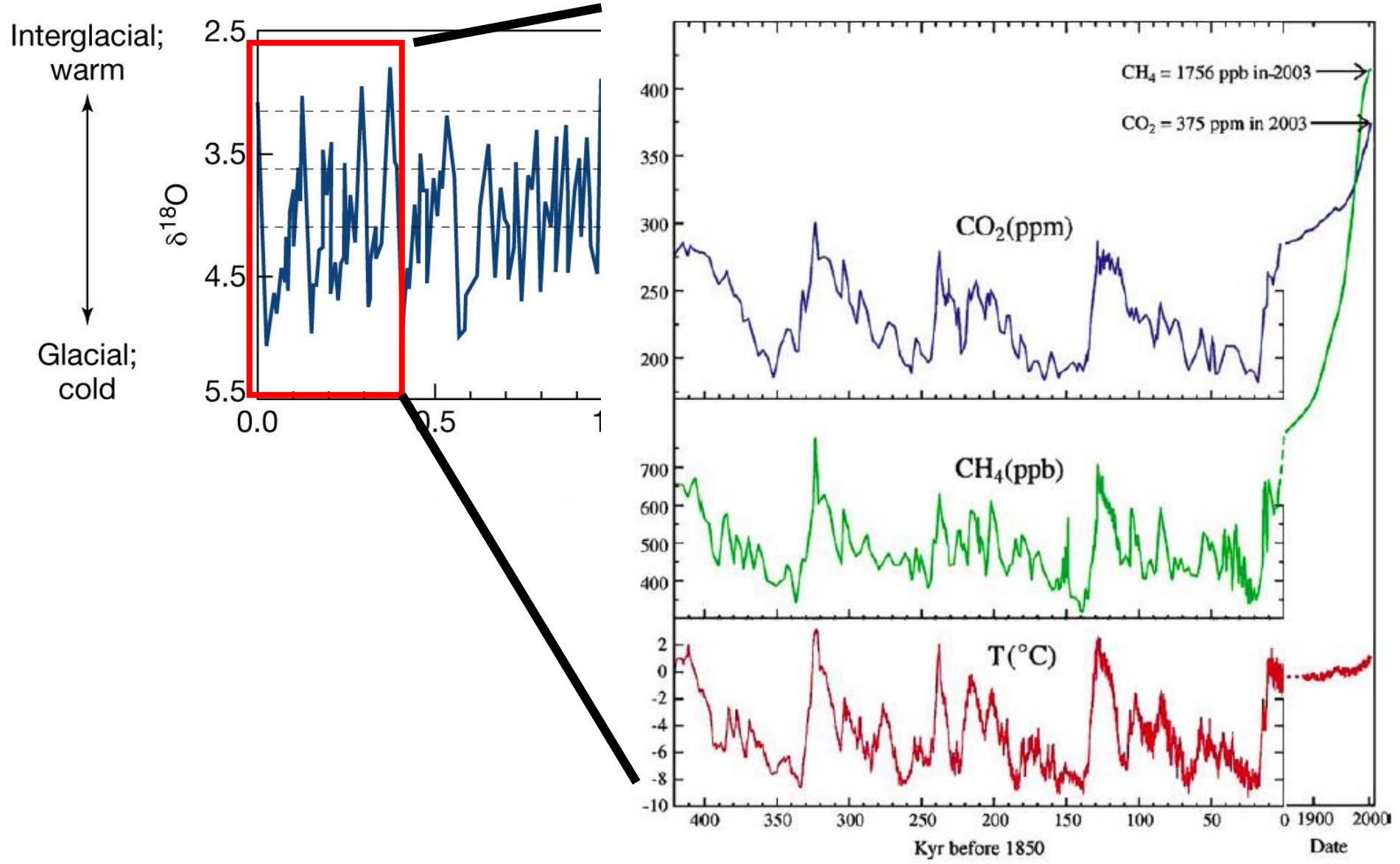


Net glaciation (ice sheet growth)

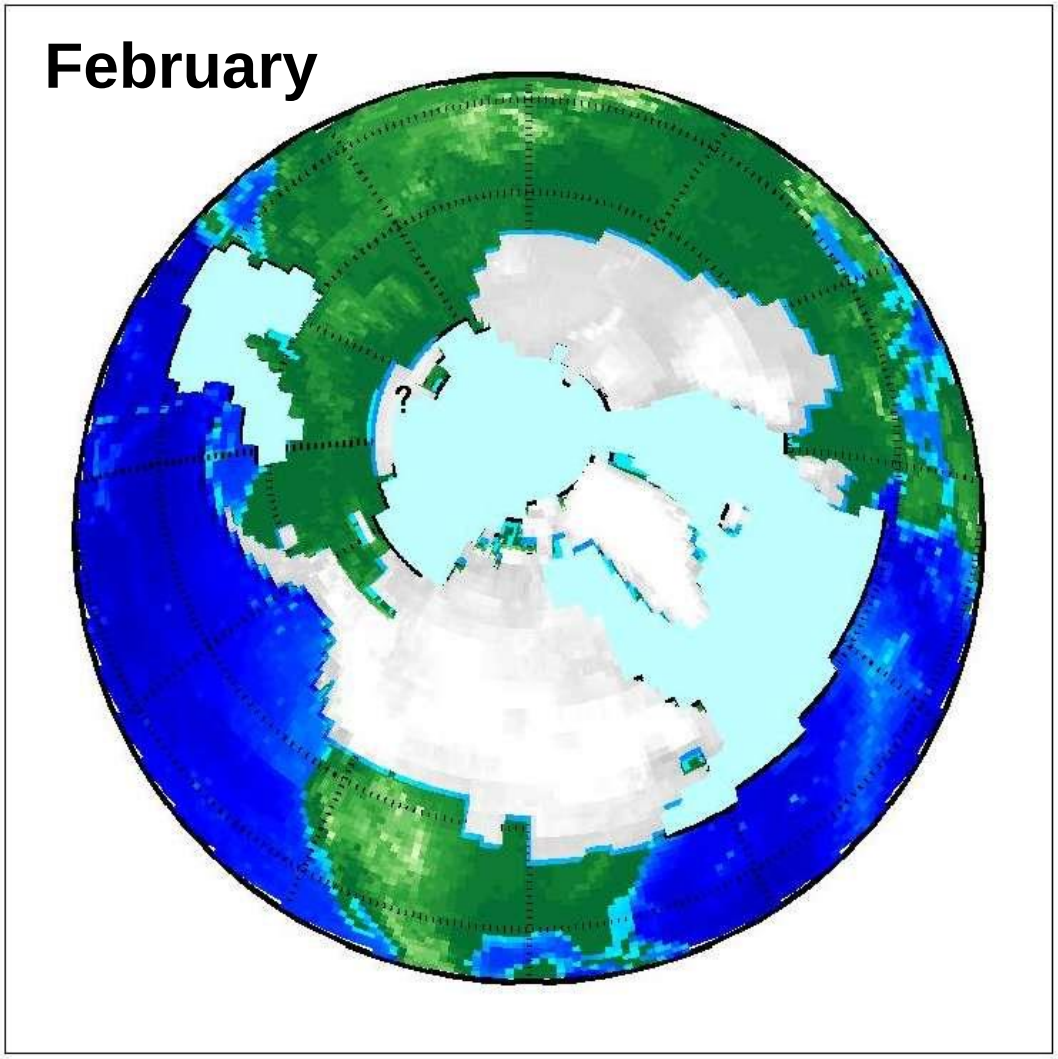
Net deglaciation (ice sheet retreat)

Total Results: 0

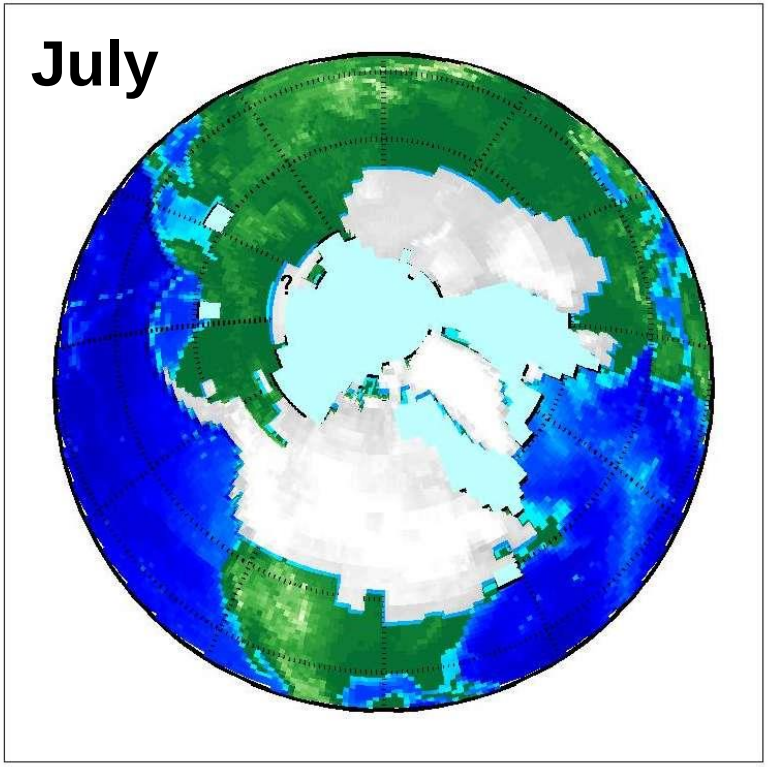
^{18}O Ratios in Sediment and Ice Core



Pleistocene Glaciations



Sea Levels lower by 100 m (300 ft)!



Reconstruction of land and sea ice
21,000 years ago (last glacial maximum)

Records of NH Glaciations

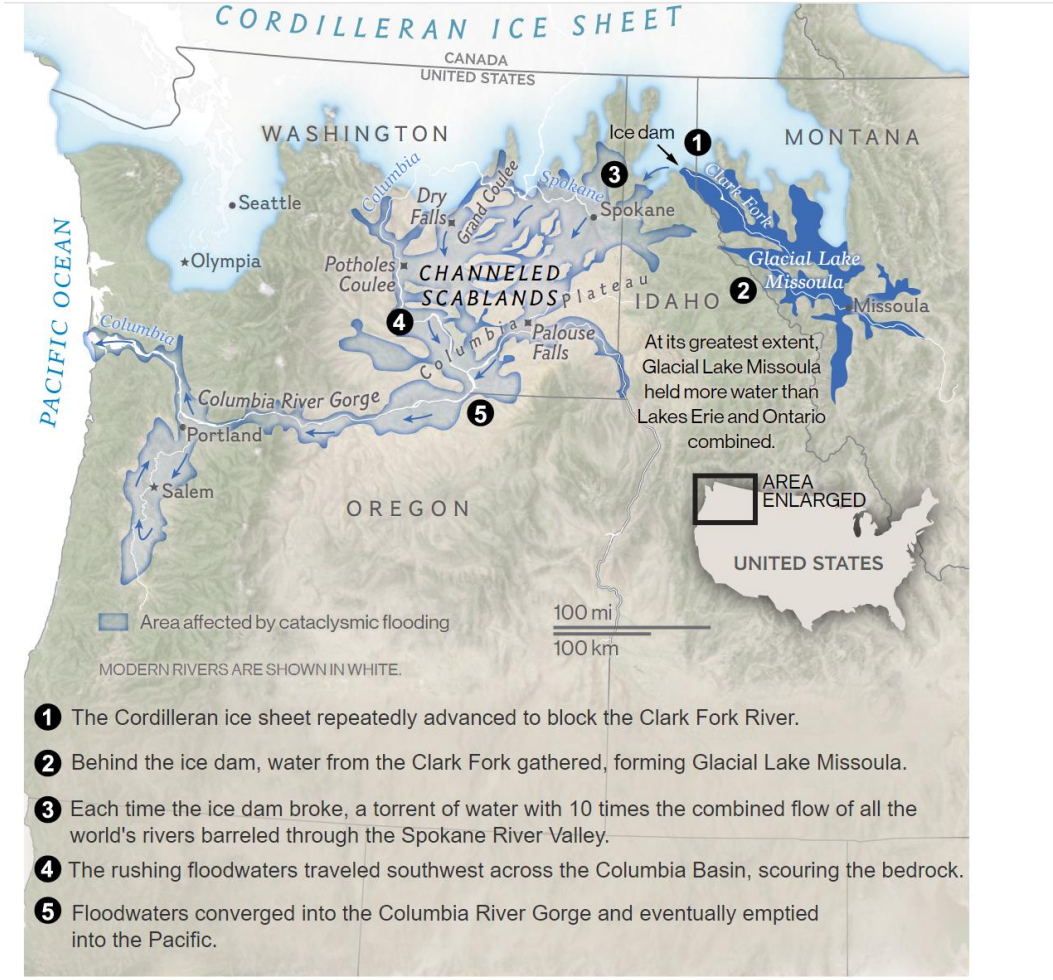
Geological Records: glacial deposits, drop stones, scarring

Cordilleran Ice Sheet

Lake Missoula

Spokane Floods (from Lake Missoula)

One of “7 Wonders of WA”: Channeled Scablands



:MARY WARDLEY, NG STAFF
SOURCES: USGS;<I> ATLAS OF OREGON</I>

https://news.nationalgeographic.com/2017/03/channeled-scablands/

One of “7 Wonders of WA”: Channeled Scablands

Drop Stone in Wedgewood Neighborhood…

The “Wedgewood Erratic” was stranded when the ice retreated. Today this massive rock sits north of the Unviersity of Washington campus - at the corner of NE 72nd Street and 28th Ave NE.

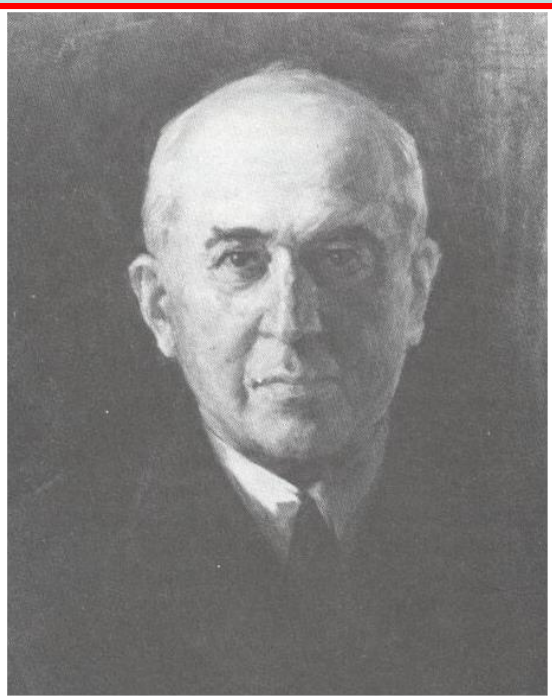
HUGEfloods.com

Milankovitch—Before sediment/ice cores

Predicts glacial and interglacial transitions based on variations in Earth's orbit

His hypothesis suggested *many* such transitions in ~ 1 million yrs (he was right)

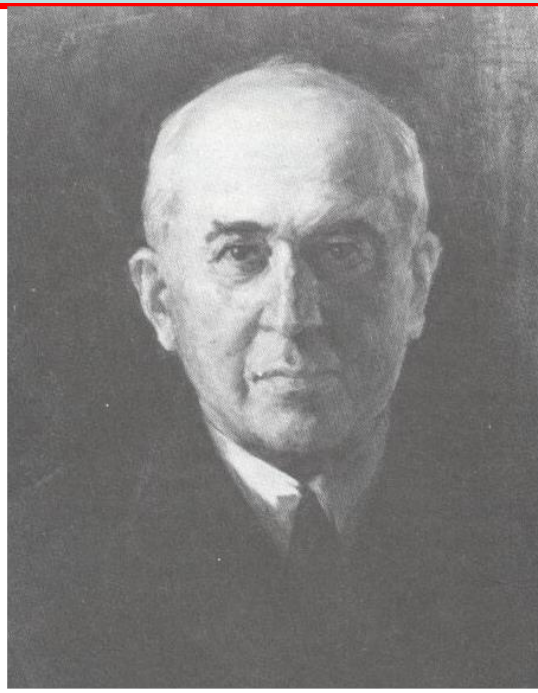
—at the time, no observable records show that many, so his work widely criticized



Milutin Milankovitch

Milankovitch Continued

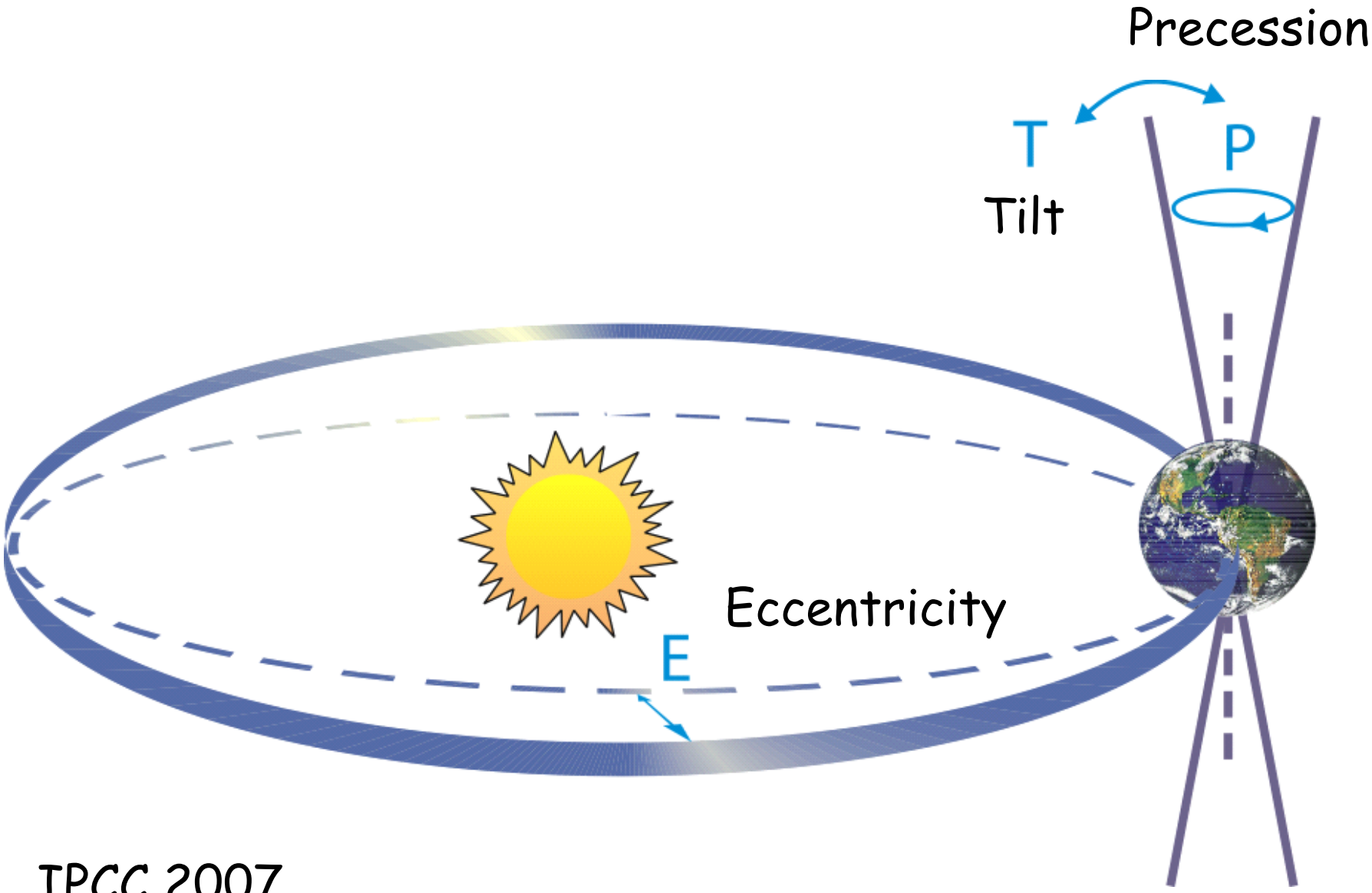
While lacking patience for critics, he did not lack confidence



Milutin Milankovitch

“I do not consider it my duty to give an elementary education to the ignorant, and I have also never tried to force others to use my theory, with which no one could find fault.”

Orbital Forcing Summary



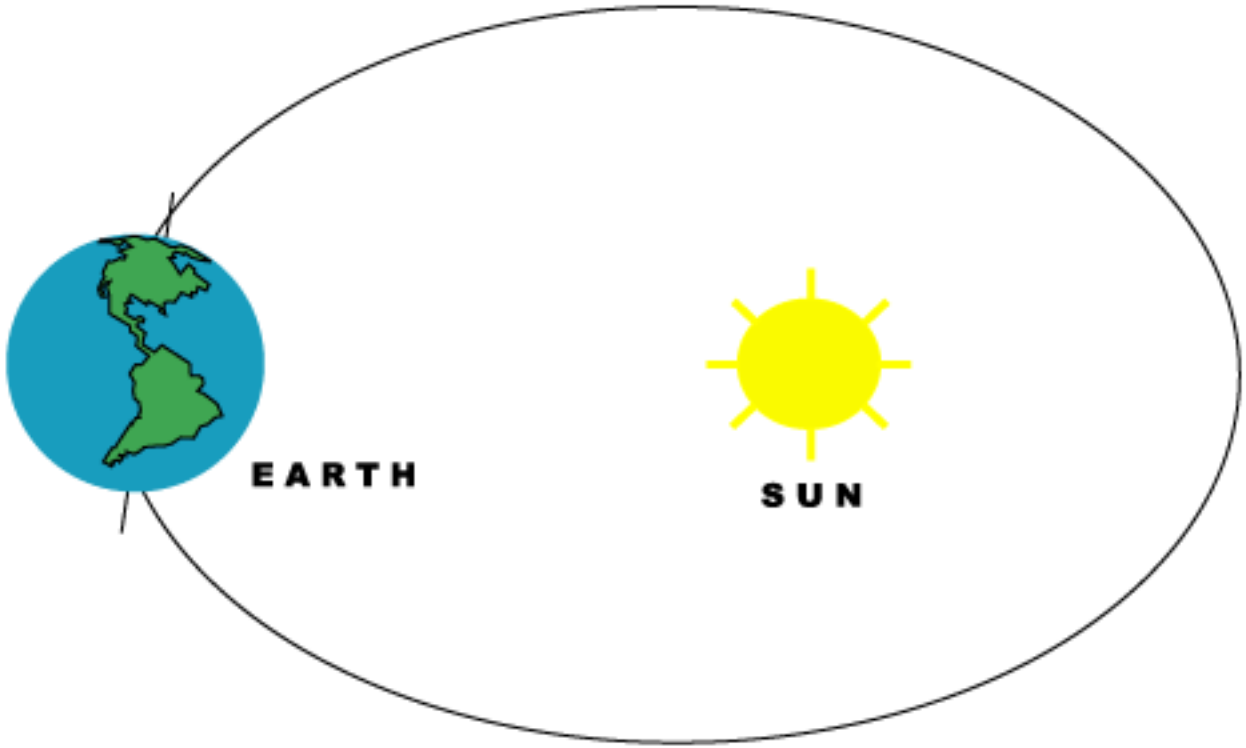
IPCC 2007

Orbital Forcings

Orbital Forcings – Milankovitch Cycles

- **Small variations in Earth's orbital parameters affect seasonal distribution of solar insolation**
- **Three oscillations (eccentricity, obliquity, precession) occur "in parallel", each with a characteristic frequency**
- **Net effect: glacial – interglacial "heartbeats" of Pleistocene (2.5 Ma – 10Kyr before present)**

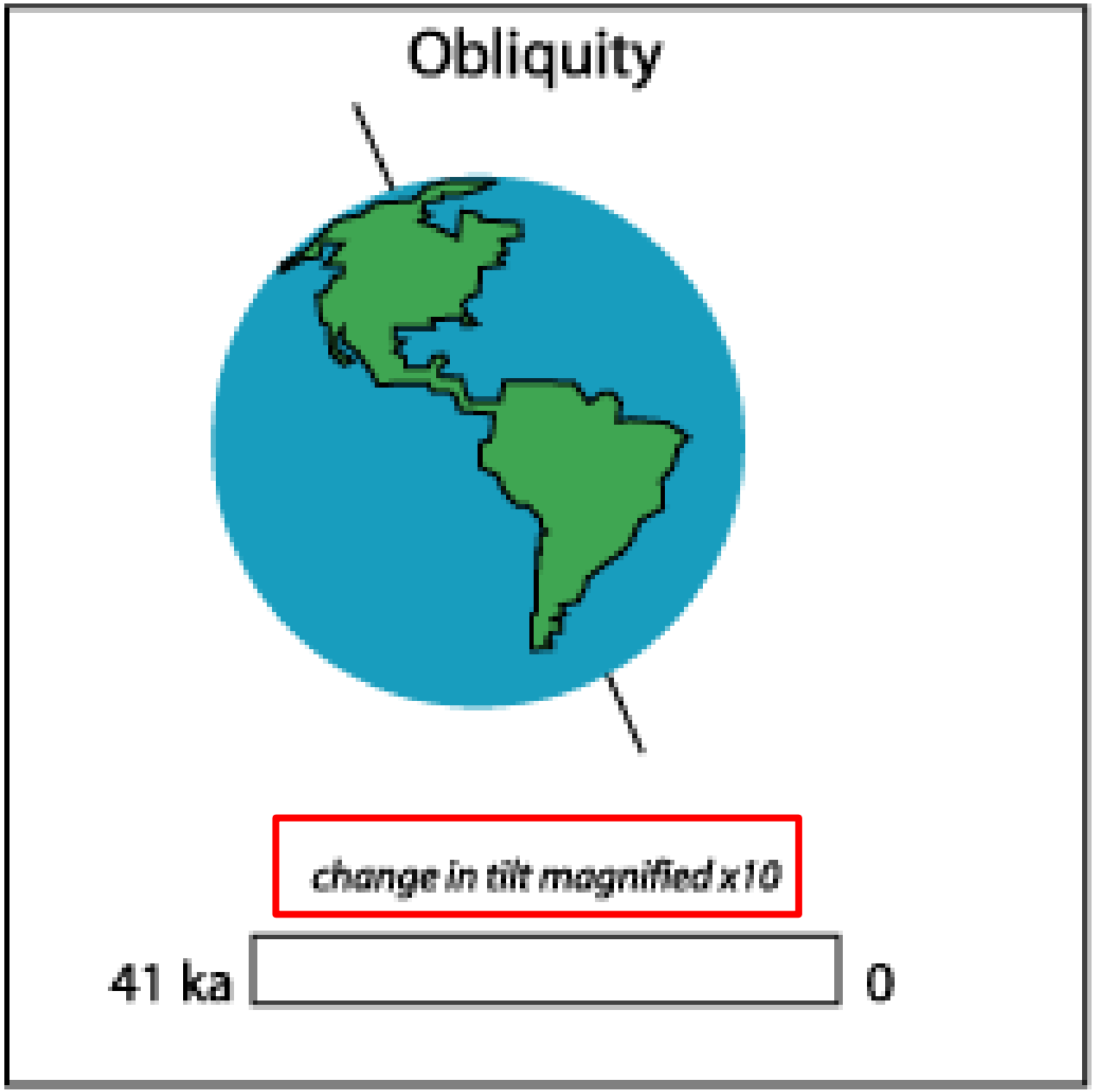
Eccentricity: More to Less Circular



100 90 80 70 60 50 40 30 20 10 0

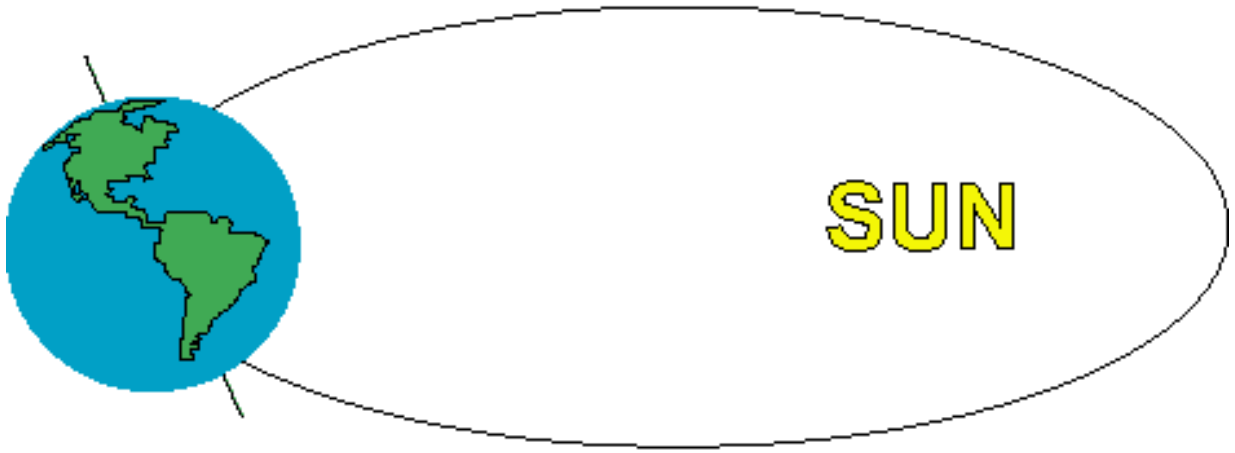
Time * 1000 years ago

Obliquity: More or Less Seasonality

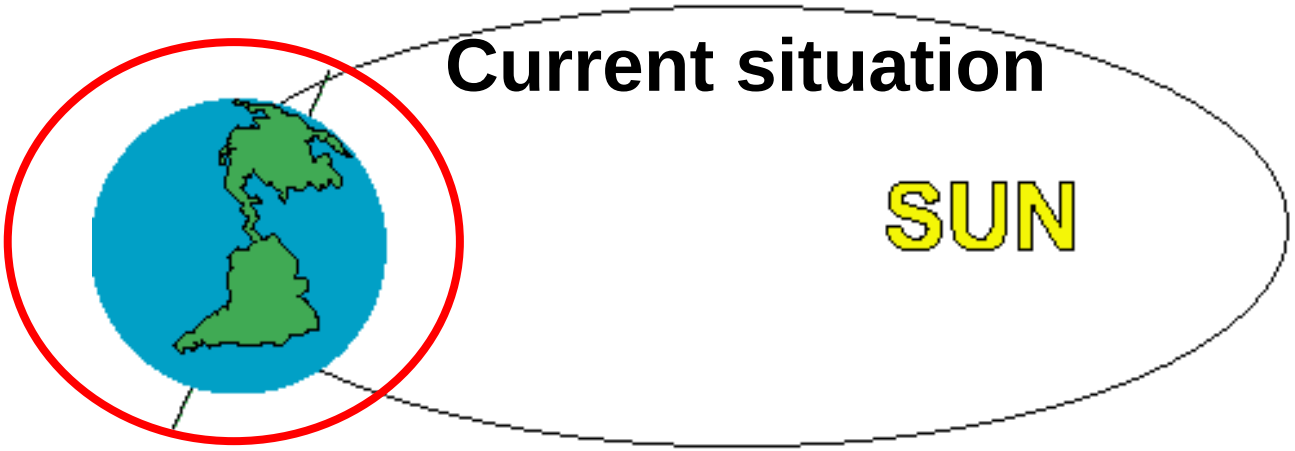


Must Consider Precession *and* Eccentricity Cycles

Precession of the Equinoxes (19 and 23 k.y.)



Southern Hemisphere tilted toward the Sun at aphelion



Northern Hemisphere tilted toward the Sun at aphelion

Currently NH summer takes place at aphelion, in about 11,000 years, NH summer will occur at perihelion. At this time, SH seasonality will be

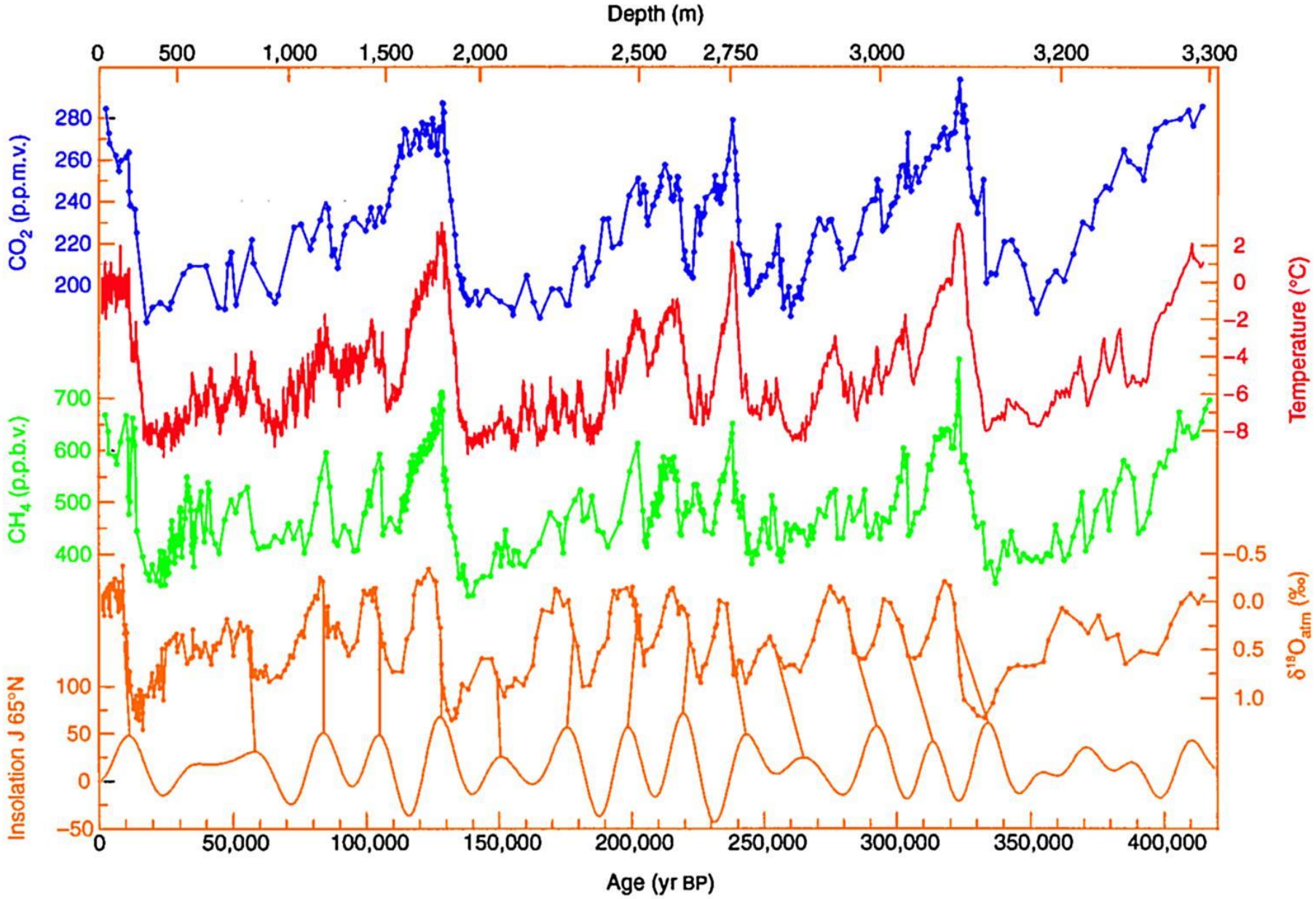
Respond at **PollEv.com/thornton211**

Text **THORNTON211** to **22333** once to join, then **1 or 2**

Stronger than it is now	1
Weaker than it is now	2

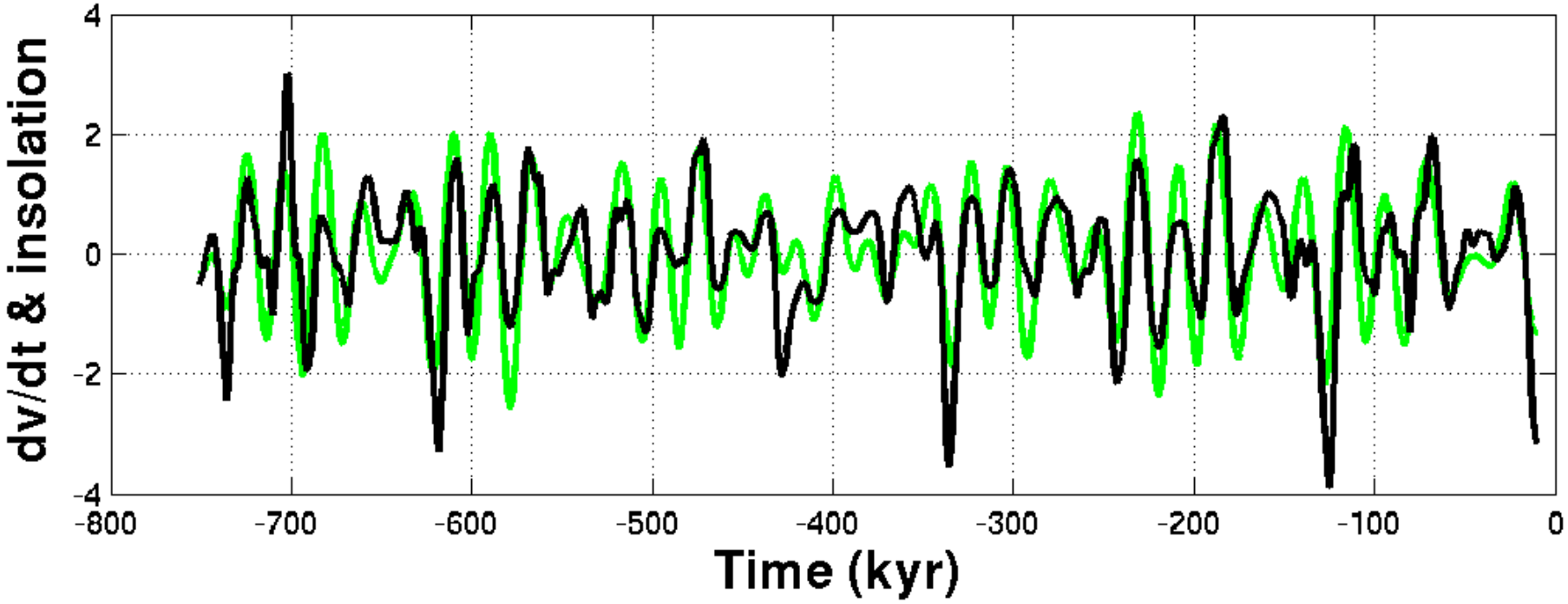
Total Results: 0

Solar Insolation at 65N and Glaciation



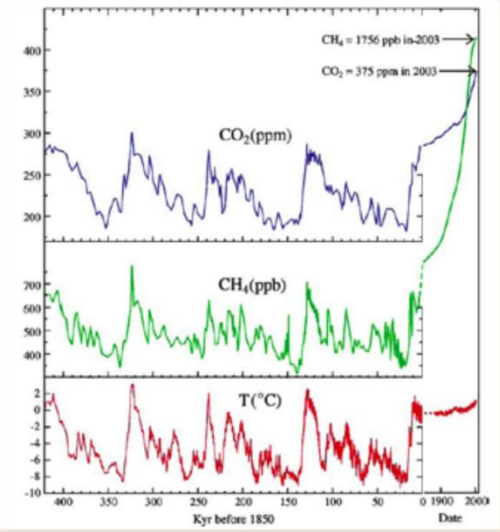
UW Research – Gerard Roe (ESS)

Rate of change of ice volume and NH solar insolation



W Globally averaged solar insolation varies by 0.2% every 100Kyr, equivalent to a -0.5 W/m2 forcing. From this info and the T record in the ice core, only, estimate a climate sensitivity parameter.

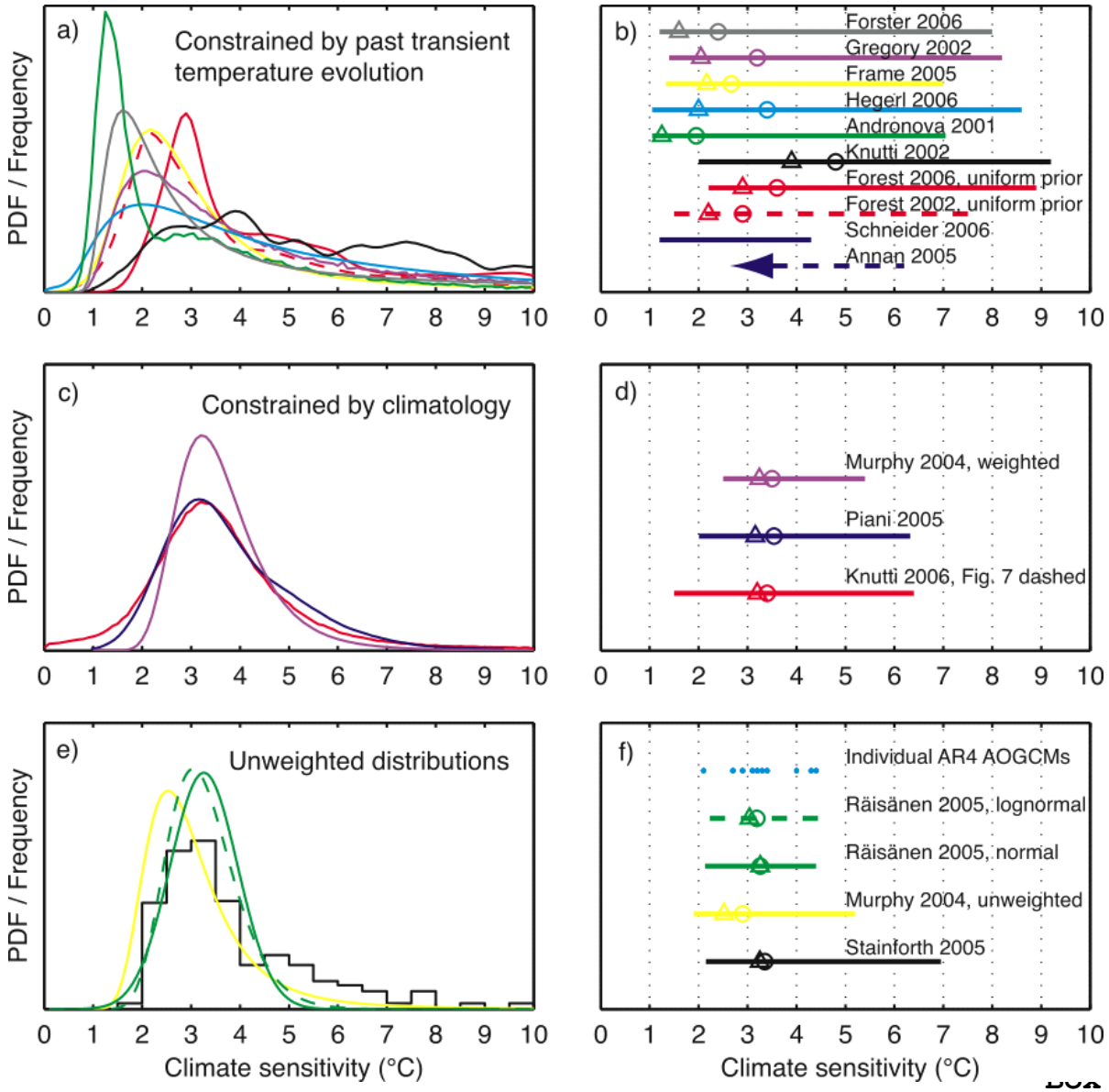
Poll locked. Responses not accepted.



- 10 to 16 K/W/m2
- 3 to 5 K/W/m2
- 1 to 2 K/W/m2

Total Results: 0

Estimates of Climate Sensitivity

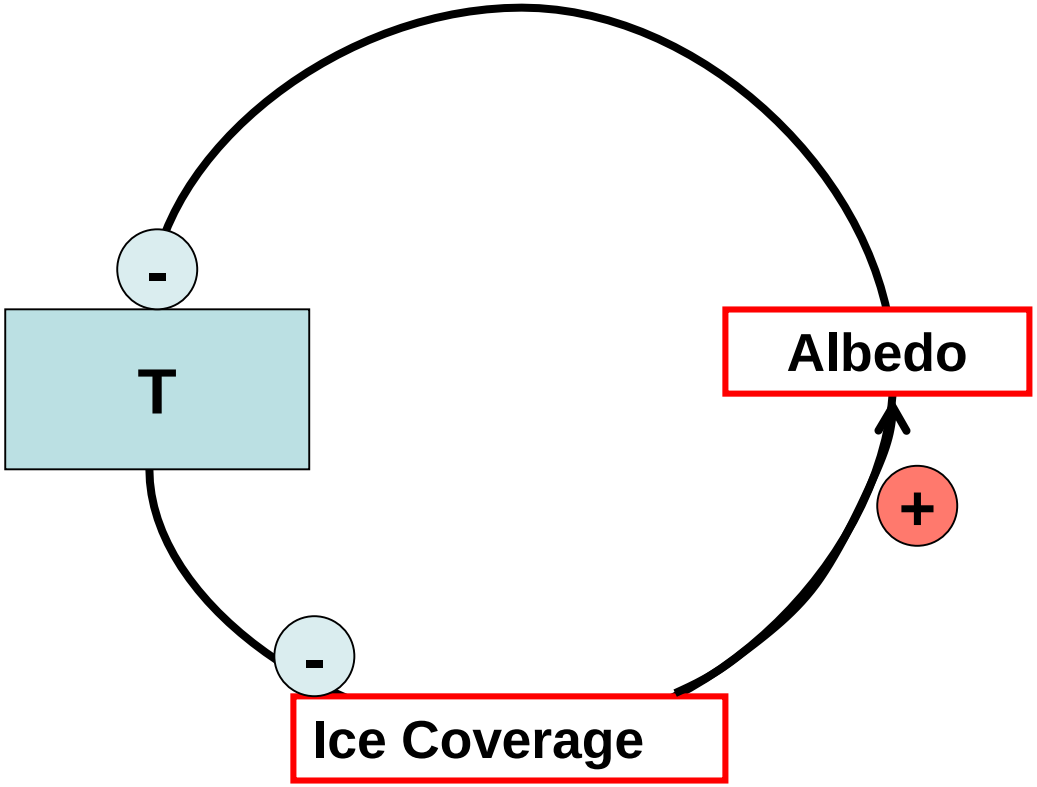


T change for a 4 W/m² forcing (i.e. "double CO_2")

Most probable λ ~ 0.75 to 1 K/(W/m²)

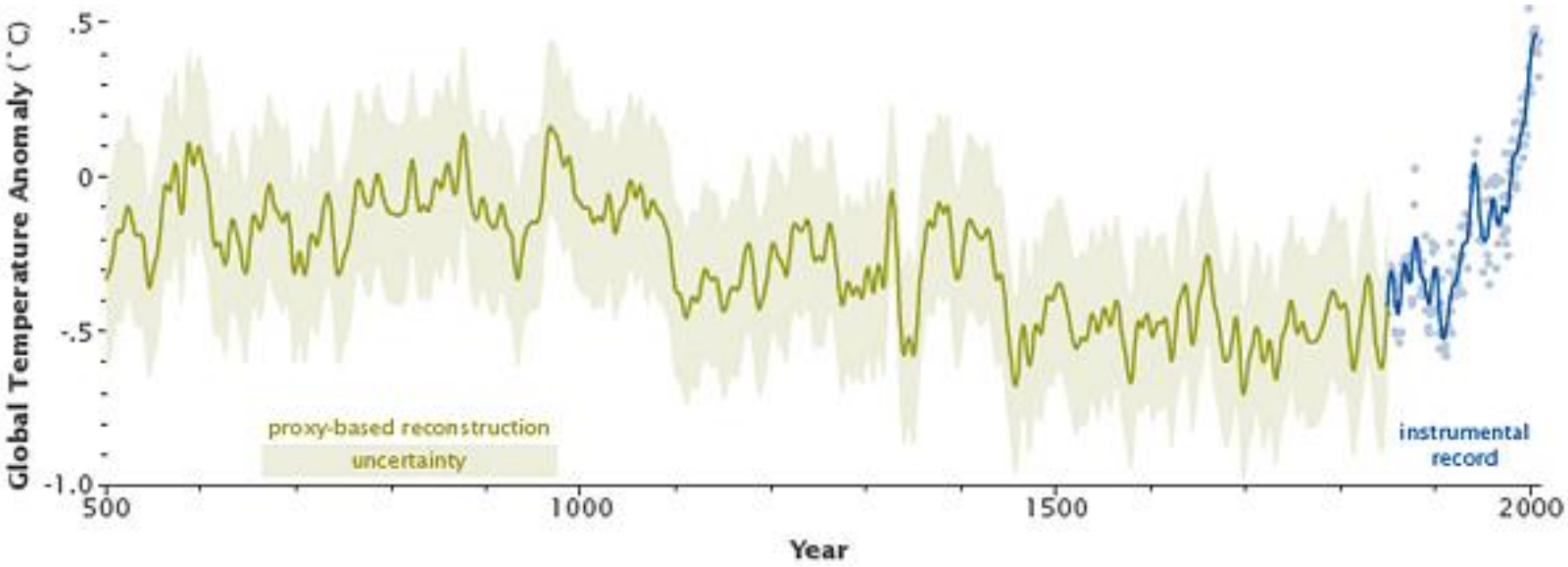
A Crucial Feedback: Ice Albedo Feedback

Solar insolation in NH summer appears to be key for *maintaining glaciation*. Ice sensitive to melting!



Overall positive (destabilizing) feedback

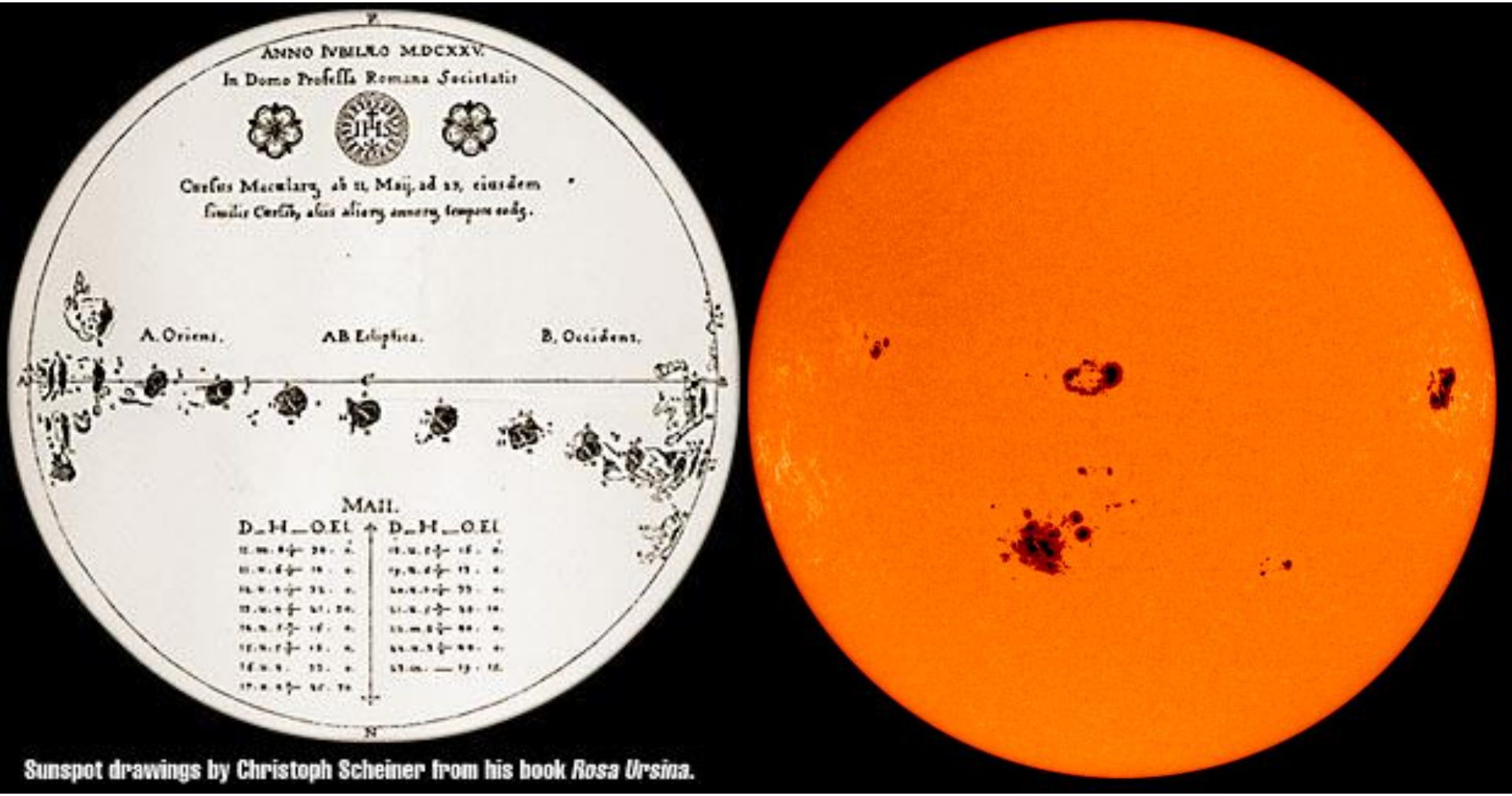
Recent Millenial Temperature Record



Natural Short-term Forcings

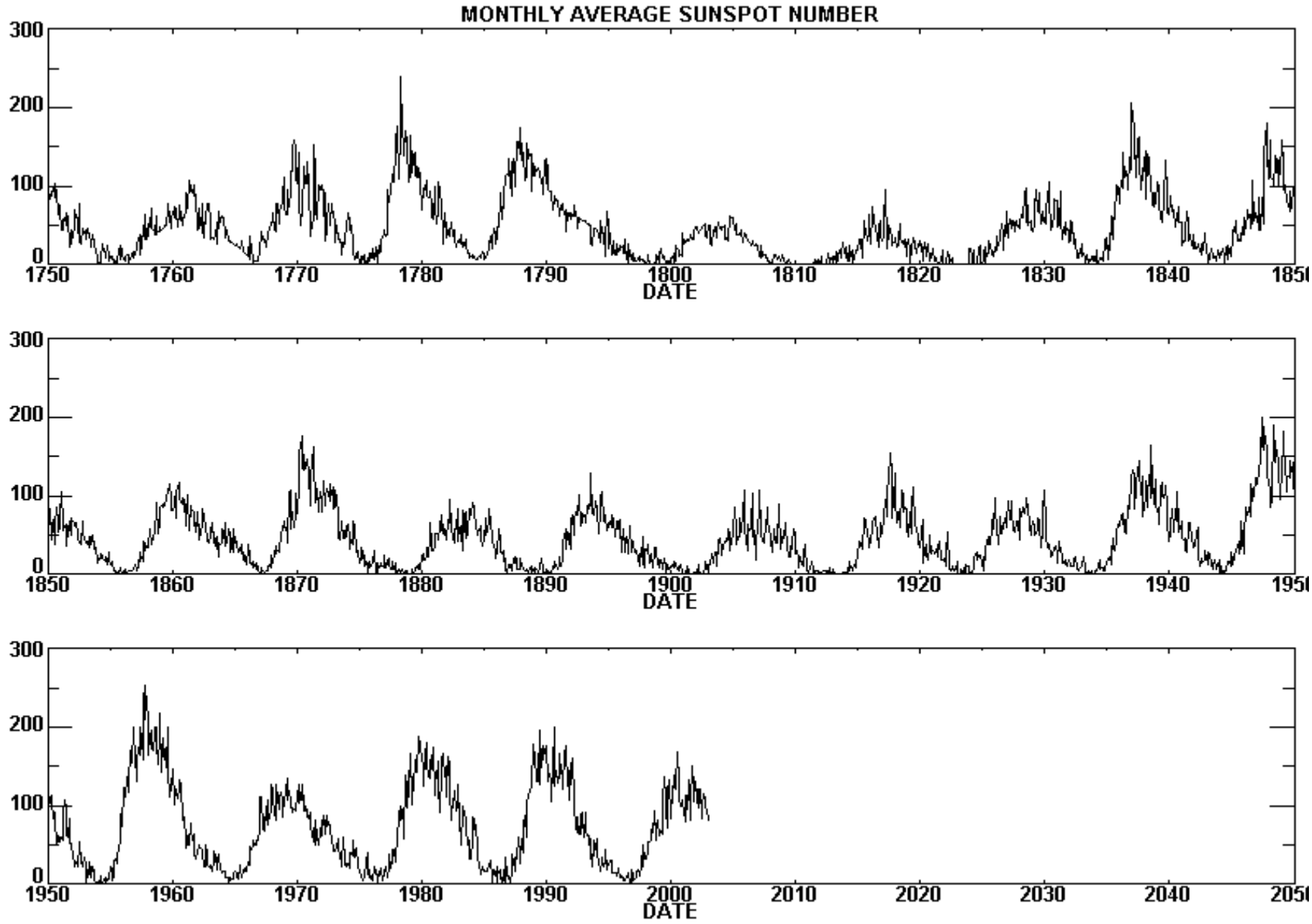
- “It is all caused by natural variations”
- 11 year Solar Cycle (Sunspot Cycle)
- Volcanic (Aerosol) Forcing

Sunspots – Cyclic Changes in Solar Output (S_o Forcing)



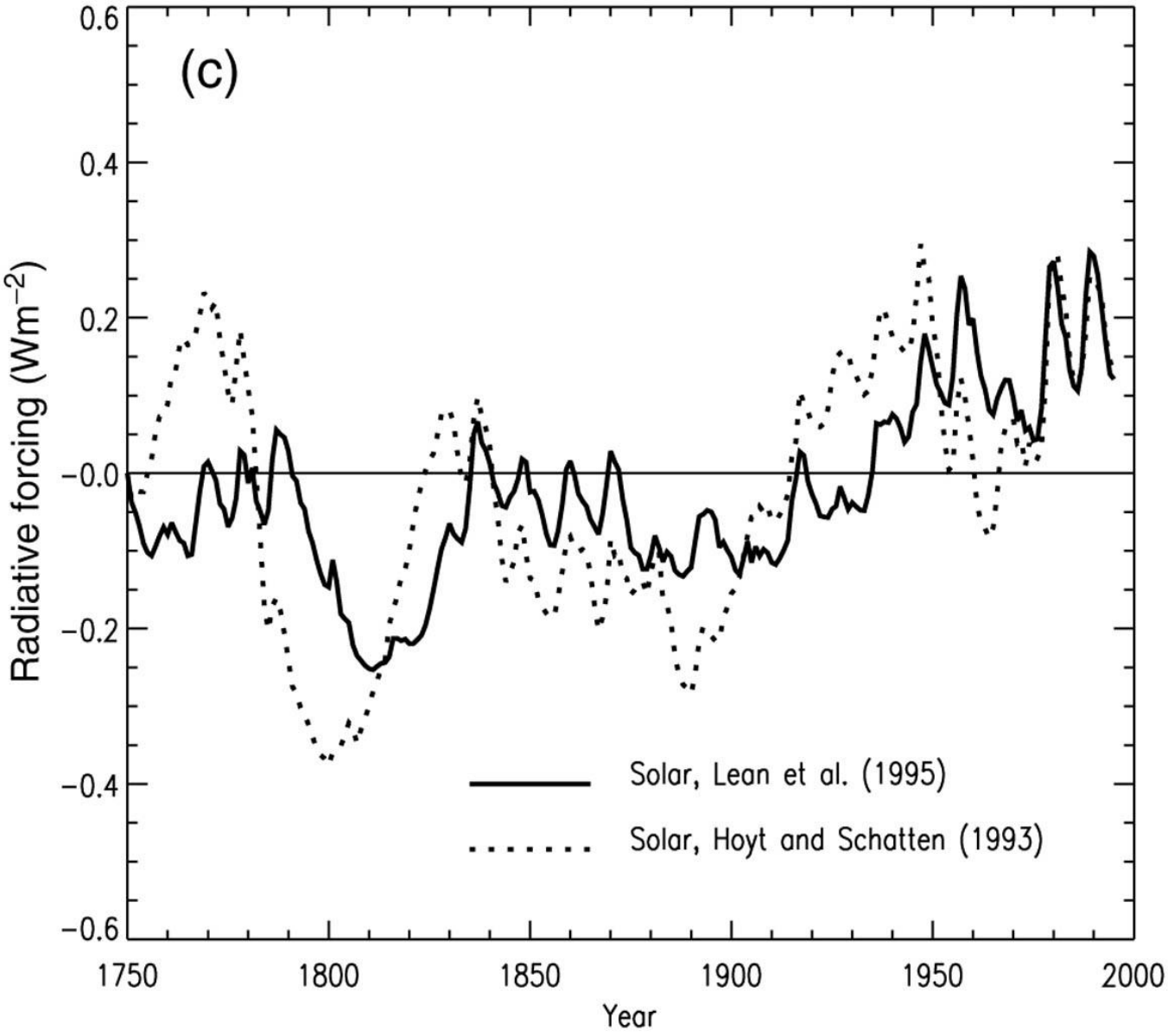
Sunspot drawings by Christoph Scheiner from his book *Rosa Ursina*.

~11 year Sunspot Cycle



Solar (“Sunspot”) Cycle

Radiative Forcing by Solar Cycle



Poll Question

Earth's global average temperature has increased by about 1 K since 1900. The solar cycle forcing has been about 0.3 W/m2 since 1900. Assuming a climate sensitivity parameter of 1K/W/m2, the solar forcing explains

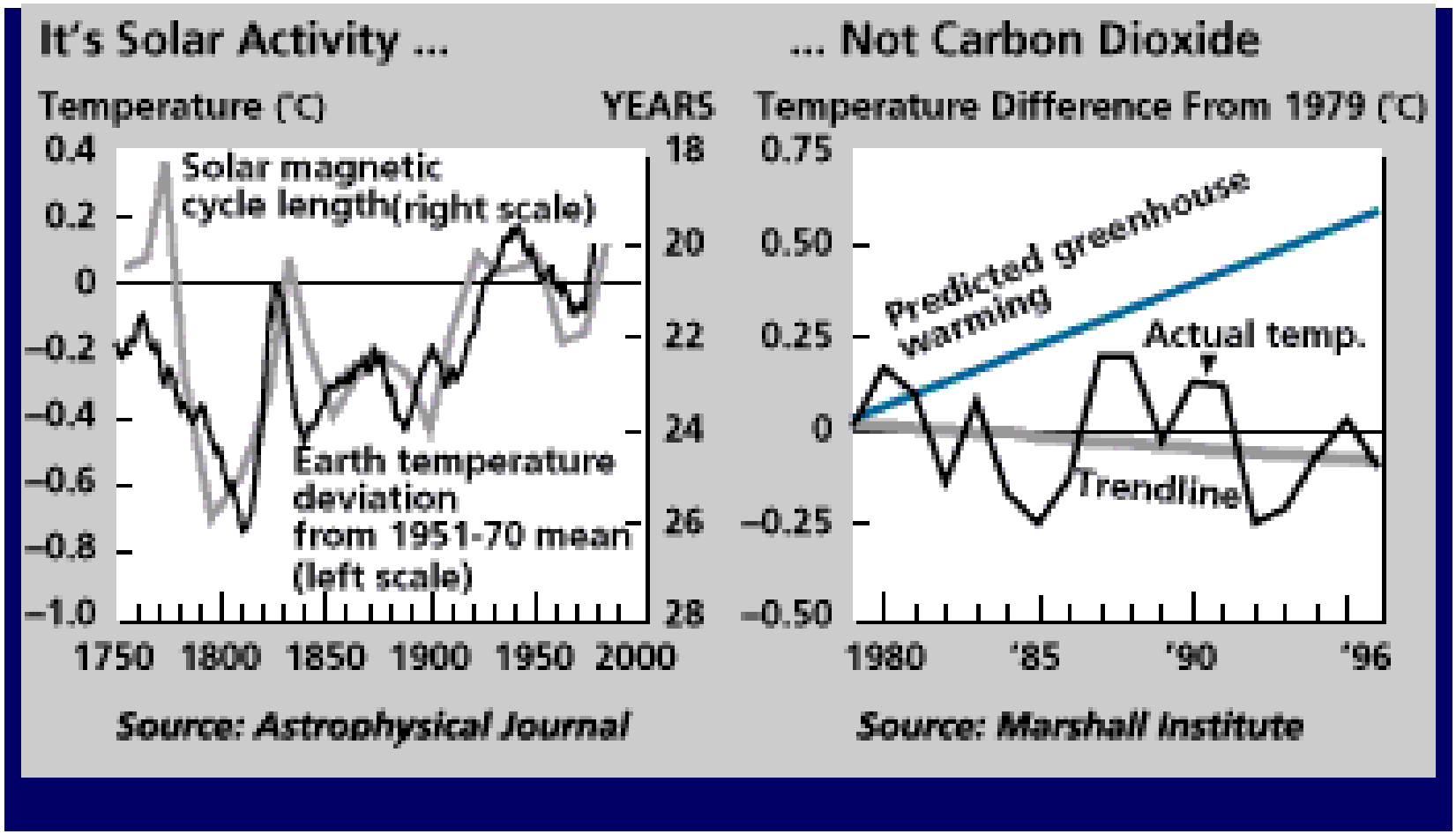
When poll is active, respond at **PollEv.com/joelathornto254**

Text **JOELATHORNTO254** to **22333** once to join

- 65-75% of the observed T increase
- 45-55% of the observed T increase
- 25-35% of the observed T increase

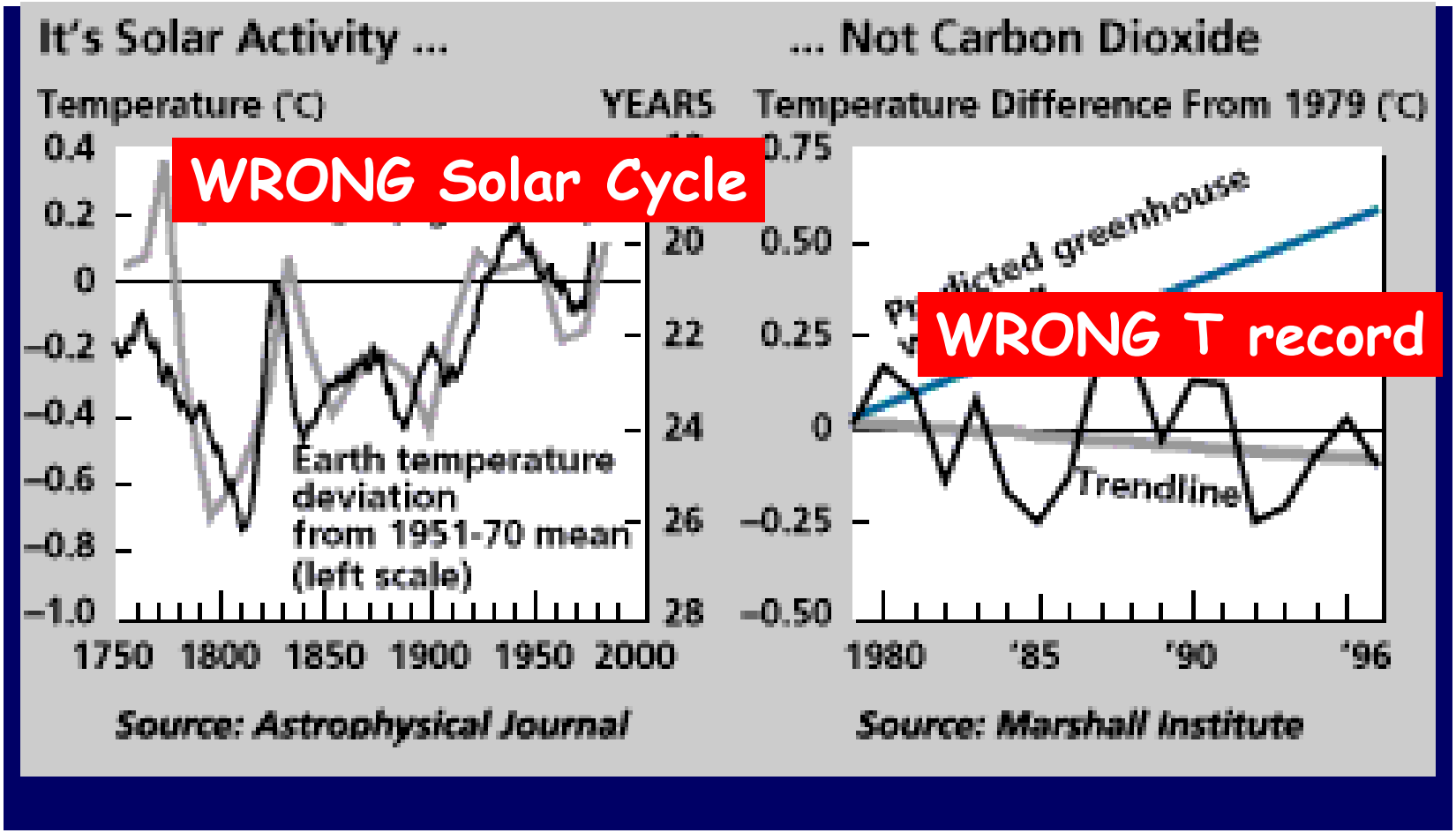
Total Results: 0

False Assertions: Sun – Global Warming



Originally from WSJ Article written by two chemists named Robinson

False Assertions: Sun – Global Warming



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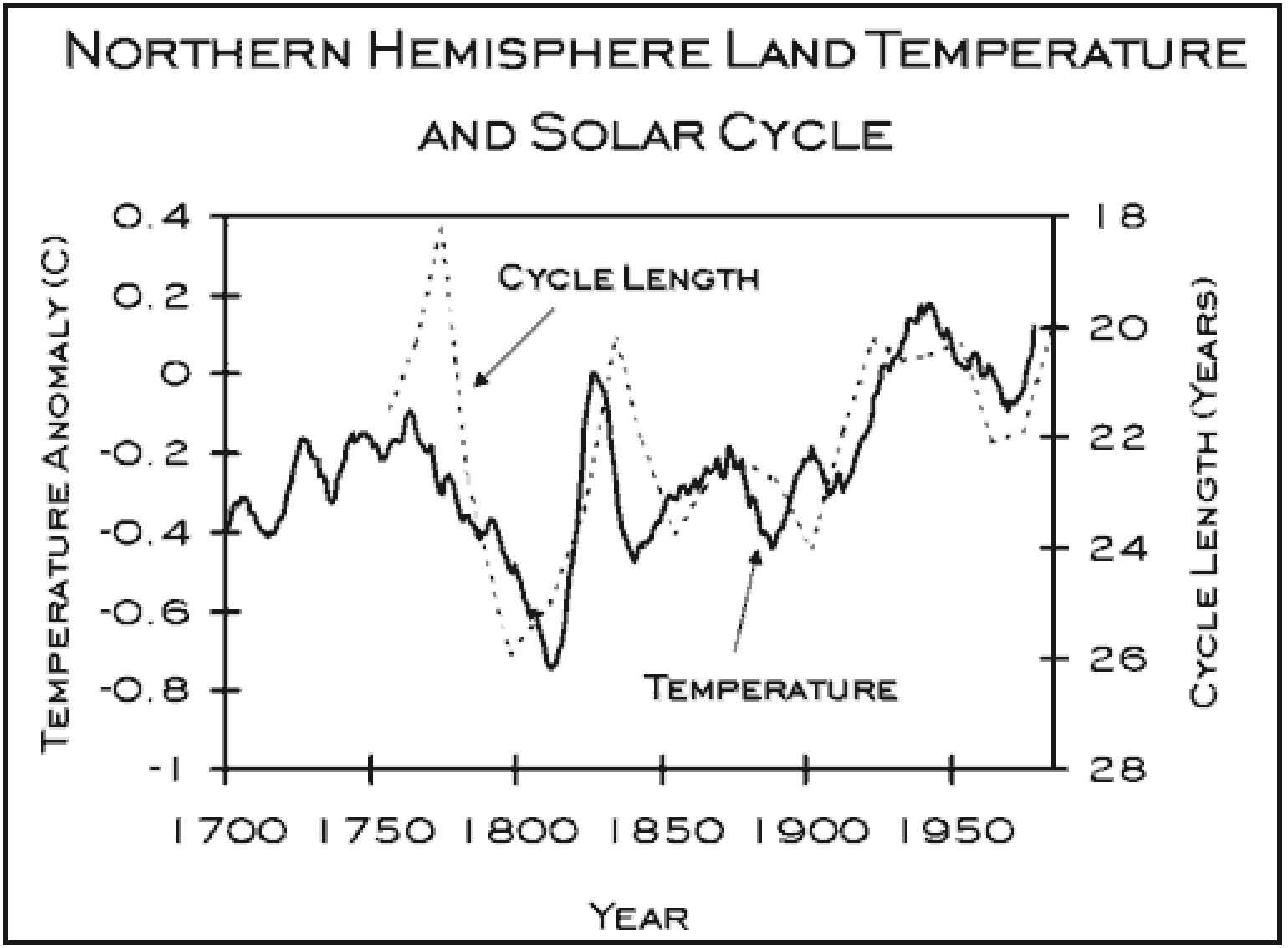
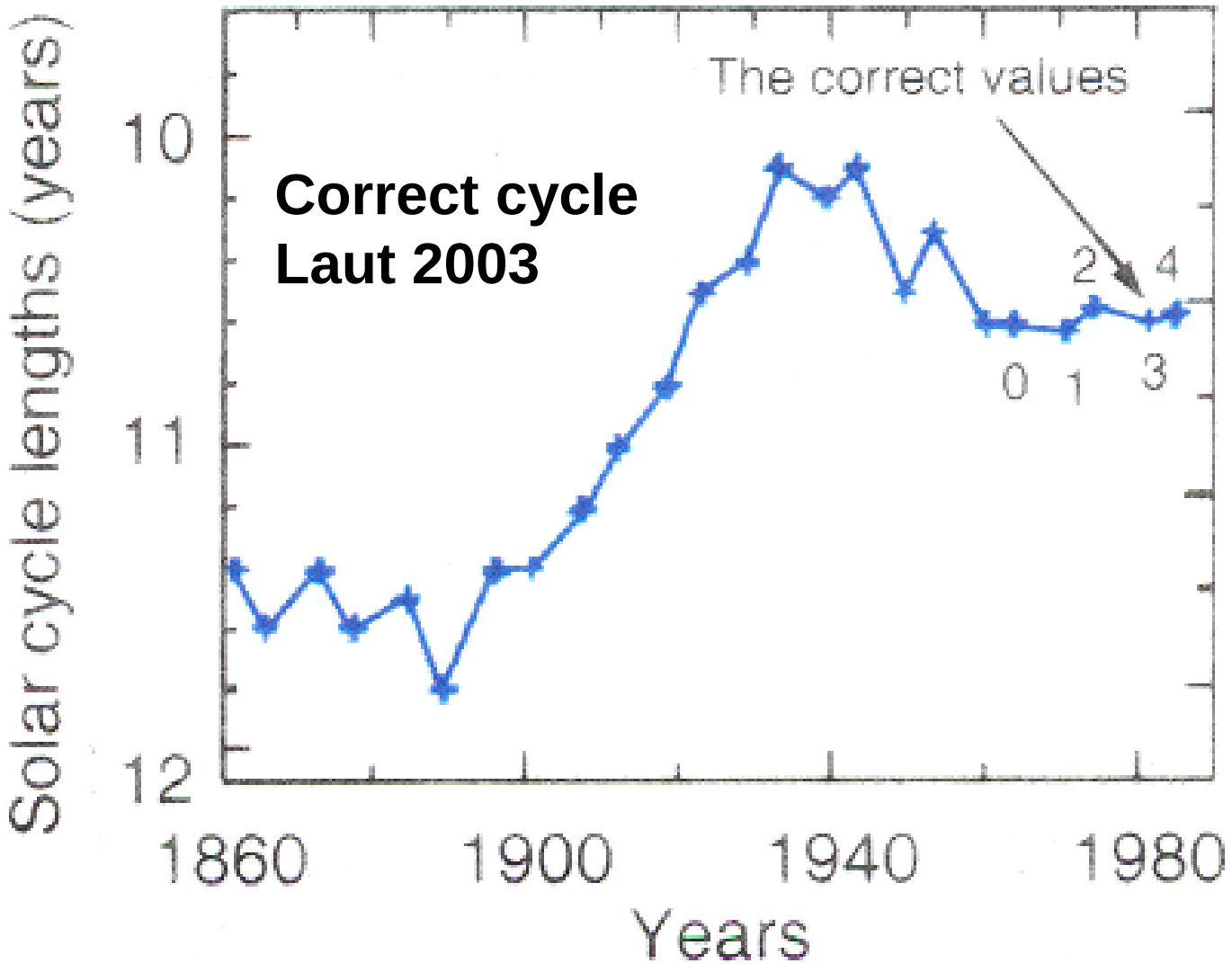
False Assertions: Sun – Global Warming



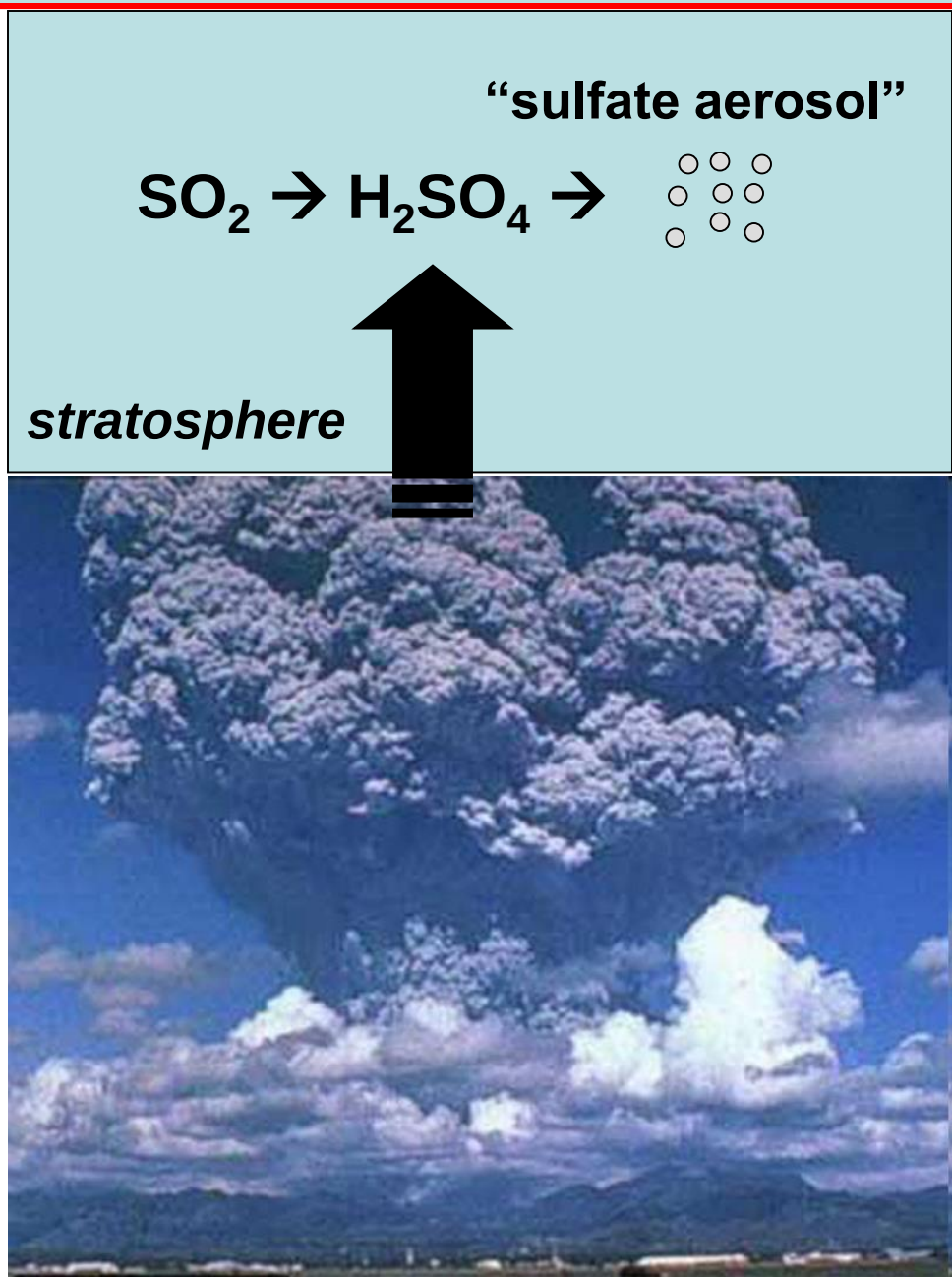
SOURCE: S. Baliunas and W. Soon / Astrophysical Journal

False Assertions: Sun – Global Warming



Volcanic Aerosol Forcing (in stratosphere)

- **5 – 30% by volume of volcanic emissions are SO_2 or H_2S**
- **A single large eruption can inject 20 Mtons of S as SO_2 *into stratosphere***

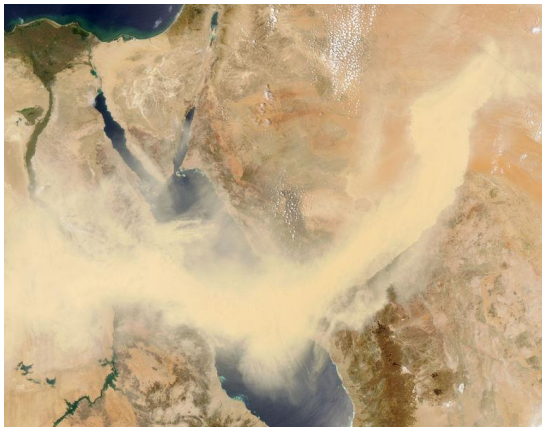


Sunrise over Texas From Space Shuttle

Stratospheric aerosol layer – a natural component of atmospheric albedo

Aerosol Particles aka Particulate Matter

- Suspended solids or liquid particles in air



Soil/desert dust

Sea spray

Smoke

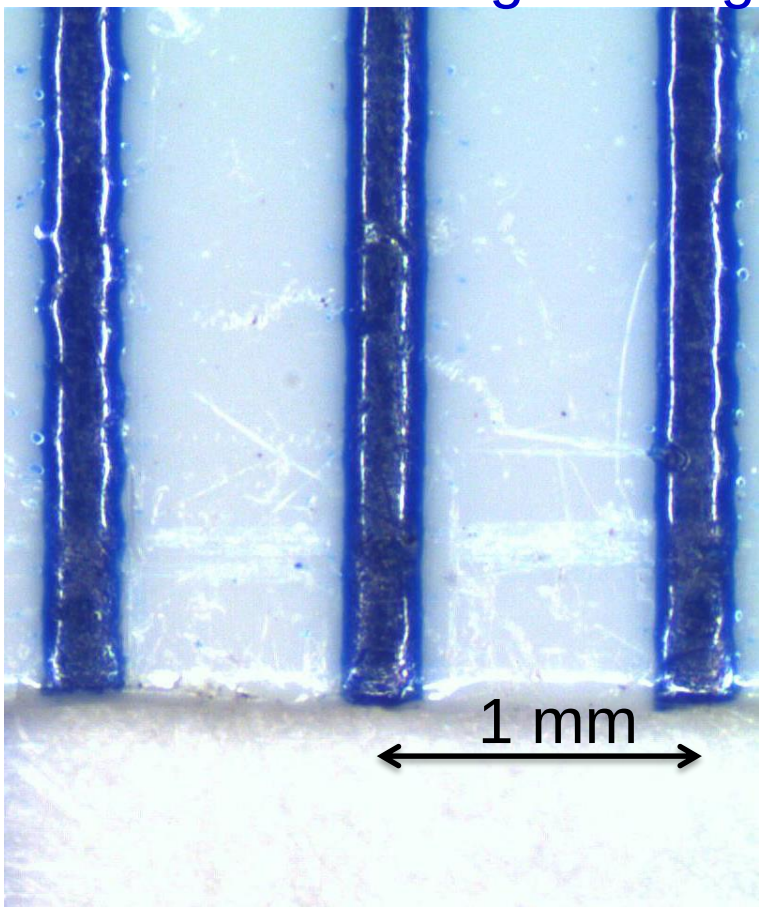
Volcanoes

Fuel Combustion

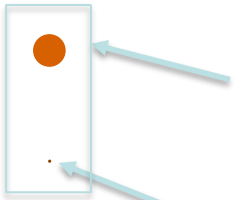
Biogenic emissions

Aerosol particles sizes

Ruler scale through a magnifying glass:



Large aerosol particles to scale:



Big particle, e.g. pollen (0.1 mm = 100 µm)

“Smaller” particle, e.g. soil dust (10 µm)

Aerosol particle sizes

0.1 µm = 100 nm particle
(smoke, soot, or grown)

10 nm particle
(smoke, soot, virus, or grown)

A few molecules

500x zoom

1 nm

Dozens of molecules

70x zoom

3-4 nm

1 µm particle
(fine desert dust, smoke, bacteria, pollution)

Soil dust particle, 10 µm

Aerosol “Haze”

Visual Range (hourly): **56 miles**
$PM_{2.5}$ (24-hour avg): **9.25 µg/m³**
AQI: **30**

Visual Range (hourly): **139 miles**
$PM_{2.5}$ (24-hour avg): **3.26 µg/m³**
AQI: **11**

Puget Sound Clean Air Agency Visibility camera Queen Anne Hill (looking South)

Aerosol Particle Affects on Radiation

Poll Question

Combustion of diesel, wood, and other organic carbon based fuels can lead to the emission of soot (aka "black carbon") aerosol particles. Increased emissions of soot particles could represent a

When poll is active, respond at **PollEv.com/joelathornto254**

Text **JOELATHORNTO254** to **22333** once to join

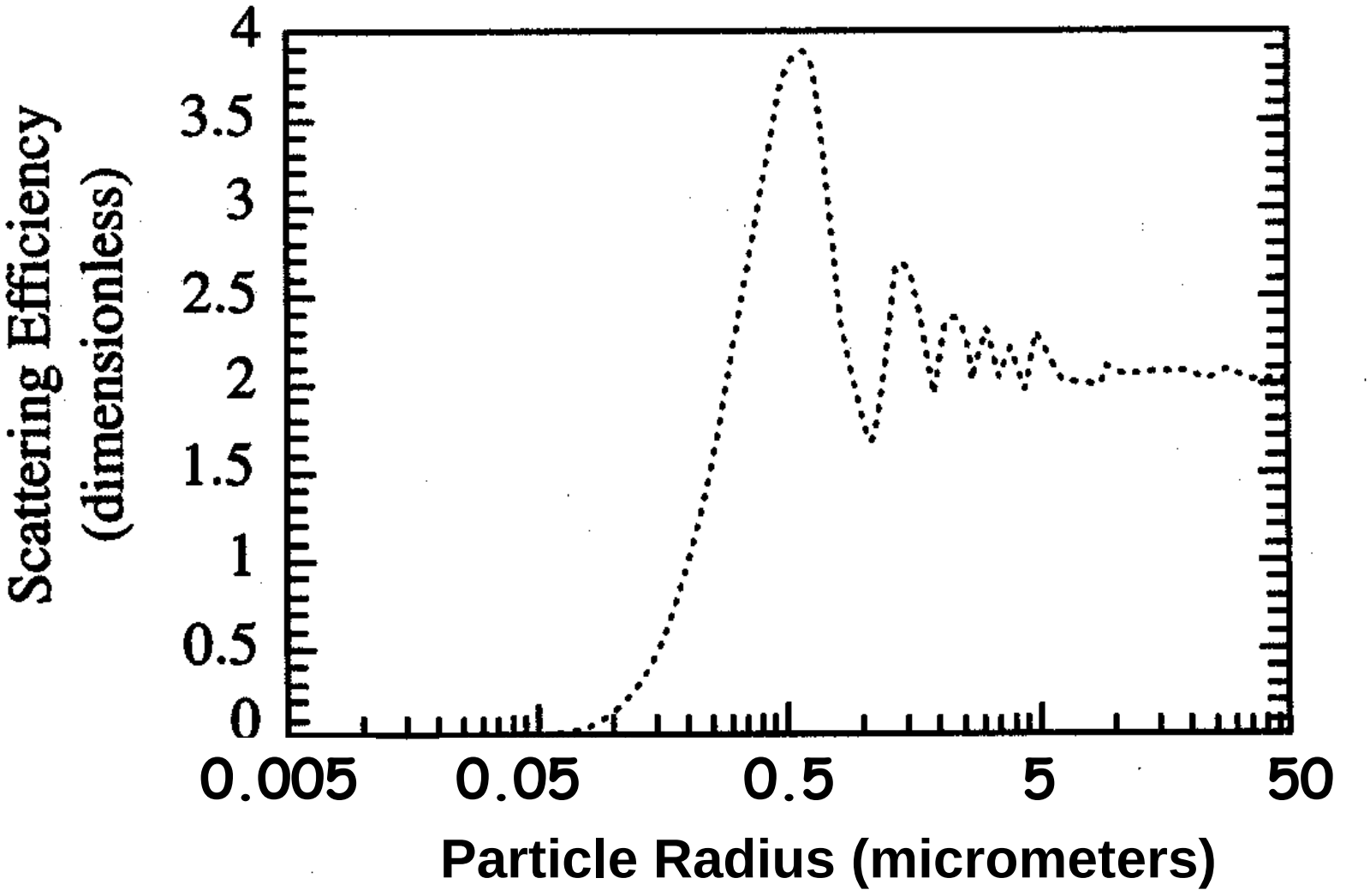
positive radiative forcing due to absorption of solar radiation

negative radiative forcing due to absorption of solar radiation

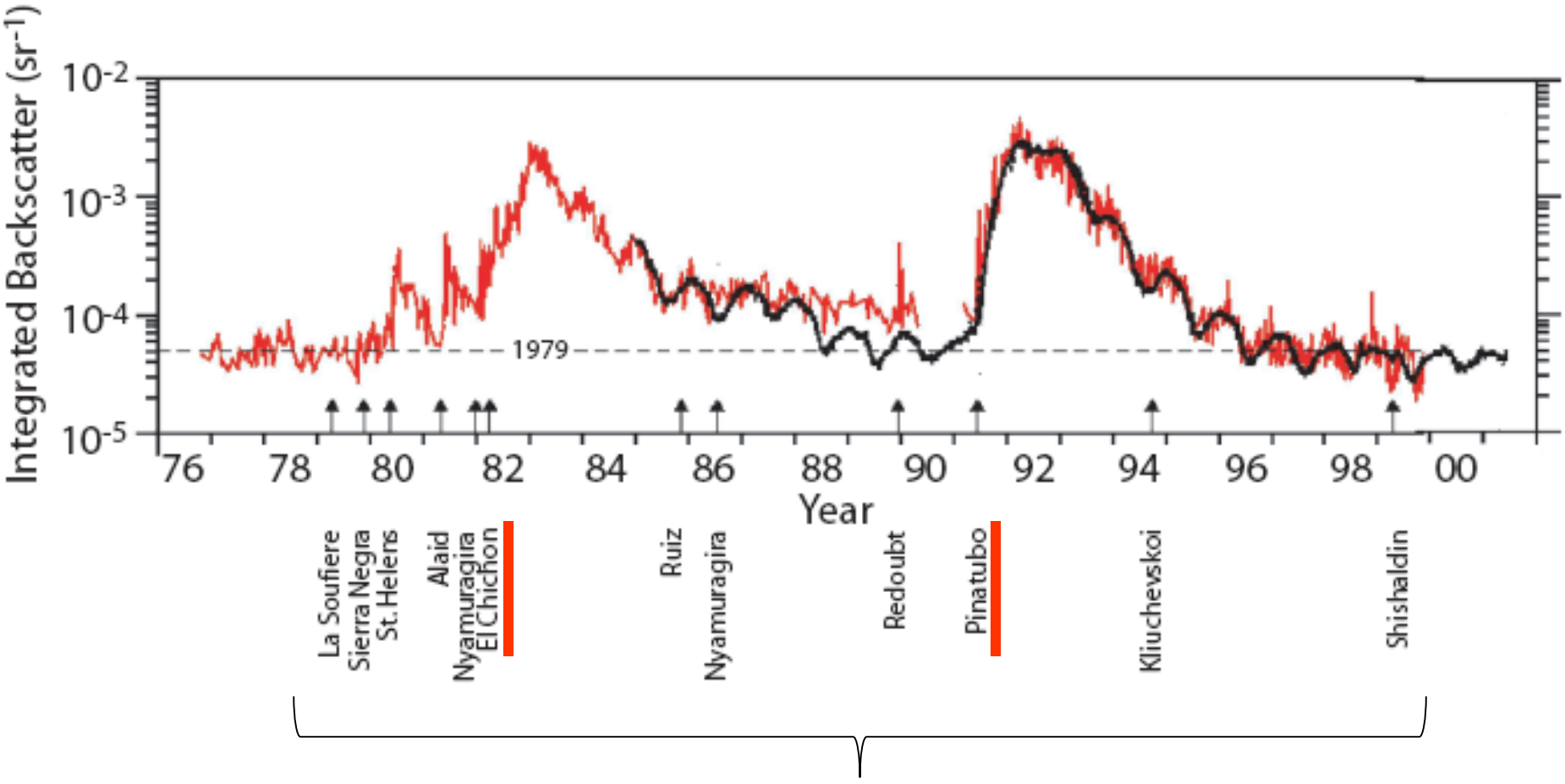
Total Results: 0

Scattering of Radiation Depends on Particle Size

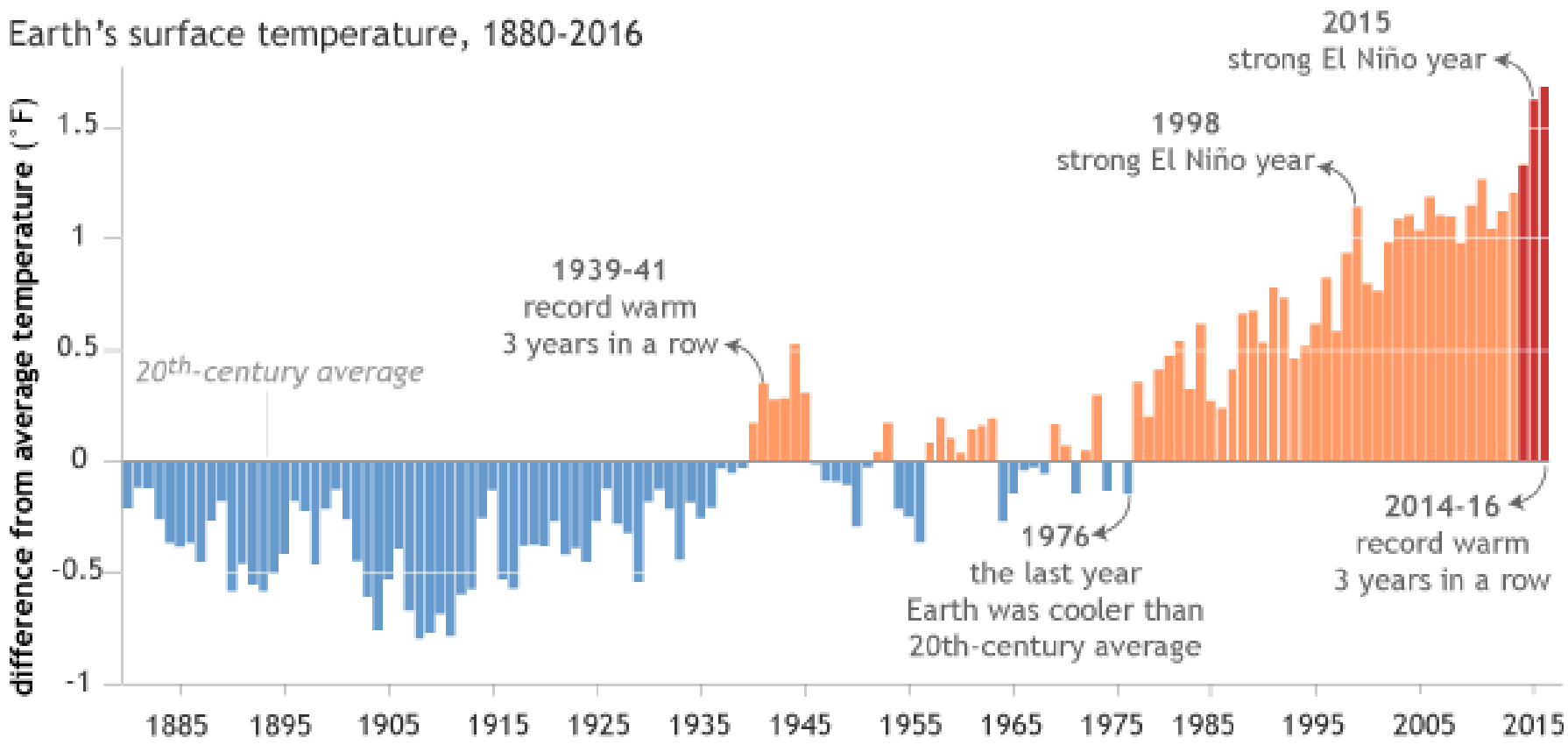
Efficiency calculated assuming sunlight has wavelength of 0.5 μm



Stratospheric Aerosol Layer Backscatter vs. Time

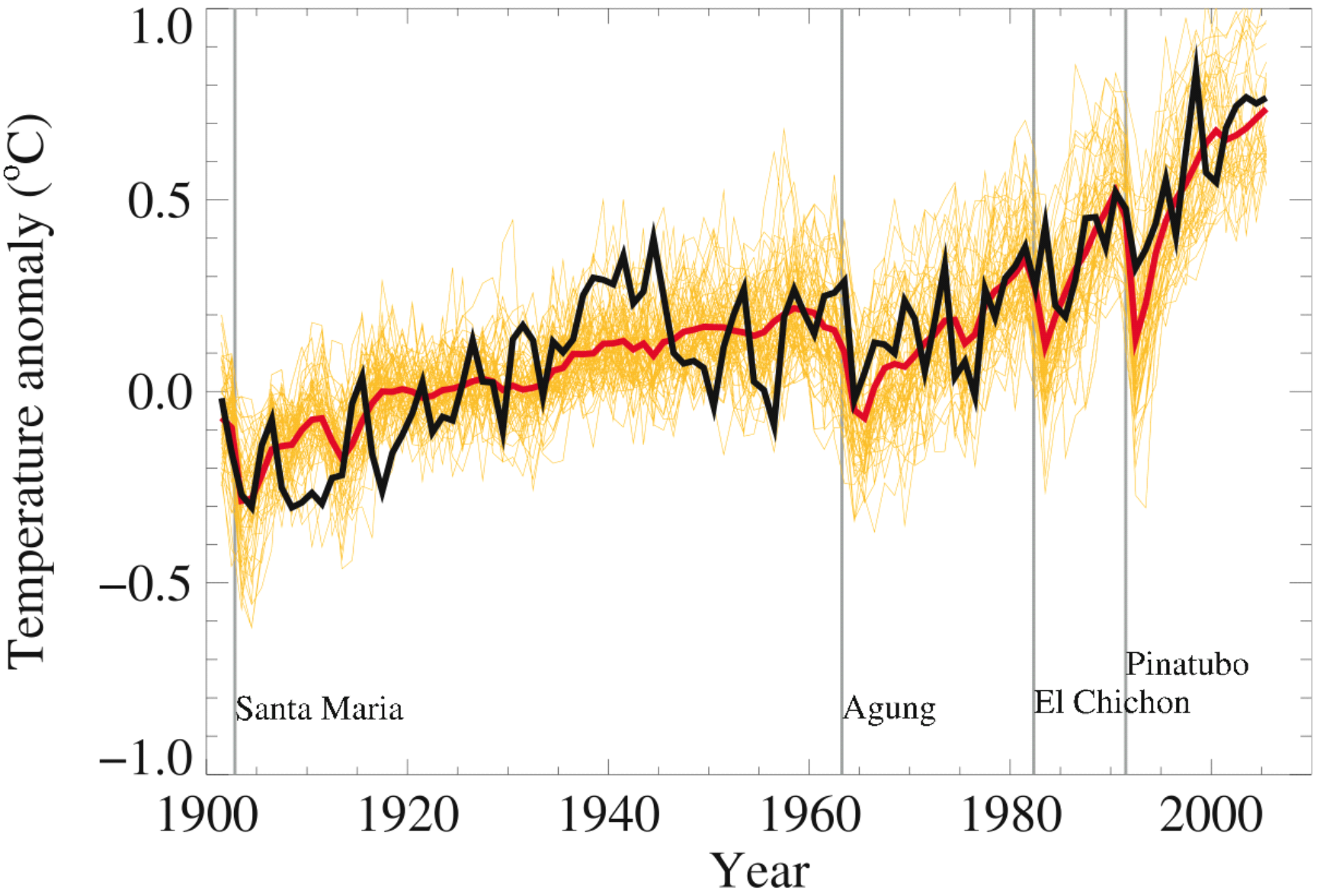


Modern Temperature Record



NOAA Climate.gov

T Response After Major Eruptions

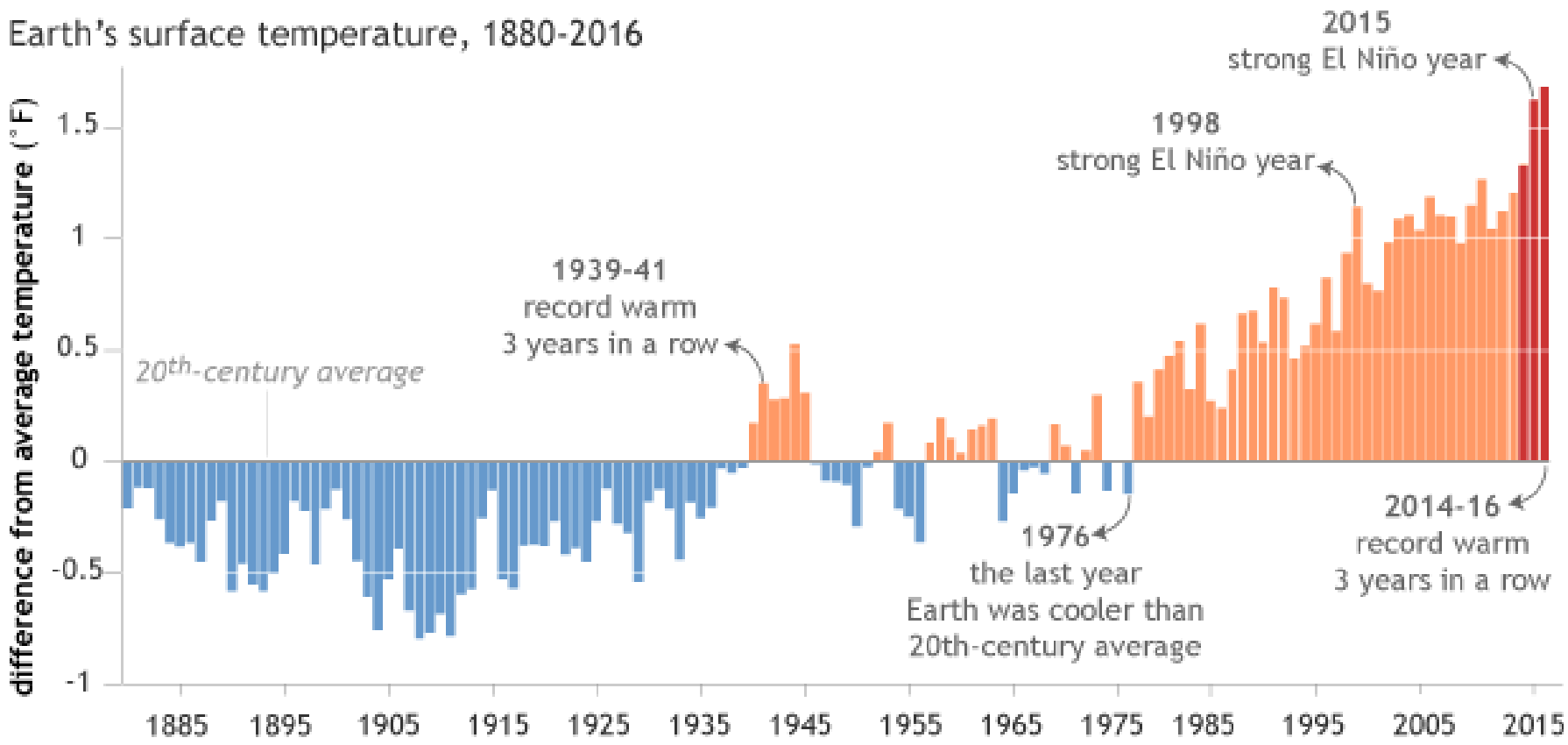


Volcanic Aerosol Forcing

Volcanic Aerosol Forcing

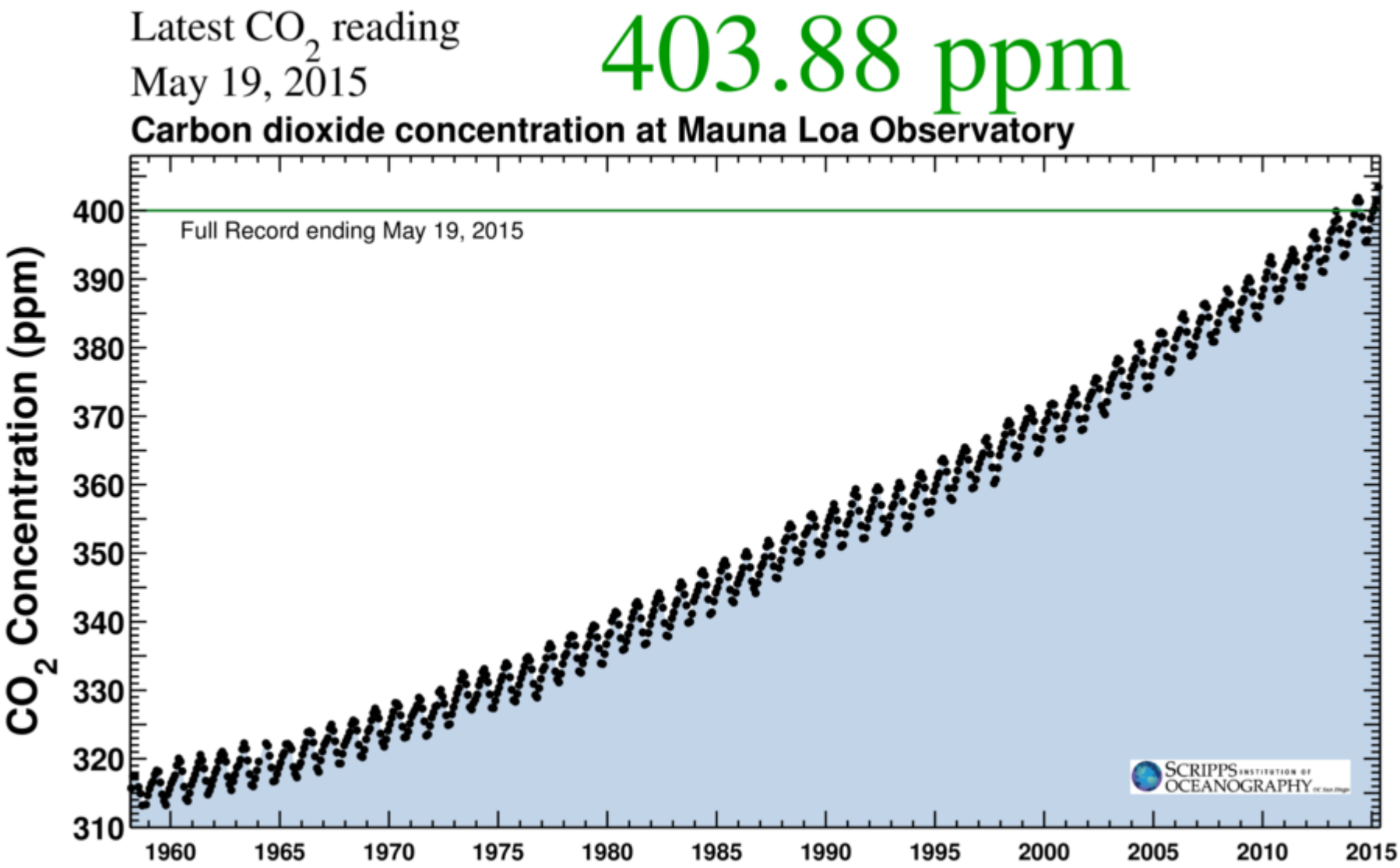
- Large volcanic eruptions in the tropical regions enhance the S.A.L.
- Enhanced S.A.L. means higher albedo, volcanic eruptions are $\Delta F<0$. Noticeable effect on global average T.
- Effect on S.A.L. decays away after a few years (loss of particles from S.A.L.)

Modern Temperature Record

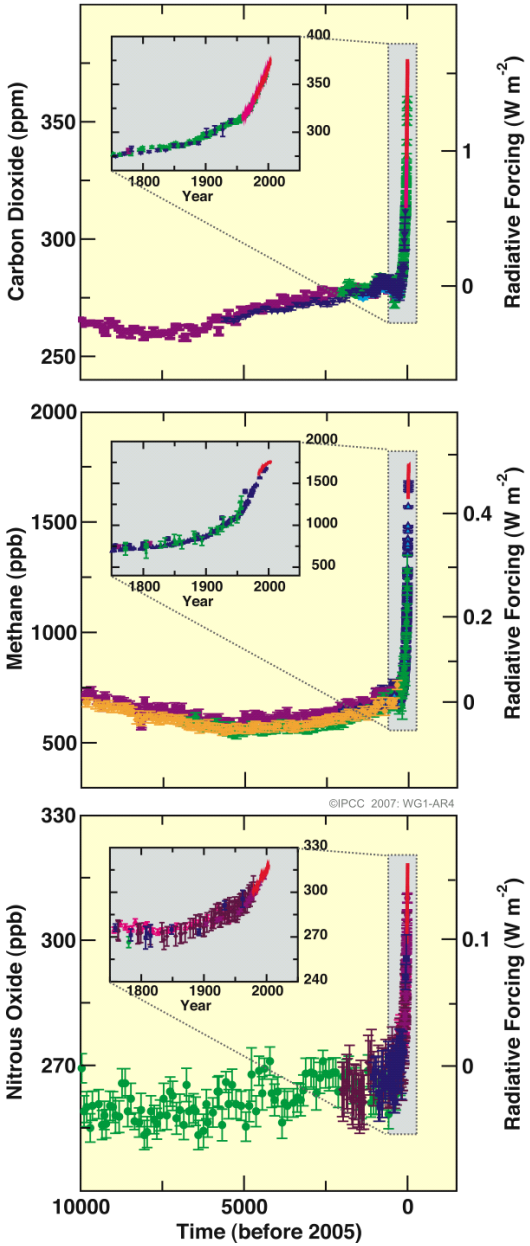


NOAA Climate.gov

Anthropogenic GHG Forcing



Long-Lived GHG Concentrations



Carbon Dioxide: CO_2
Fossil Fuel Burning

Methane: CH_4
Agriculture and Gas Extraction/Use

Nitrous Oxide: N_2O
Agriculture

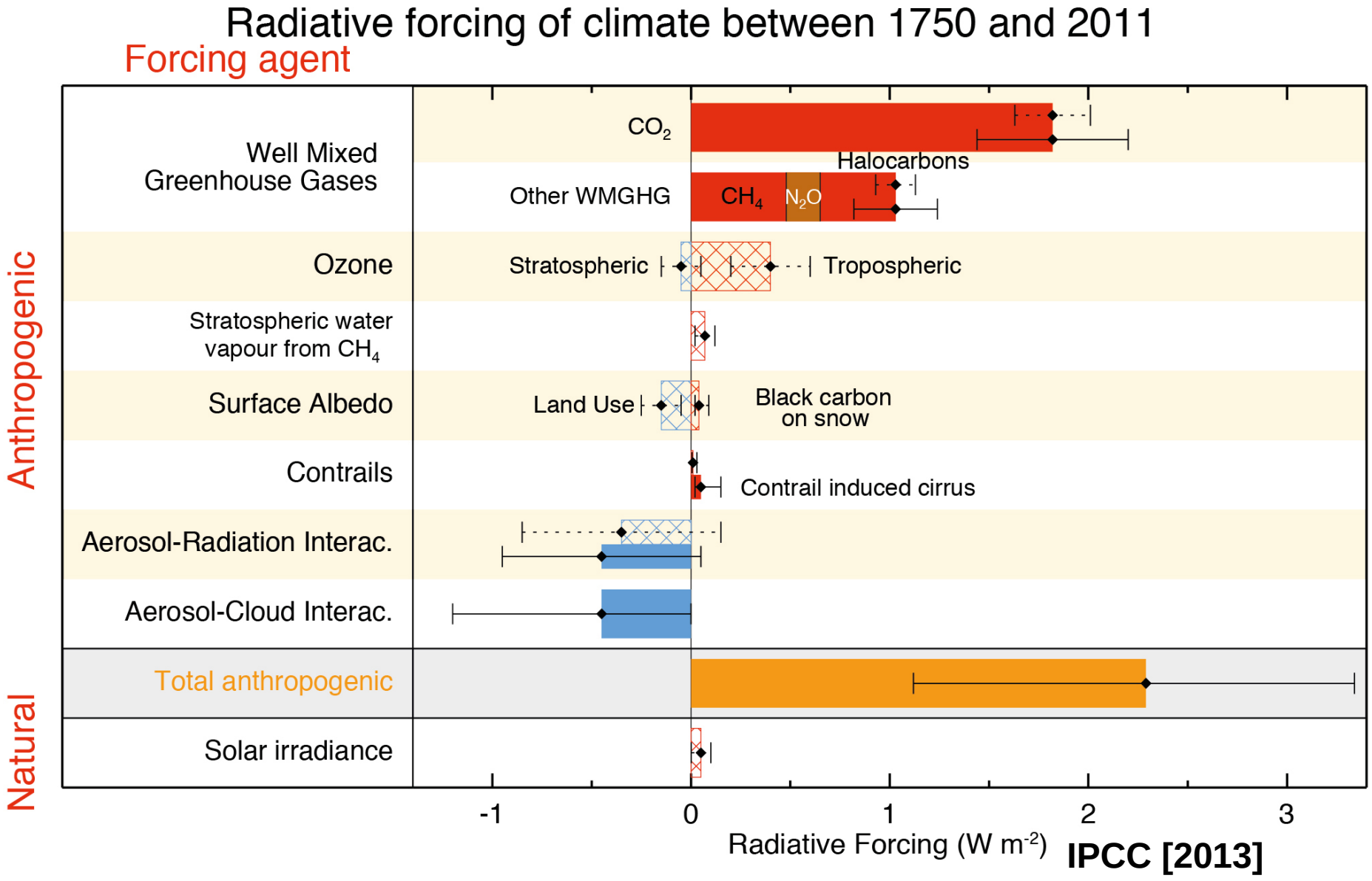
Increasing GHGs

- **Mainly CO_2, but others also important (methane, nitrous oxide, ozone, CFCs)**

- **Anthropogenic contributions to CO_2 mostly from combustion and land-use change**
  - **How do we "know" this?**
  - **Is all the CO_2 that we emit accumulating in the atmosphere?**

- **How do we predict future CO_2 emissions?**

Anthropogenic Global Radiative Forcing of Climate



Atmospheric CO_2 and Source Attribution

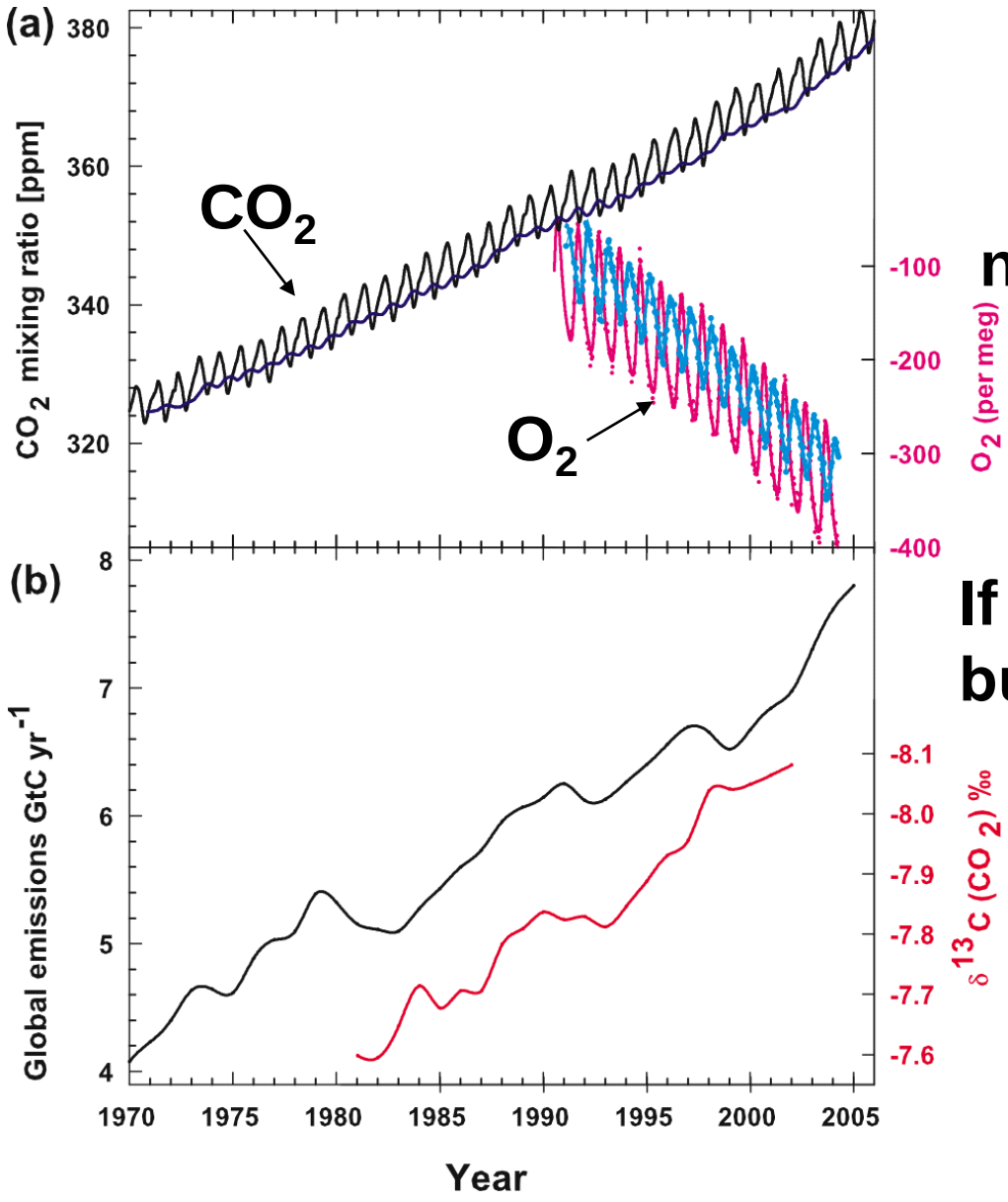
Fuel Combustion:

$$nCH_2O + nO_2 \rightarrow nCO_2 + nH_2O$$
$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

If CO_2 increase is due to fuel burning…

→ O_2 should decrease!

Atmospheric CO_2 and Source Attribution



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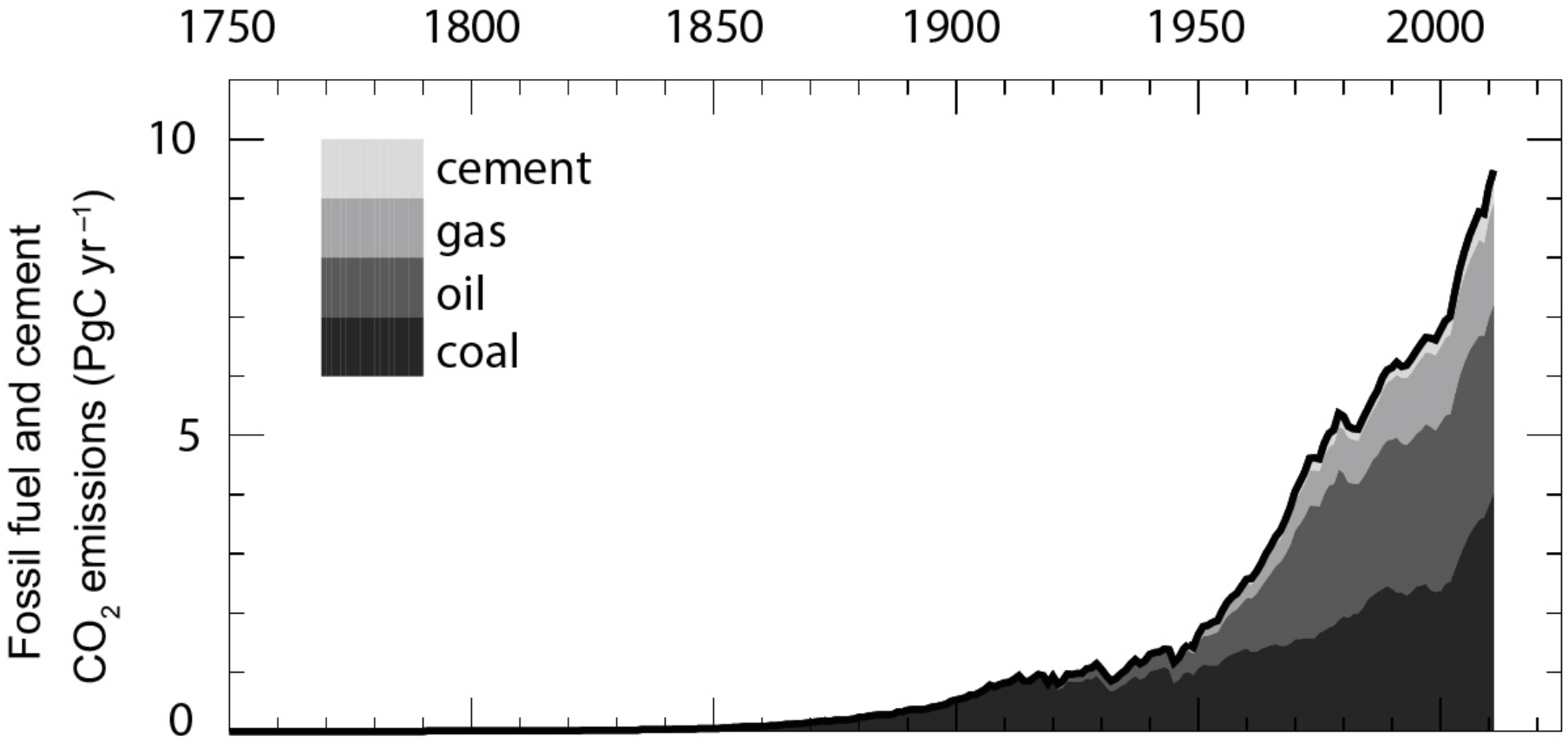
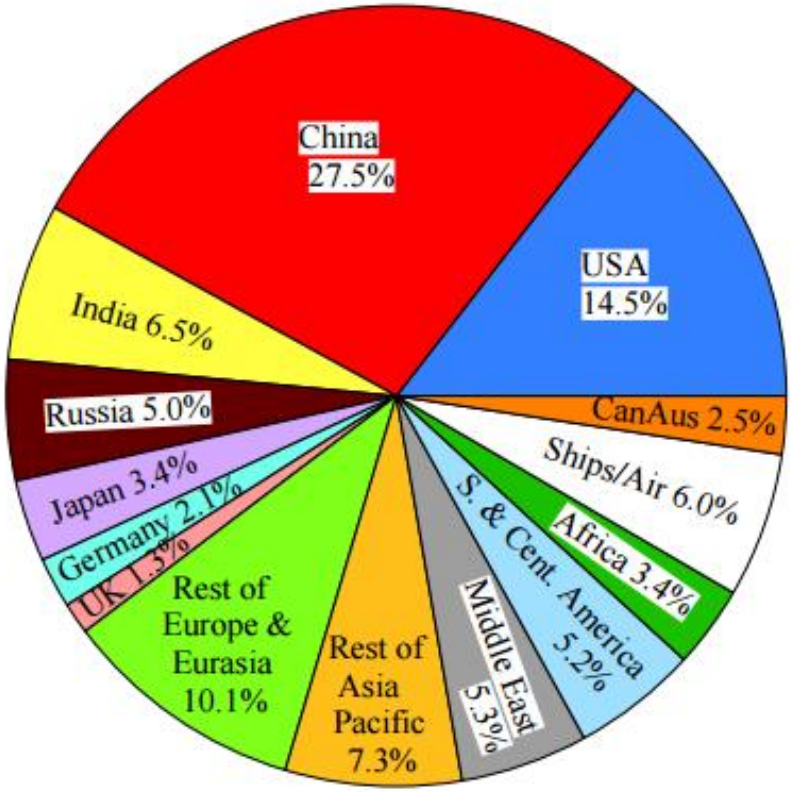
Anthropogenic CO_2 emissions since pre-industrial



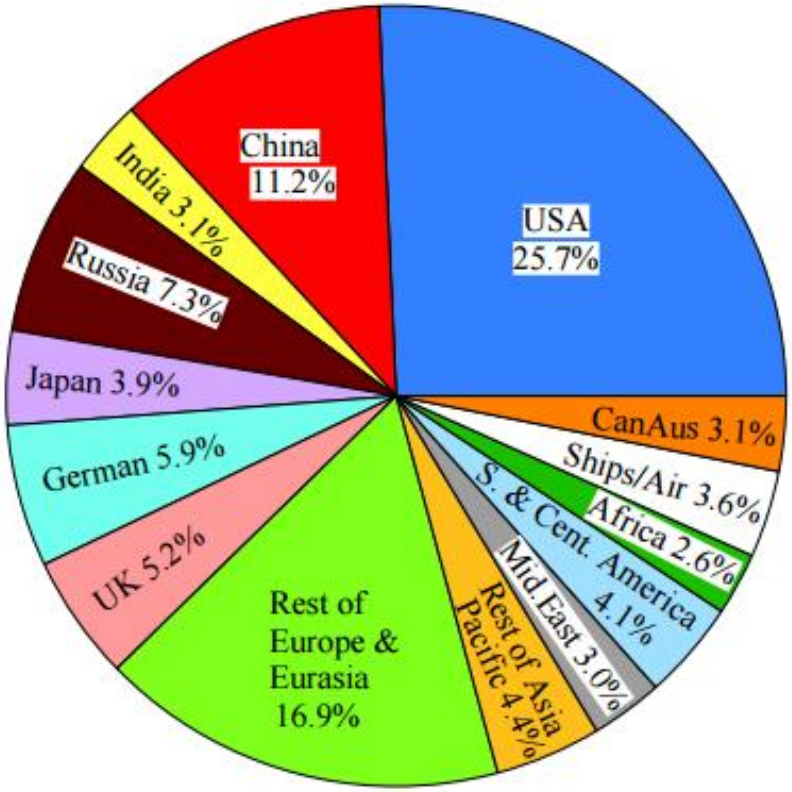
IPCC 2014

Current and Cumulative Emissions by Country

(a) 2013 Annual Emissions (9.9 GtC/yr)

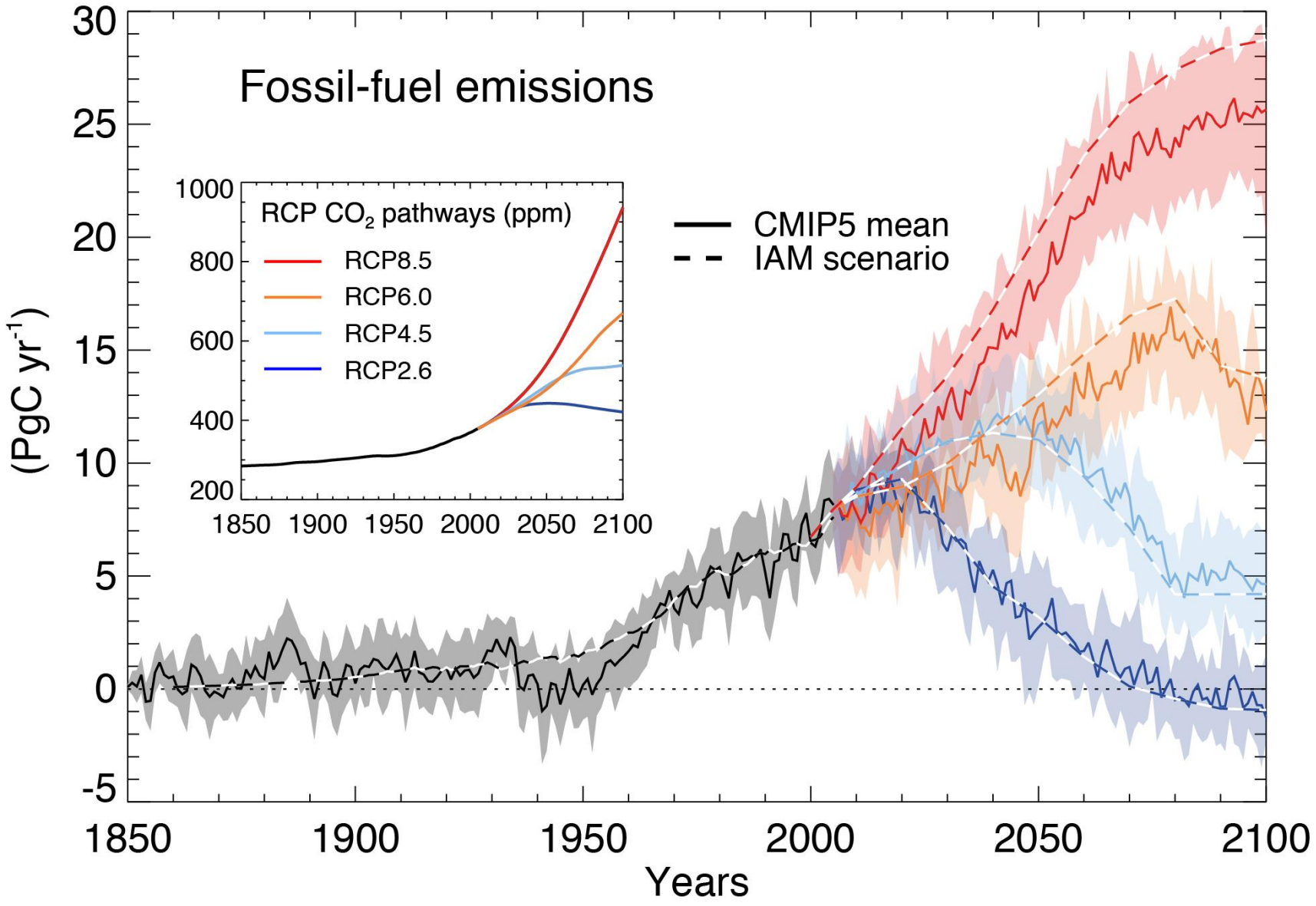


(b) 1751−2013 Cumulative Emis. (394 GtC)



Columbia Univ. and EIA.gov

Projections of Future Emissions



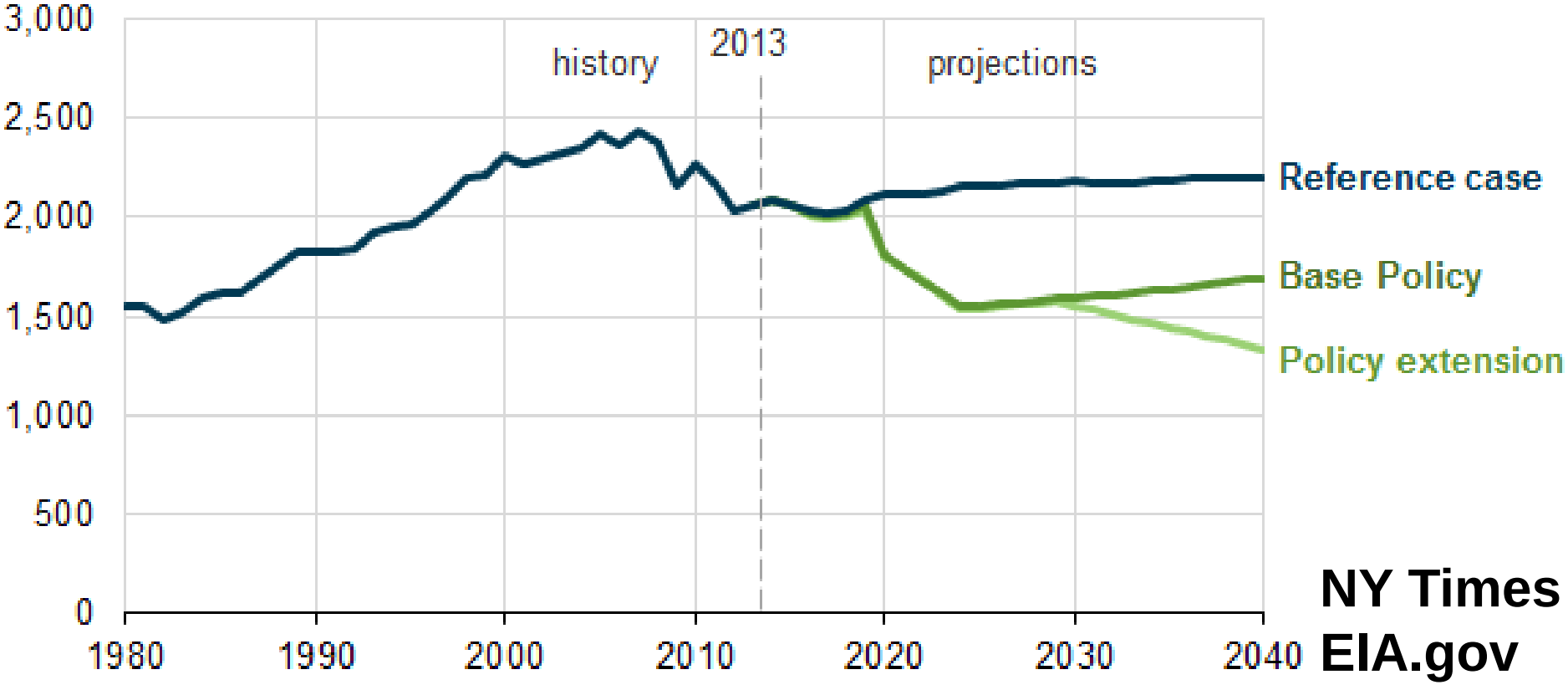
U.S. Proposed Policy

POLITICS

EPA Seeks to Cut Power Plant Carbon by 30 Percent

By THE ASSOCIATED PRESS JUNE 1, 2014, 7:41 P.M. E.D.T.

Carbon dioxide emissions from the electric power sector, 1980-2040
million metric tons



NY Times
EIA.gov