

**Joint SIPES HGS luncheon meeting
July 19, 2007**

Global Climate Change

A Geologist's view

What do the data tell us?



M. Ray Thomasson, PhD

Thomasson Partner Associates, Inc.

Denver, Colorado

OUTLINE

- I. Three Hypotheses**
- II. Principles of Earth – Atmosphere – Sun**
- III. Major Drivers of Climate Change**
 - A. Astronomical Causes**
 - A look at temperature
 - B. Tectonic Causes**
 - C. Atmospheric Causes**
 - Greenhouses Gases
 - Water Vapor and CO₂
- IV. Global Climate Models**
- V. The Sun**
- VI. Cosmic Ray Flux**
- VII. Miscellaneous**
- VIII. Conclusions**

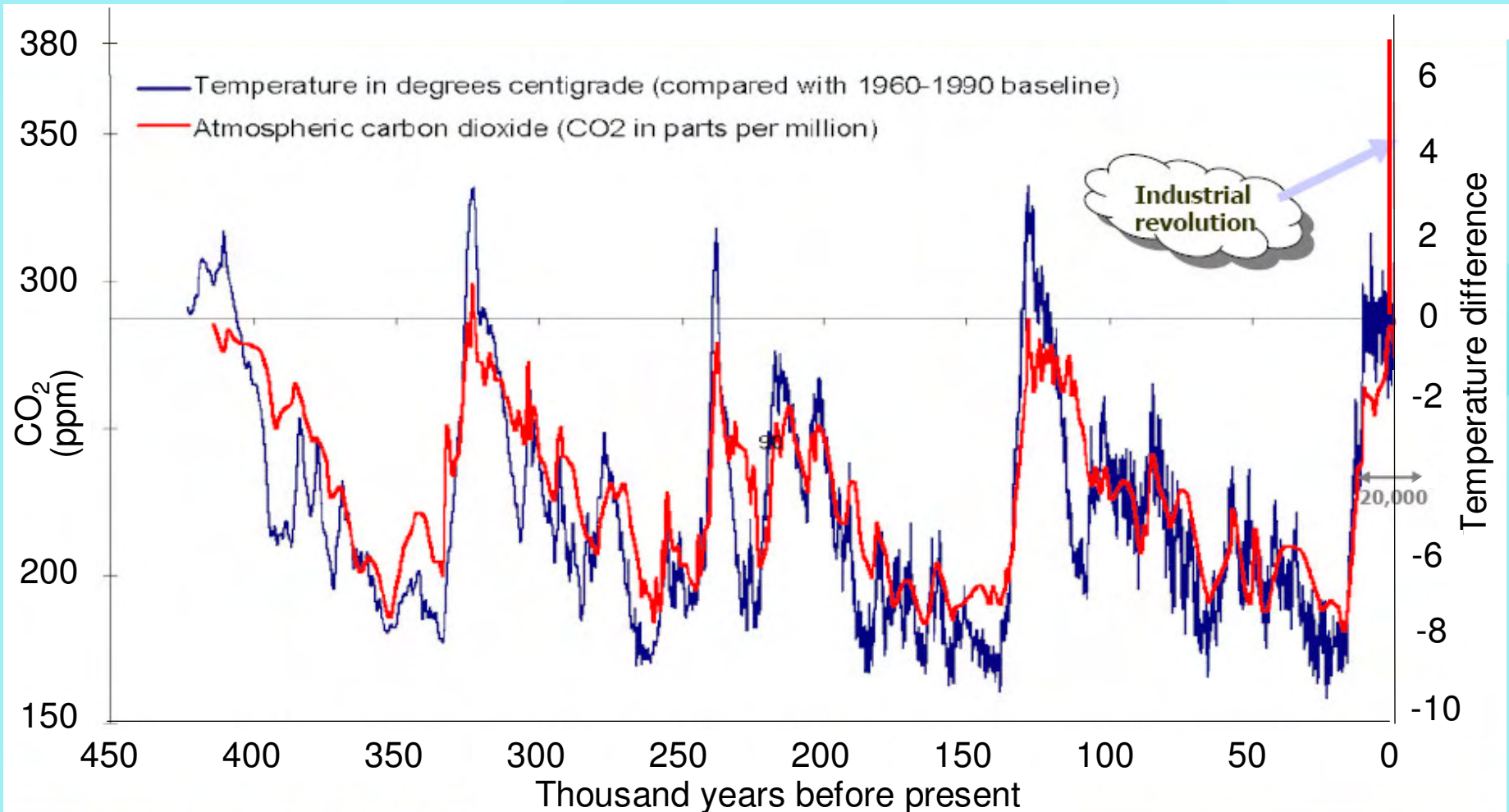
This I believe ...

- Conserving energy and reducing all unnecessary emissions are important to sustainable environments and economies
- We must do everything possible to plan for both a warmer and a colder future

Three hypotheses

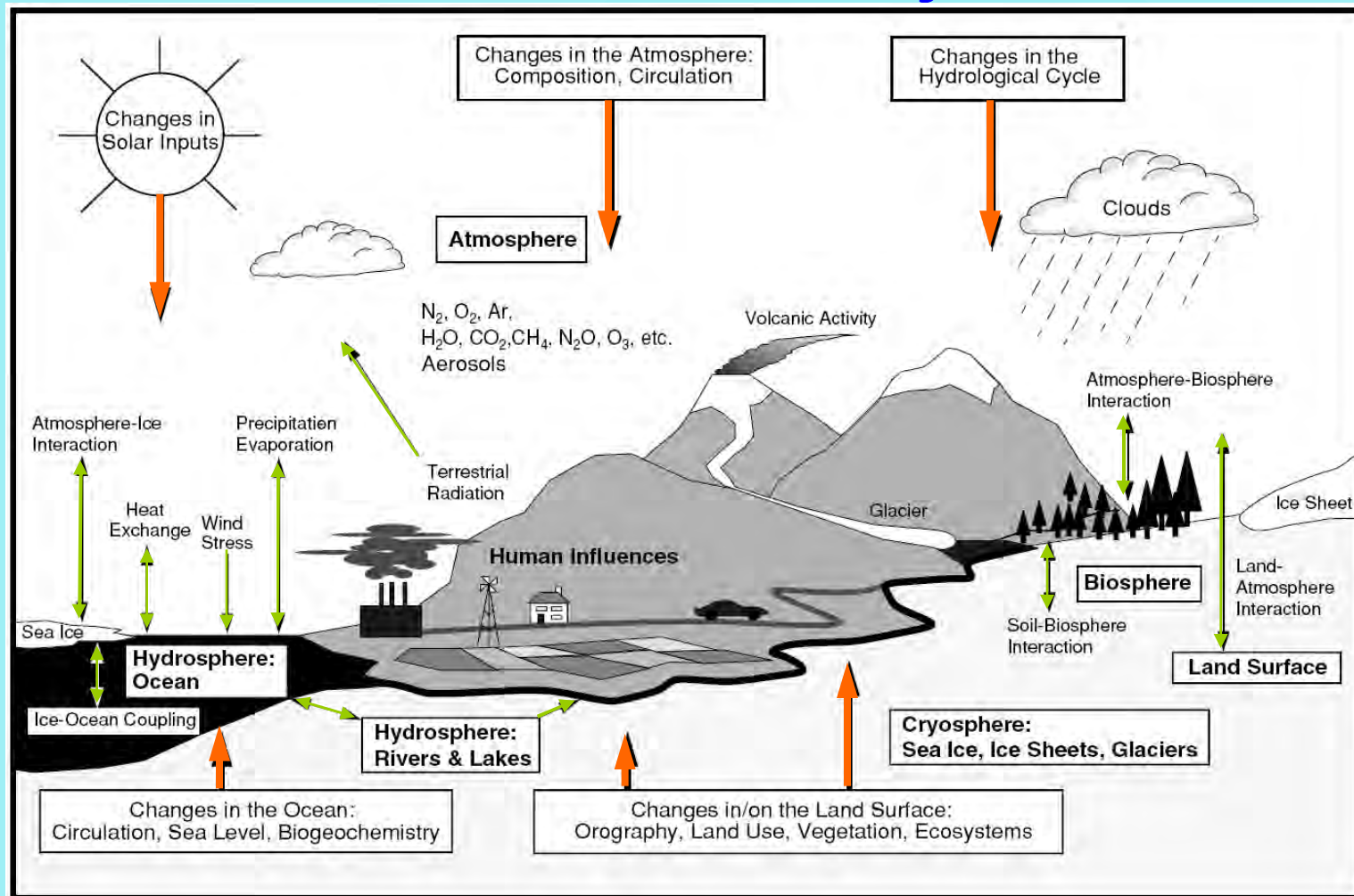
1. Climate is changing, and is warmer over the last 250 years
2. Anthropogenic emissions of greenhouse gases are the most significant driver of climate change
3. Natural processes are the most significant climate drivers

Excellent correlation of global Temperature and CO₂ over 400,000 yrs



Source: Intergovernmental Panel on Climate Change (1990, 1995, 2001)

Global climate system

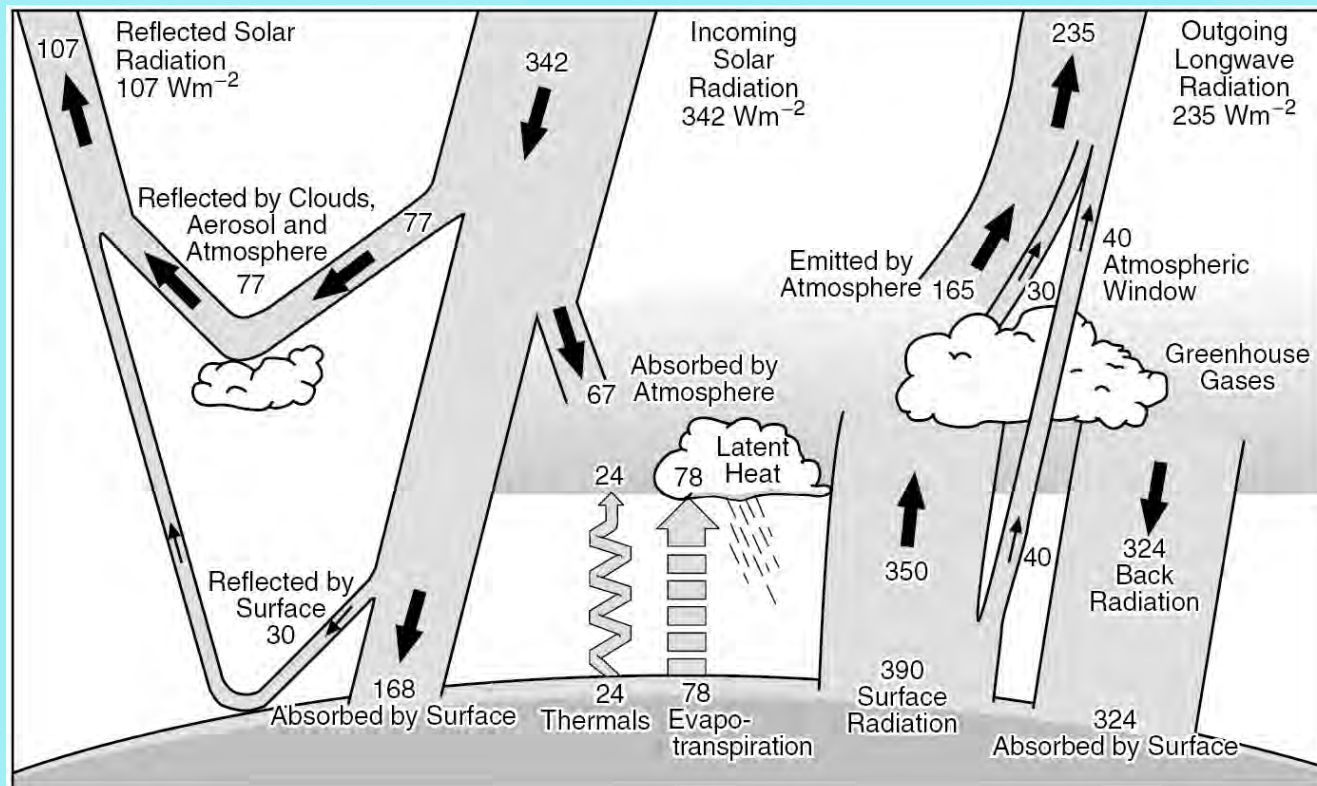


Processes and interactions – thin arrows

Aspects that may change – bold arrows

Earth's energy balance

expressed in watts per square meter (Wm^{-2})

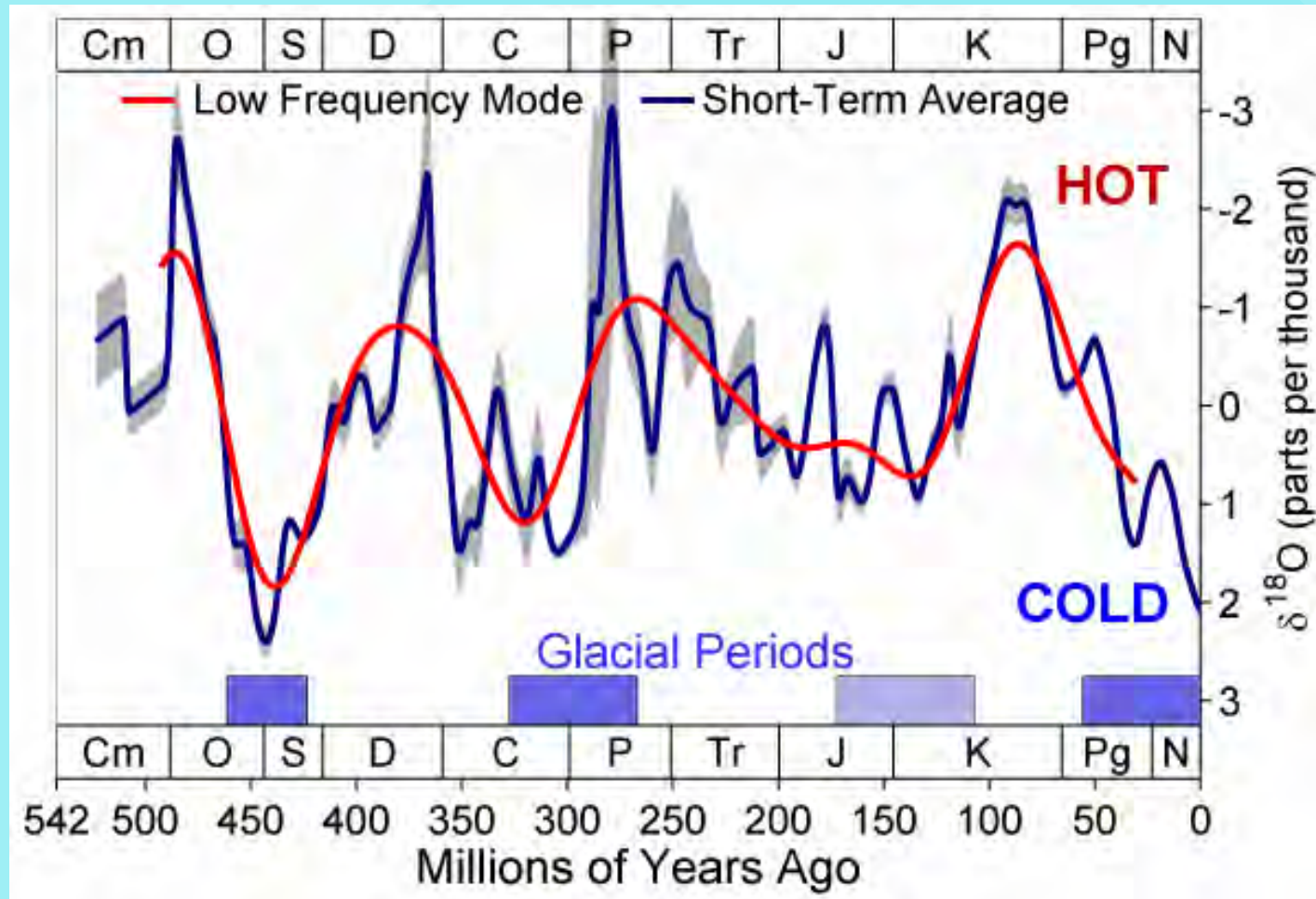


- There is relatively little direct reflection and radiation from surface to space, but significant exchange via the atmosphere
- The surface receives almost twice the energy from the atmosphere as it does directly from the sun

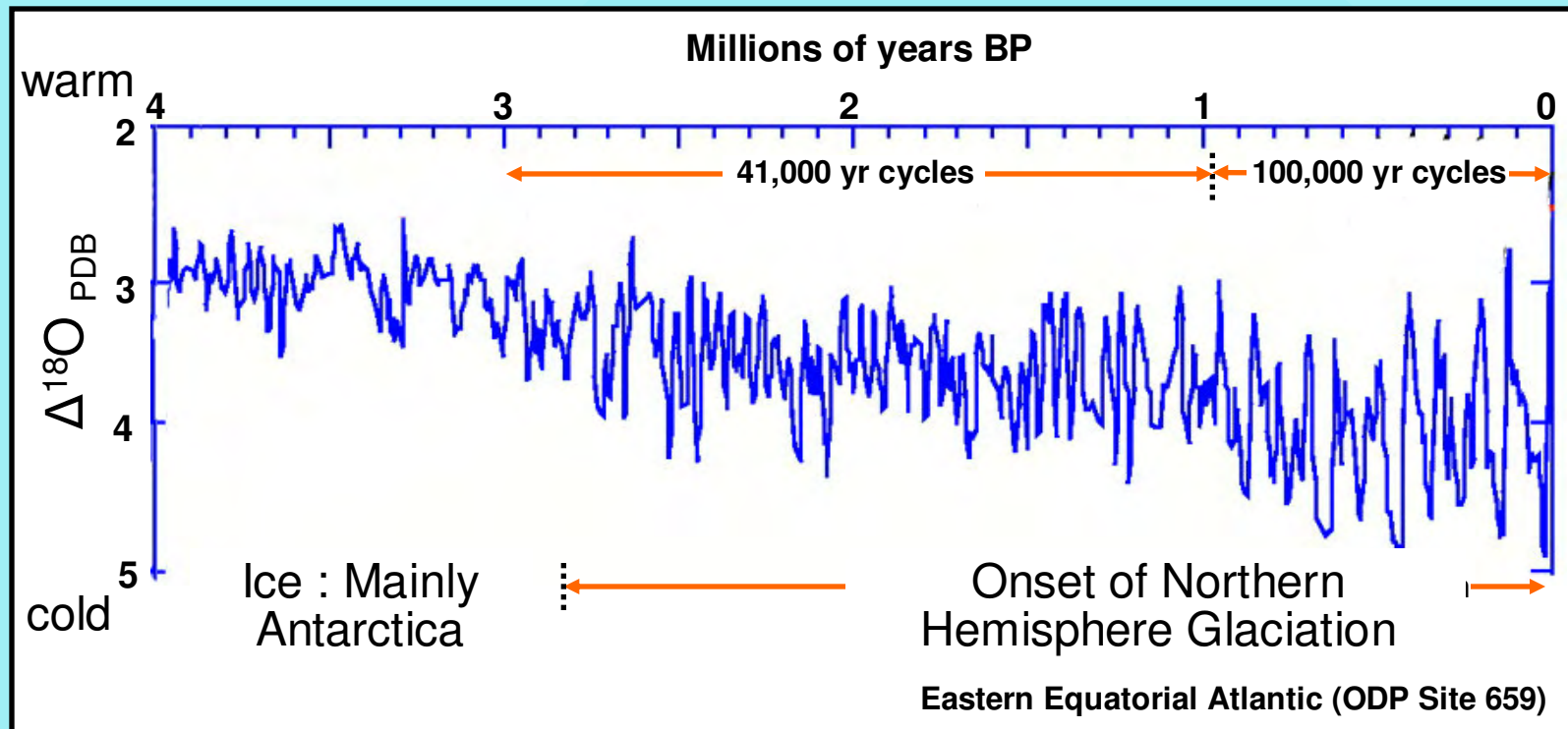
Major Drivers of Climate Change

- Astronomical Causes
 - Eccentricity – 100,000 year cycles
 - Tilt – 41,000 year cycles
 - Equinox Precession – 25,800 year cycles
 - Sun Spots – 11, 80, and 1100 year cycles
 - Cosmic Rays (Geomagnetic Index)
- Atmospheric Causes
 - Greenhouse Gases (CO₂, Methane, Mostly Water Vapor)
 - Solar Reflectivity (Volcanic Dust, Clouds, Ice Caps)
- Tectonic Causes
 - Landmass Distribution (Shifting Continents, Ocean Currents)
 - Undersea Ridge Activity (Continental Drift)

Phanerozoic Climate Change

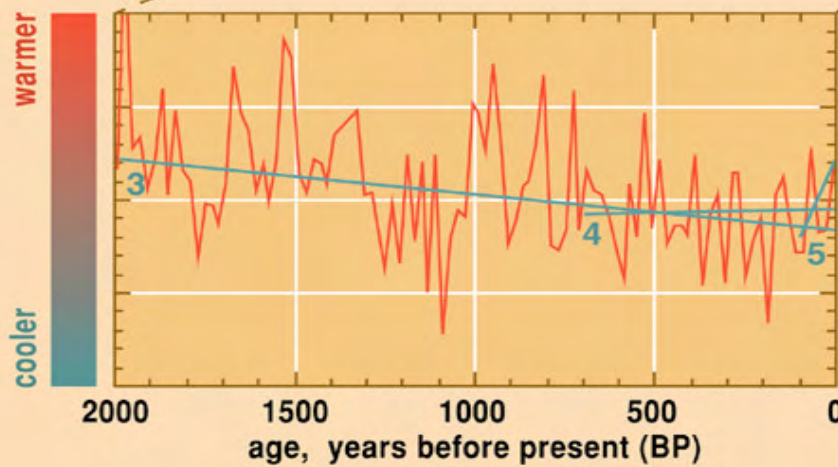
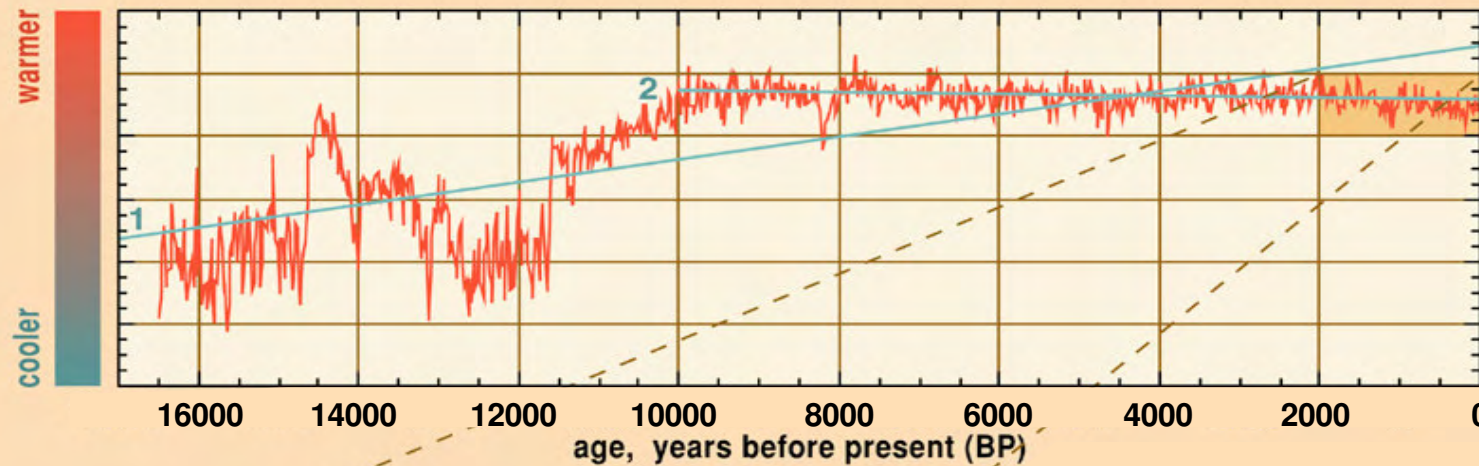


Earth's climate Record : The 4 million year perspective



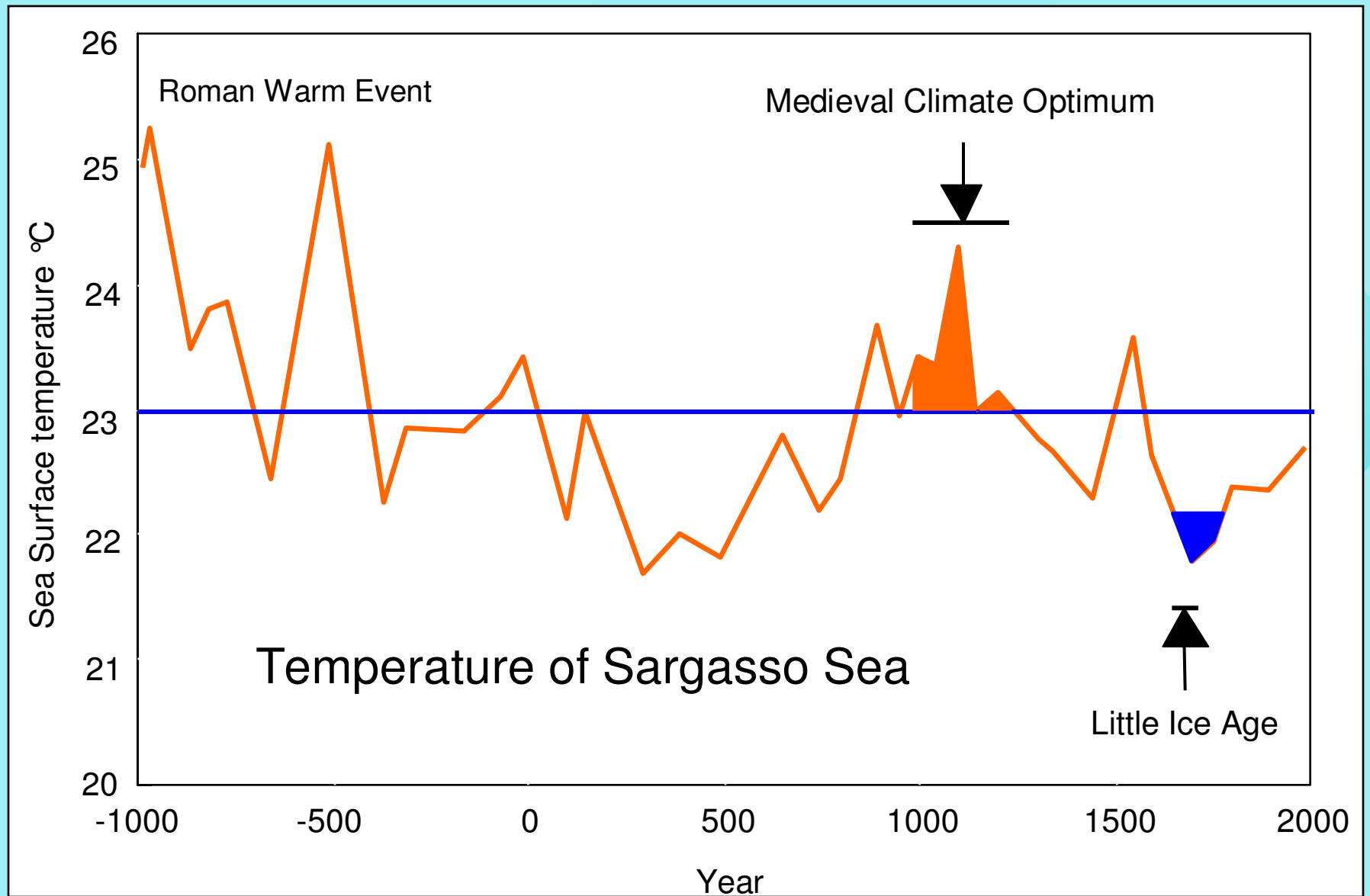
- From 3 → 1 mill yrs BP, climate was dominated by earth's axis tilt (obliquity) – 41,000 year cycles
- From 1 mill yrs BP → present, earth's eccentricity dominated climate – 100,000 year cycles

Earth temperature history from Greenland ice core data

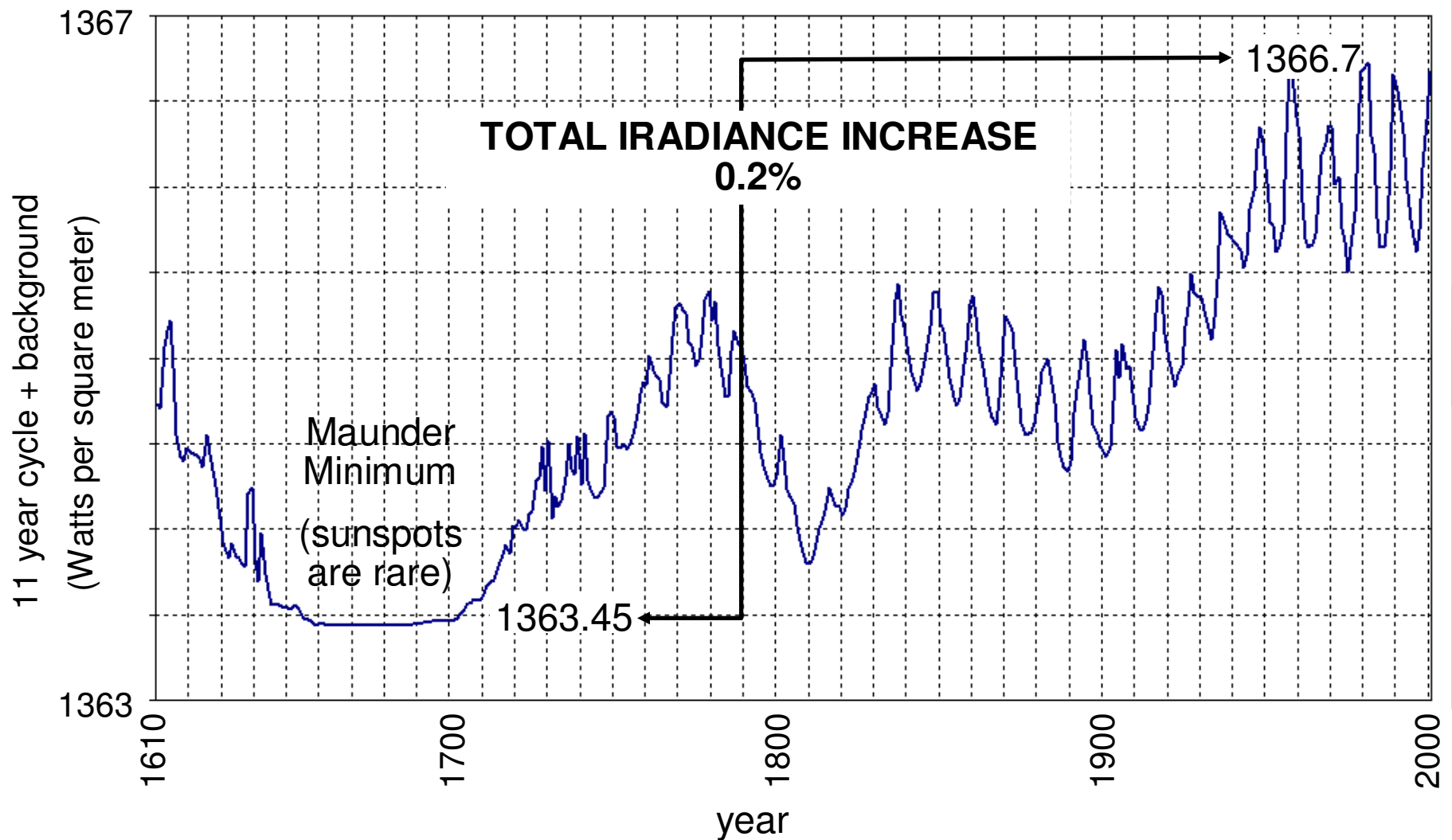


1. Warming since beginning of ice core record
2. Cooling since 10,000 BP
3. Cooling since 2,000 BP
4. Slight warming since start of little ice age, 700 BP
5. Warming since start of industrial Revolution, 100 BP

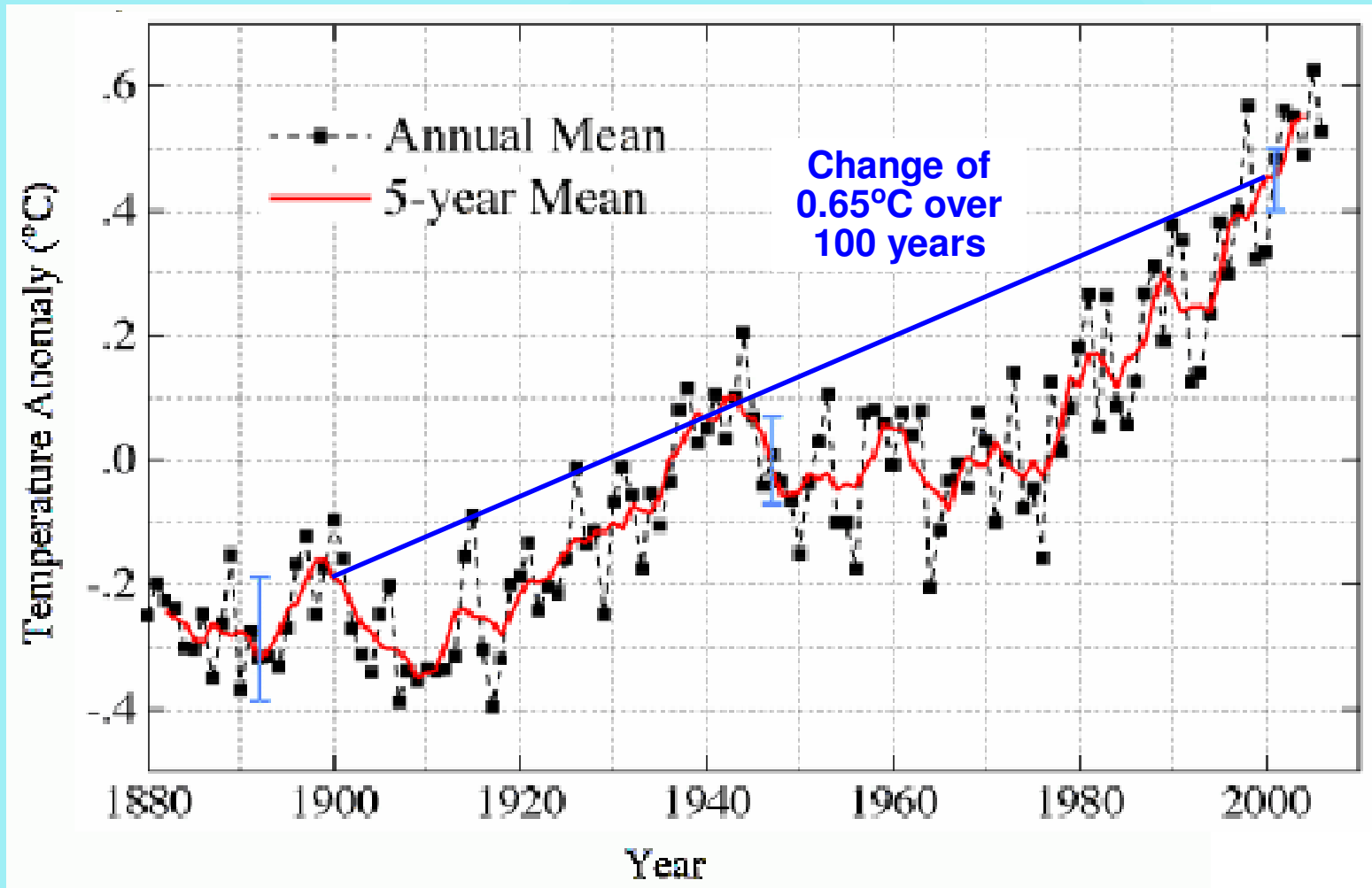
Temperature of Sargasso Sea



Solar Irradiance

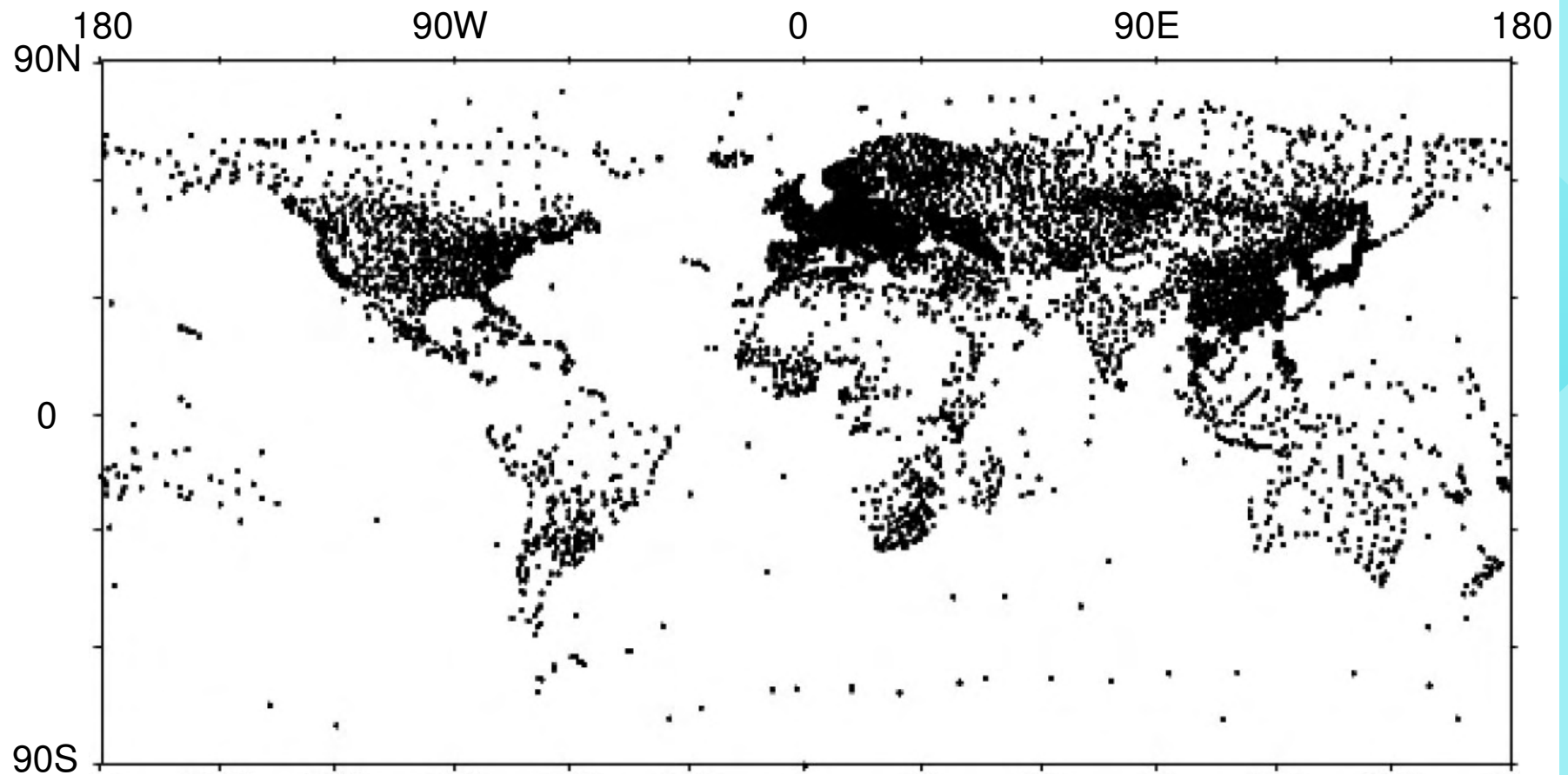


Global Temperature

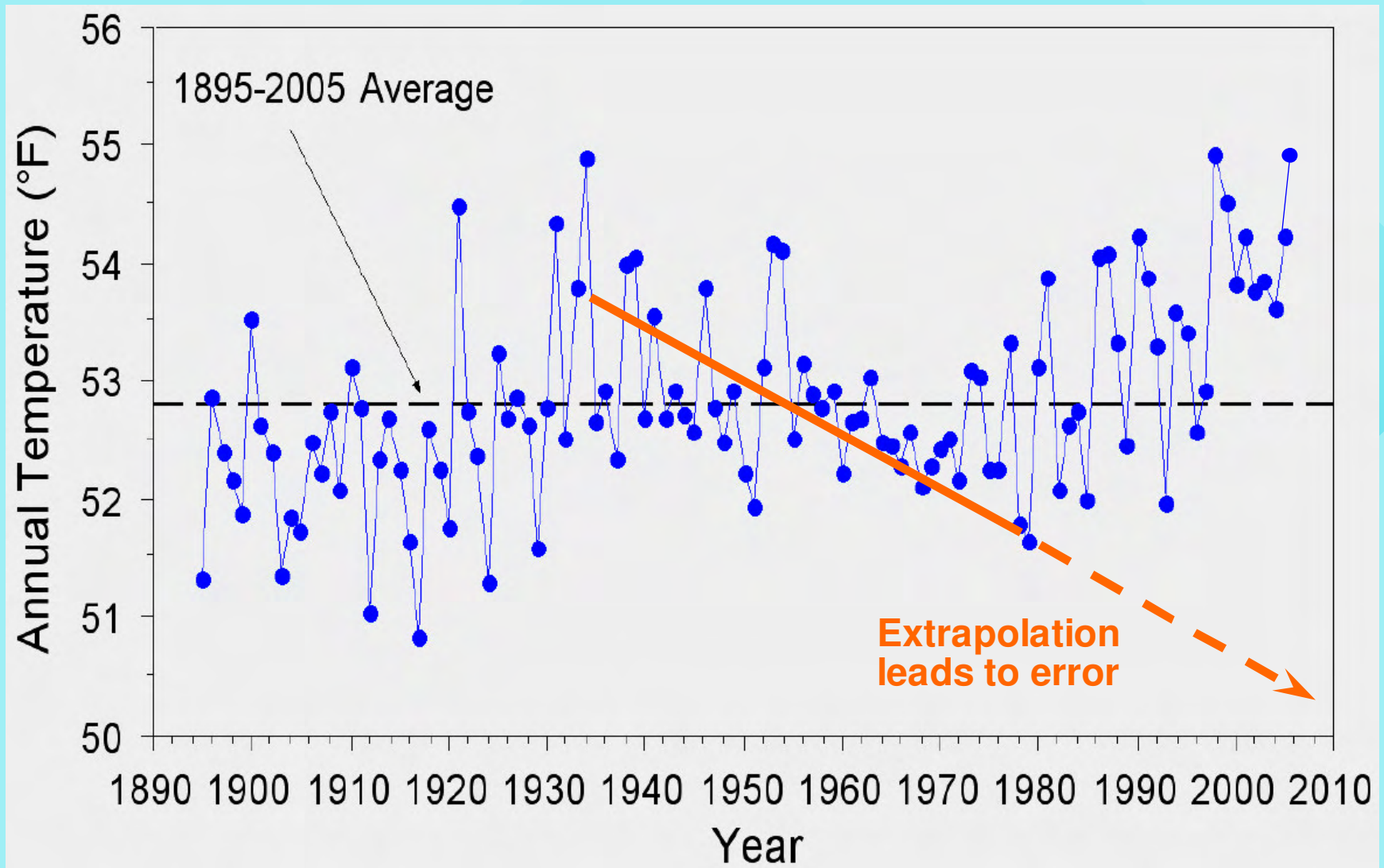


- Over the past 100 years, the Earth has warmed by 0.65°C or 1.1°F

Distribution of the approximately 8,000 weather stations



United States Annual Average Temperature 1895 - 2006



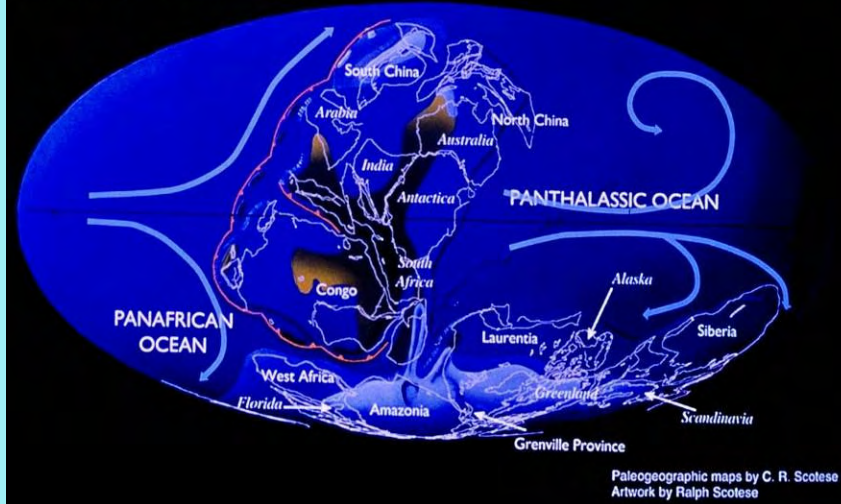
Time magazine cover illustrating the expected coming cold and perhaps ice-age conditions



This view was formed by the extrapolation of the 30 year global cooling curve (1945 – 1975)

Equatorial currents determine climate

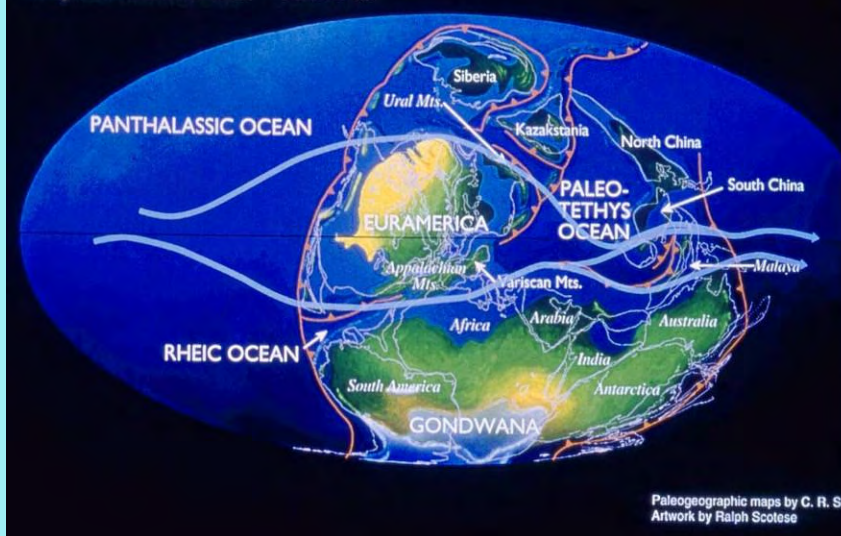
Late Proterozoic 650 Ma



Early Devonian 390 Ma



Early Carboniferous 356 Ma



Late Carboniferous 306 Ma



Modern World



Atmospheric composition

Dry atmosphere – no water vapor

Nitrogen	78.084%
Oxygen	20.946%
Argon	0.934%
Carbon Dioxide	0.038%
Misc.	0.0003% (everything else) *

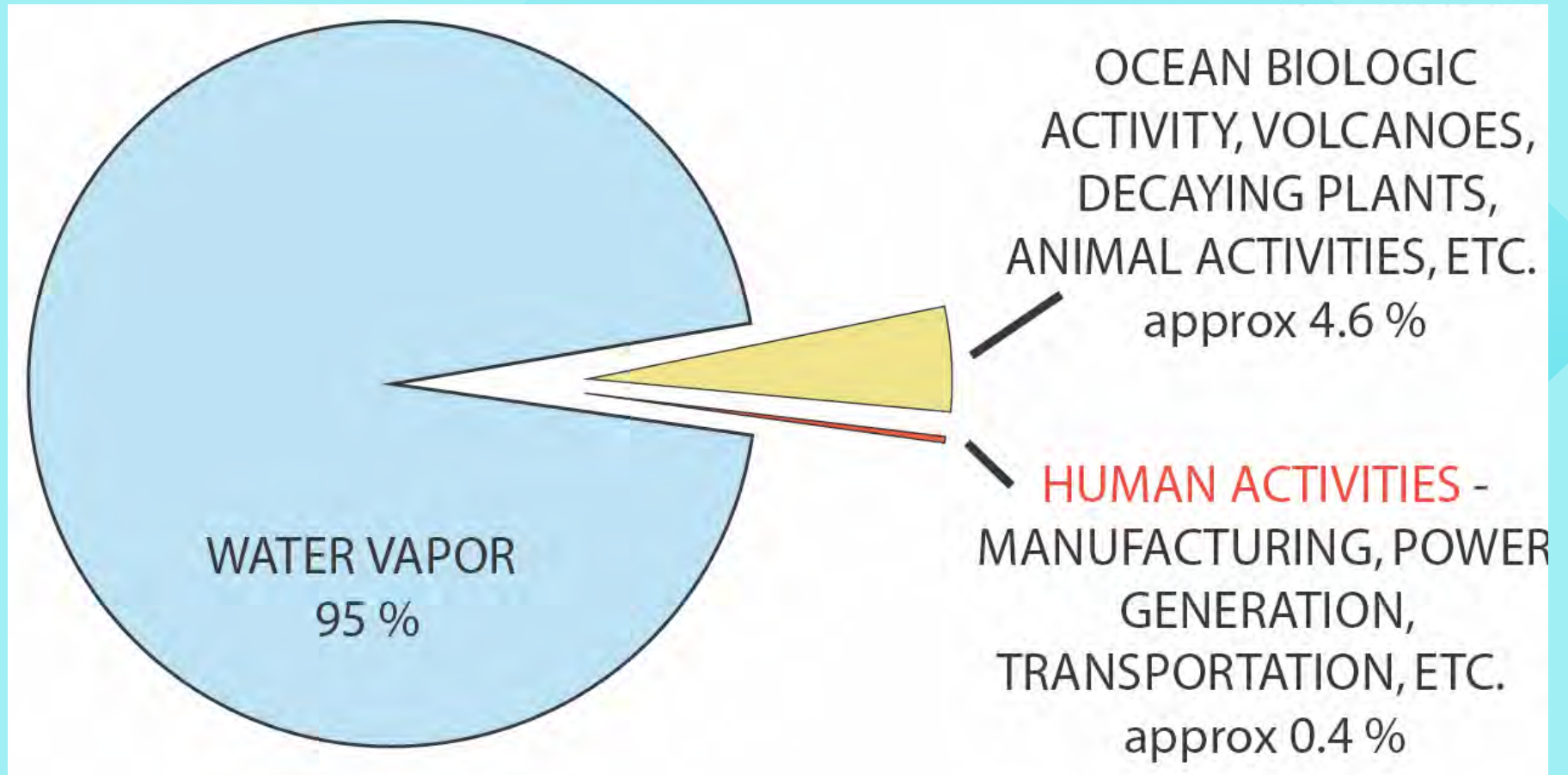
* Methane is 0.00002%

Water vapor averages approx. 2.0%, and is as much as 4.0% in the tropics

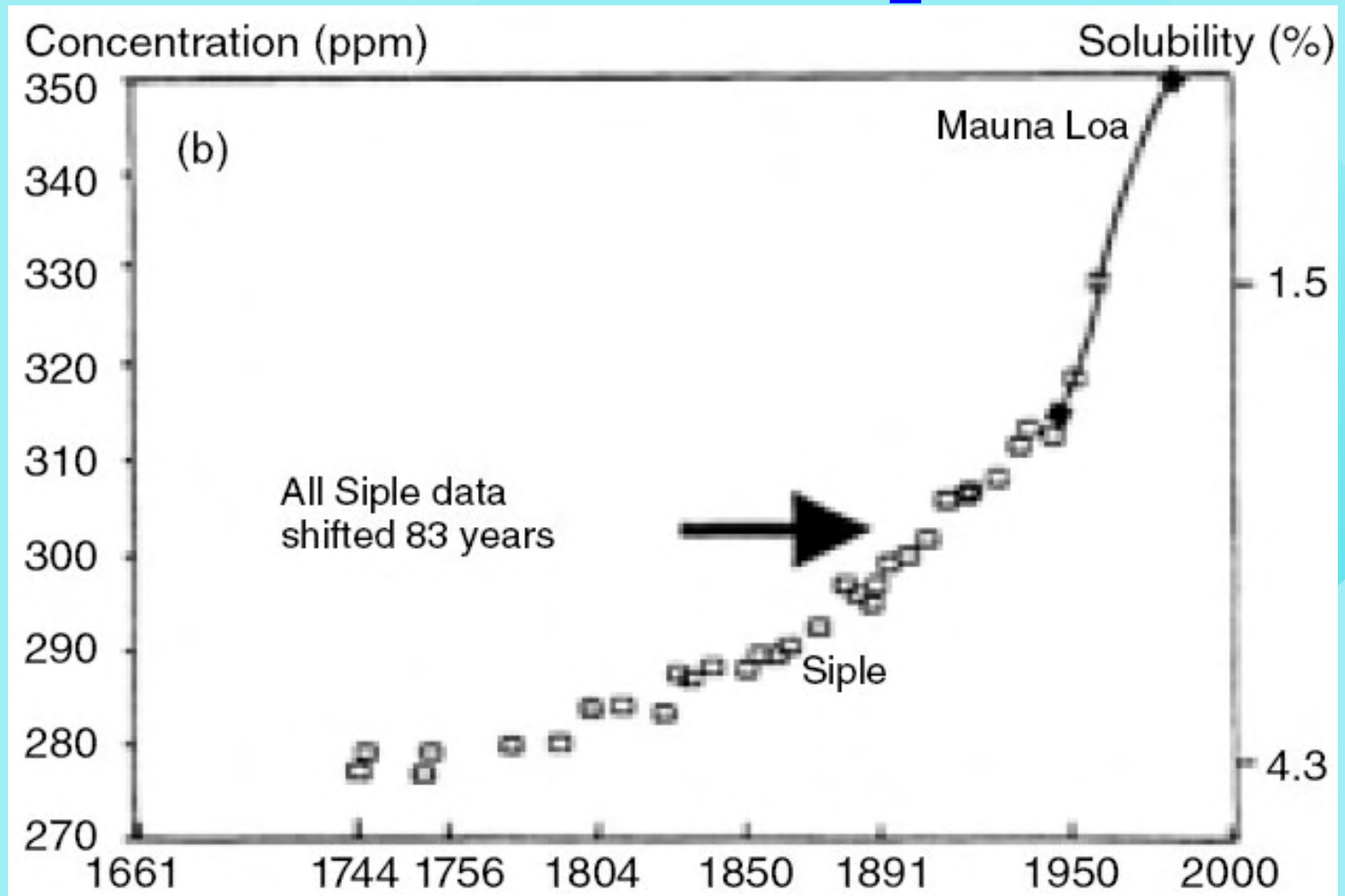
Worldwide estimated Sources and Sinks of Carbon

Sources and Sinks	Range (Billion metric tons)	% averaged
Sources		
Natural		
Biomass Respiration	22-65	22.5
Biomass decay	18-55	19
Ocean Release	100-110	54
Anthropogenic (Man-made)		
Fossil Fuel Burning	5.5-6.5	3.1
Industrial sources	~0.1	0.0005
Deforestation and land use changes	1.1-3.6	1.2
Sinks (Natural)		
Biomass Photosynthesis	102.5-112.5	
Uptake by the ocean	40-120	
Unidentified "missing sink"	2.2-3.7	
Atmospheric Increase	3.2-3.6	

Sources of Greenhouse gases

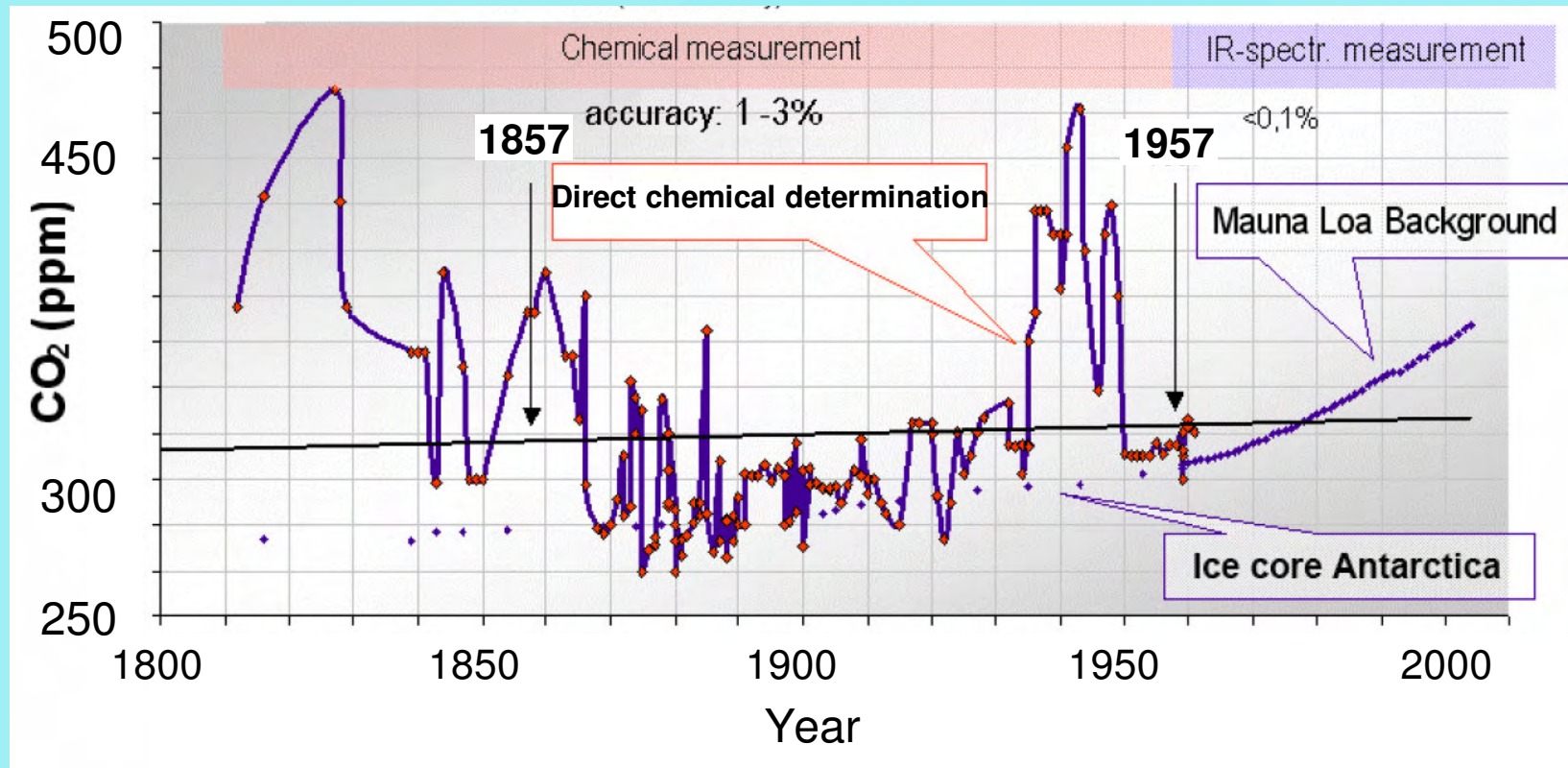


SIPLE CO₂ core data and Mauna Loa CO₂ data



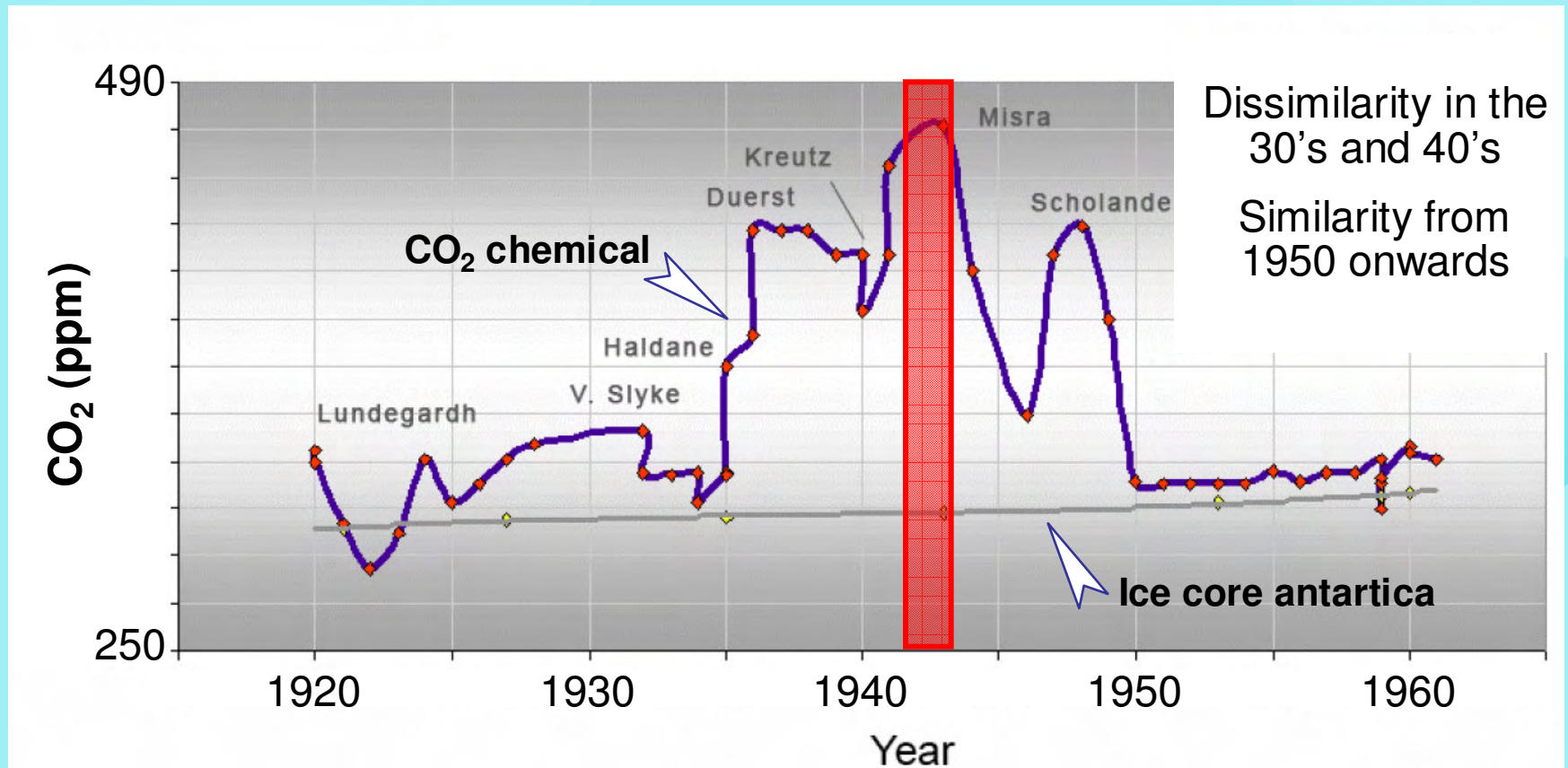
Siple Data – with an 83-year-younger age of air than the age of the enclosing ice

CO₂ Measurements 1812 - 2004



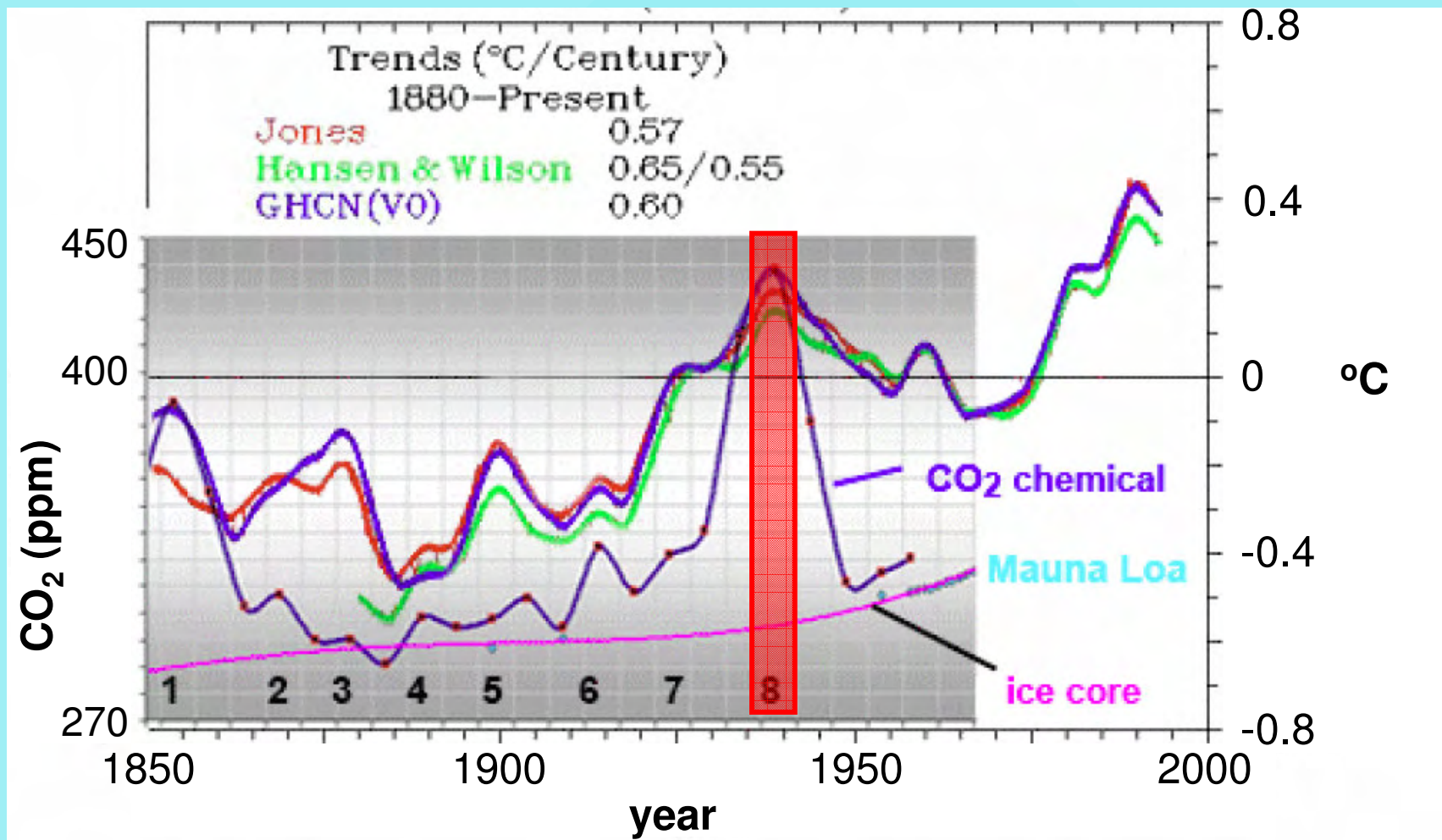
- 138 yearly average from 1812 to 1961 chemical determination (raw data)
- A thorough review of existing literature (175 in this study) reveals some 90,000 accurate measurements by chemical methods before 1957 back to 1812 with an accuracy better than 3%
- These pioneers of chemistry, biology, botany, medicine and physiology laid foundations for today's knowledge of metabolism, nutrition science, biochemistry and ecology

CO₂ 1920 – 1961, Northern Hemisphere, chemical



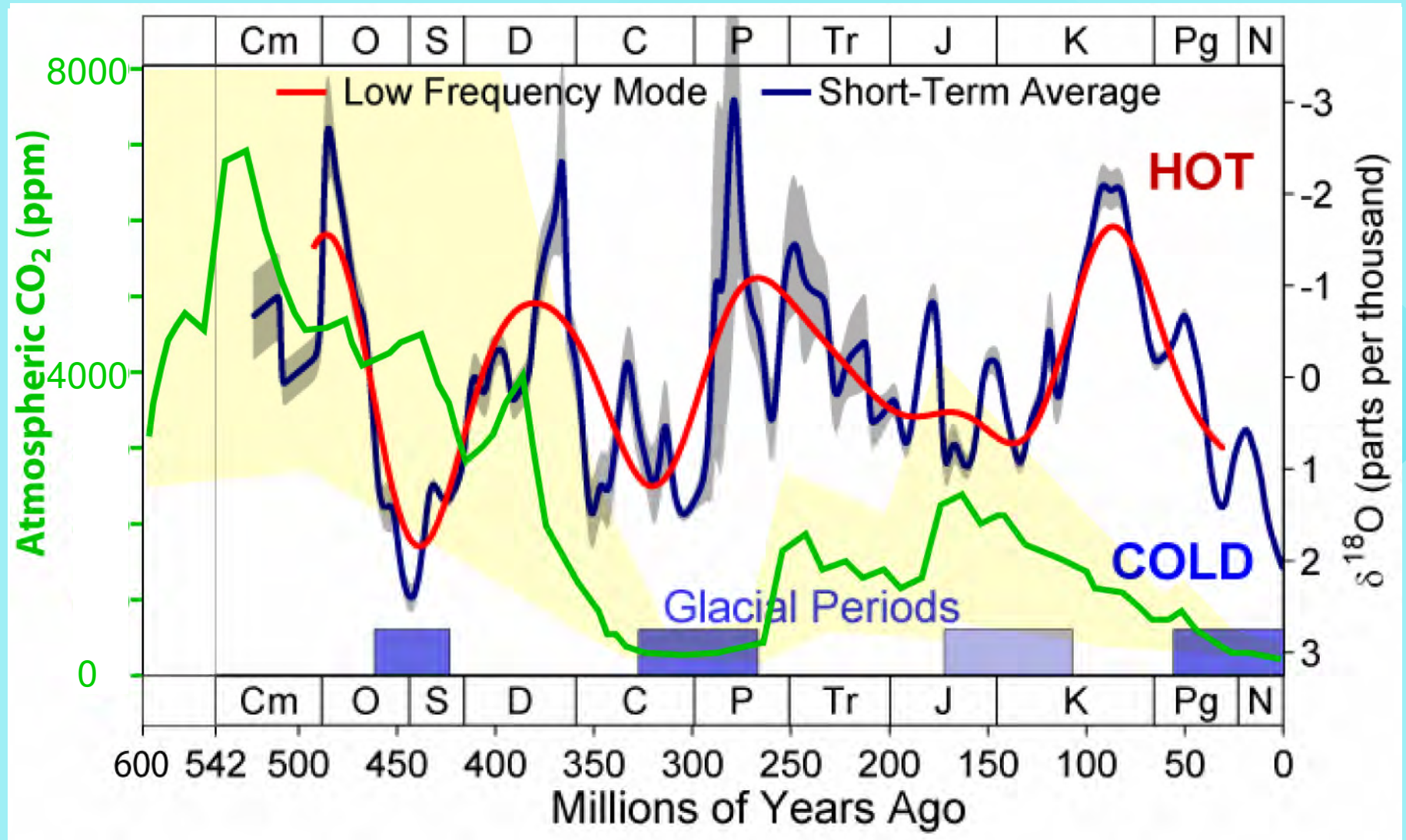
- The 1942 maximum detected with chemical analysis
- Stations in Europe, USA, Atlantic, Alaska, India and Antarctica
- Measurements made by competent experts
- Verified that stations had no exceptional contamination by local sources

Northern Hemisphere - Land

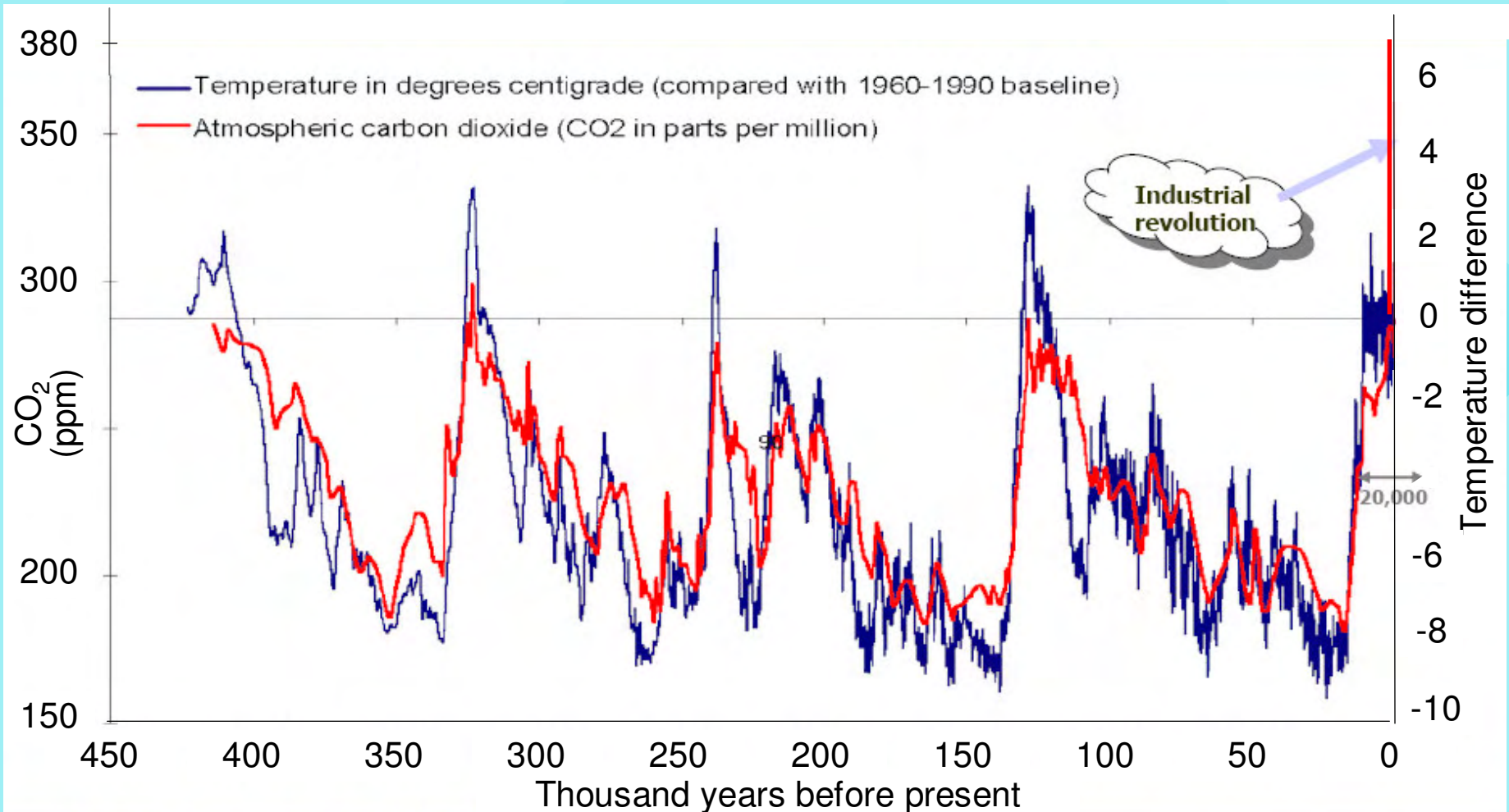


Comparing measured temperature in northern hemisphere from 1850 with CO₂ fluctuations

Phanerozoic Climate Change



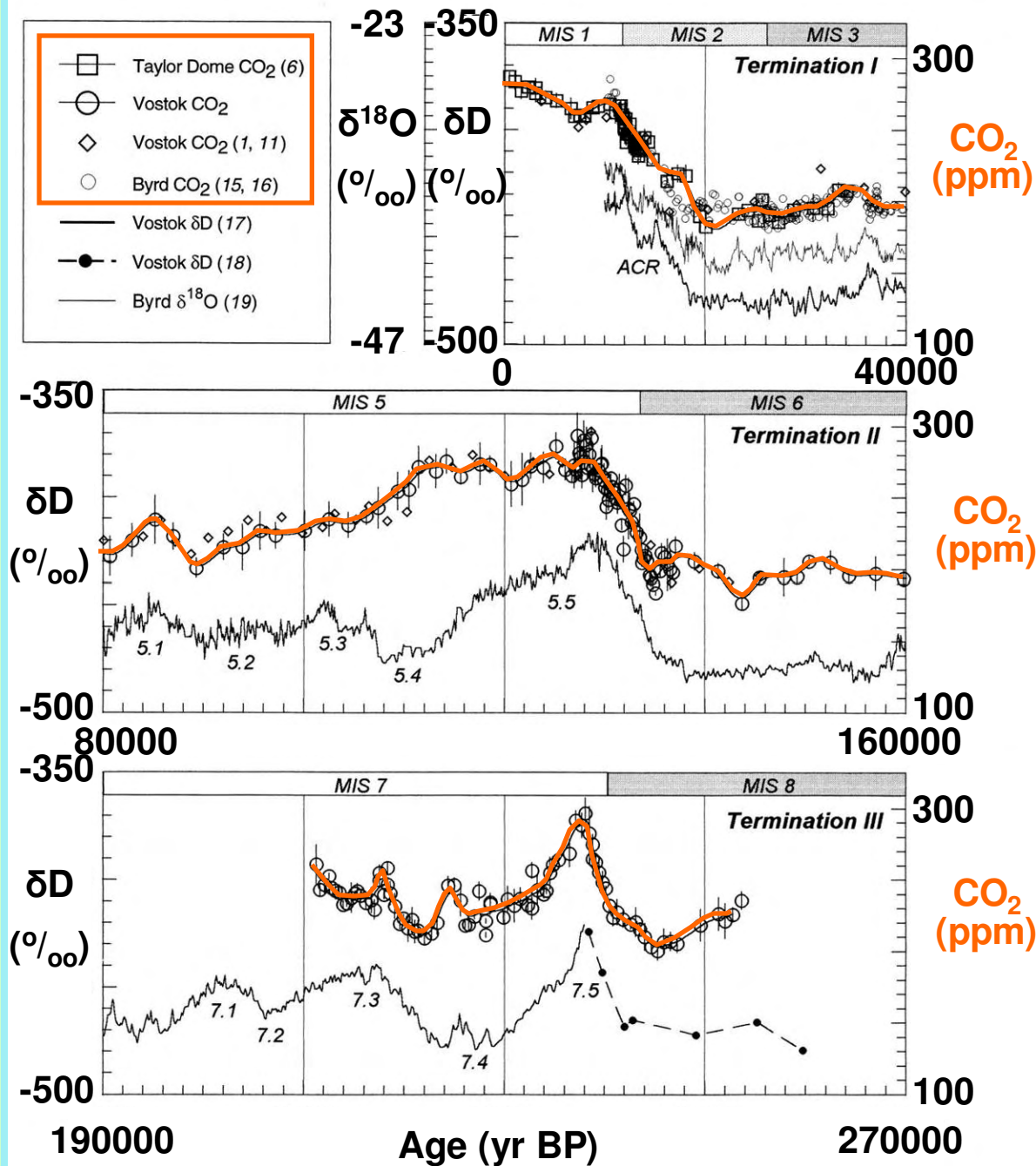
Excellent correlation of global Temperature and CO₂ over 400,000 yrs



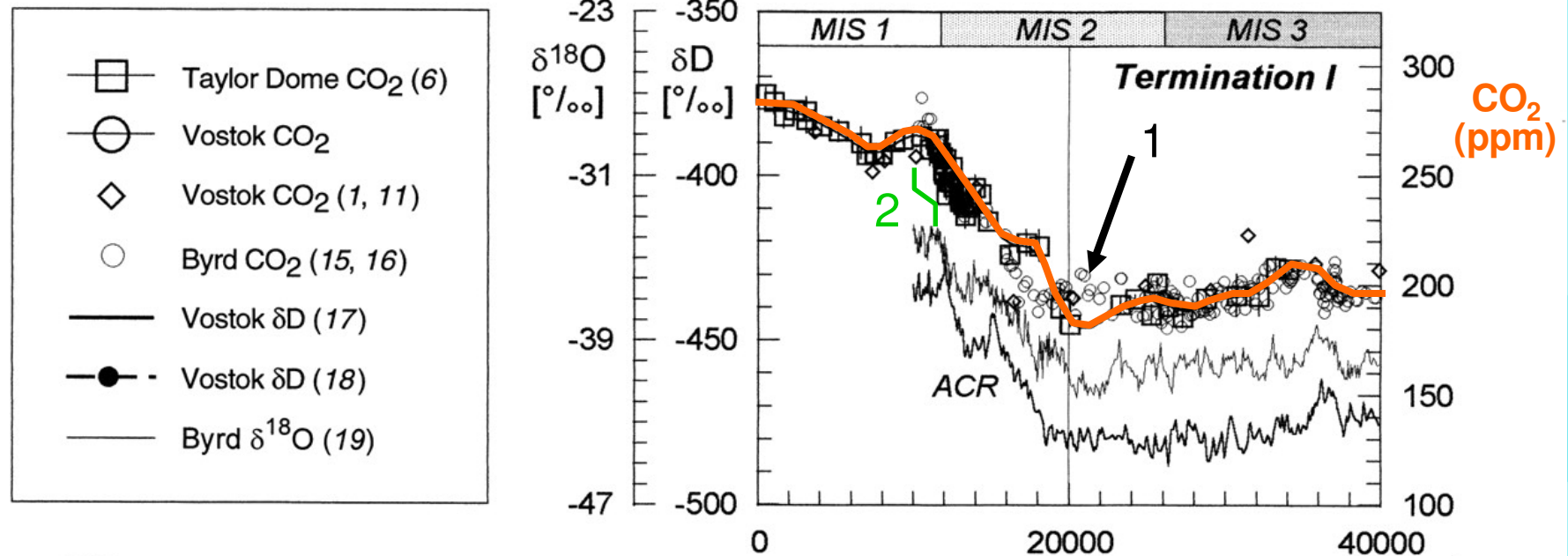
Source: Intergovernmental Panel on Climate Change (1990, 1995, 2001)

Atmospheric CO₂ concentration and Isotope temperature records

Data taken over the last three glacial terminations

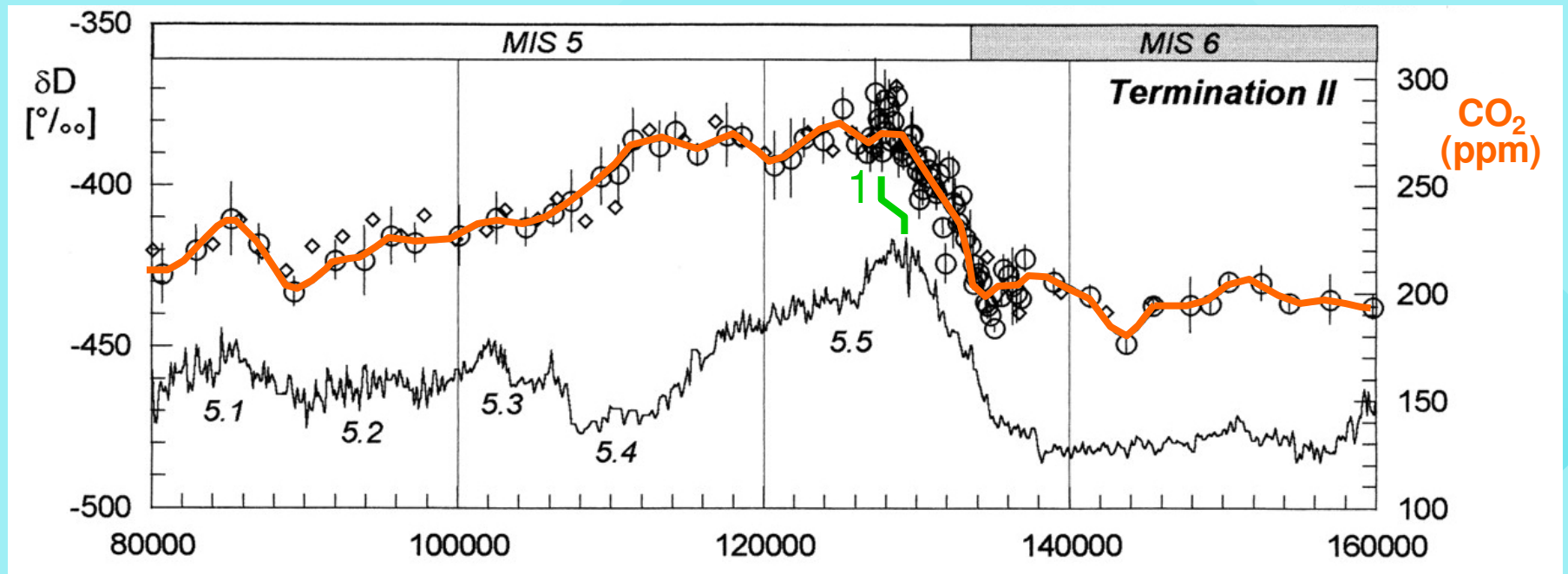


The last three Glacial Terminations



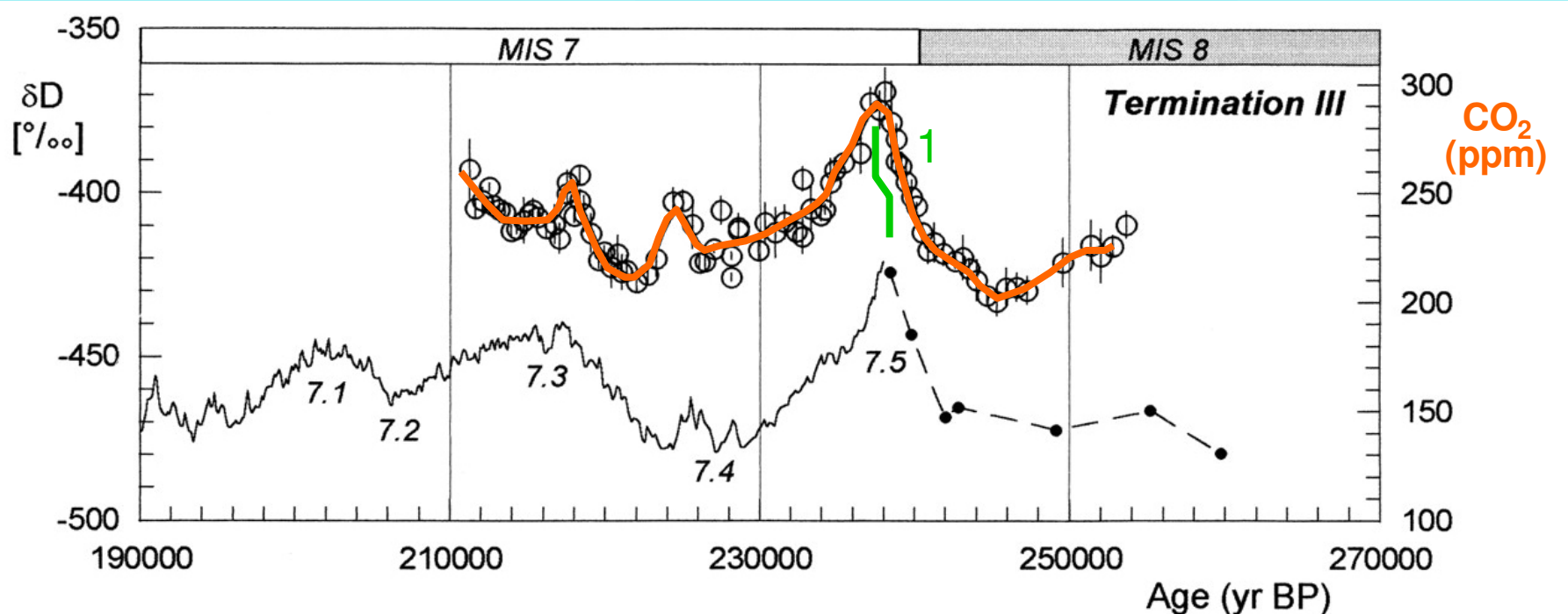
1. During Termination 1, Taylor Dome recorded the onset of CO_2 increase at 19 to 20 ky B.P.
2. Maximum CO_2 concentrations are reached at 10.5 ky BP, 600 –1000 years after the $\delta^{18}\text{O}$ Byrd temperature peak

The last three Glacial Terminations



1. The onset of major warming in Term II is hard to define, but CO_2 concentrations reach their maximum 400 ± 200 years later than Antarctic temperatures

The last three Glacial Terminations

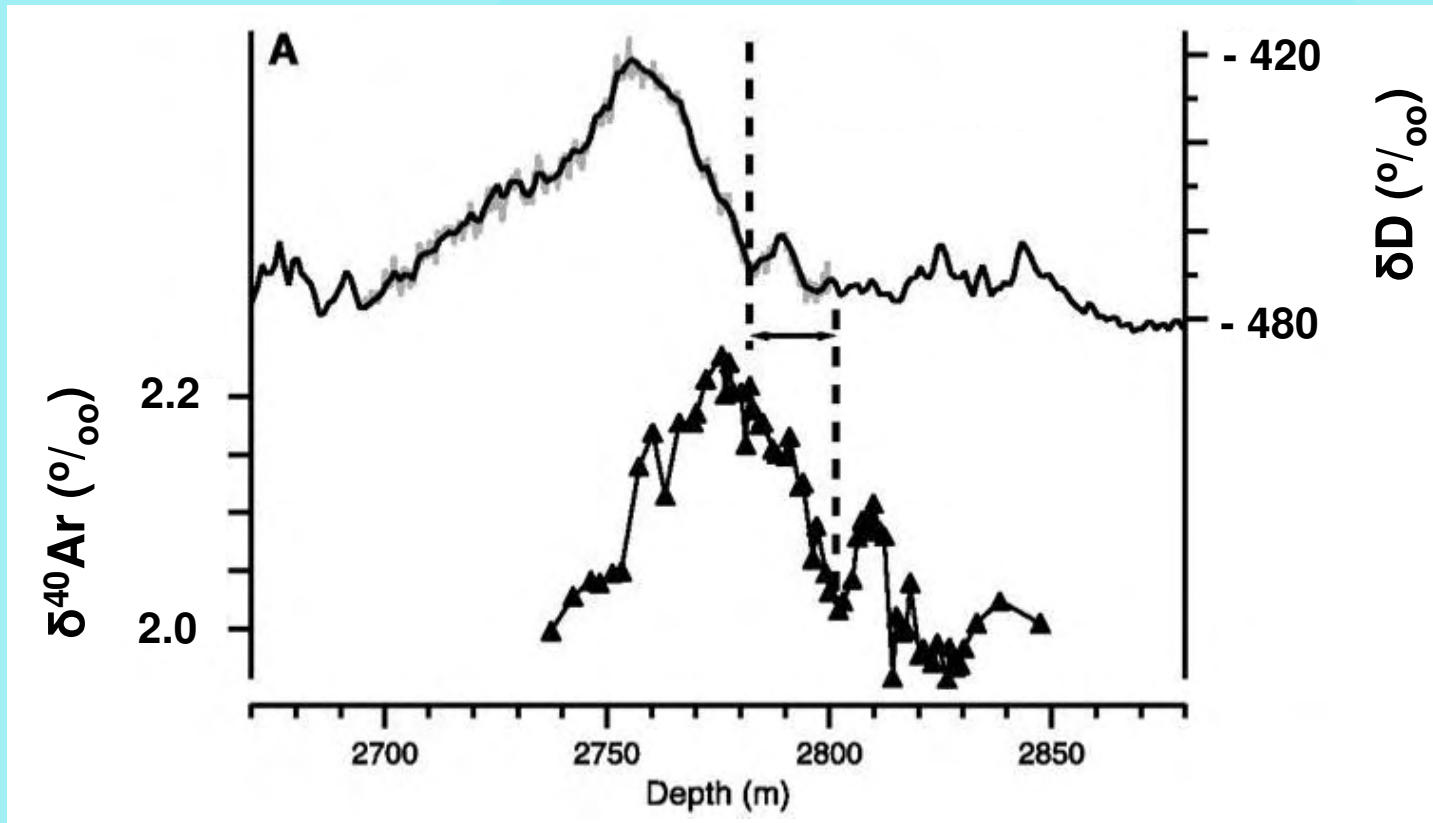


1. For Term III, the major increase in CO₂ tends to lag temperature during the transition, reaching a max 600 ± 200 years after the δD peak

The last three Glacial Terminations

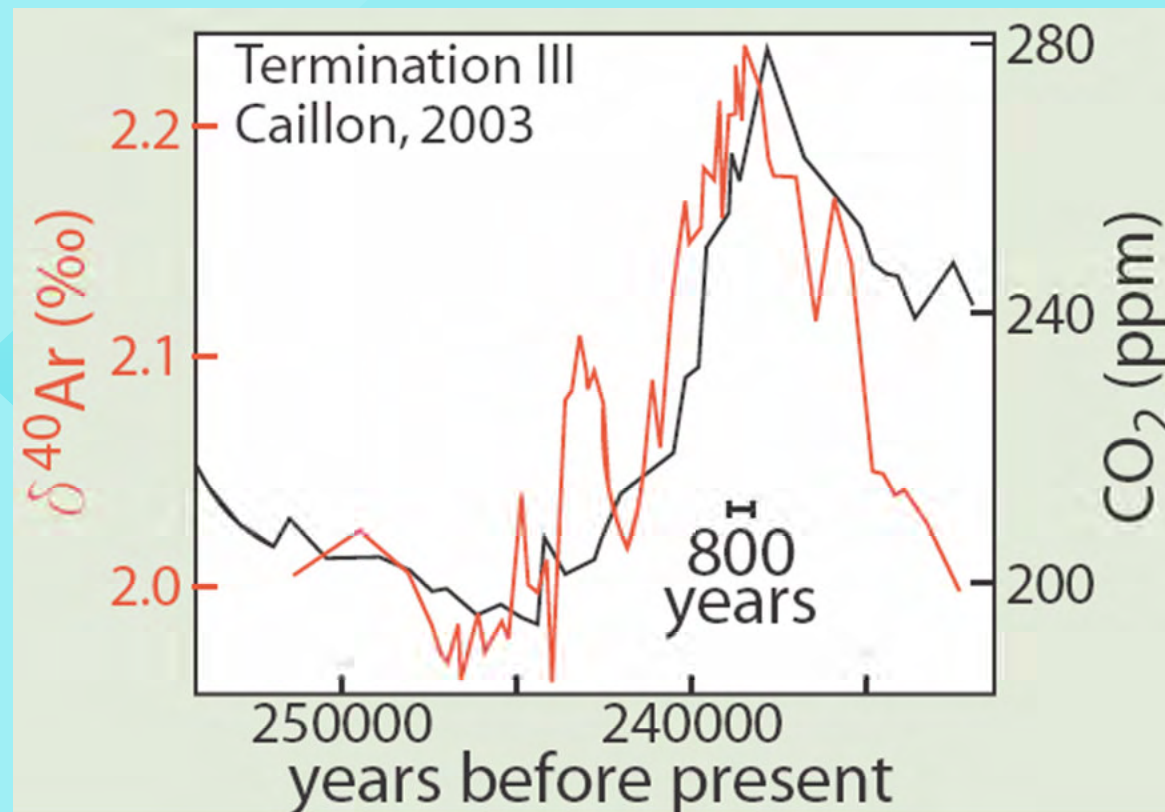
- Atmospheric CO₂ concentrations show a similar increase for all three terminations, connected to a climate driven net transfer of carbon from the ocean to the atmosphere
- The time lag of the rise in CO₂ concentrations with respect to temperature change is on the order of 400 to 1000 years during all three glacial-interglacial transitions
- In the case of recent anthropogenic warming, the external climate forcing by CO₂ emissions **leads** climate variations, so applying the CO₂-climate relation seems not to be straightforward

Vostok records covering Termination III



The deuterium measured in ice shown in line above along with the $\delta^{40}\text{Ar}$ of gas trapped in air bubbles shown as triangles

Vostok records of $\delta^{40}\text{Ar}$ and CO_2 with respect to gas age

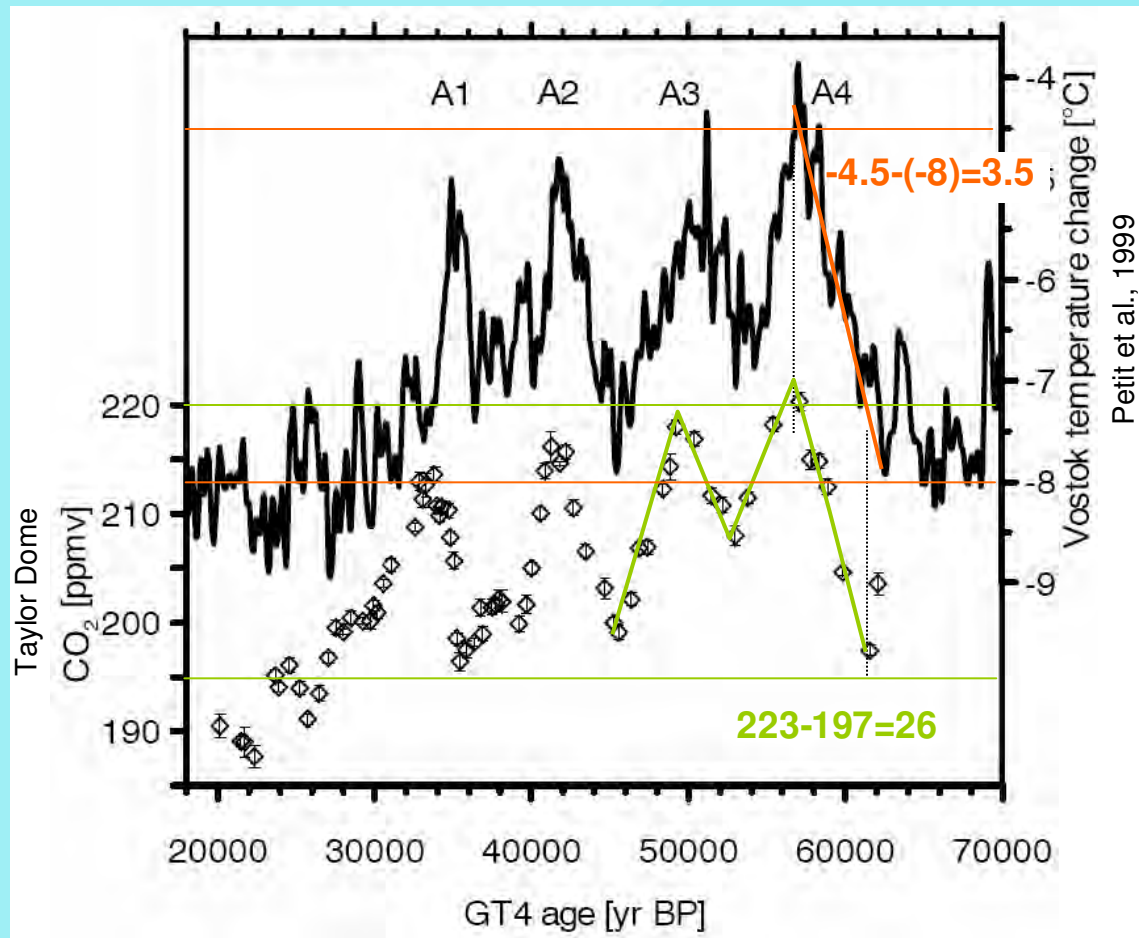


The age scale for the CO_2 proxy has been shifted by a constant 800 years to obtain the best correlation of the two datasets

Timing of Atmospheric CO₂ and Antarctic Temperature Changes Across Termination III

- A temperature proxy measured in air bubbles is most accurate
- The increase in CO₂ lags Antarctic warming by 800 ± 200 years
- CO₂ is not the forcing that initially drives increased temperature
- “This sequence of events is still in full agreement with the idea that CO₂ plays, through its greenhouse effect, a key role on amplifying the initial orbital forcing”

If CO₂ drives temperature -



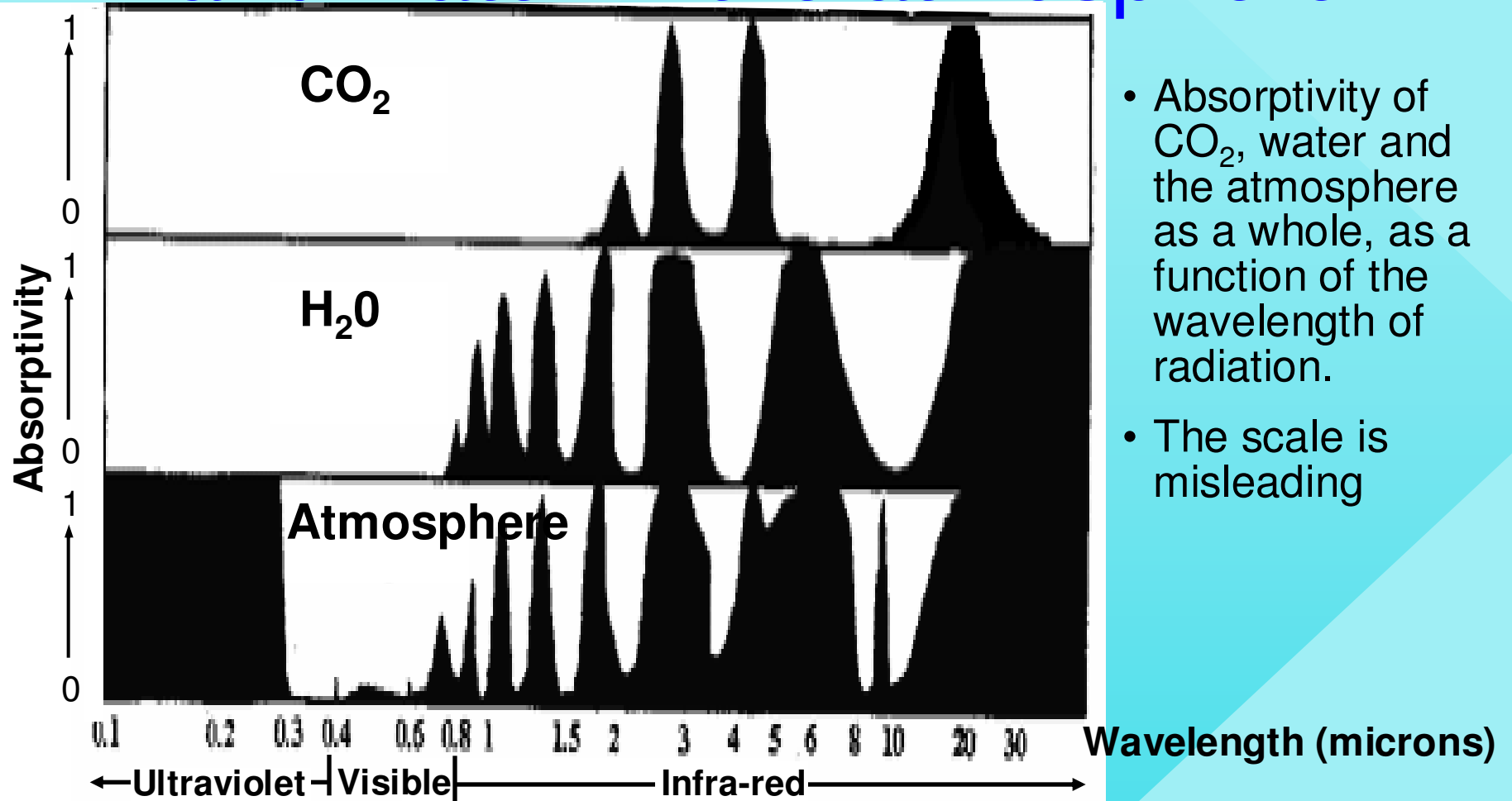
CO₂ has increased from 280ppm to 380ppm in the past century (100 ppm)

$$\frac{3.5}{26} = \frac{x}{100} \quad x = 13.5^{\circ}\text{C}$$

An 100 ppm CO₂ change should cause a temperature increase of 13.5°C

In reality the temperature increase has only been 0.6°C at a maximum

Emission and Absorption by CO₂ and water in the atmosphere

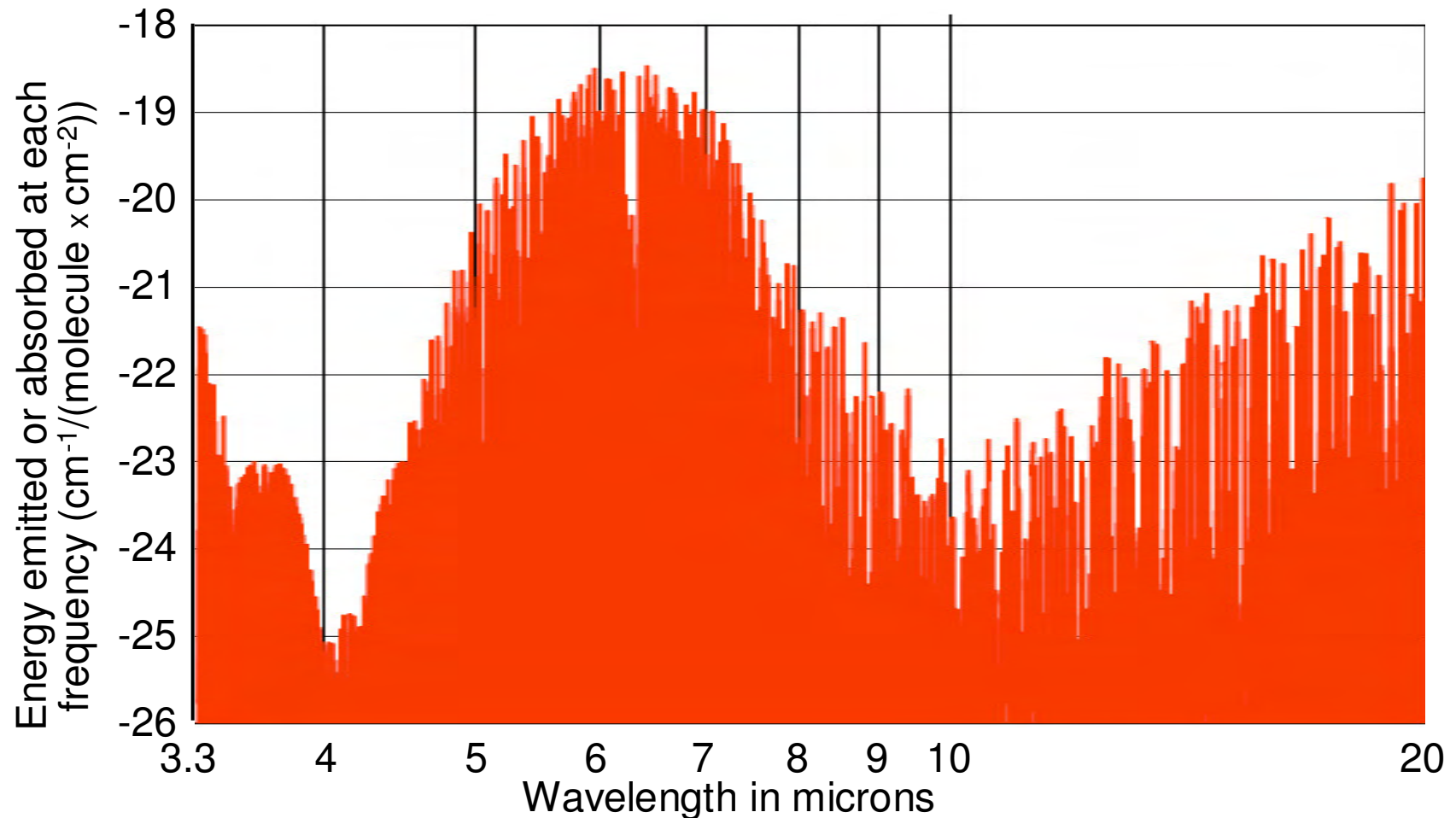


An absorptivity of zero means no absorption while a value of one means complete absorption. The dominant absorbers of infrared radiation are water vapor (H₂O) and carbon dioxide (CO₂).

Adapted from Howard, 1959, and Goody and Robinson, 1951.

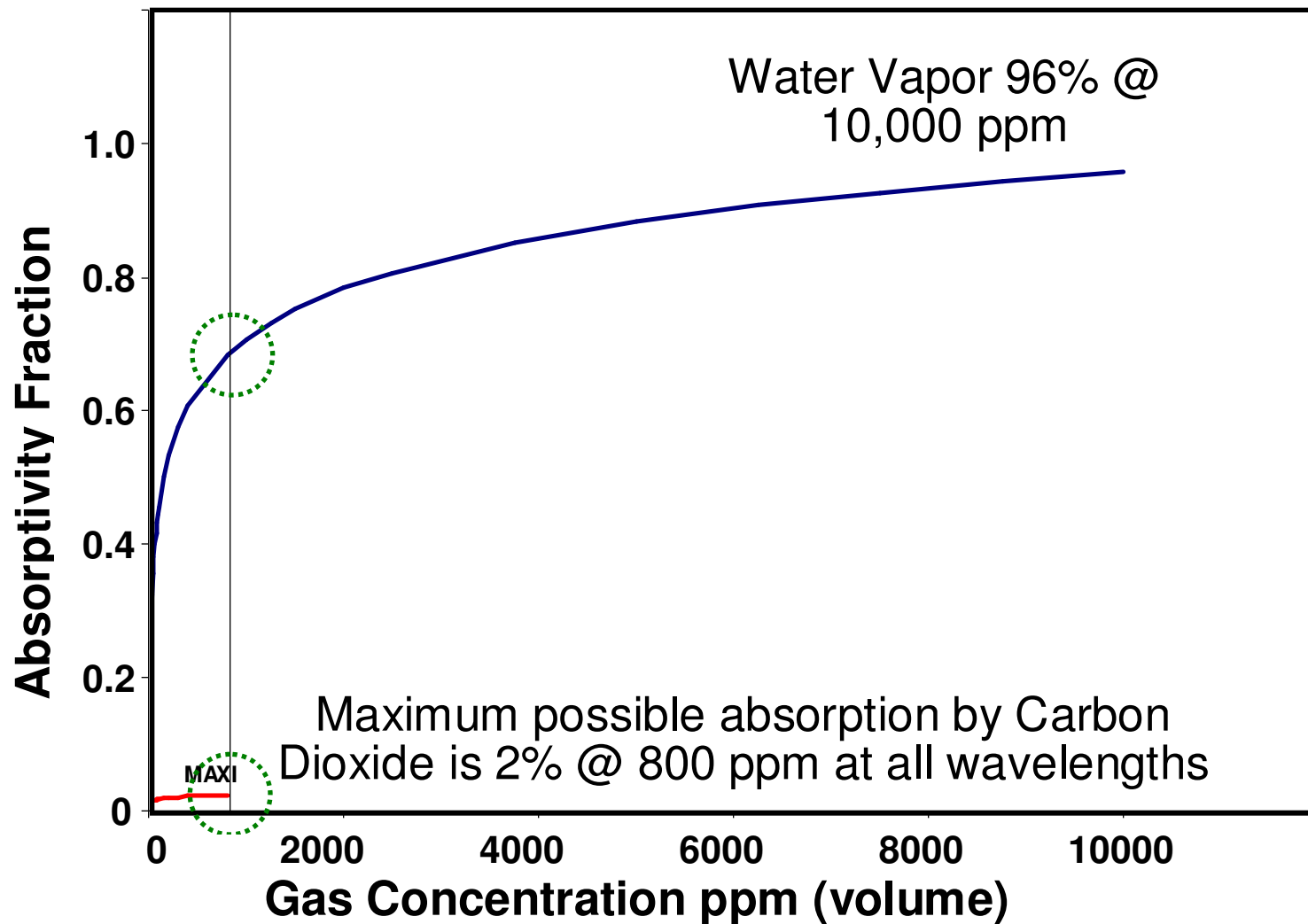
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Detailed (line by line) infrared absorption spectrum of water, ice and vapor

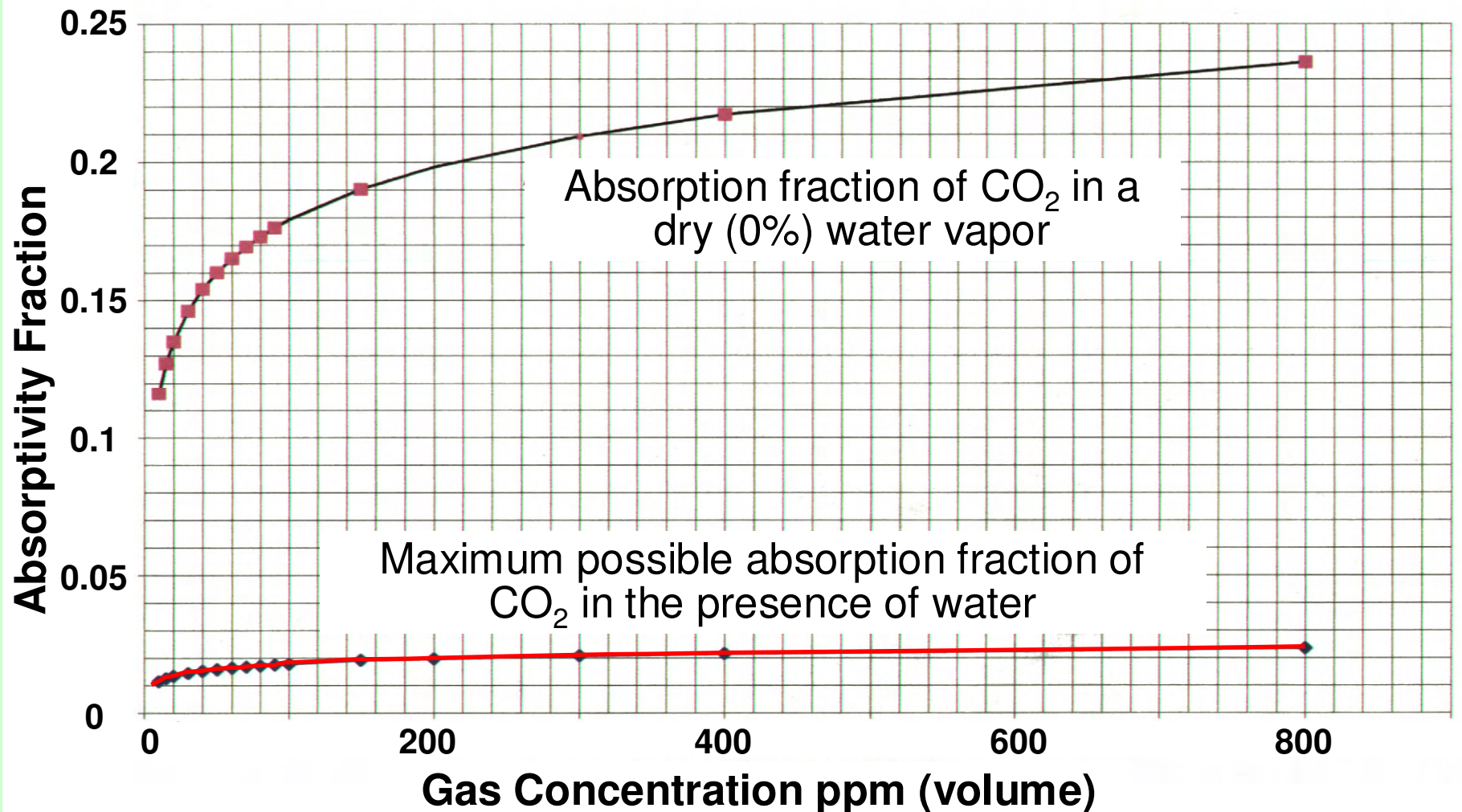


- There are no gaps in the water, ice and vapor spectrum

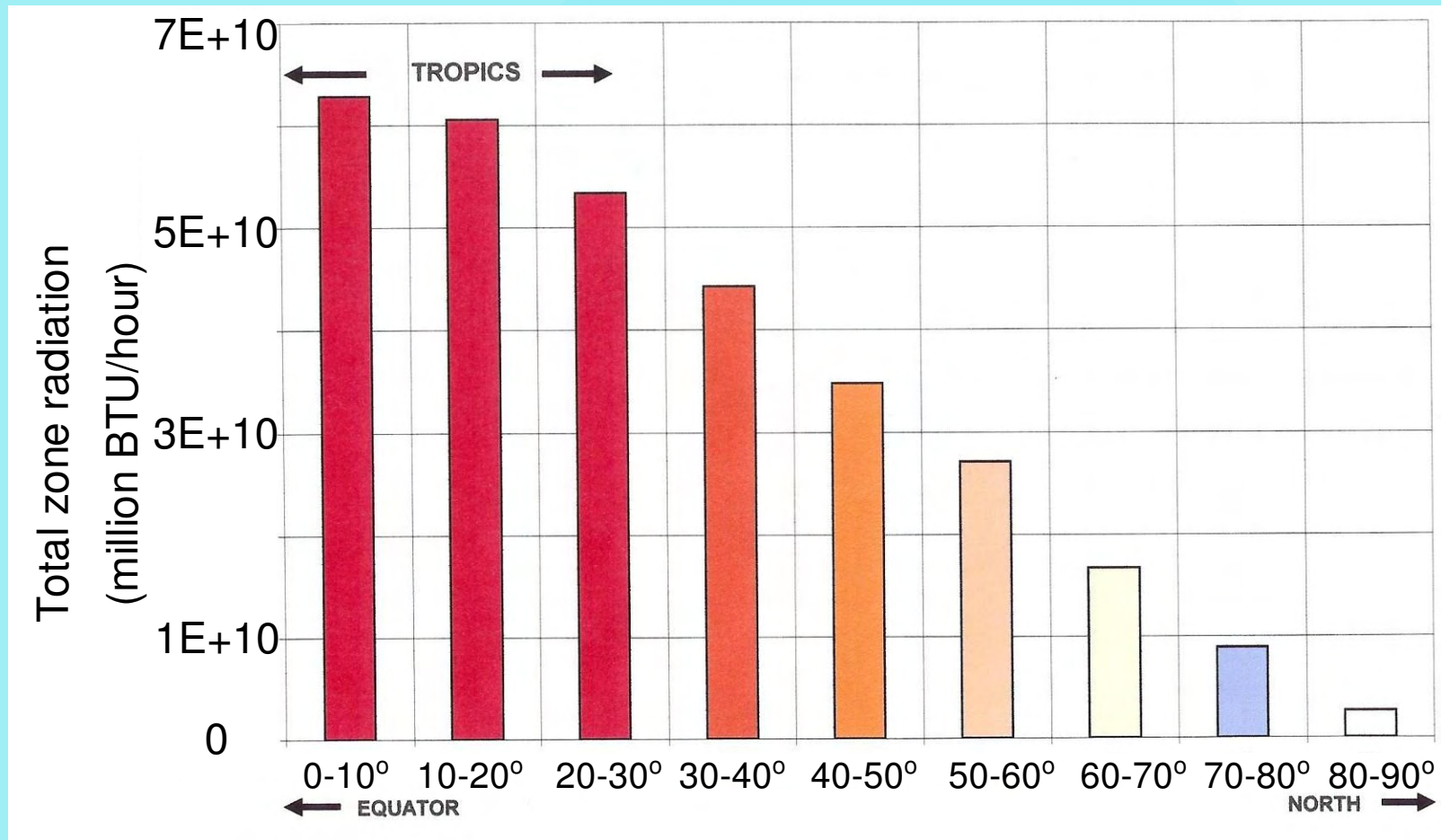
Infrared Absorption Strengths of Water Vapor and Carbon Dioxide



Absorptivity of CO₂ in the atmosphere

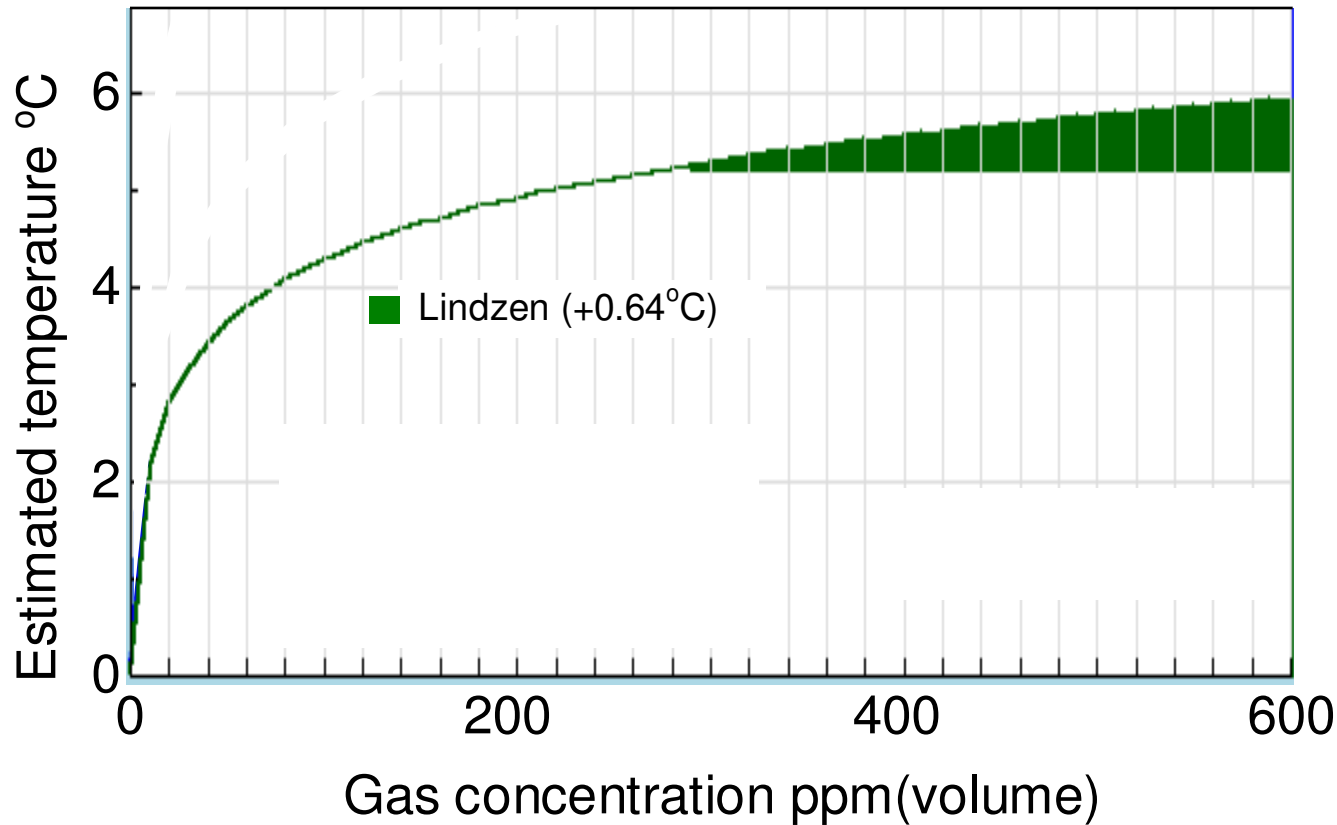


Surface emitted thermal radiation from each 10° latitude zone



- About 57% of the total northern hemisphere thermal radiation occurs at the tropics
- Only 9% is radiated above 60° North

Estimated Clear Sky Greenhouse Effect from Doubling CO₂



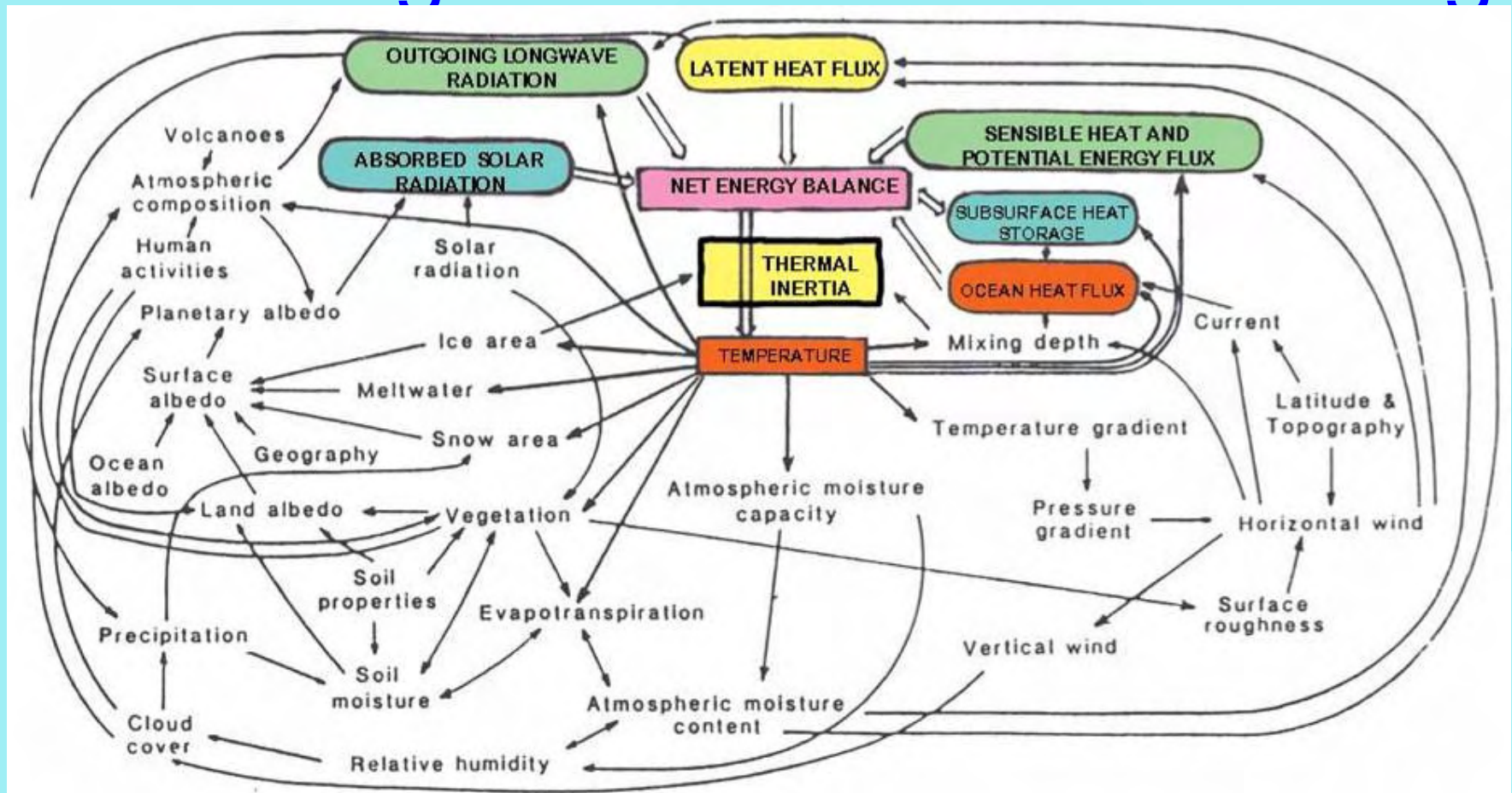
- With 0% cloud cover Lindzen calculates a +0.64°C increase
- With 40% cloud cover Lindzen calculates a +0.22°C increase
- Lindzen – MIT meteorologist – Past President National Academy of Science

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Models

- Approximately 30 currently recognized models for global climate change
- There are 12 that have come close to simulating the last century
- All 12 give different results for the next 100 years
- The three best models in the U.S. are
 - NASA
 - NOAA
 - NCAR

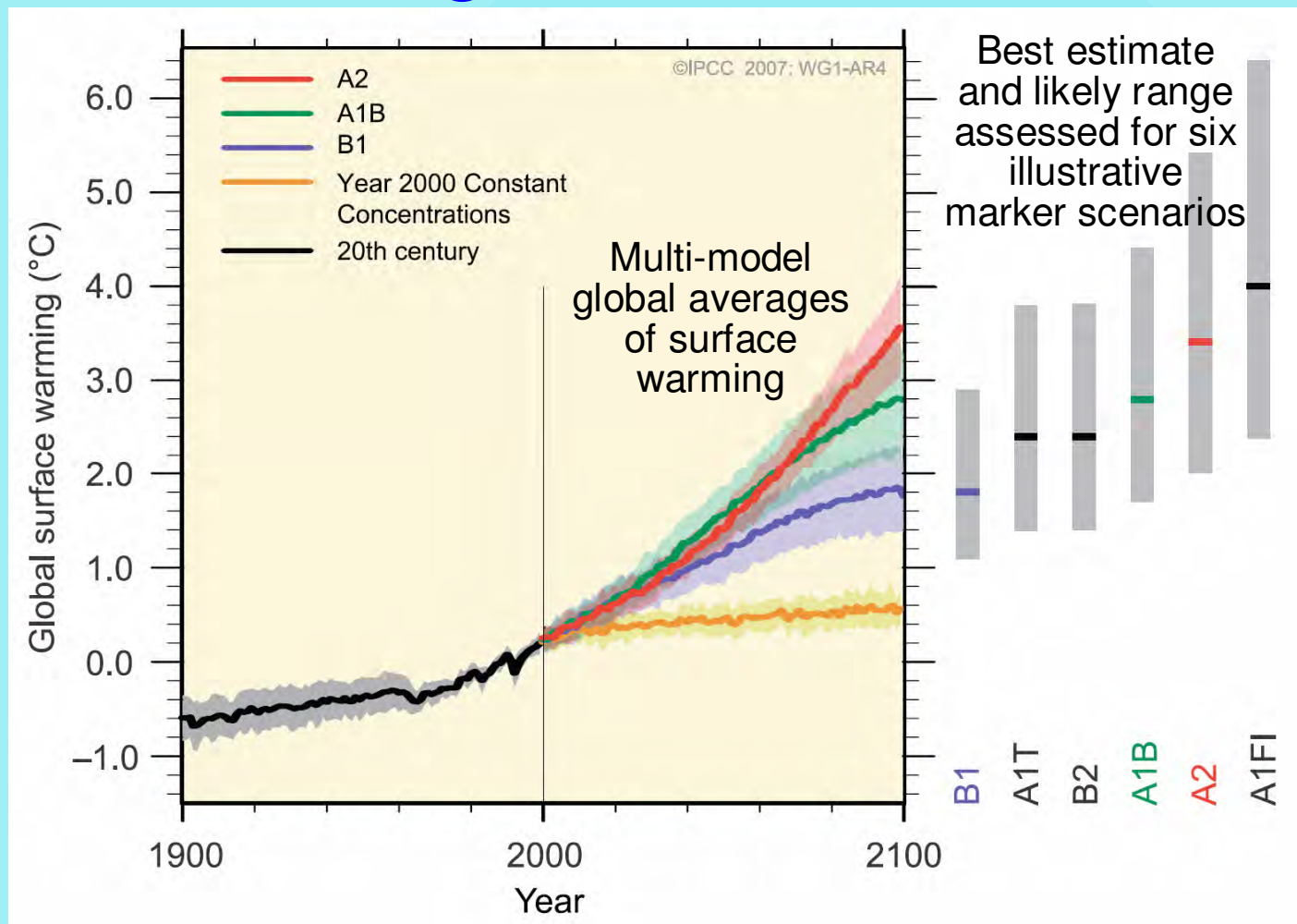
Flow diagram for climate modeling



Massive, complicated physical processes and multiple non-linear feedback loops

An impossible task to accurately model climate forecasts

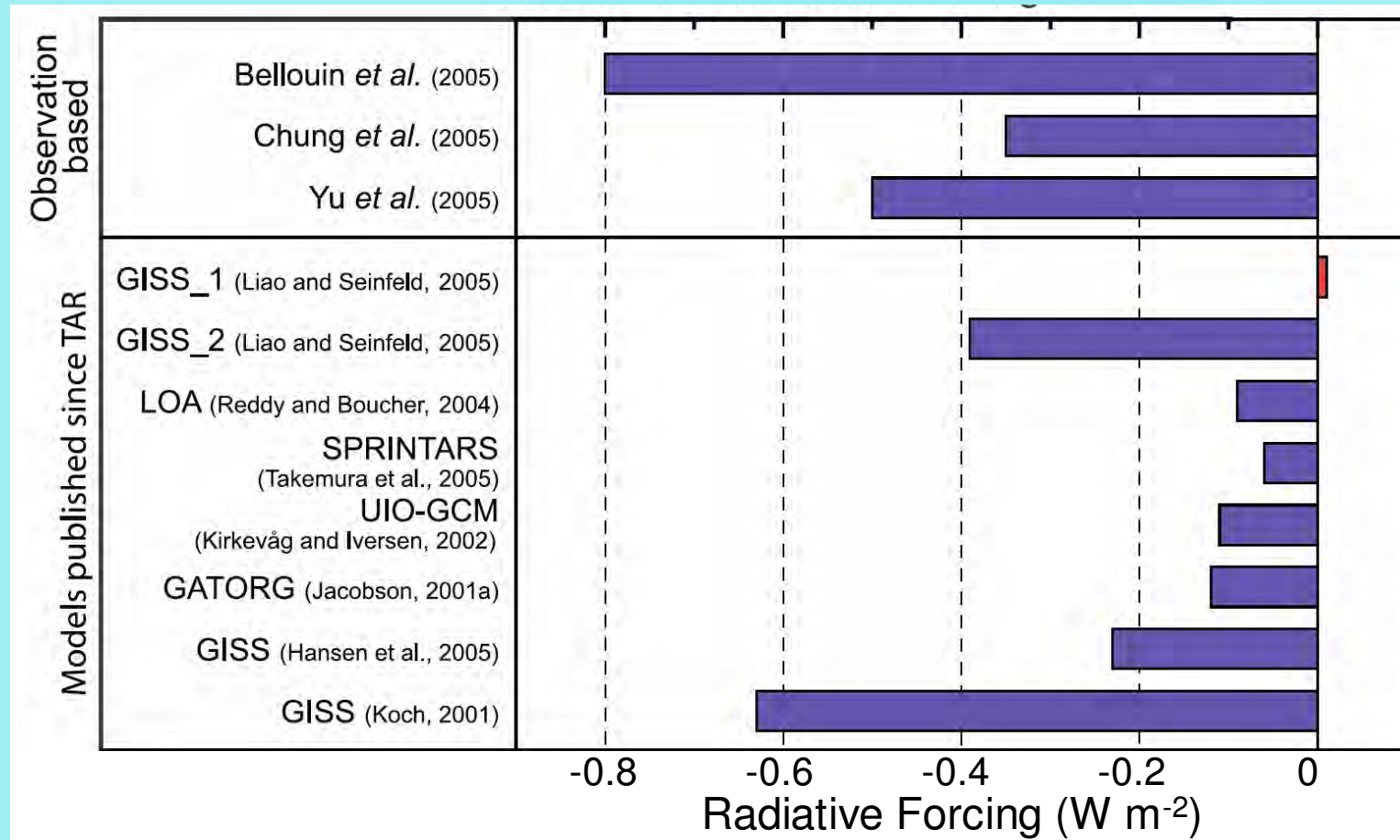
IPCC – 2007: Multi-model averages and assessed ranges for surface warming



- Year end 2100 surface warming estimates used in models range from 1.1°C to 6.4°C

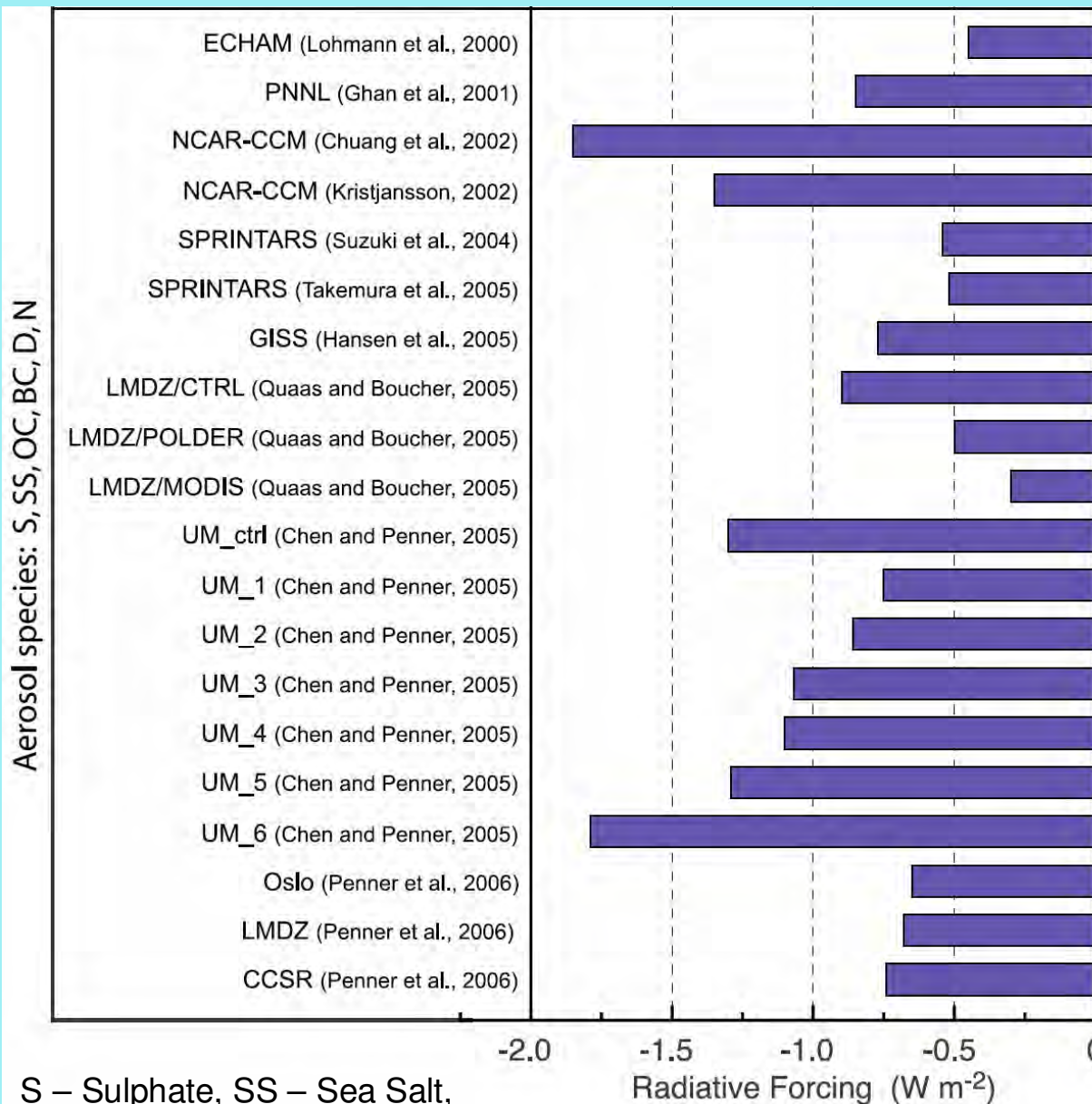
IPCC – 2007

Aerosol Direct Radiative Forcing



- Estimates of the direct aerosol RF from observationally based studies and independent modeling studies.
- Model range is from approx. +0.01 to -0.63 W m (64:1)

IPCC – 2007 Radiative forcing from Cloud Albedo Effect



S – Sulphate, SS – Sea Salt,
OC – Organic Carbon, BC – Black
Carbon, D – mineral dust, N - Nitrate

Range from
–0.3 to –1.75 W m⁻²
(greater than 5 :1)

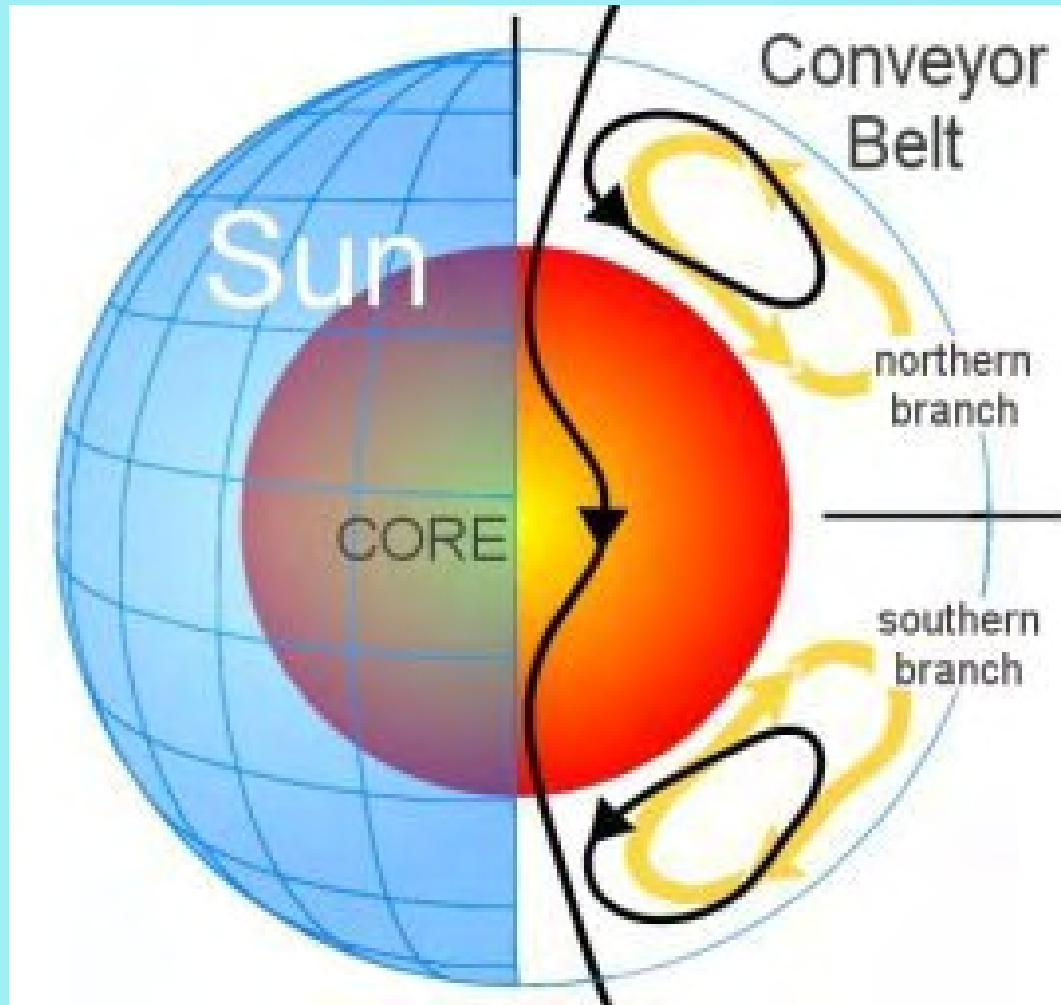
Computer Model Limitations

- Models must reasonably back-model recorded climate history. No GCM so far has been able to replicate either the Medieval or Roman events.
- All models are based on multiple dependent and independent variables
- The reasons for their failure are:
 - The system is infinitely complex
 - Very poor level of understanding of the various elements of the complex system particularly clouds and their effect

What do we know about sunspots..?

- Sunspots can be 700 times larger than the surface of the earth
- Fusion of four hydrogen nuclei into one helium nucleus releases enormous energy by the equation $E = mc^2$
- The sun is hot – 15,000,000 °C at the center and 5780 °C at the surface
- Intensity of sun spots seems to correlate with temperature.
- During the “Little Ice Age” in the mid to late 1600’s there were very few sun spots

The Sun's Great Conveyor Belt

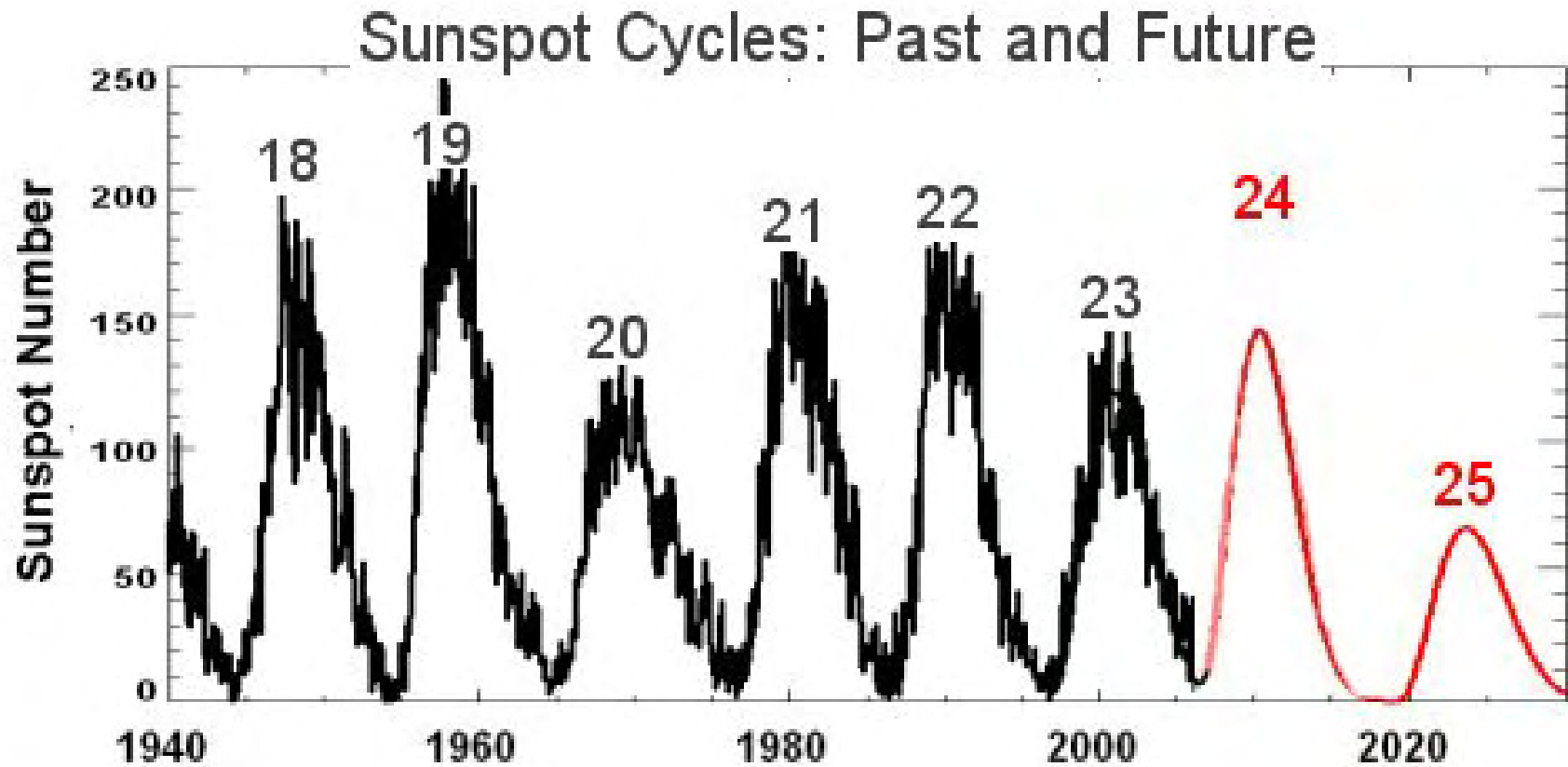


A massive circulating current of fire (hot plasma) within the sun

North and south branches take ~40 years to complete a circuit

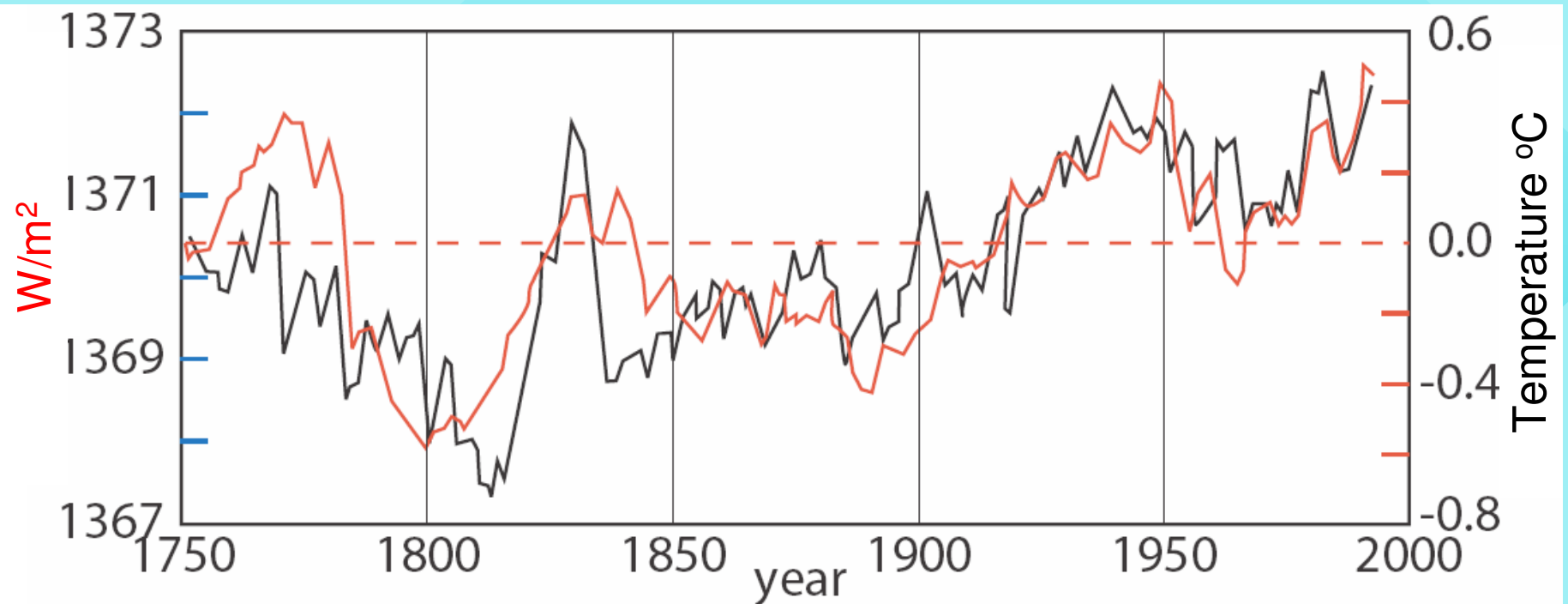
Average speed in 20th century has been 1m/s, but in recent years has decelerated to 0.75 - 0.35 m/s

The slower belt foretells lower solar activity



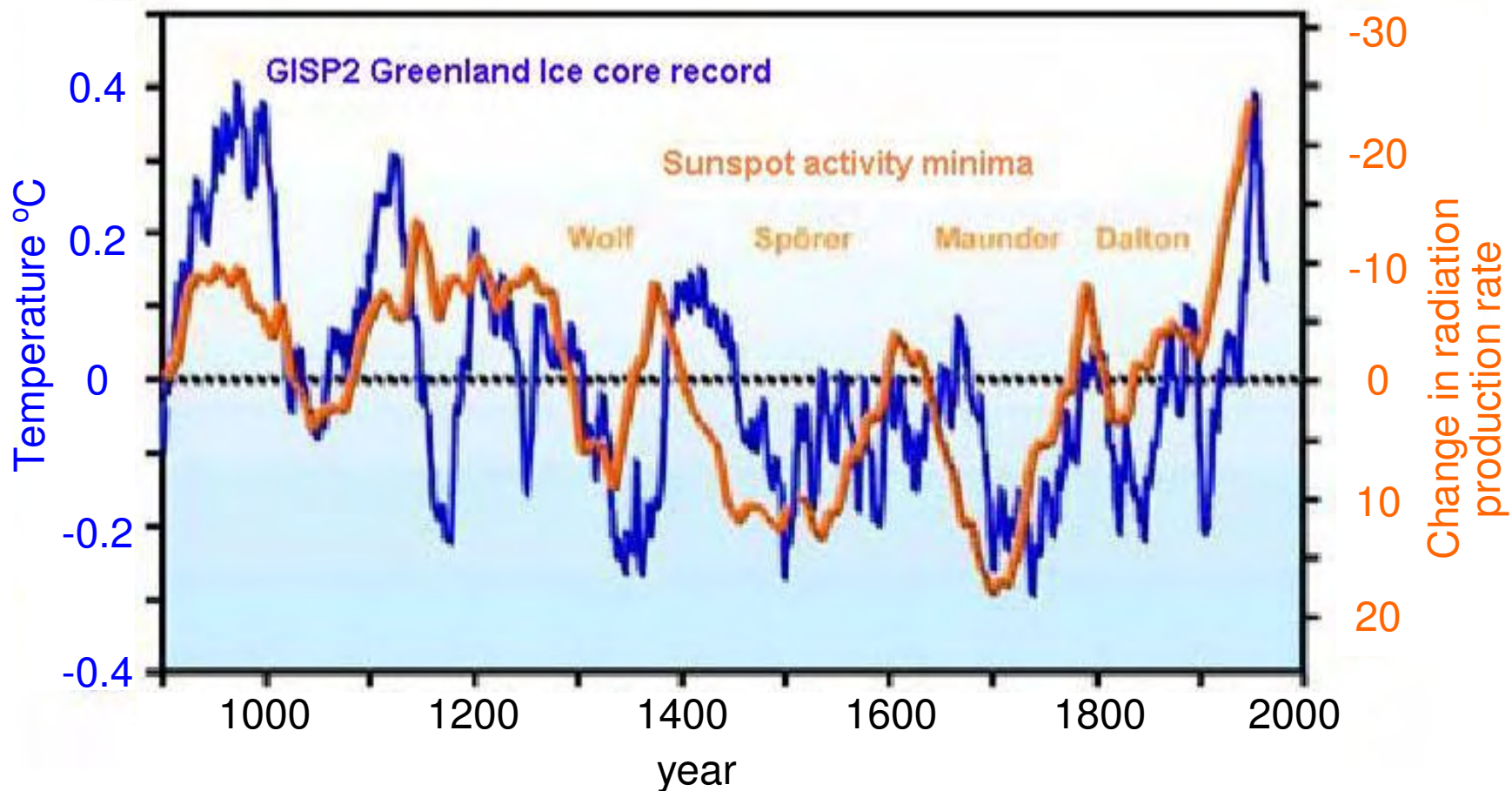
- Prediction of solar cycle intensity, suggesting that 2020 will see measurable solar cooling. David Hathaway's prediction for cycles 24 and 25.
- Solar conveyor belt slowdown indicates that the Solar Cycle 25 could be one of the weakest in centuries

Northern hemisphere average Terrestrial Temperature and Solar Irradiance



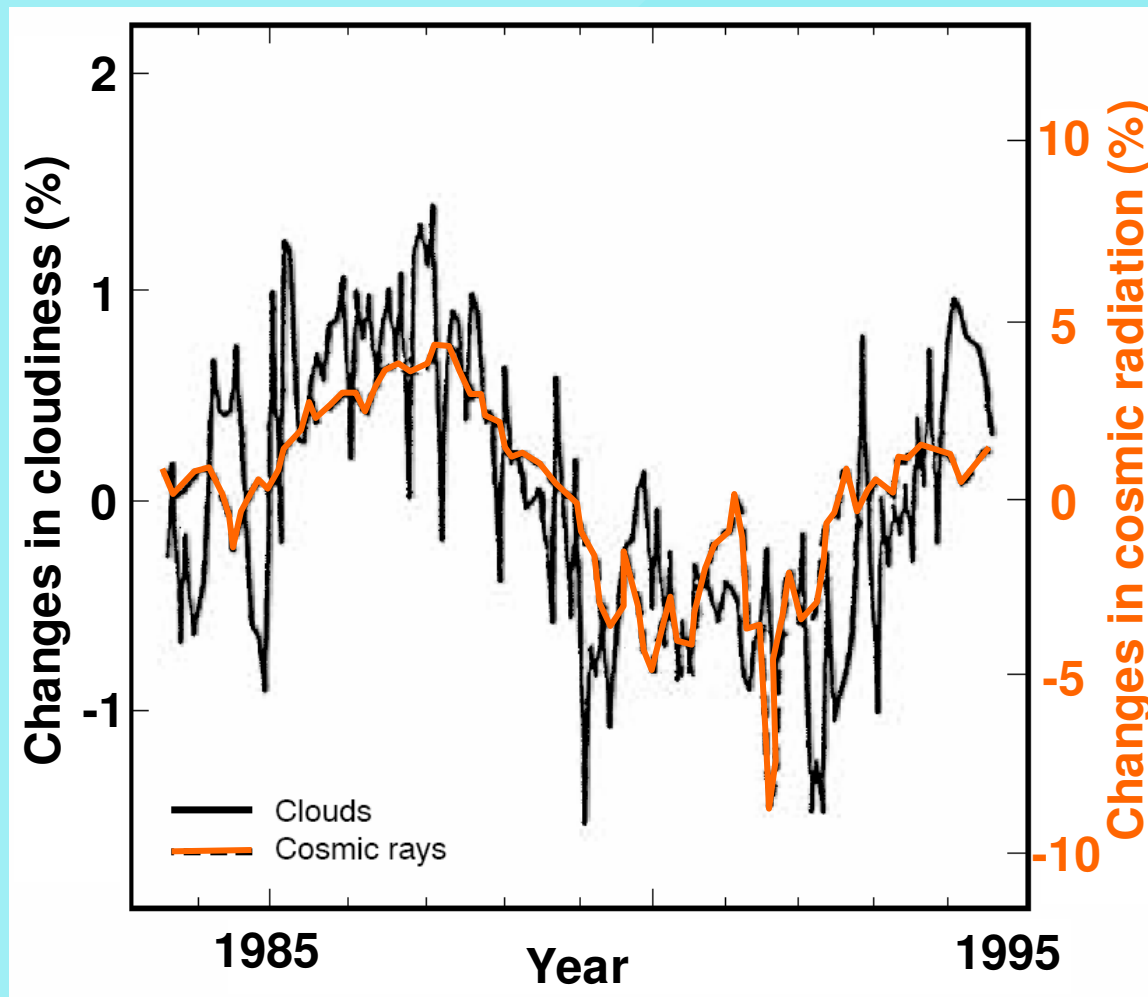
Surface temperature can be correlated to solar irradiance.

Temperature and Solar Activity



Surface temperature can be correlated to solar activity

Variation in Cosmic Ray Intensity and Cloud Cover



- Cosmic radiation enables cloud formation
- During increased sun activity, solar magnetic fields drive part of the cosmic radiation away from the earth – fewer clouds are formed in the troposphere and the earth becomes warmer

Solar Activity and Climate Change

- Solar activity including sunspots and solar eruptions cause :
 - Enhanced thermal energy flux
 - More intense solar wind
- Solar wind attenuates the Cosmic Ray Flux (CRF)
- Cosmic Ray Flux correlates convincingly with low altitude cloud cover

THUS

Brighter sun

enhanced thermal flux
plus solar wind

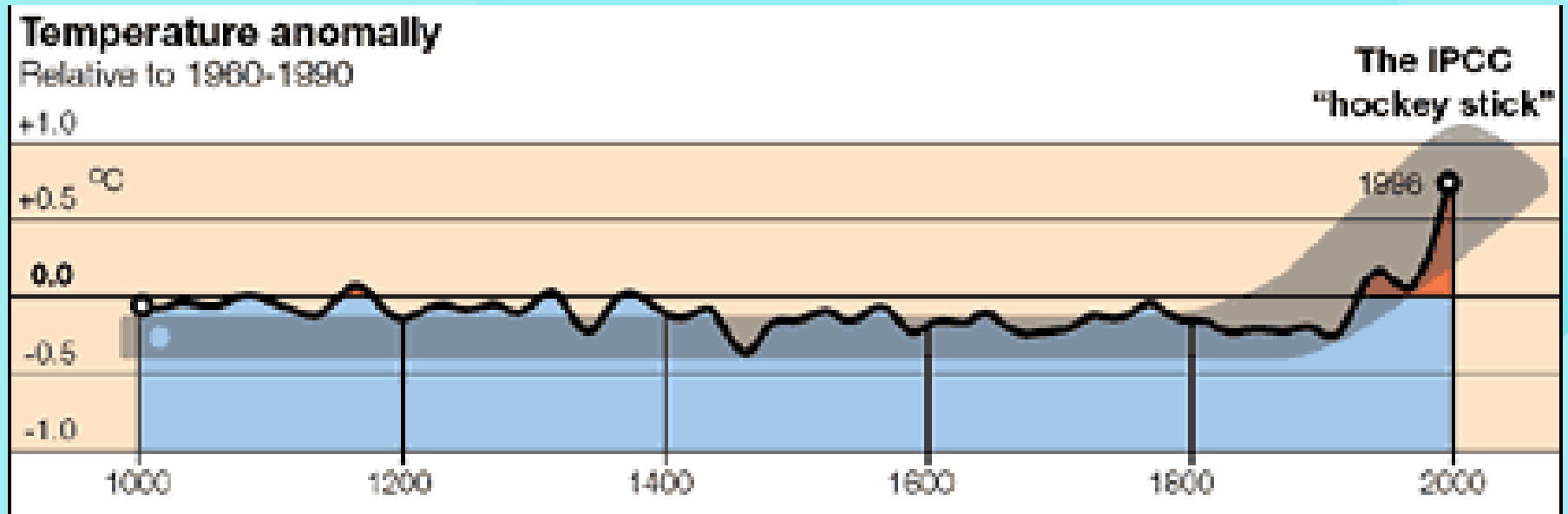
muted CRF

less low
level cloud

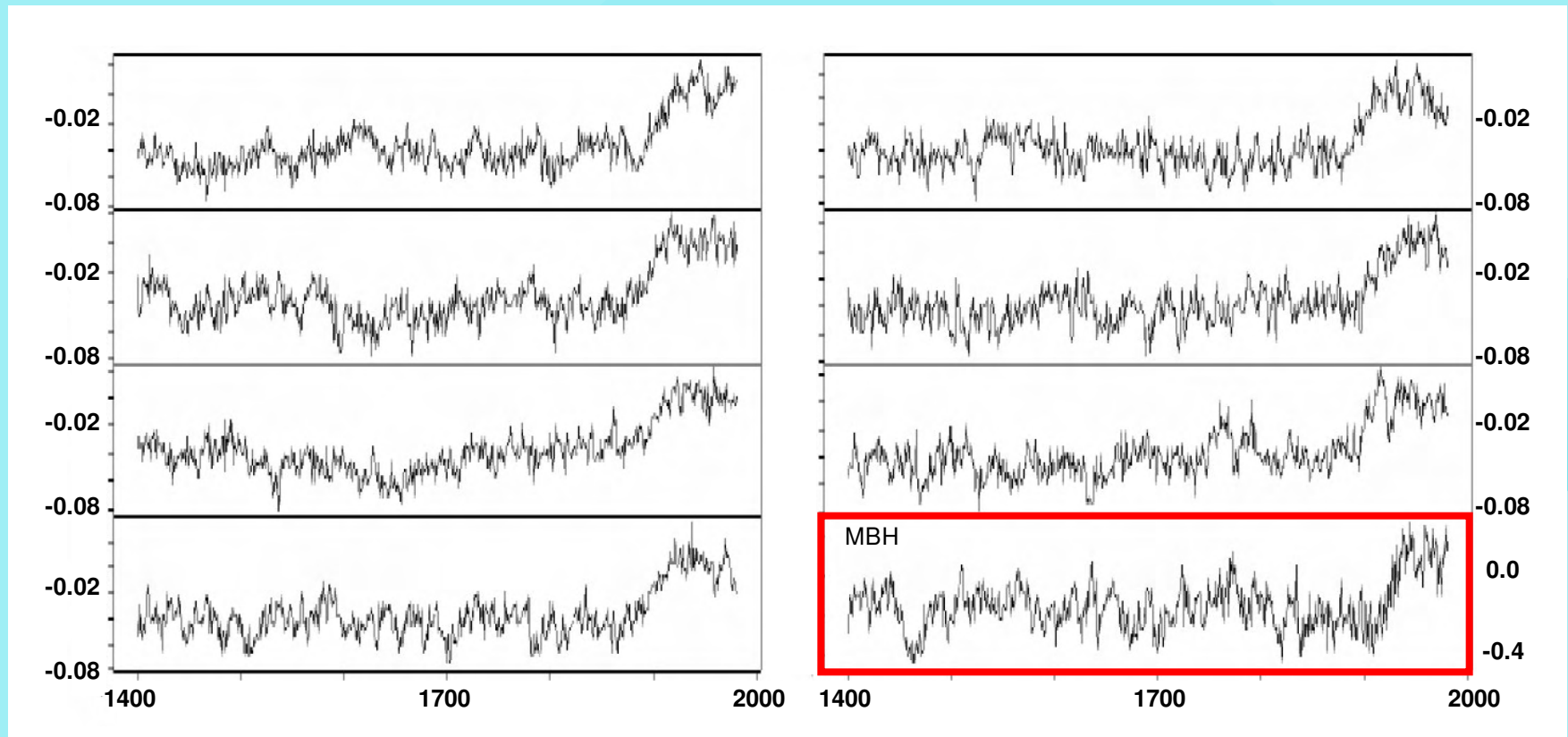
less Albedo

warmer climate

The Hockey Stick



Testing the Mann et al. algorithm



Graphs using Mann et al. algorithm on 7 sets of random “red” noise and the Mann data set

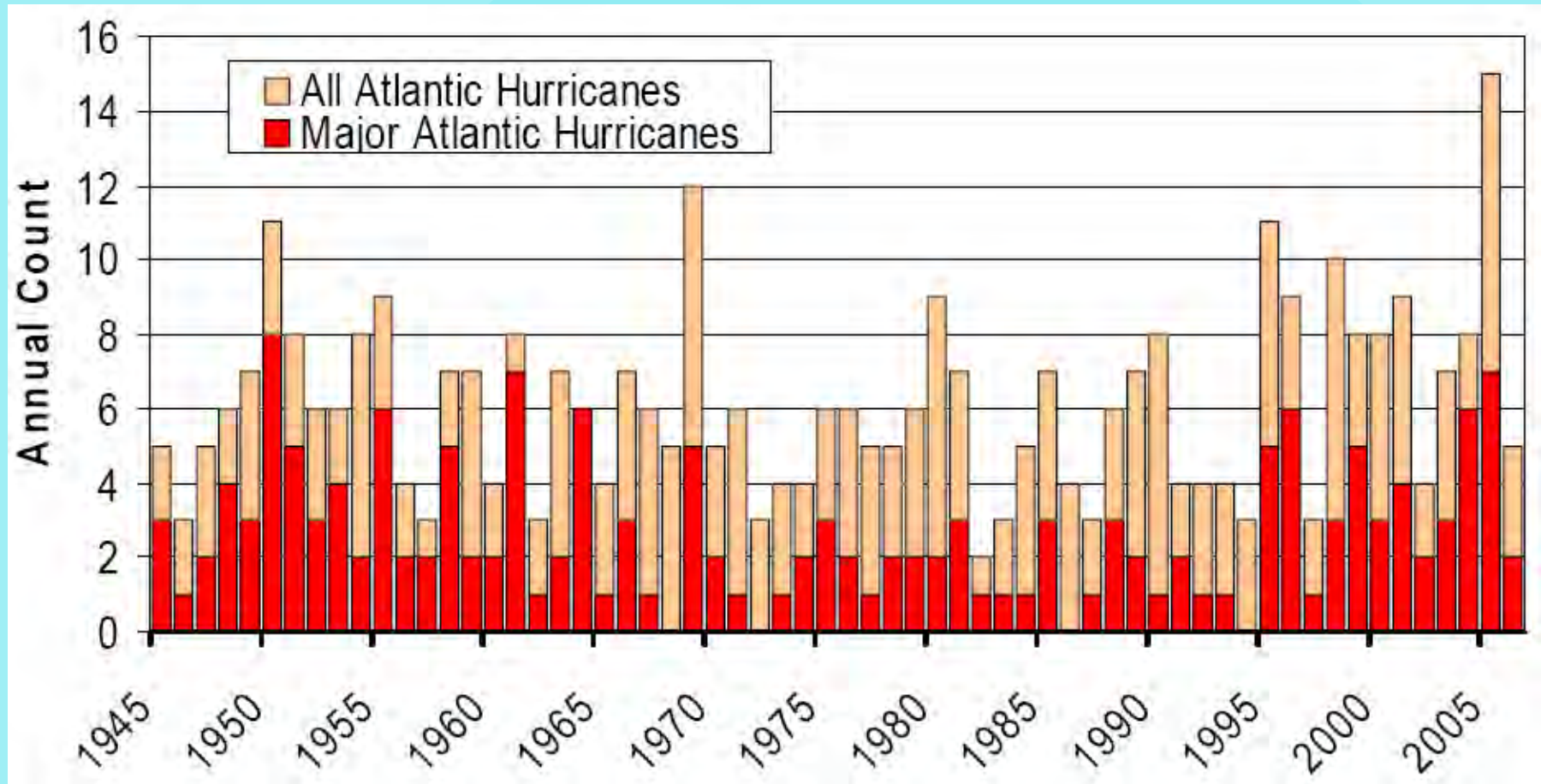
The Hockey Stick

A review by a National Academy of Science
12 person panel

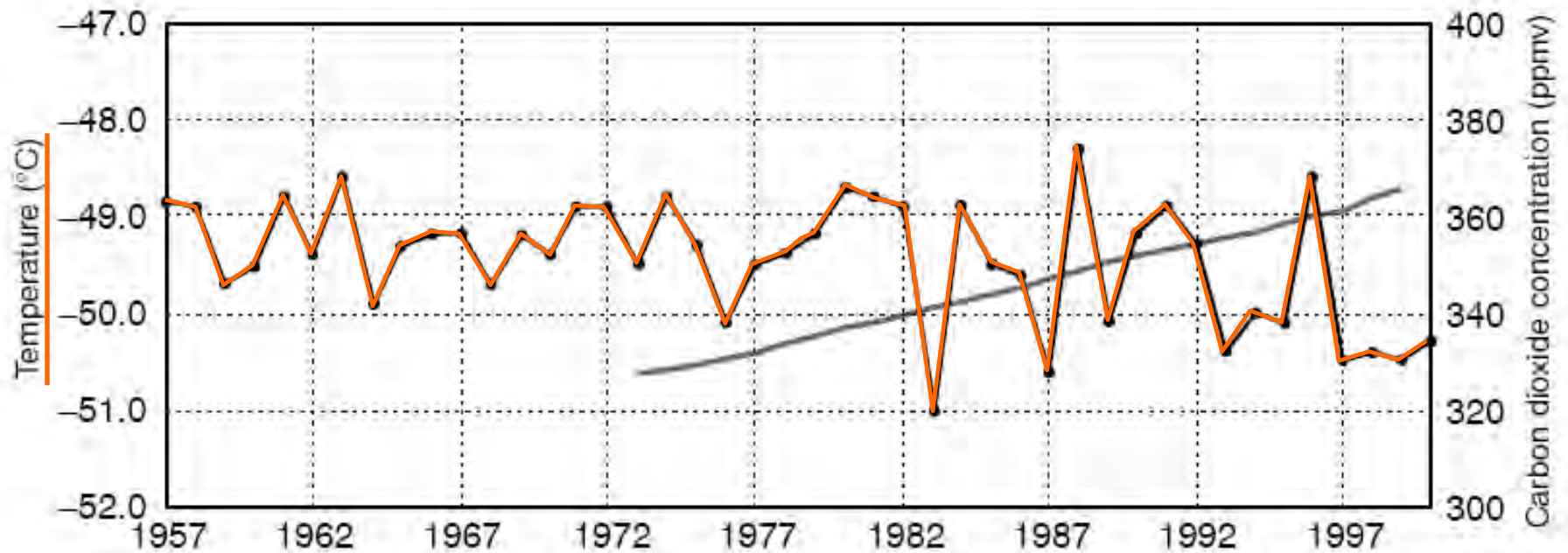
The NAS has agreed that:

- Mann's principal components were biased toward producing hockey stick-shaped series
- Bristlecones are not a reliable temperature proxy
- Mann's reconstruction failed important verification tests
- Mann's data and methodology did not permit him to claim that 1998 was the warmest year of the millennium or that the 1990's were the warmest decade

Annual number of hurricanes in the Atlantic basin 1945 - 2006



Surface Temperature and Carbon Dioxide at the South Pole



What is the connection between CO₂ and temperature at the South Pole?

– Either cooling or no correlation

Polar Bears Extinction

- Myth
 - Arctic ice has shrunk, polar bears are swimming long distances to find food and drowning, leading to their extinction
 - Scientists predict polar bears could be extinct within the next century
 - Environmentalist sued to place the polar bear on the endangered list
 - The Wall Street Journal, 2005
- Fact
 - The world's population of polar bears is approx. 22,000
 - Regions with the greatest temperature increase have rising bear populations
 - Remaining areas, both temperature and bear populations have been relatively stable
 - Dr Patrick Michaels, 2004

Conclusions

- Climate is constantly changing. It has been warming for the last 300 years and certainly the last 25 years.
- Geologic historical changes have been dominated by natural processes.
- Ocean currents dictated by plate movements have been very important.
- CO₂ is a second order greenhouse gas after water vapor.
- Man has introduced a lot of CO₂ into the atmosphere.
- Up to a concentration of about 150 ppm CO₂ can play a very important role in global warming. Beyond 150 ppm its role diminishes.
- The history of CO₂ may be much more complicated than previously thought.
- Ice core data from the Pleistocene and more recent data indicate temperature drives CO₂.

Conclusions

- The earth's climate is a dynamic, nonlinear inter-dependent complex system and may be impossible to model effectively.
- Varying degrees of solar activity seem to correlate well with temperature, however there is a divergence in the data for the last 10 years.
- Cosmic rays may play a significant role in temperature patterns.
- At this time there is no rock hard evidence that the sun or that CO₂ are necessarily controlling temperature.
- Clouds – their increases and decreases are critical to temperature changes, are very poorly understood and may be the missing link in the equation.
- More research needs to be focused on the causes (such as clouds) rather than the effects of climate change.