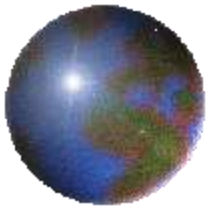
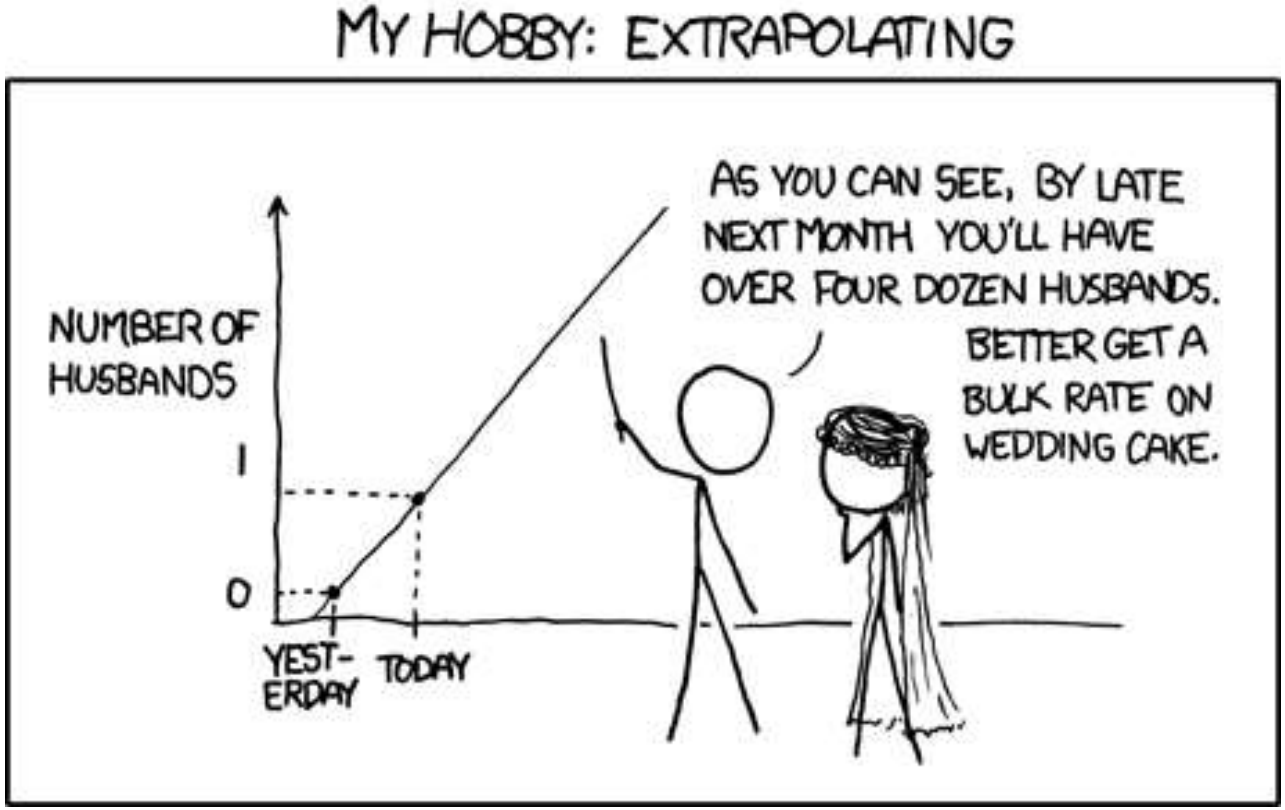


Paleoclimatology

Anna Klene

Department of Geography
University of Montana

How do we know climate has changed over long periods of time?

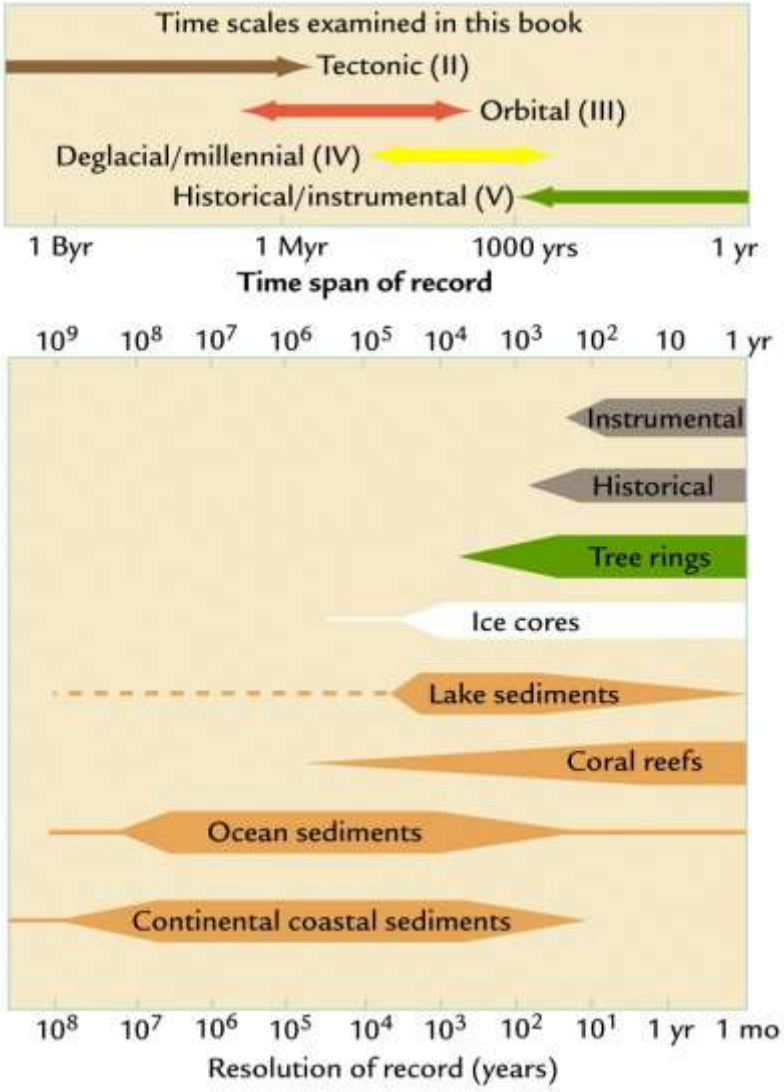


- **http://www.xkcd.com/605/**

3 Objectives

- Discuss climate archives
  - Piecing the puzzle together
- Discuss key climate events using these different archives
  - Current understanding of atm evolution
- Review key time periods of interest to current warming

Time scales for Proxy Data



Ruddiman, 2008

Archives of Climate Change:

Geological

Biological: Fossils & Pollen

Cryological: Ice Cores

Historical

Biological: Tree-Rings

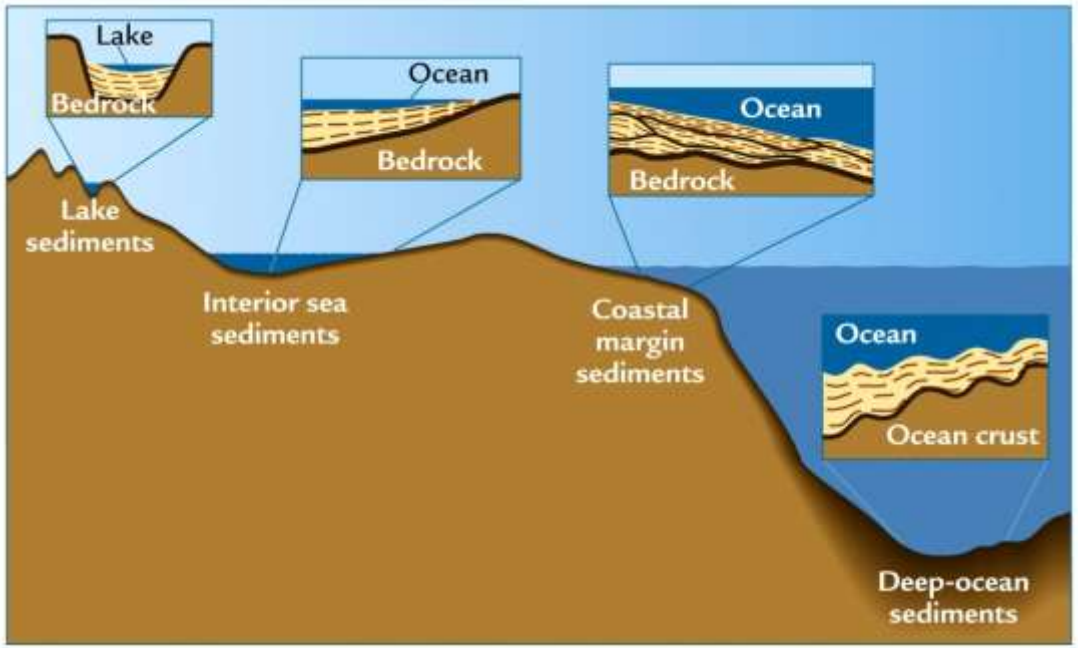
Instrumental Records

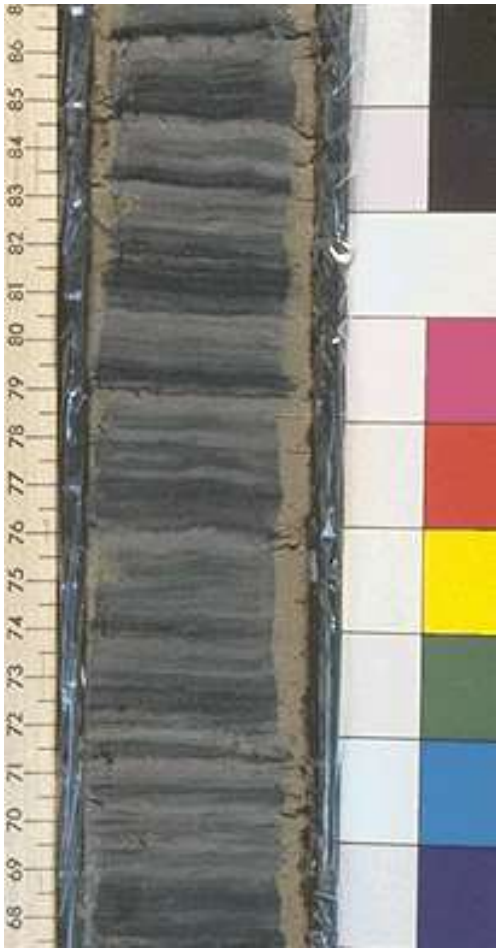
- Proxy: Using one thing in place of another...
- Always better if 2 different, independent proxies agree ☺

Archives of Climate Change:

Geological

Sediment structures & material (loess)
Glacial moraines
Lake sediments
Coastal & Deep Ocean sediments

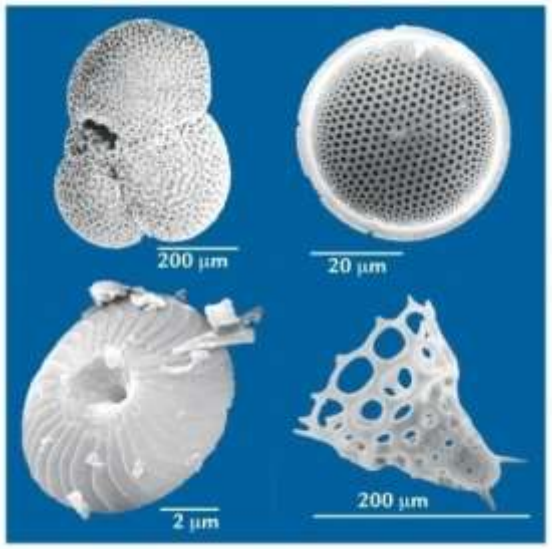




Archives:

Biological

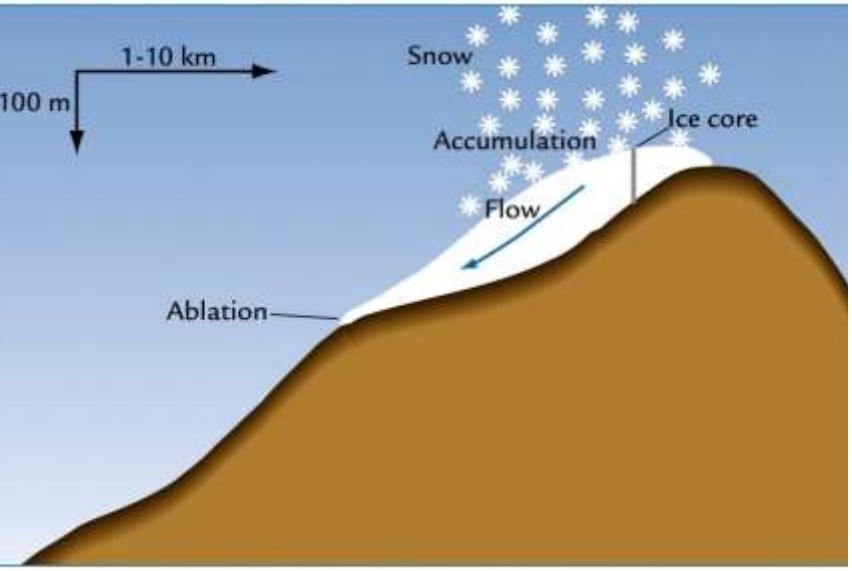
Fossils or dead material
Trees
Critters (macro: mammals, beetles, etc.
& micro: corals, plankton, forminifera, etc.)



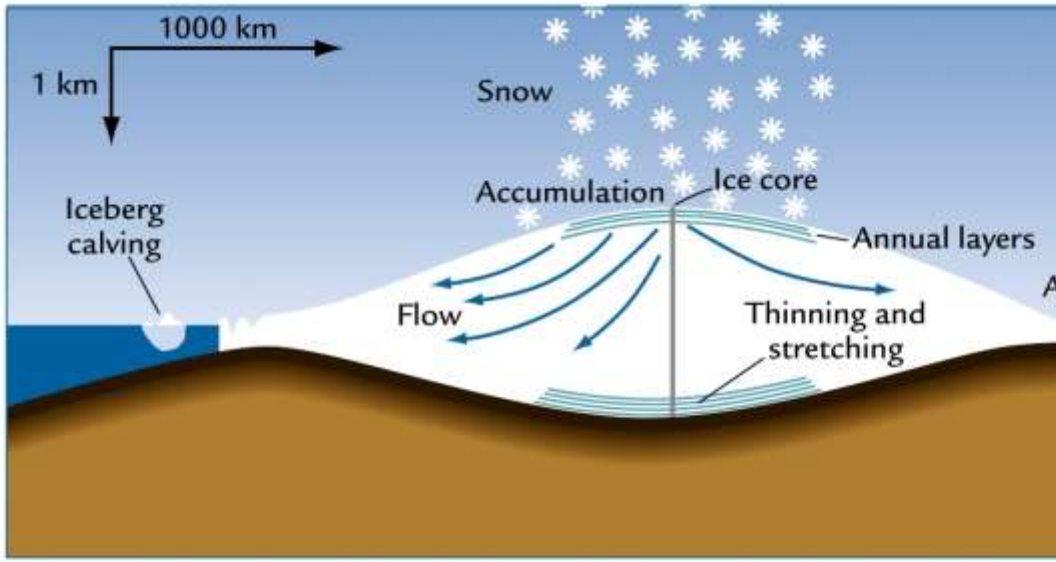
Archives of Climate Change:

Cryological

Glaciers & Ice Caps



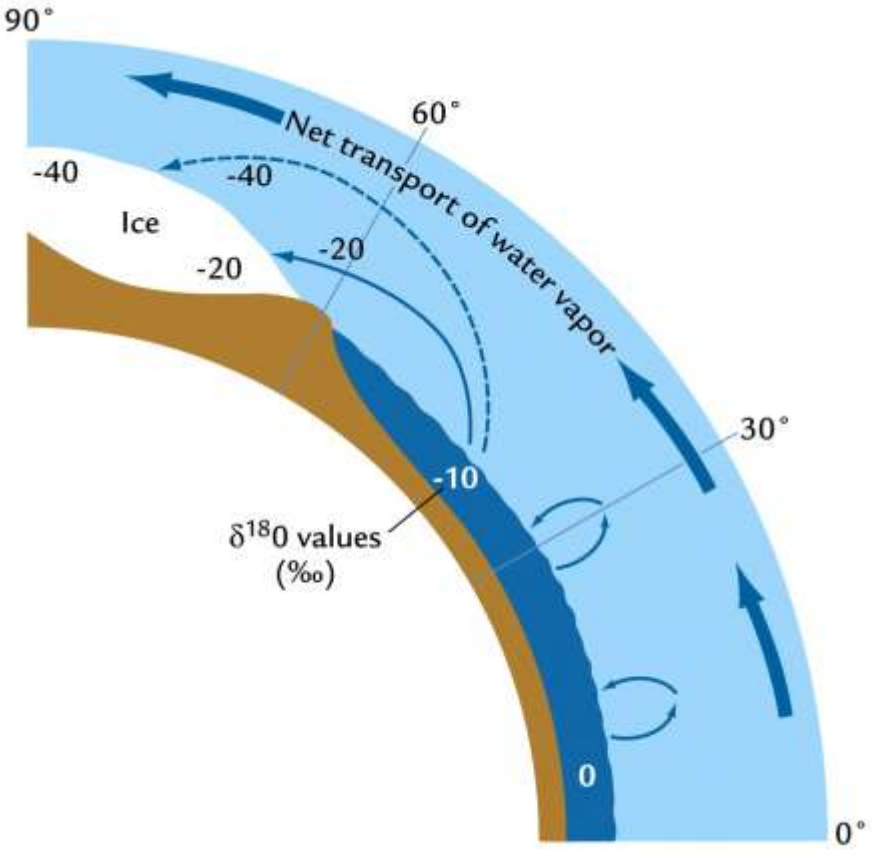
Mountain glaciers

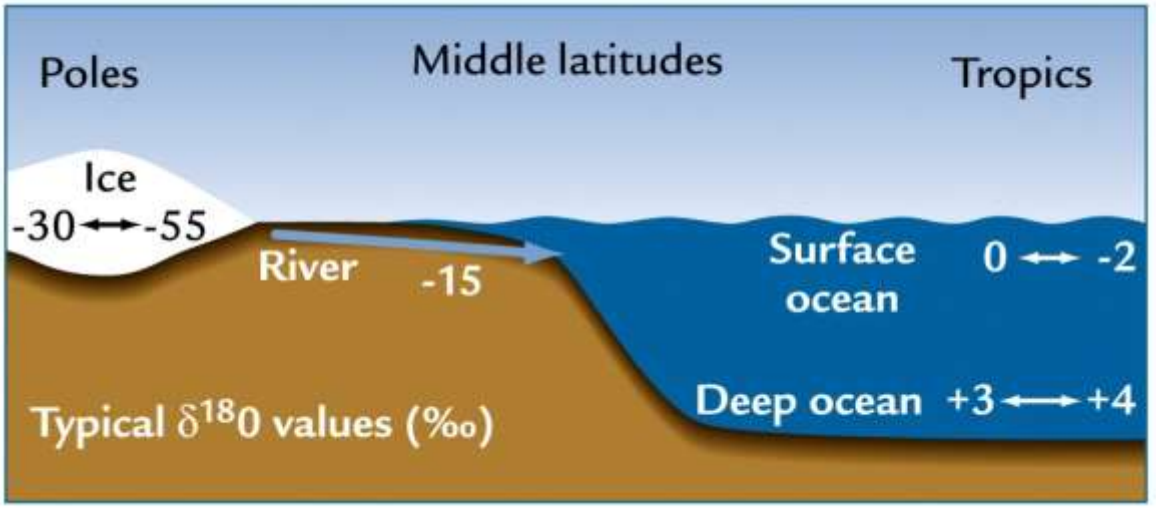


B Continental ice sheets

Ice & Sediment Cores

- Oxygen-isotope analysis:
  - **$\delta^{18}O$**
  - Measure ratio of ^{16}O to ^{18}O
  - Water from ocean enriched in 18 as 16 evaporates better…
  - When glaciers advance, more 16 frozen, so even more 18 in water…





Ice Cores & Sediment Cores

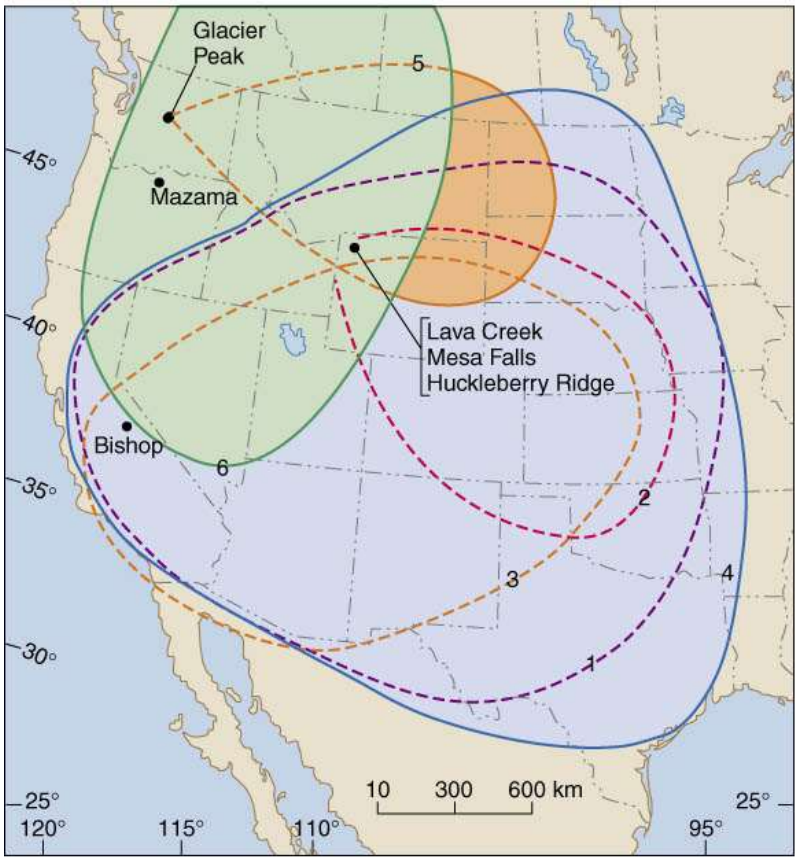
- deuterium/hydrogen ratio:
  - δD‰
  - Measure ratio of ^{2}H to ^{1}H…
  - Deuterium is heavier than normal Hydrogen, so it takes more energy to evaporate any water molecule made with “heavy hydrogen”.
  - The result is that the colder it gets, the less Deuterium ends up in precipitation.
  - The smaller the D/H ratio, the colder the climate.

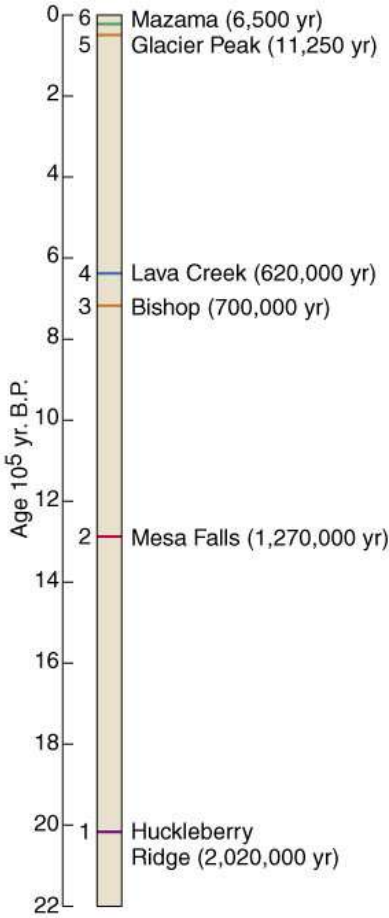
Ice Cores

- Ice cores:
  - volcanic ash
  - particulates (dust),
  - pollen,
  - chemical composition of the air trapped inside,
  - etc..

Archives

- Volcanic Ash
- Source by chemical signature
- Provides a calibration layer across variety of deposits

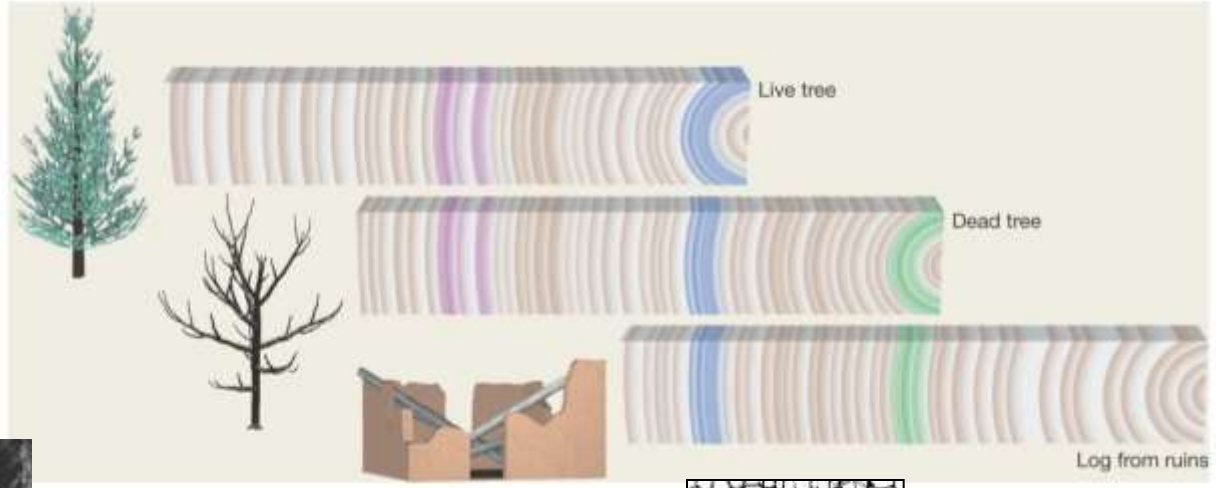


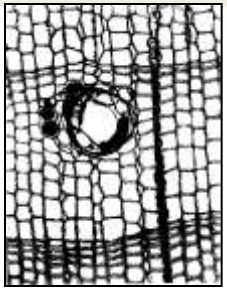


From Skinner

Tree-rings:

- Annual layers of growth
  - Depends on temp, precip, evapotrans.
  - Varies from species to species





http://web.utk.edu/~grissino/gallery.htm

Archives of Climate Change:

Historical Records

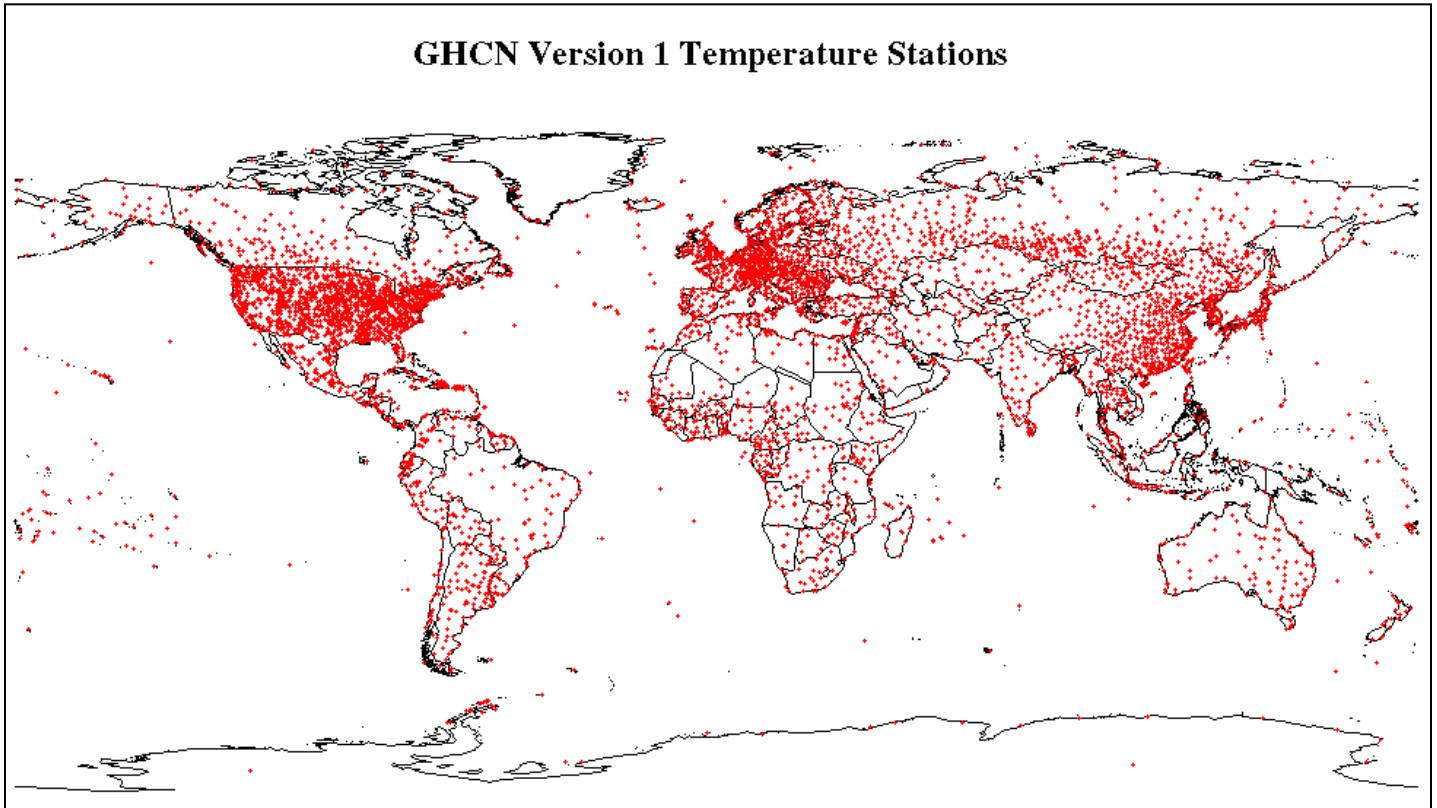
Letters, Diaries, Other Records

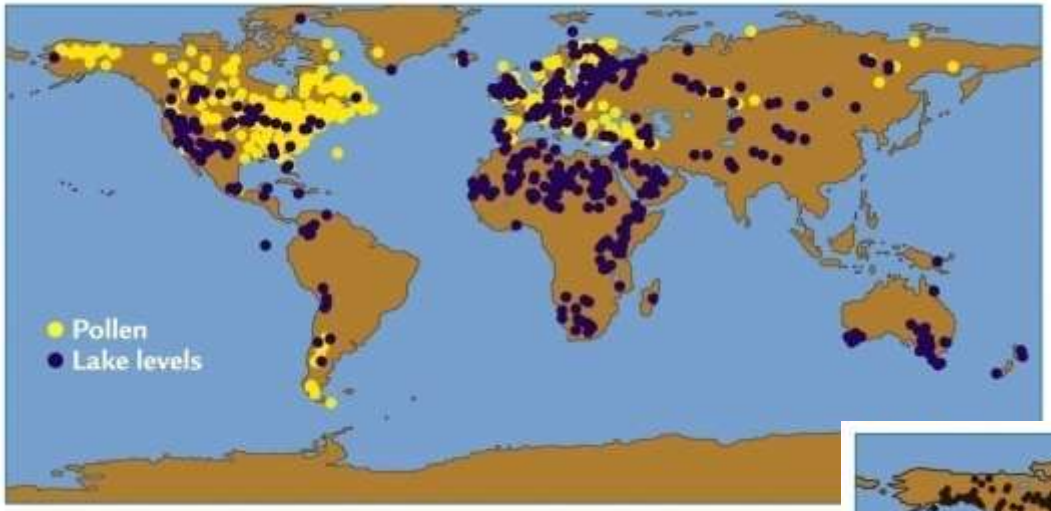
- ***Hunters in the Snow***, 1565
  Pieter Bruegel the Elder
  (Netherlandish, ca. 1525/30—1569)
  Oil on panel; 46 1/8 x 63 7/8 in. (117 x 162 cm)
  Image courtesy of the Kunsthistoriches Museum, Vienna

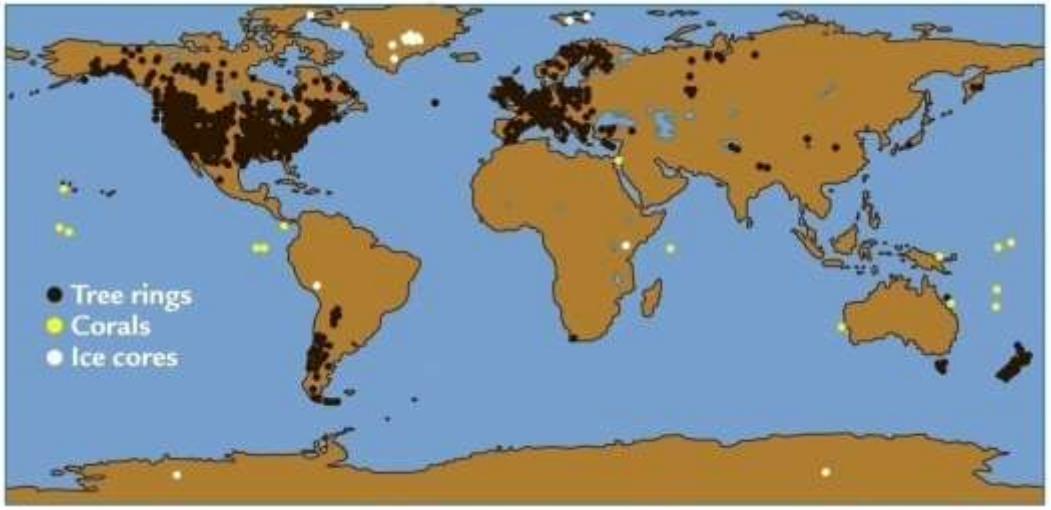
Archives of Climate Change:

Instrumental Records

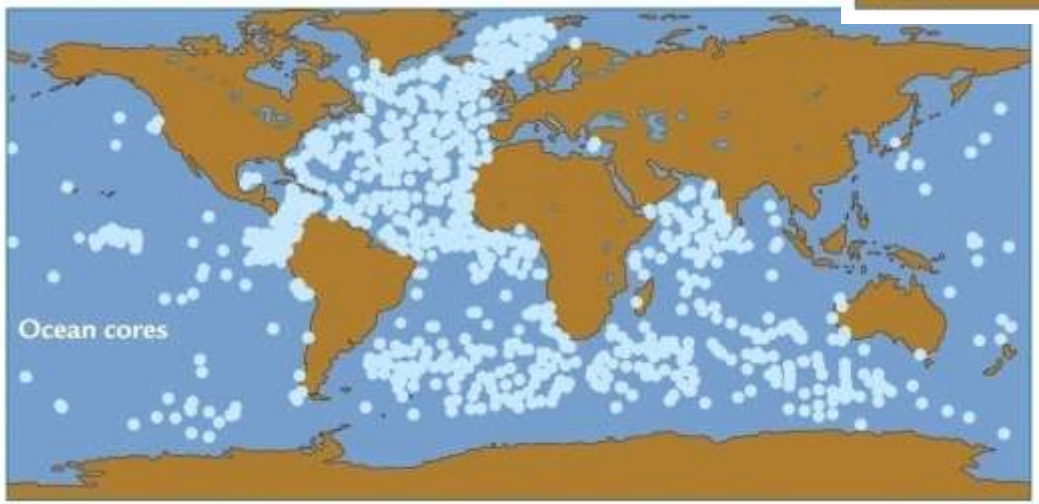
Only within last ~200 years







- Location, location, location!



Earth's Evolution

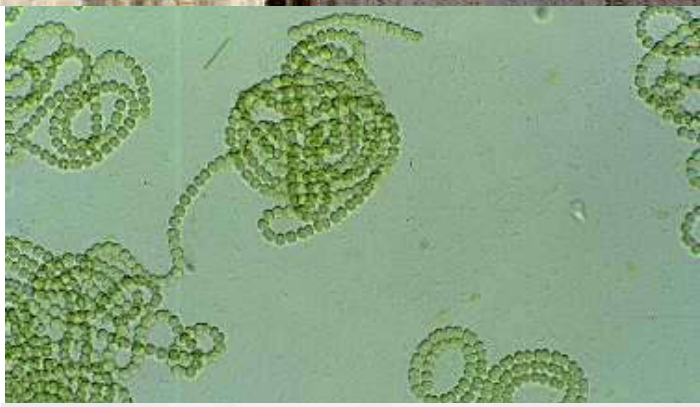
- ~4+ BYA: All blown away
- ~4: Magnetic field forms & atm held in place – no O_2
- ~3.8: Out-gassing continues but liquid water possible as planet cools below 100°C
- ~3.5 BYA: First life forms release O_2
- ~500 MYA: O_2 levels high enough for ozone layer & plants & animals can now colonize land
- During the first half of the earth's geologic history, there is no evidence of ice ages

- **All from geological evidence!!**

Photosynthesis


Stromatolites

- $CO_2 + H_2O + light \rightarrow CH_2O + O_2$
- Cyanobacteria (Eubacteria) aka blue-green algae, appear ~ 3.5 bya
  - Release O_2 as byproduct
- Accumulation of O_2 in the atmosphere didn't start until oceanic Fe_2+ was oxidized (~2 bya).

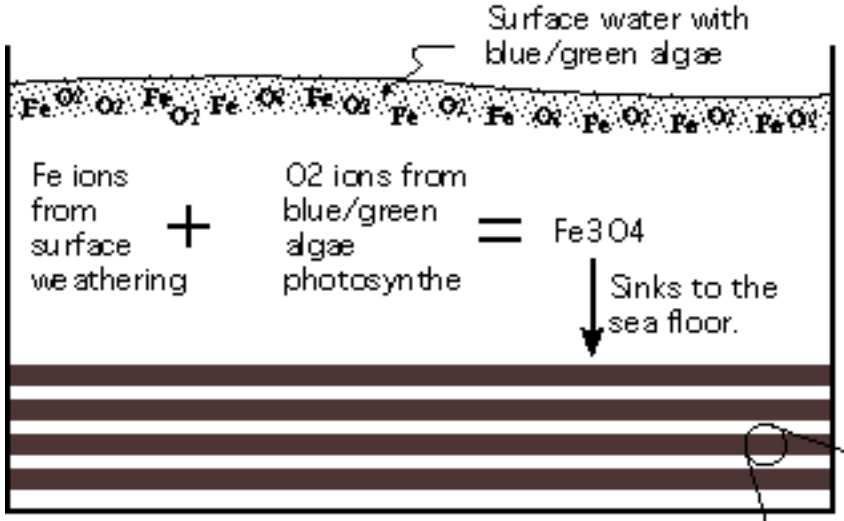



Cyanobacteria

Banded Iron Formations

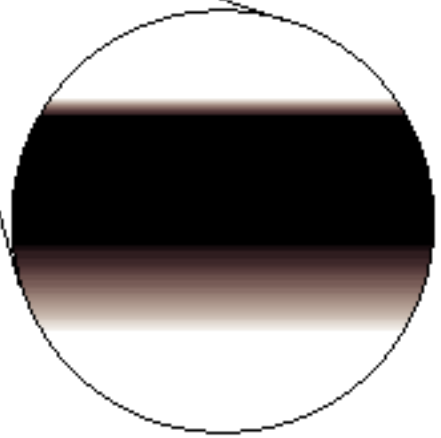
- Water with O_2 (from blue-green algae) & Fe from surface weathering.
- Get deposits (iron-rich layer) This cleans algae's environment.
- Too much algae, produce too much O_2, not enough Fe to remove it…
- O_2 toxic to algae, population collapse… (get white layer)

The red bands are hematite, and are interbedded with chert.



After combining the Fe and O2 ions into Magnetite (Fe3O4), the mineral grains sink to the sea floor, where they accumulate into iron-rich and iron-poor layers.

In an ideal setting, you would expect the magnetite-rich layers to exhibit a reversed graded bedding. Looking from the bottom up, this would involve a slow transition into the magnetite-rich layers, representing slowly increasing O2 levels in the upper sea water in response to the increasing population of blue/green algae. The upper contact of each magnetite-rich layer would be relatively abrupt, reflecting the sudden extinction of the population due to O2 poisoning, and the resulting loss of available O2 in the water to combine with the iron ions.



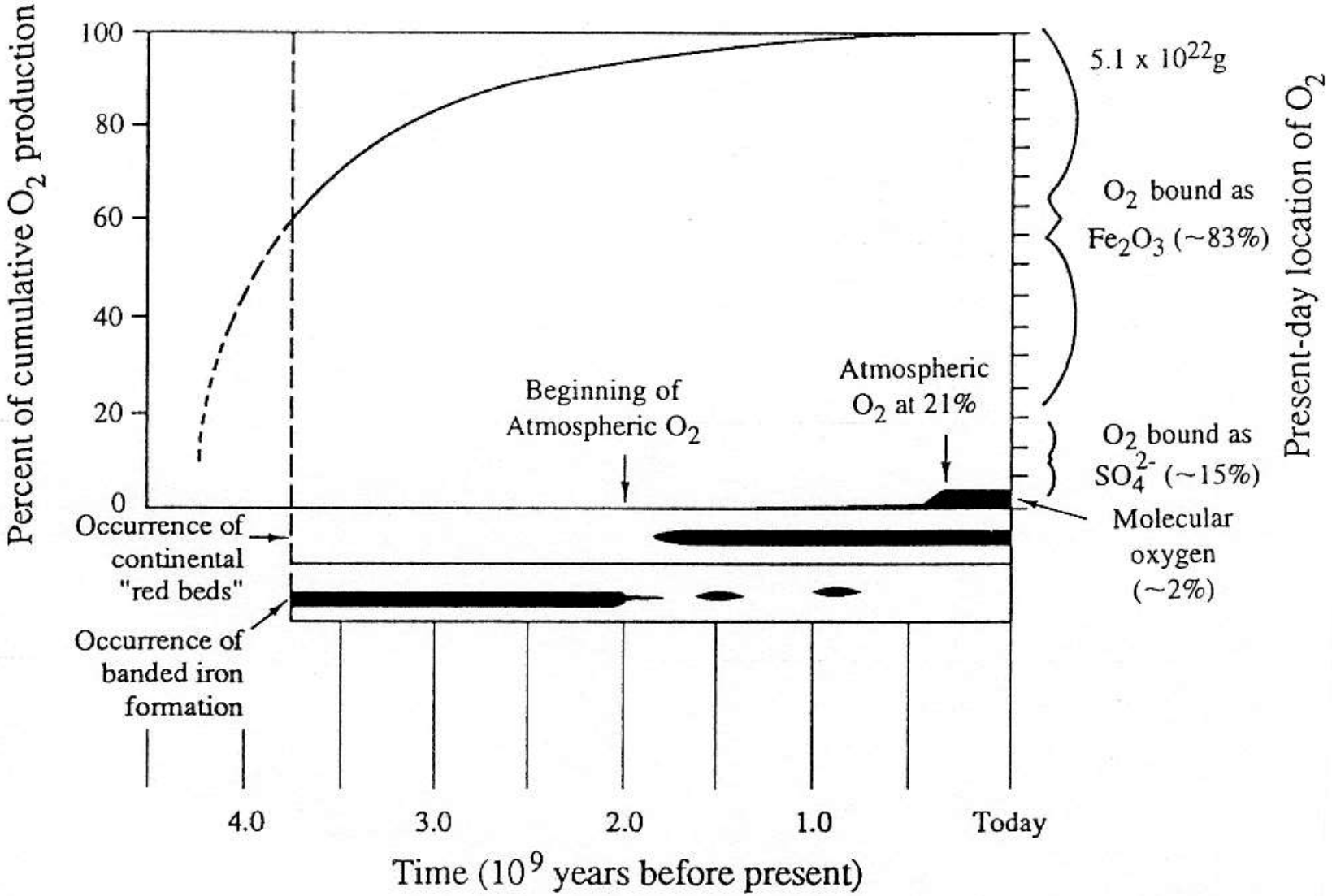
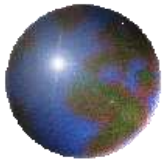


Figure 2.7 Cumulative history of O_2 released by photosynthesis through geologic time. Of more than 5.1×10^{22} g of O_2 released, about 98% is contained in seawater and sedimentary rocks, beginning with the occurrence of Banded Iron Formations at least 3.5 billion years ago (bya). Although O_2 was released to the atmosphere beginning about 2.0 bya, it was consumed in terrestrial weathering processes to form Red Beds, so that the accumulation of O_2 to present levels in the atmosphere was delayed to 400 mya. Modified from Schidlowski (1980).



Core from the Permian red beds that underlie the High Plains aquifer in southwestern Kansas and the Oklahoma panhandle

Red Beds

- ~1.8 BYA once all iron in ocean reacted with O_2, it could build up in the atmosphere, leading to the oxidation of iron on exposed surface.

- This Fe_2O_3 is seen in geological formations called Continental Red Beds

- Only after the surface iron reacted could O_2 then build up in the atmosphere

Carachipampa Volcano and Red Beds, N.W. Argentina

Earth's Evolution

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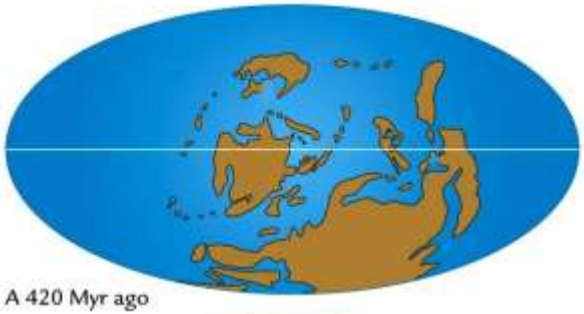
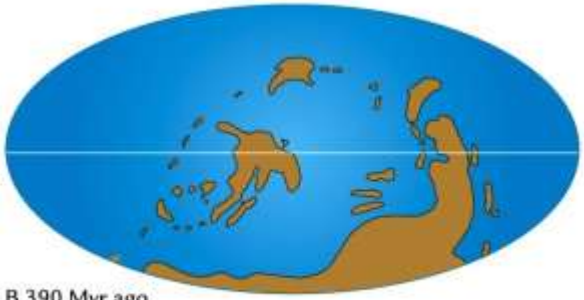
- ~500 MYA: O_2 levels high enough for ozone layer & plants & animals can now colonize land
- During the first half of the earth's geologic history, there is no evidence of ice ages
  - **All from geological evidence!!**

The last 500 MYA or so…



A 420 Myr ago

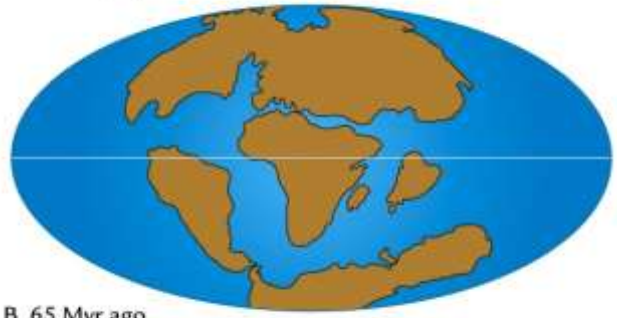


B 390 Myr ago

C 350 Myr ago

D 260 Myr ago

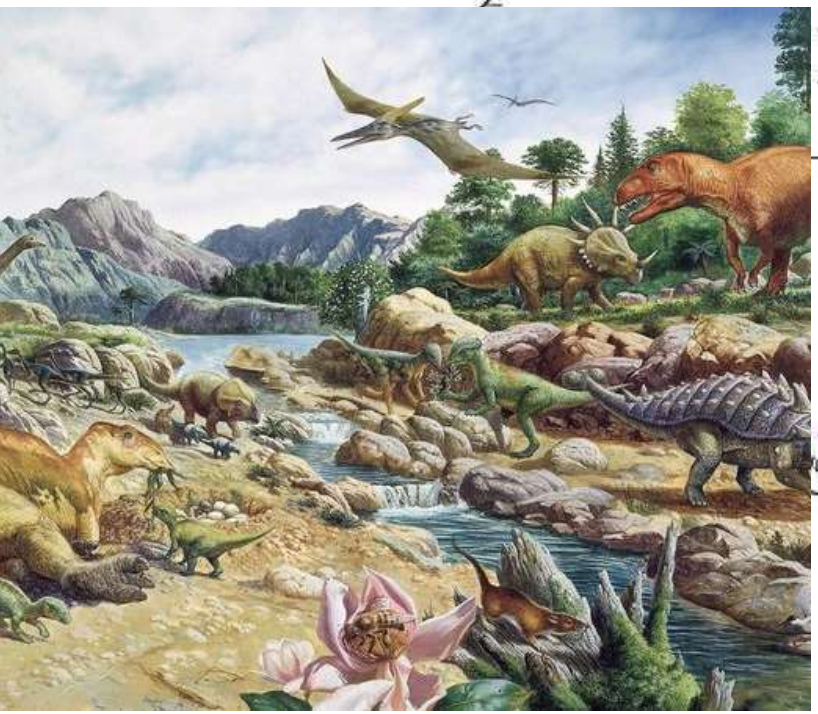
A 200 Myr ago

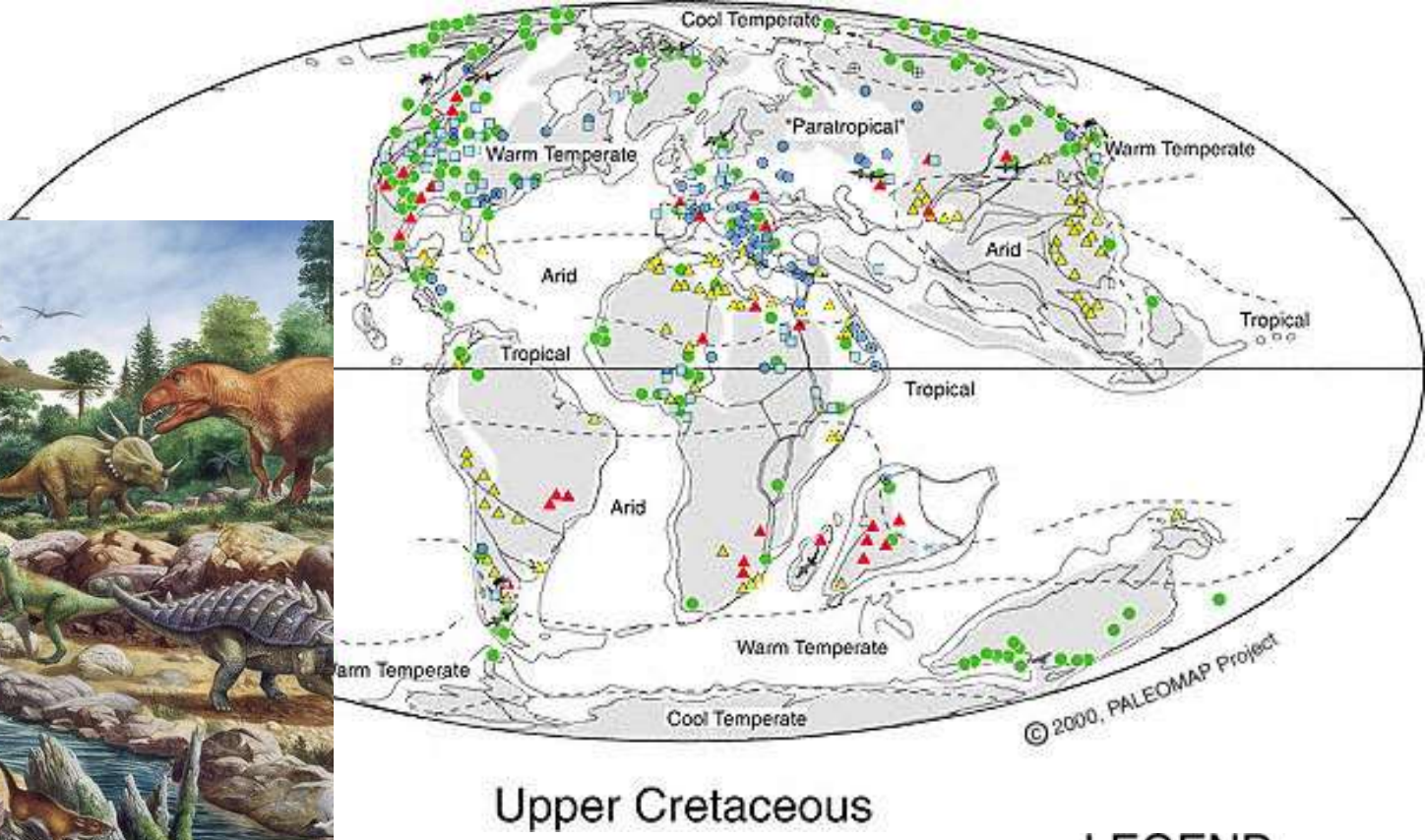


B 65 Myr ago

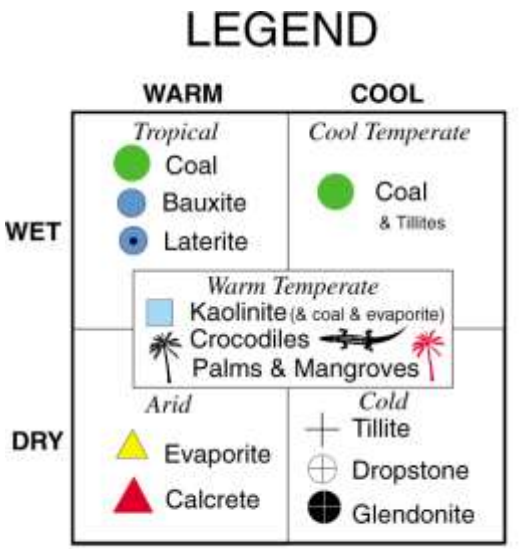
C Today

Fossils





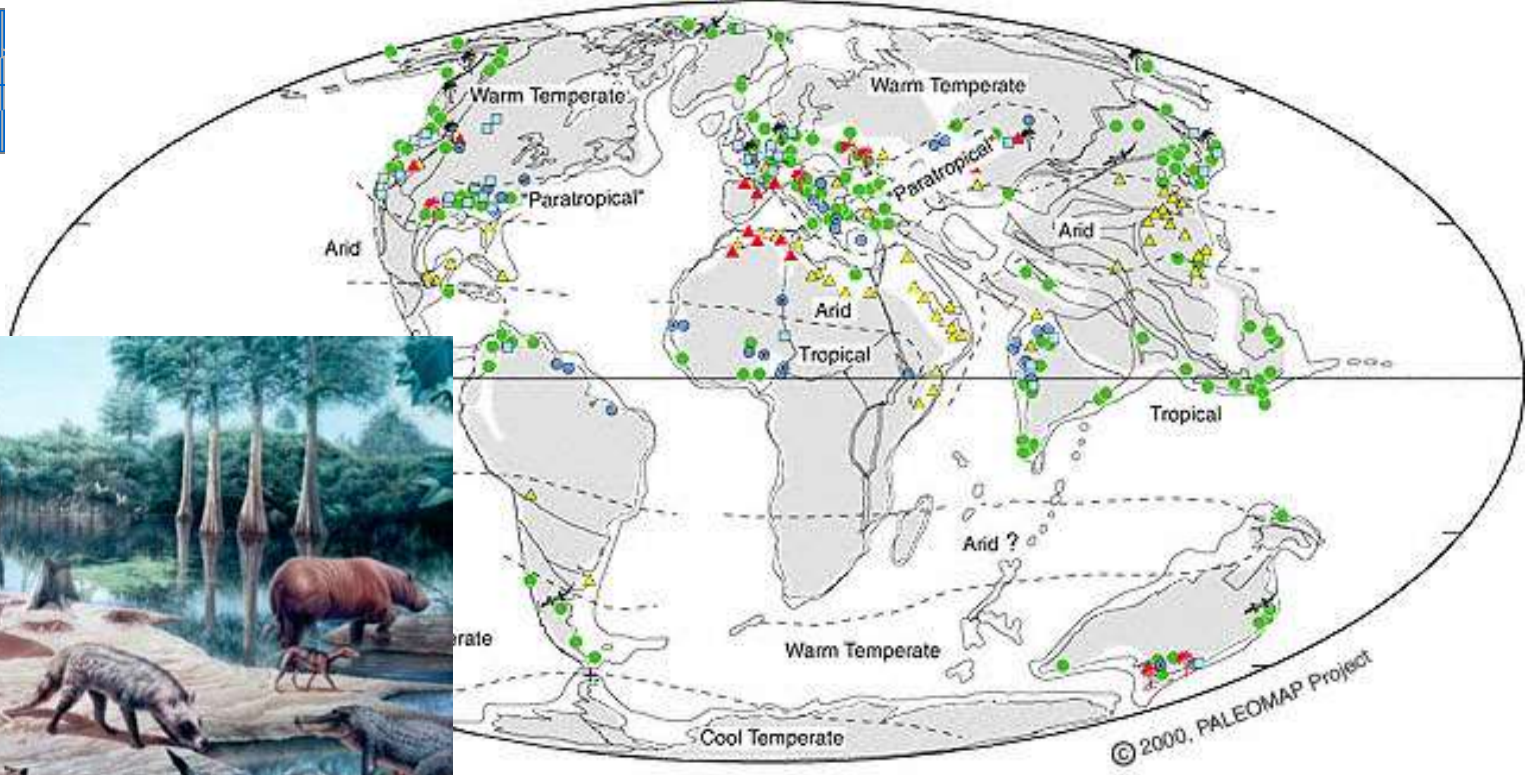
Upper Cretaceous



- Cretaceous (100 million ya): +15°C warmer than now
  - Sea level 200 m higher

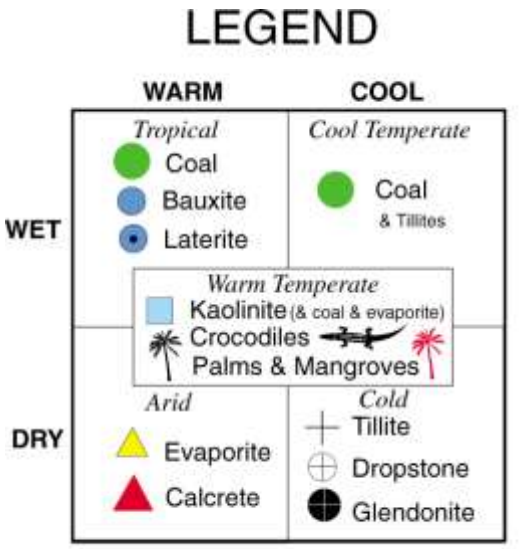
http://www.scotese.com/Default.htm

Fossils



Lower Eocene

- Early Eocene (55 million ya): +7°C warmer than now
- Spike may have been a methane release



http://www.scotese.com/Default.htm

Ice-House World

- Antarctica with ice since 35 MYA
  - Increases 13 & 6 MYA
- Andes 4-7 MYA
- Greenland 3-7 MYA
- Alaska 5 MYA
- N. America & Europe 2.7 MYA

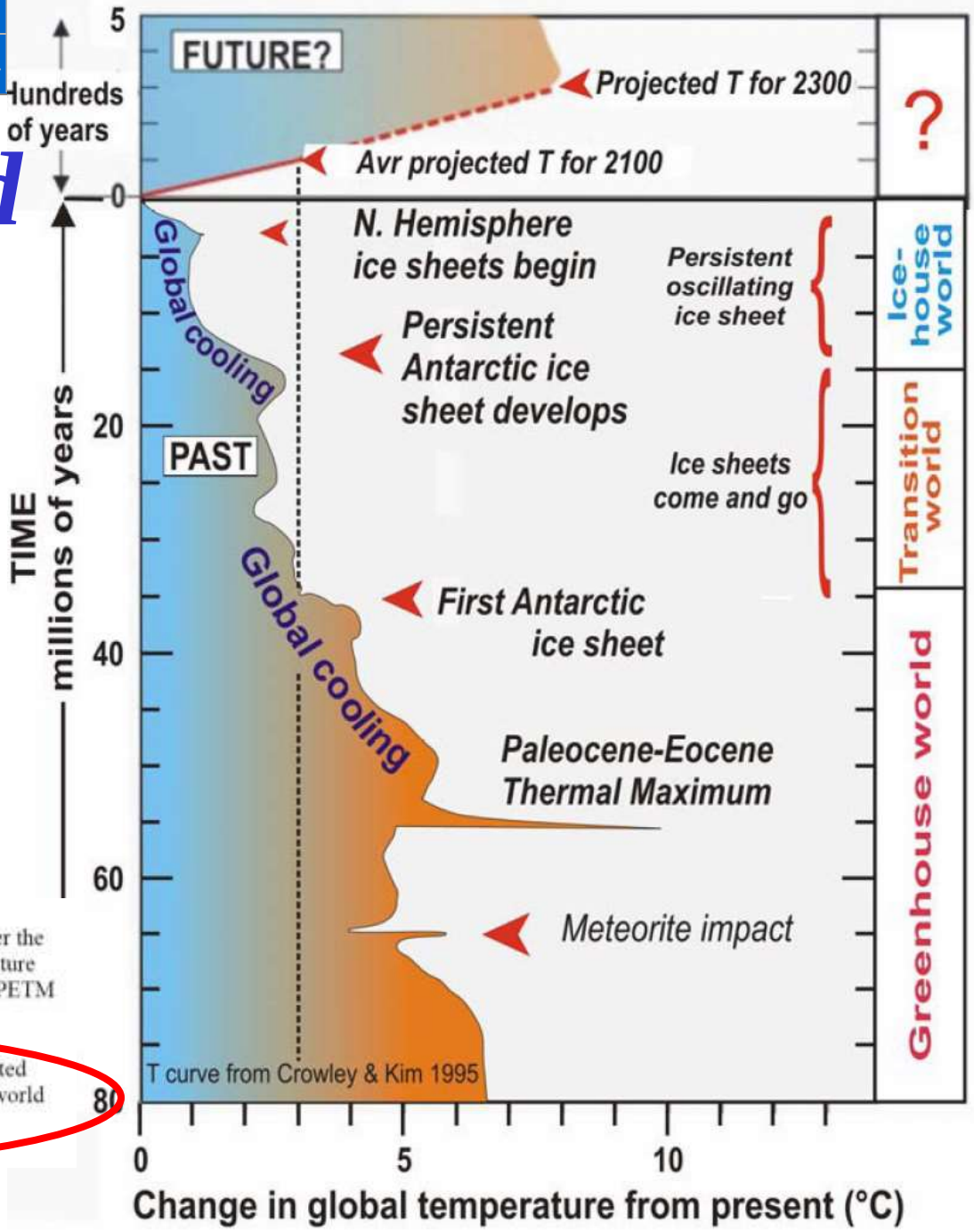
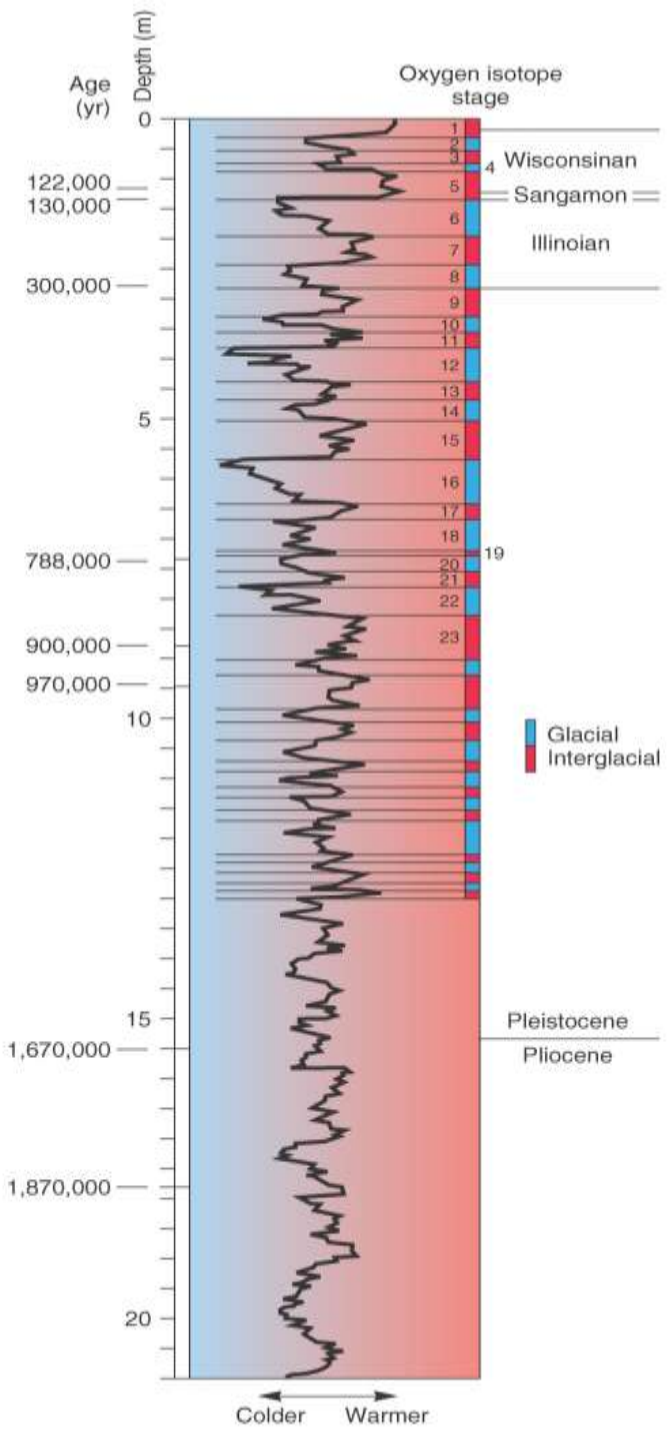


Figure 3. A graph showing the change in average global temperature over the last 80 million years (modified from Barrett, 2003, based on the temperature curve of Crowley and Kim, 1995, with the addition of the effects of the PETM methane discharge described by Zachos et al., 2005).

The "Future" part of the graph shows the rise in temperature to be expected from energy projections, with the earth warming into the "greenhouse" world of more than 34 million years ago soon after the turn of this century.

Past 2.75 Million Years

- From deep-sea drilling:
  - At least 50 glacial-interglacial cycles superimposed on the long term cooling trend…
  - 90% of last 0.9 MY there were ice sheets on Earth

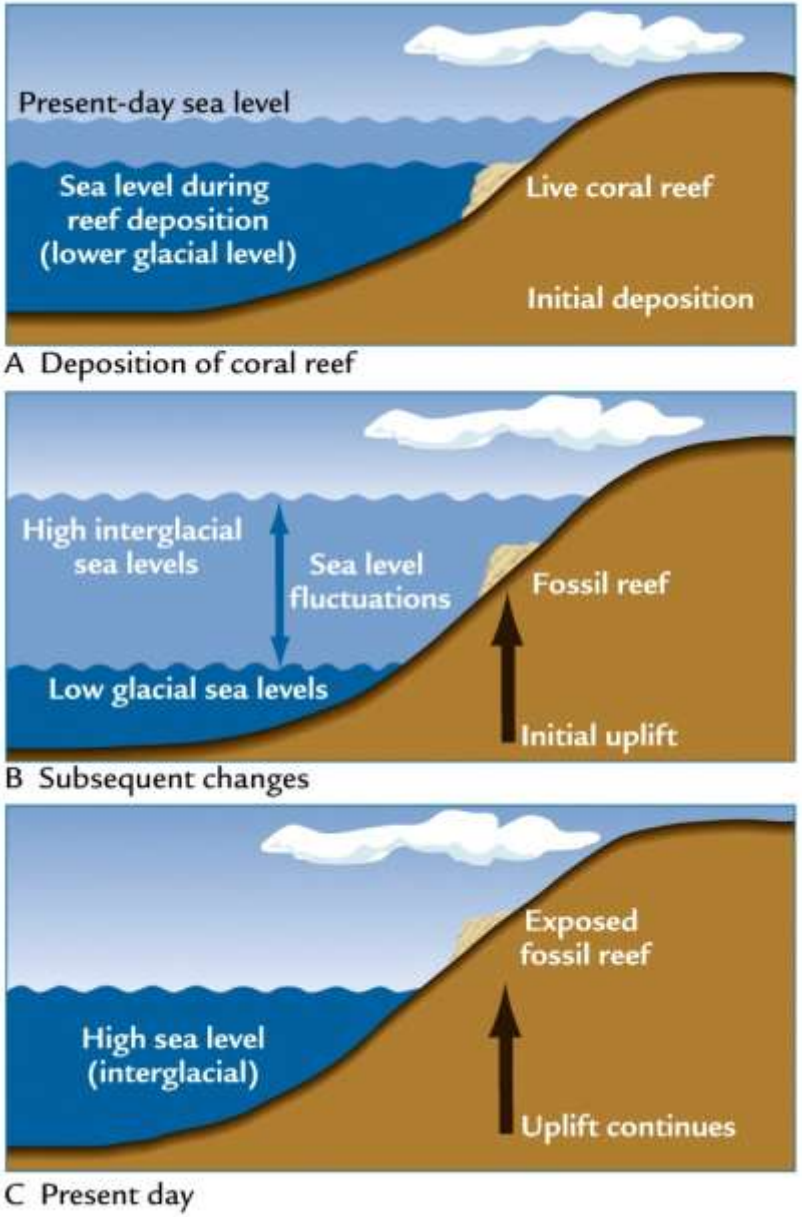


Milankovitch Cycles

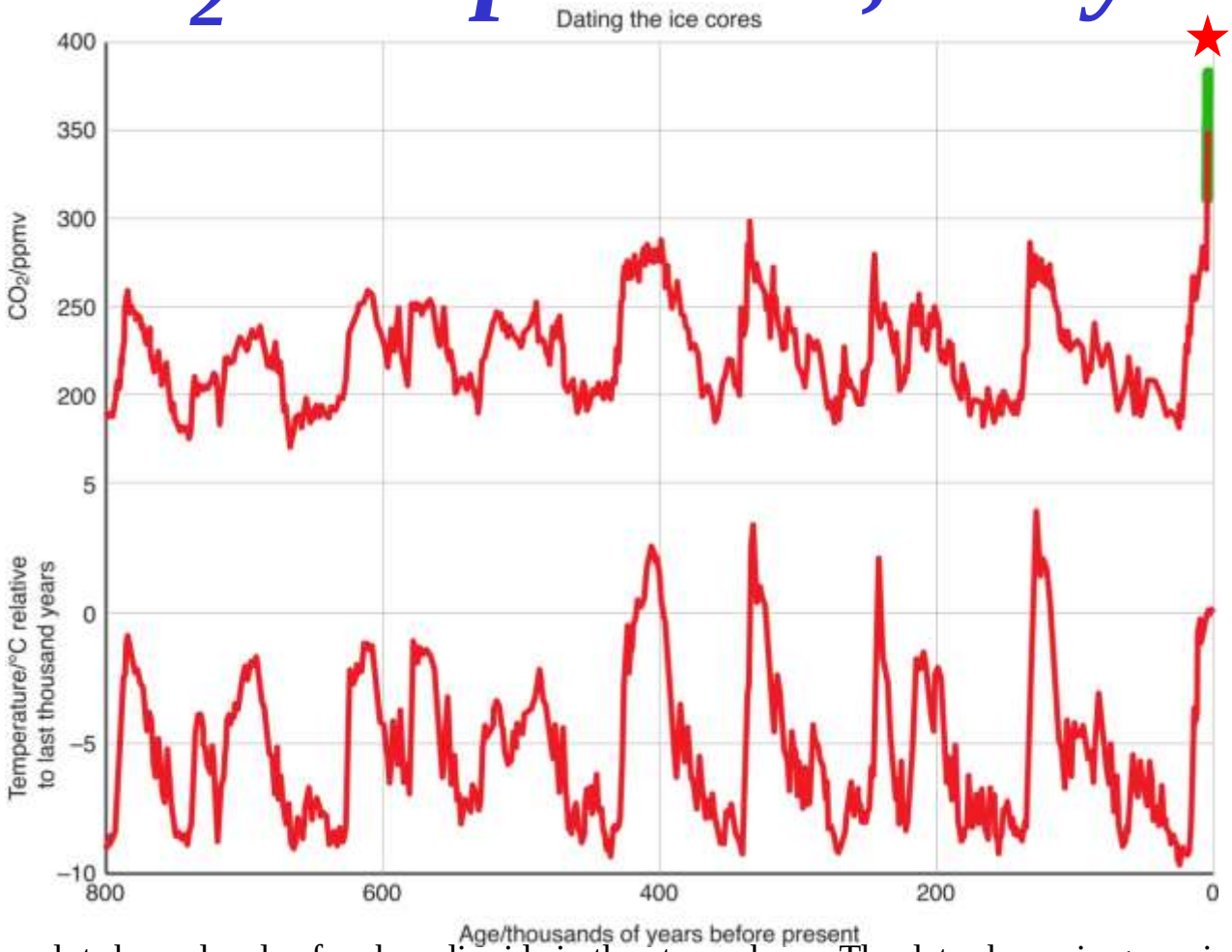
- 1911: Milutin Milankovitch proposes:
  - All 3 cycles (23, 41, & 100 KYA) together control ice ages
  - Summer insolation is driver

Milankovitch Cycles

- 1976: Jim Hays, John Imbrie, and Nick Shackleton publish first confirmation of Milankovitch theory
  - Used corals to give dates with uranium decay isotope analysis



CO_2 over past 800,000 years



★ 400 ppm in 2013

The top plot shows levels of carbon dioxide in the atmosphere. The data shown in green is actual concentrations measured at Mauna Loa in Hawaii. The red line on the CO_2 plot is from Law Dome and the remaining data from two other ice core sites in Antarctica; Vostok and Dome C.

Plots courtesy of EPICA. Data from Luethi et al 2008 (CO_2) and Jouzel et al 2007 (temperatures). Thanks to Eric Wolff of BAS for supplying the information

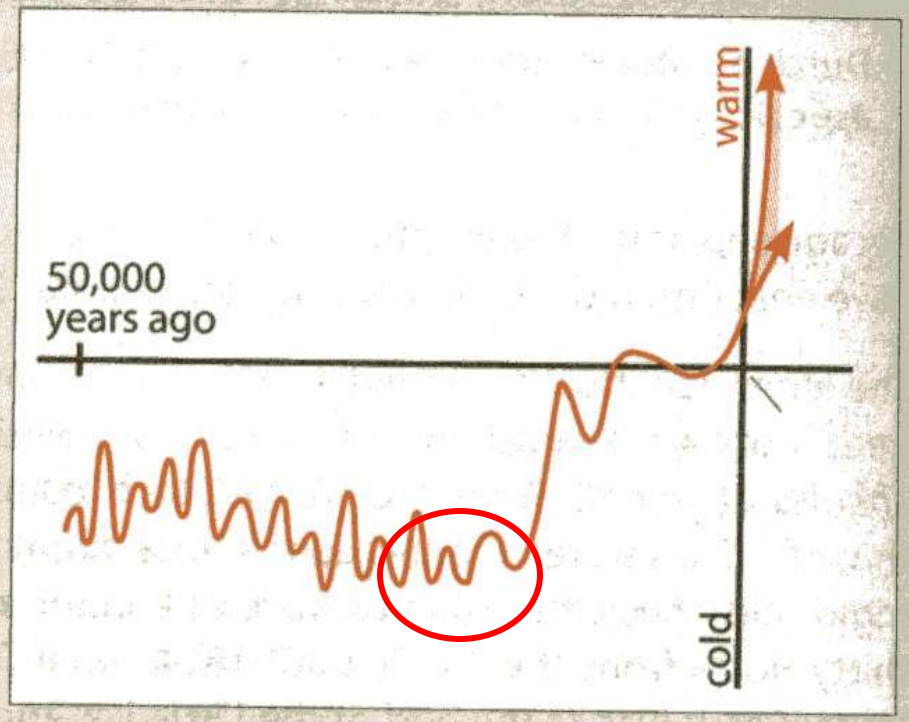
Chronology of Pleistocene Glaciations

North America	Alpine Region	Years before Present
		— 10,000
WISCONSINIAN	Würm	— 75,000
Sangamon	Riss-Würm	— 125,000
ILLINOIAN	Riss	— 265,000
Yarmouth	Mindel-Riss	— 300,000
KANSAN	Mindel	— 435,000
Aftonian	Günz-Mindel	— 500,000
NEBRASKAN	Günz	— 1800,000
Pre-Nebraskan	Pre-Günz	

In North America, the glacial stages are Nebraskan, Kansan, Illinoian, and Wisconsinian. These terms correspond approximately to the Günz, Mindel, Riss, and Würm in Europe.

The Last 50,000 Years

Over tens of thousands of years The most recent ice age began about 115,000 years ago and ended about 11,500 years ago. Then came a dramatic warm-up, which lasted until about 3000 BC. Since then, Earth's temperature has changed relatively little, with a very slight cooling interrupted by warmer periods and punctuated by the last century's sharp temperature rise. More than a thousand years from now, after humans have exhausted fossil fuels and the resulting greenhouse gases have left the atmosphere naturally (mostly through slow absorption by the ocean), we may return to cooler times. If the length of the

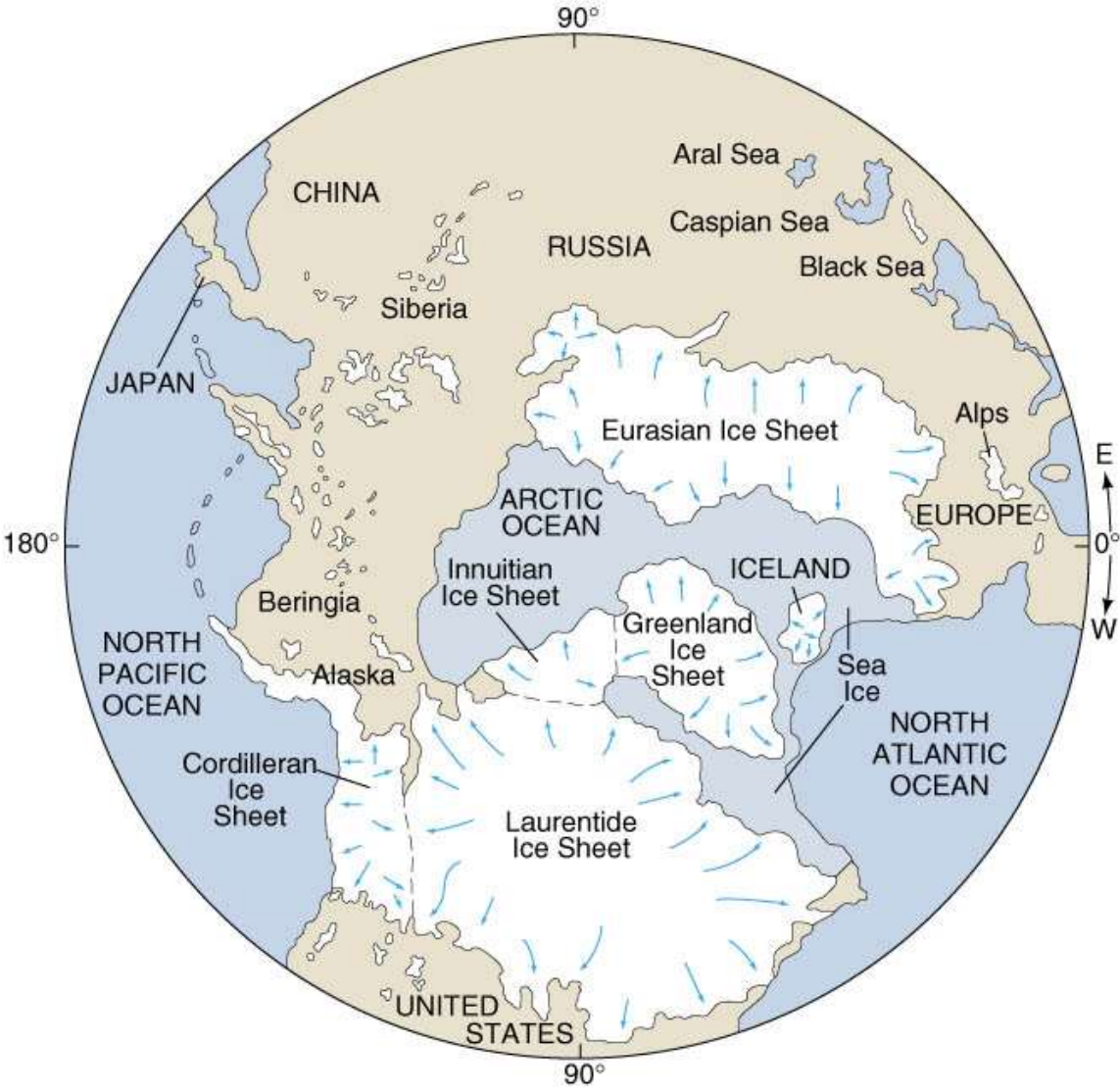


Last Glacial Maximum

• World sea level fell at least 100 m, thereby causing large expanses of the shallow continental shelves to emerge as dry land

•Disruption of major stream systems.

• The Missouri and Ohio rivers to move into new courses beyond the ice margin.



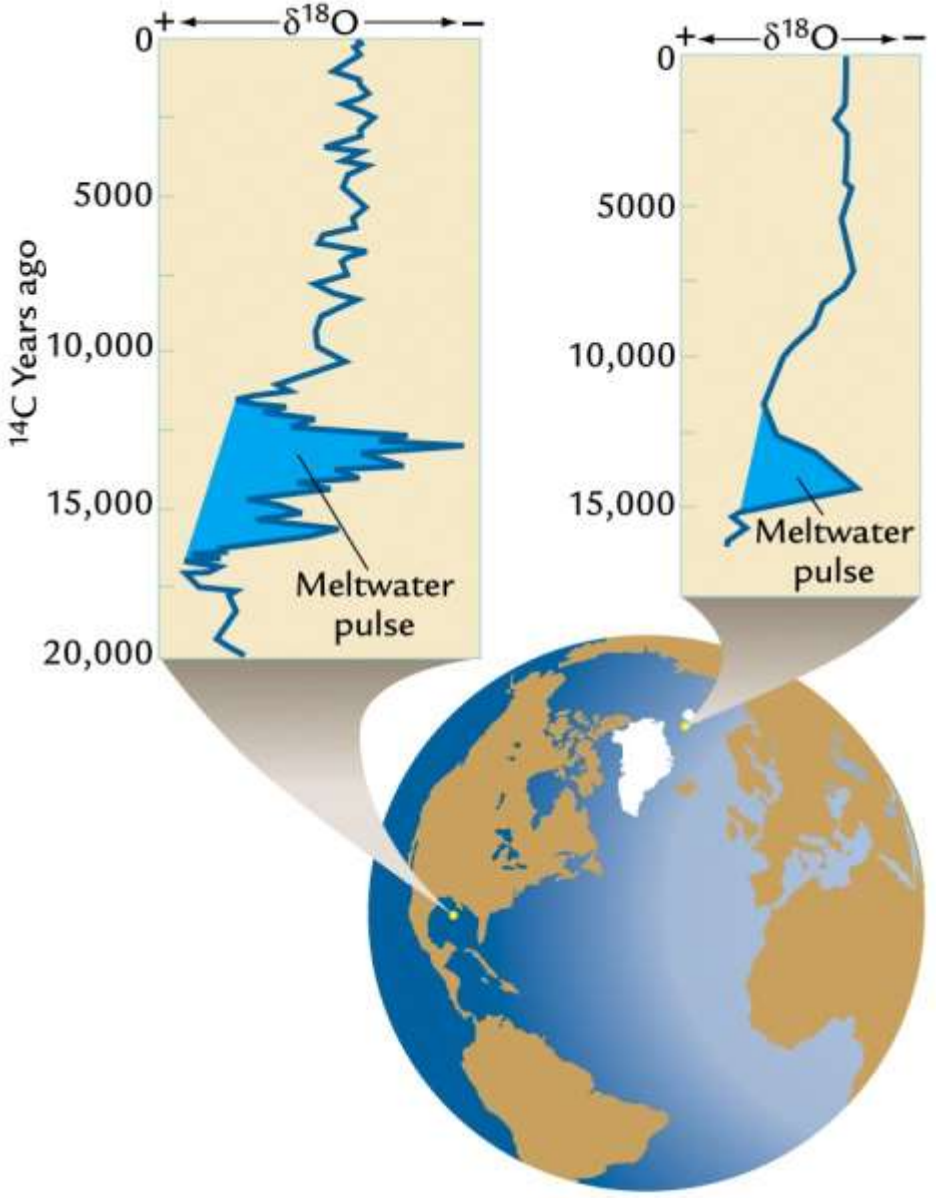
Last Glacial Maximum

(a)

(d) Severe Dry Lake

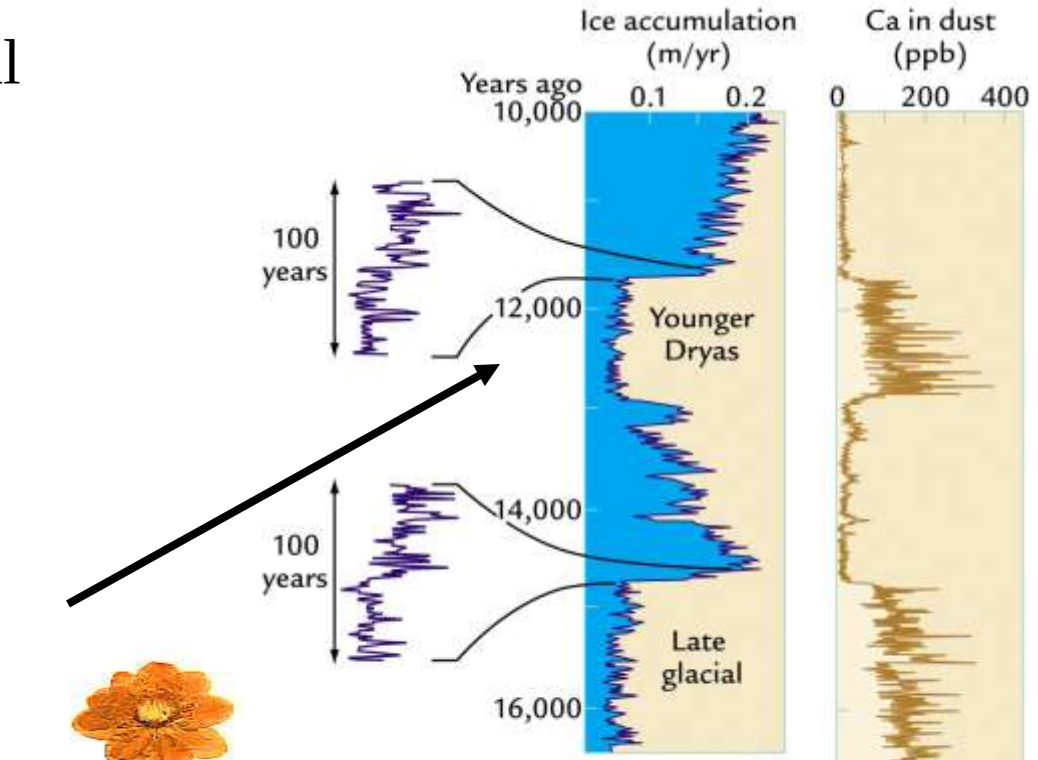
Deglaciation

- Meltwater pulses…
  - Several different ones interrupt steady retreat of ice sheets



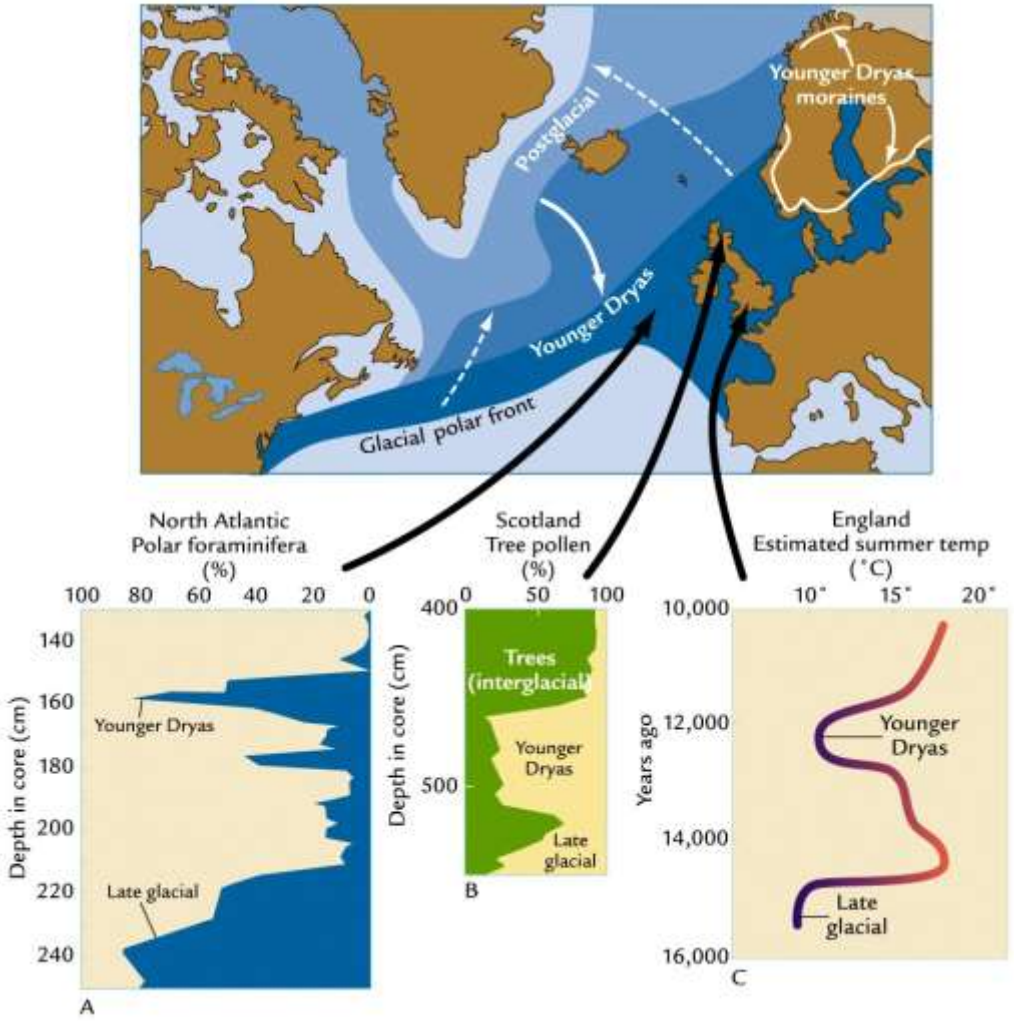
Younger Dryas

- ~3,000 year return to glacial conditions in midst of deglaciation
- "Younger Dryas"
  - 15-12,000 years ago
  - Pollen of dryas returns to Europe
  - Scary part: transitions very sudden, within a decade!!!



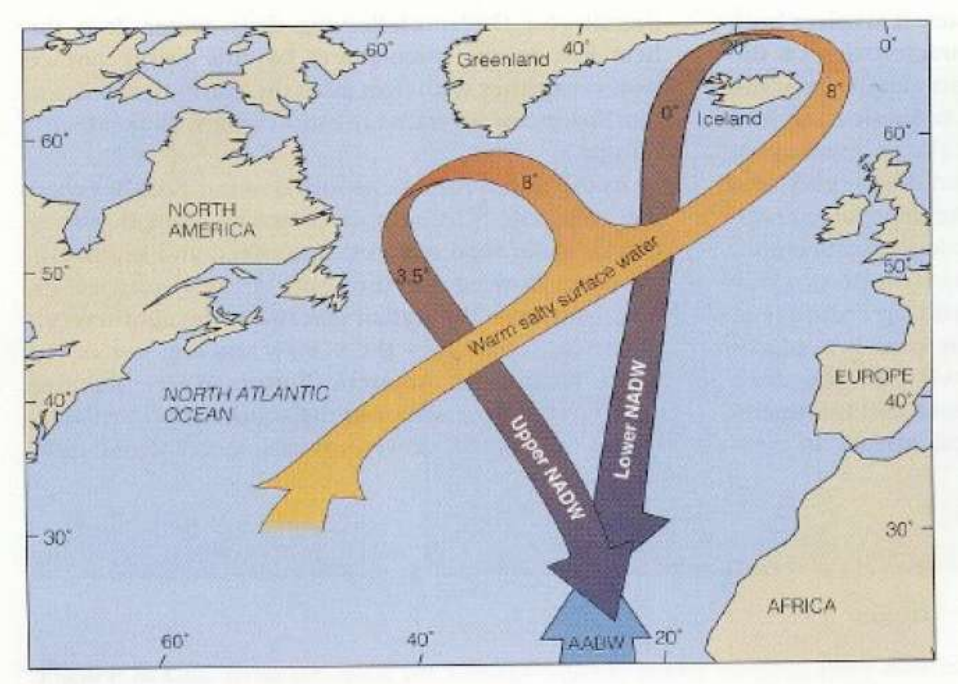
Younger Dryas

- Think caused by movement in polar front.
  - Front: area between two air masses
  - Was S of England during glacial, shifts N during interglacial.
  - During YD, it reverted…



Thermohaline Circulation

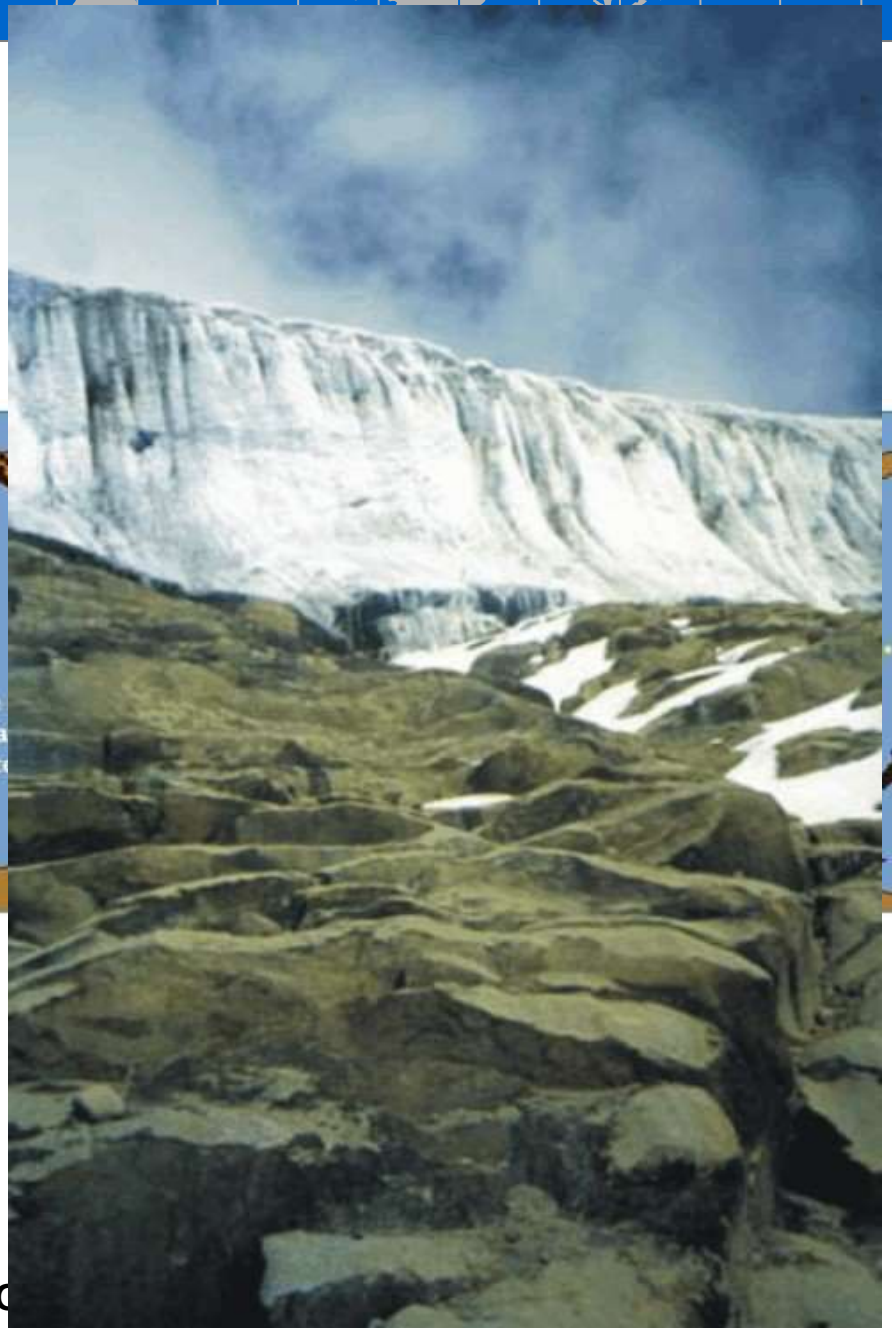
- Wally's hypothesis:
  - Cut off NADW = return to glacial conditions
  - Must suddenly change input into North Atlantic…
  - What could happen???
  - *Day After Tomorrow Movie* over-dramatized this one ☺



Quelccaya Ice Cap, Peru

1977

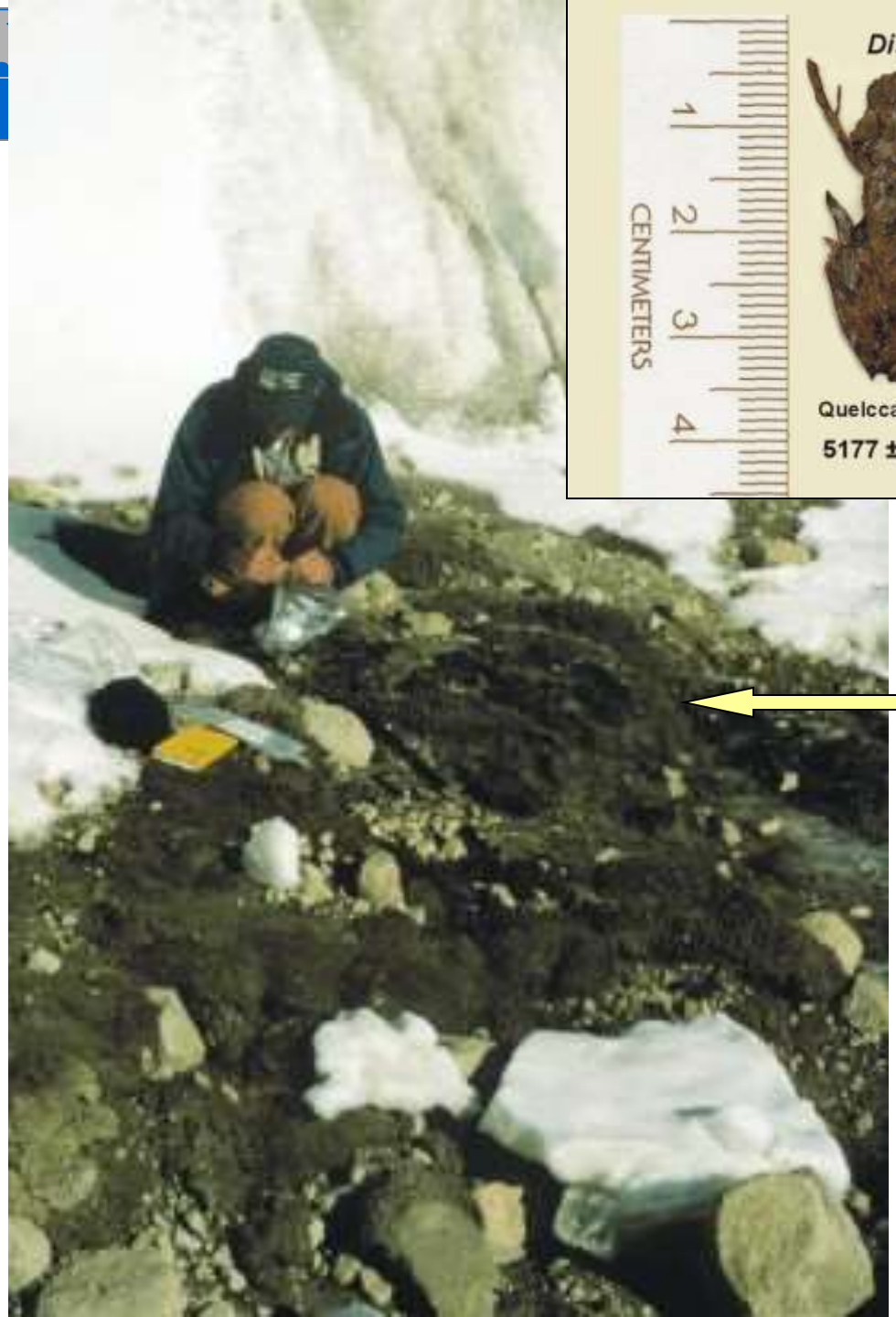
2002



Photos: Lonnie G. Thompson: C

Quelccaya Ice Cap, 2002

200 – 400 m above its modern range

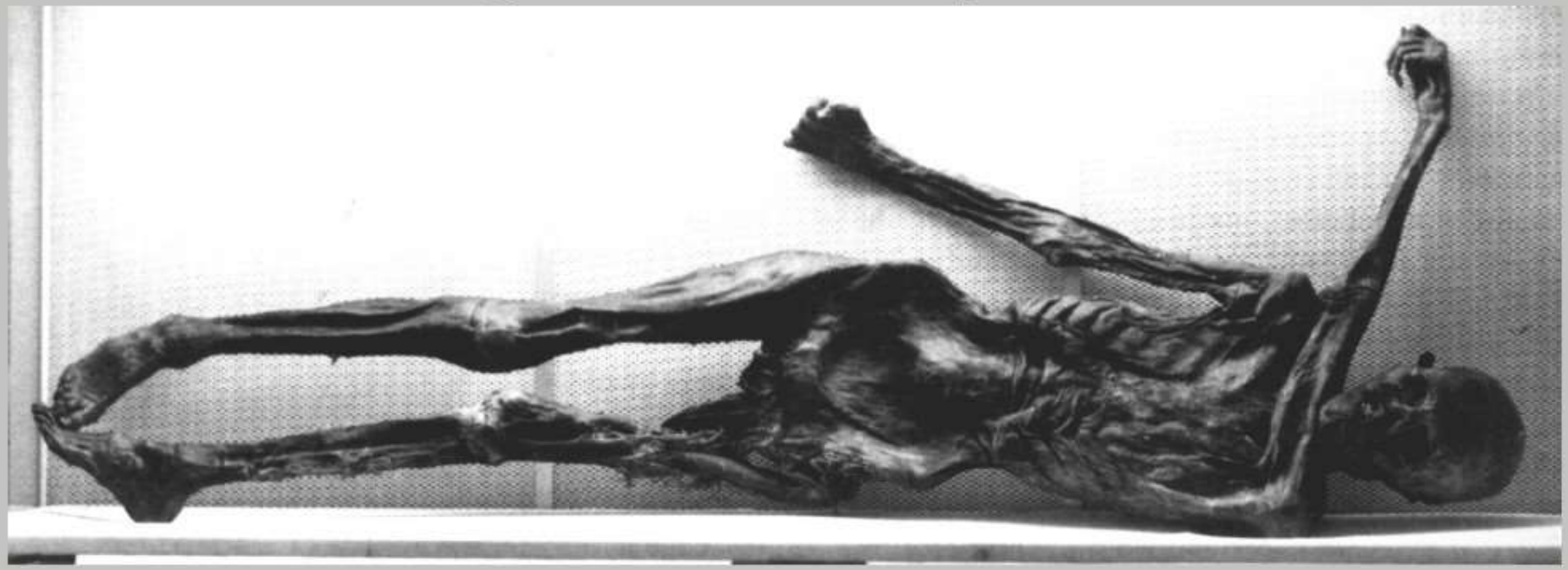


Cushion Plant

Photos: Lonnie G. Thompson
Ohio State University

"The Tyrolean Iceman" - "Ötzi"
"Man from the Hauslabjoch"

Age 5175 ± 125 years



Source: http://info.uibk.ac.at/c/c5/c552/Forschung/Iceman/iceman-en.html#Finding

"Drought Events"

- Now looking for more evidence of that shift in climate 5000 years ago…
- Kind of show both linear & cyclic trend depending on which examined…
- Very messy picture, especially on regional scale.

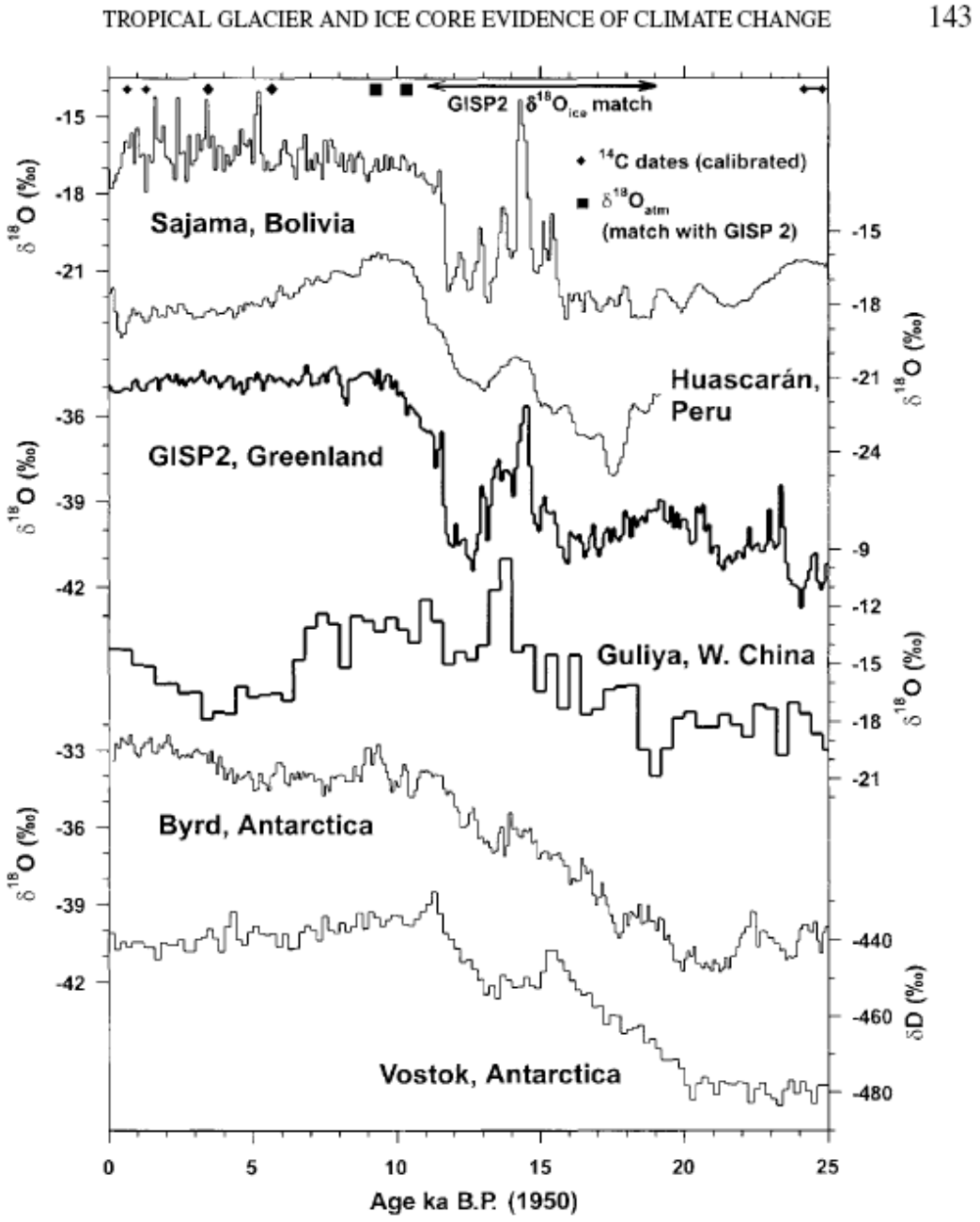
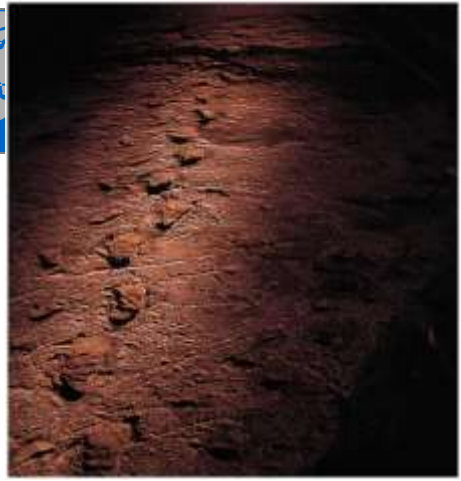
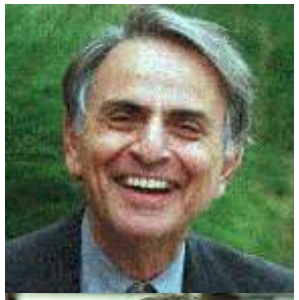


Figure 4. The $\delta^{18}O_{ice}$ histories for the last 25,000 years for six cores from the tropics to the poles show similar isotopic depletion (~5 to 7‰) in the Late Glacial Stage ice relative to Holocene ice.

Anthropocene

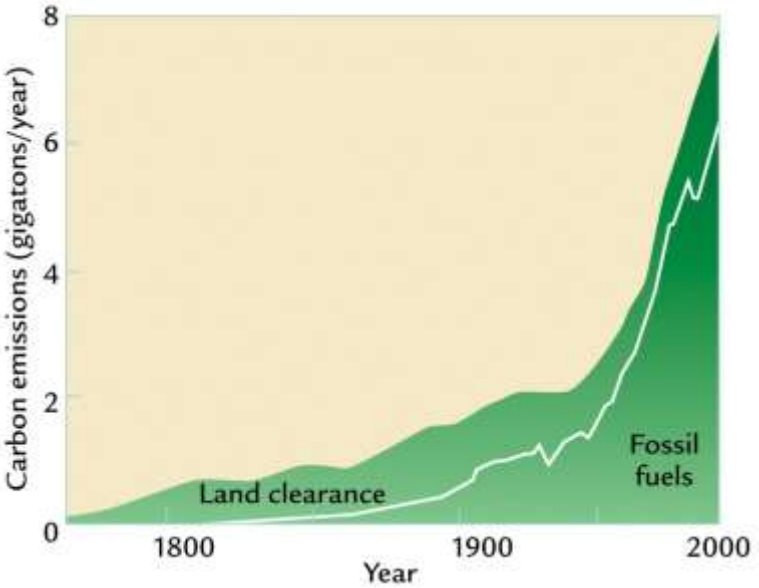




- Term used for climate where humans are the dominate controlling mechanism…
  - Concept first proposed in 1979 by Sagan
  - Phrase coined by Crutzen in 2000
    - Nobel prize winning chemist for his work on ozone depletion
  - No precise start date.
  - May be considered to start in late 18th century
    - “Start” of Industrial Revolution
  - Ruddiman proposes it started much earlier…
    - 8,000 years ago

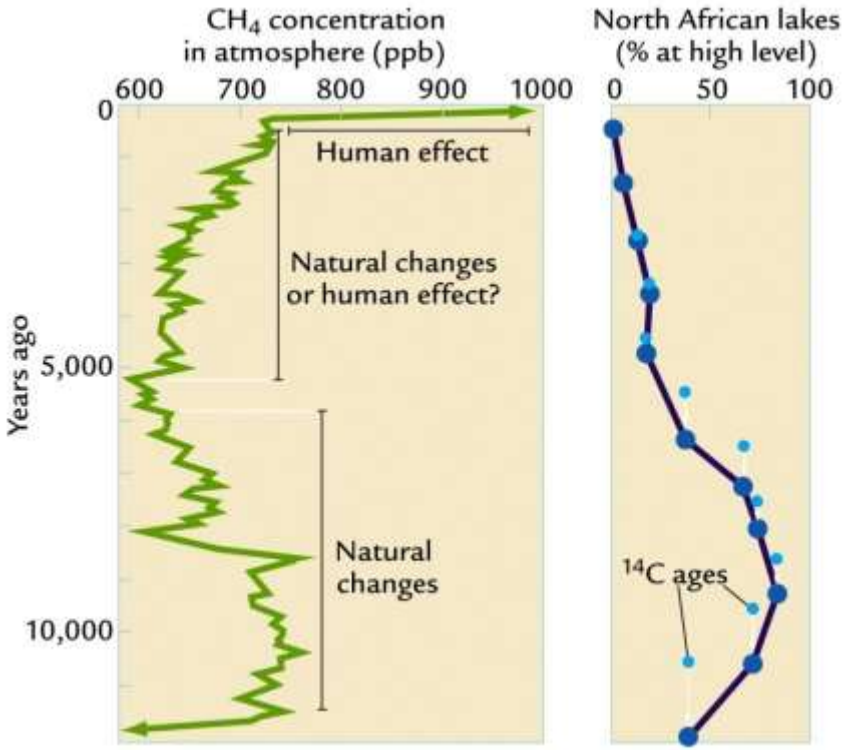
Clearing of Land

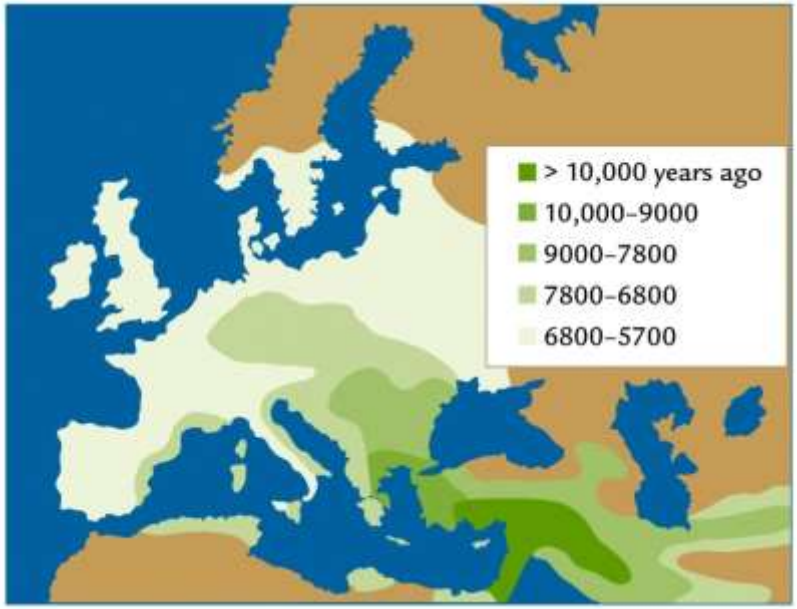
- Deforestation:
  - Since 8000 years ago in Europe…
  - Sagan proposed in 1970s
  - Ruddiman proposes change in CO_2 since then



Effects of Agriculture (& Fire?)

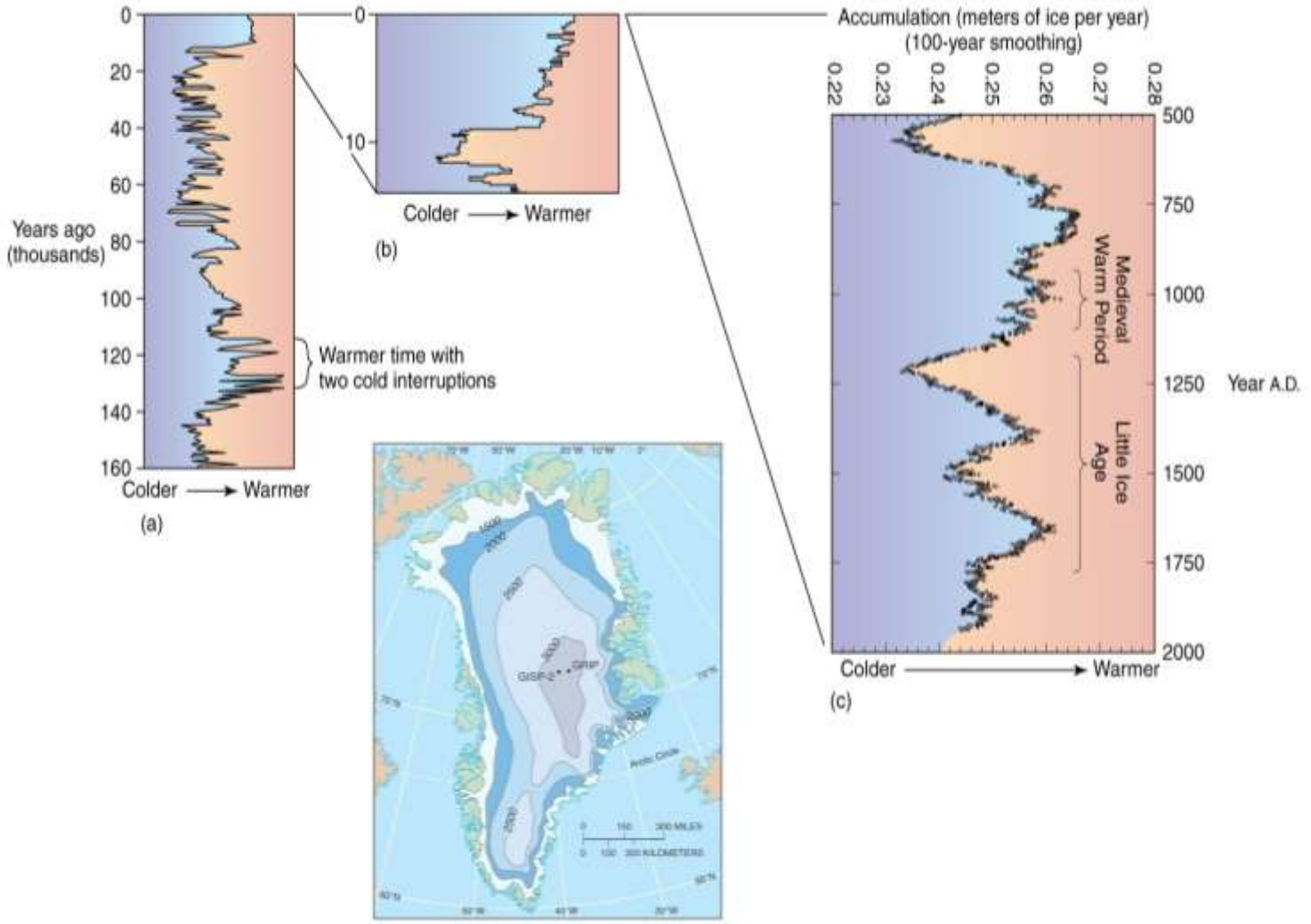
- Agriculture:
  - First arose in Fertile Crescent & Yellow River Valley in China…
  - Unexplained rise in methane
  - Ruddiman credits irrigation of rice





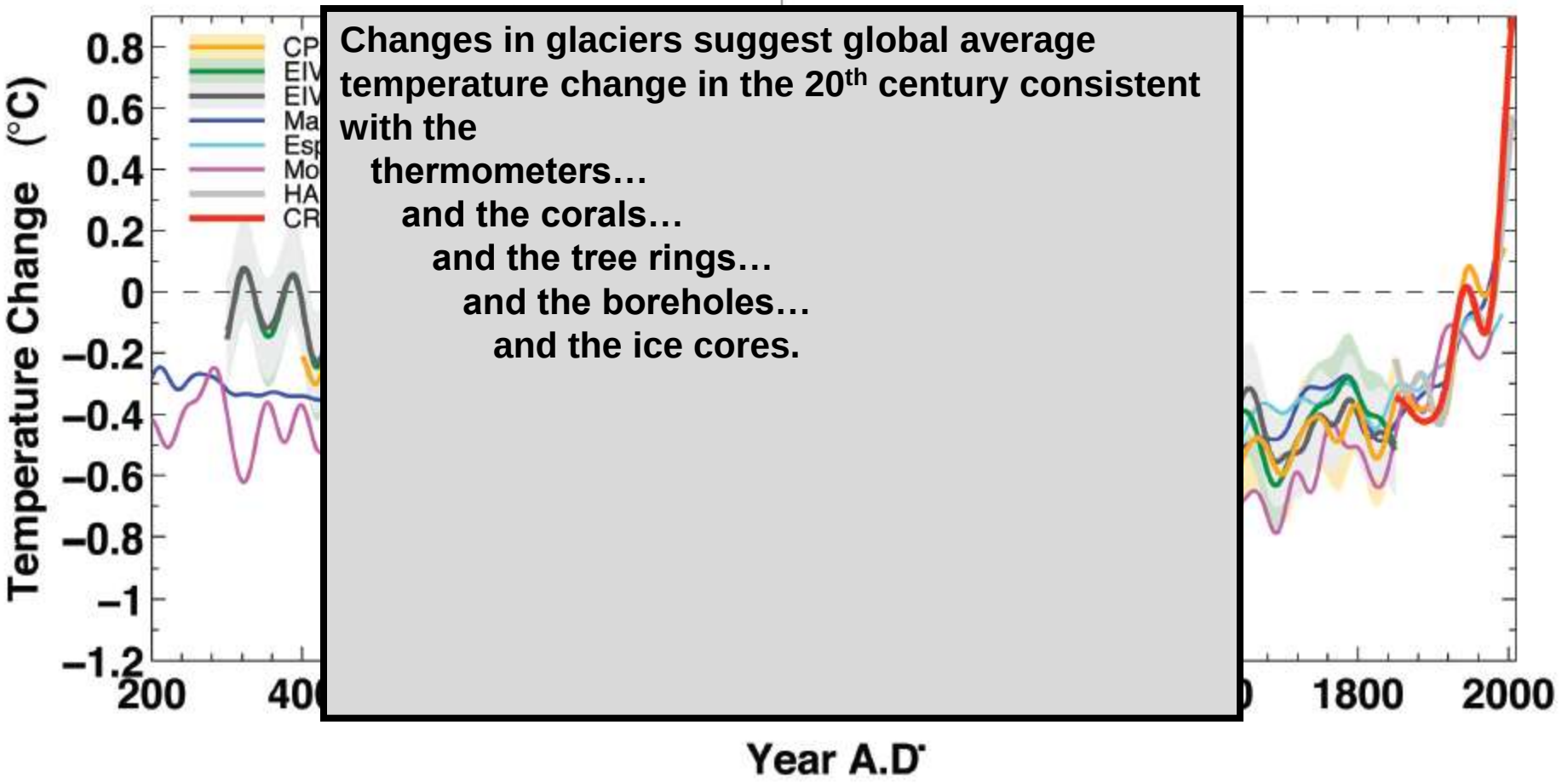
- Fire:
  - Humans have used for 1000s of years

- Greenland Ice Cores: ***Last 2000 years….***
  - High resolution record of temps near Europe…



Comparison of Northern Hemisphere Temperature Reconstructions

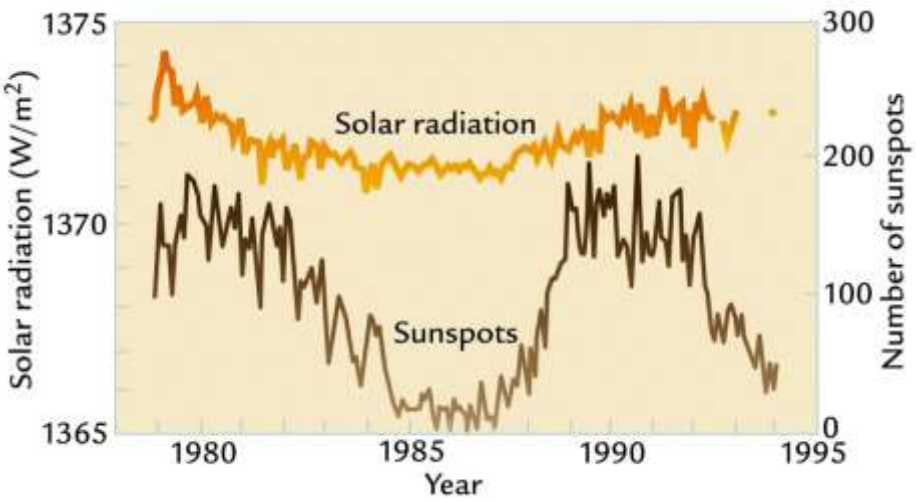
Changes in glaciers suggest global average temperature change in the 20th century consistent with the
thermometers…
and the corals…
and the tree rings…
and the boreholes…
and the ice cores.

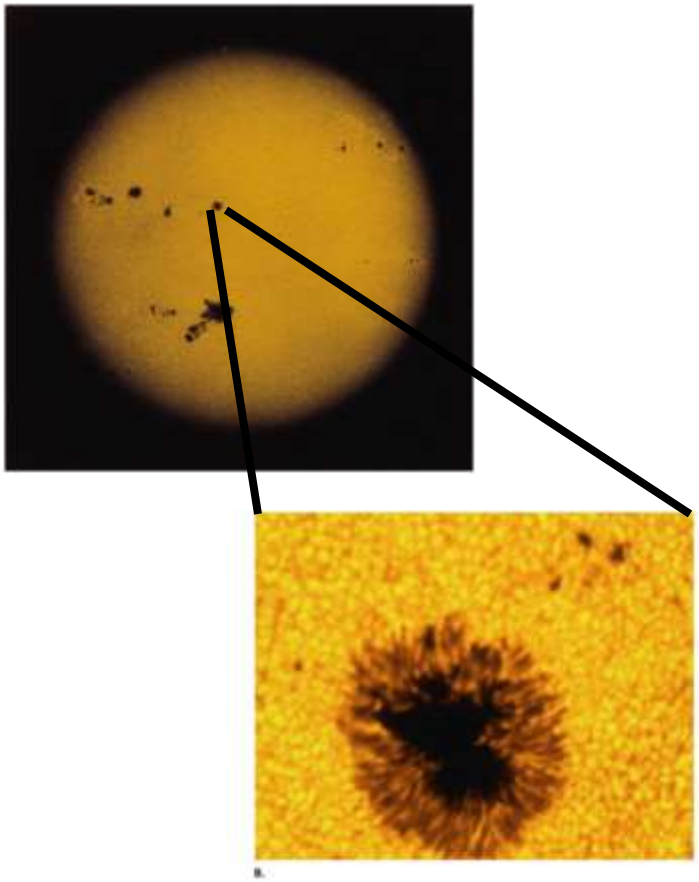


Mann et al. 2008

Sunspots

- Sun spots… huge magnetic storms
- More radiation when more storms
- 11 yr cycle
- Cause problem with satellites & more auroras…





Sunspots

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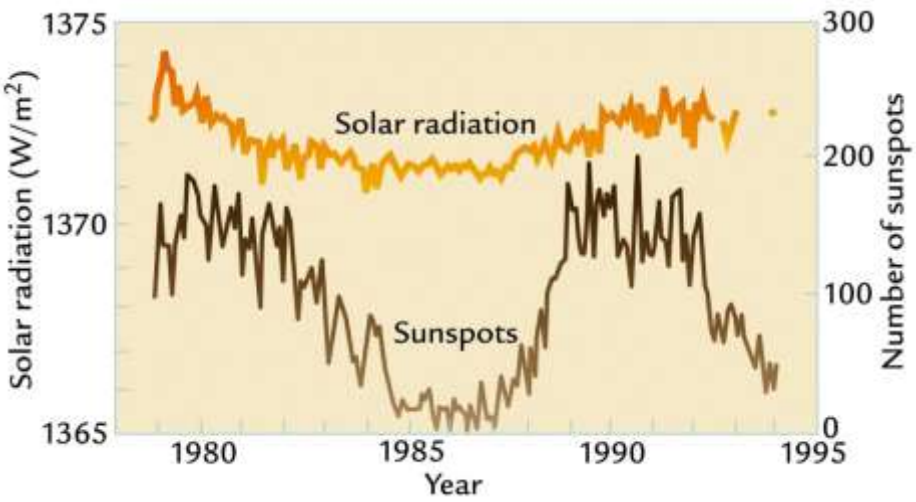
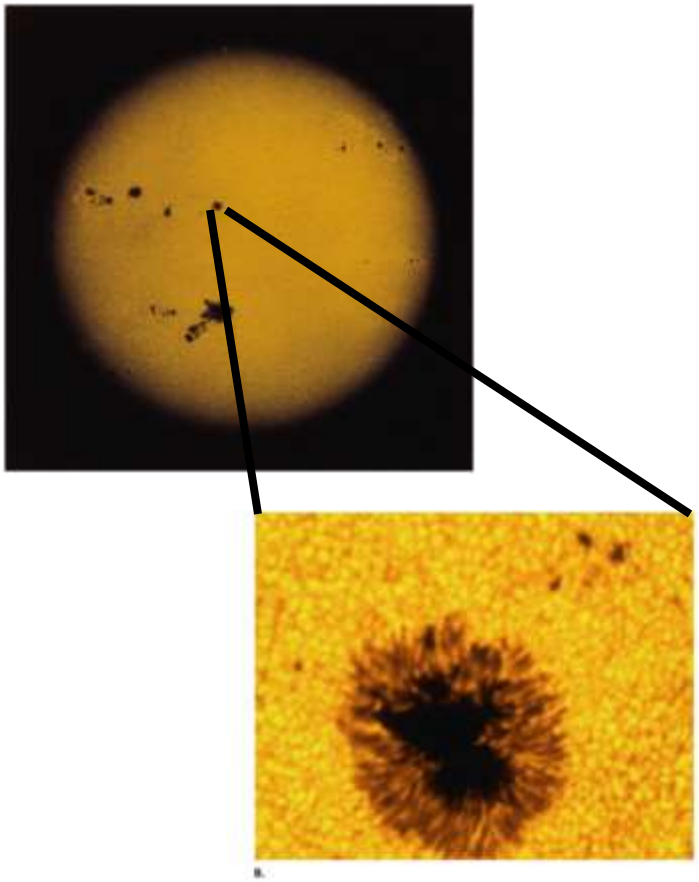
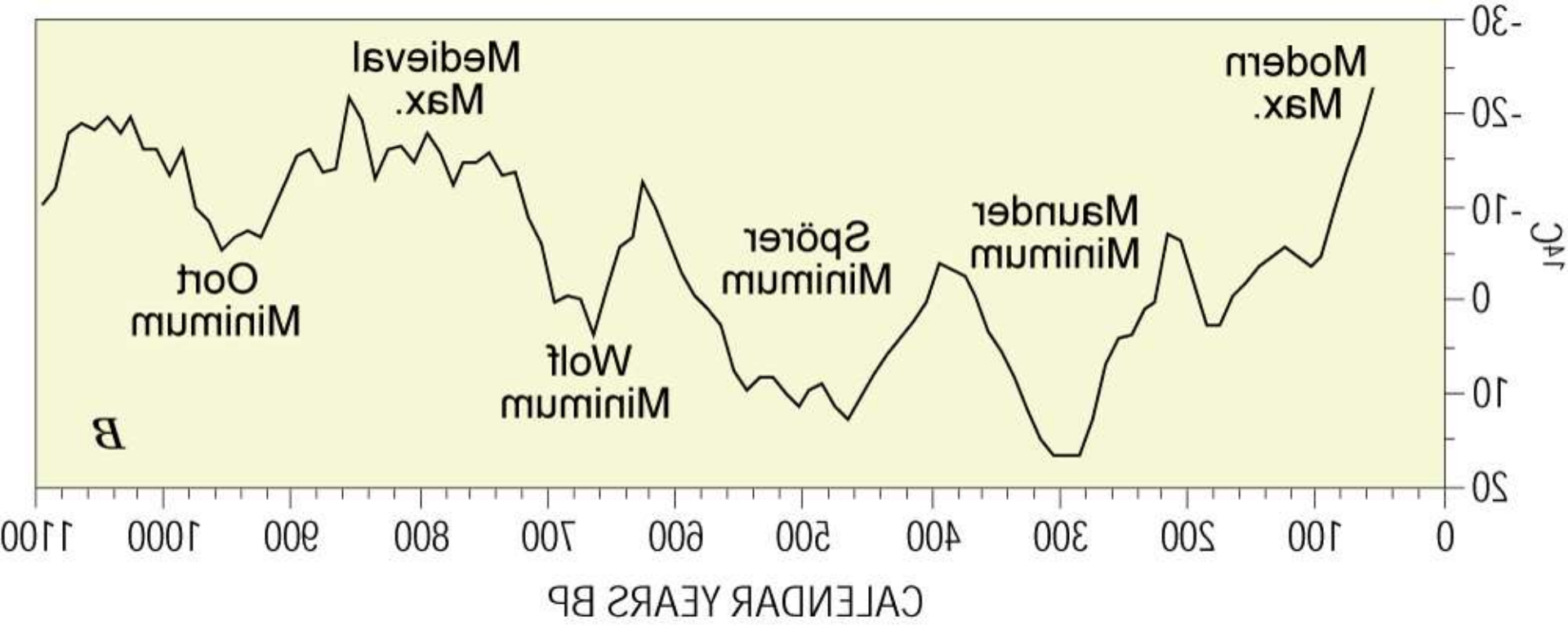
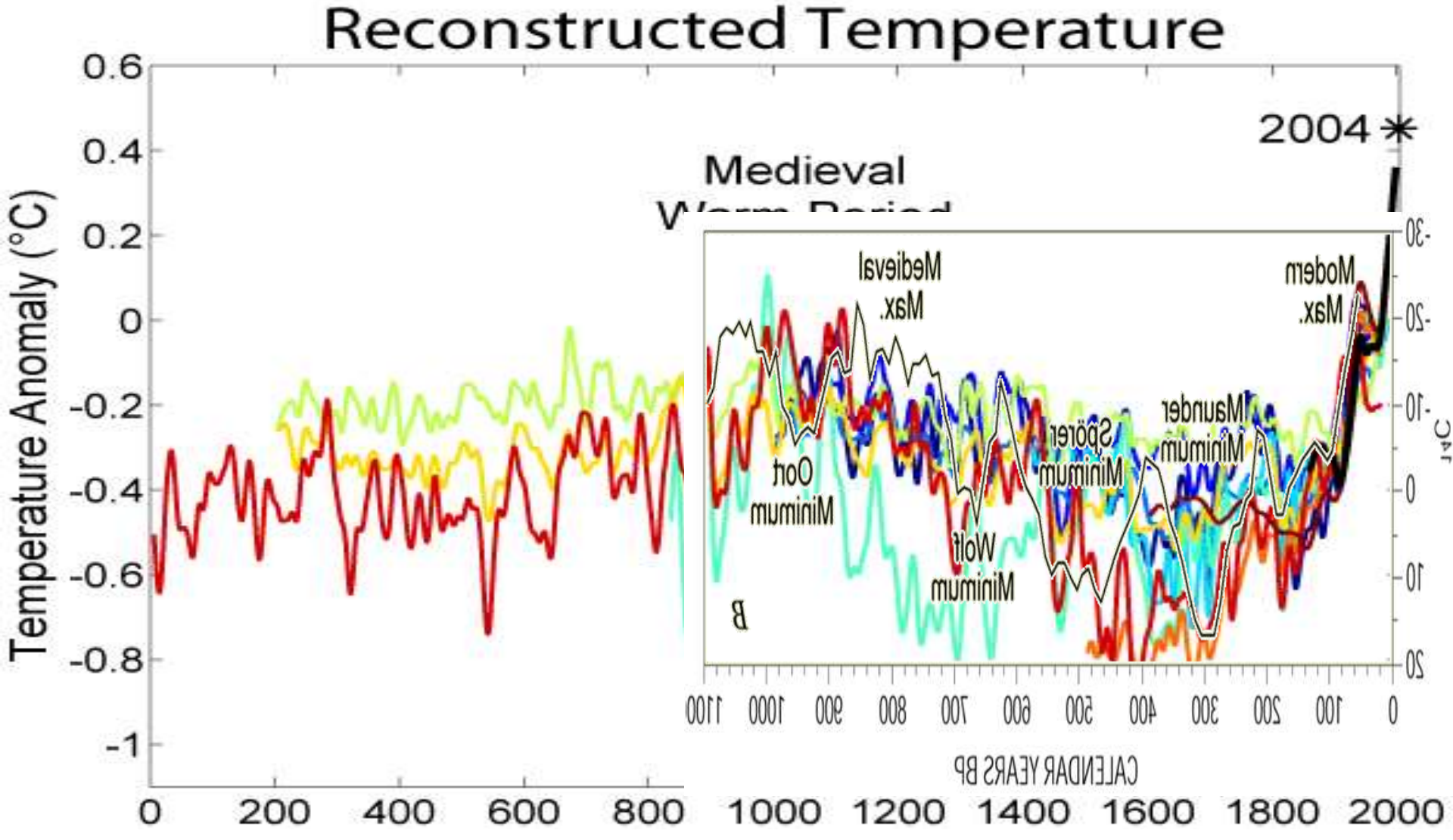




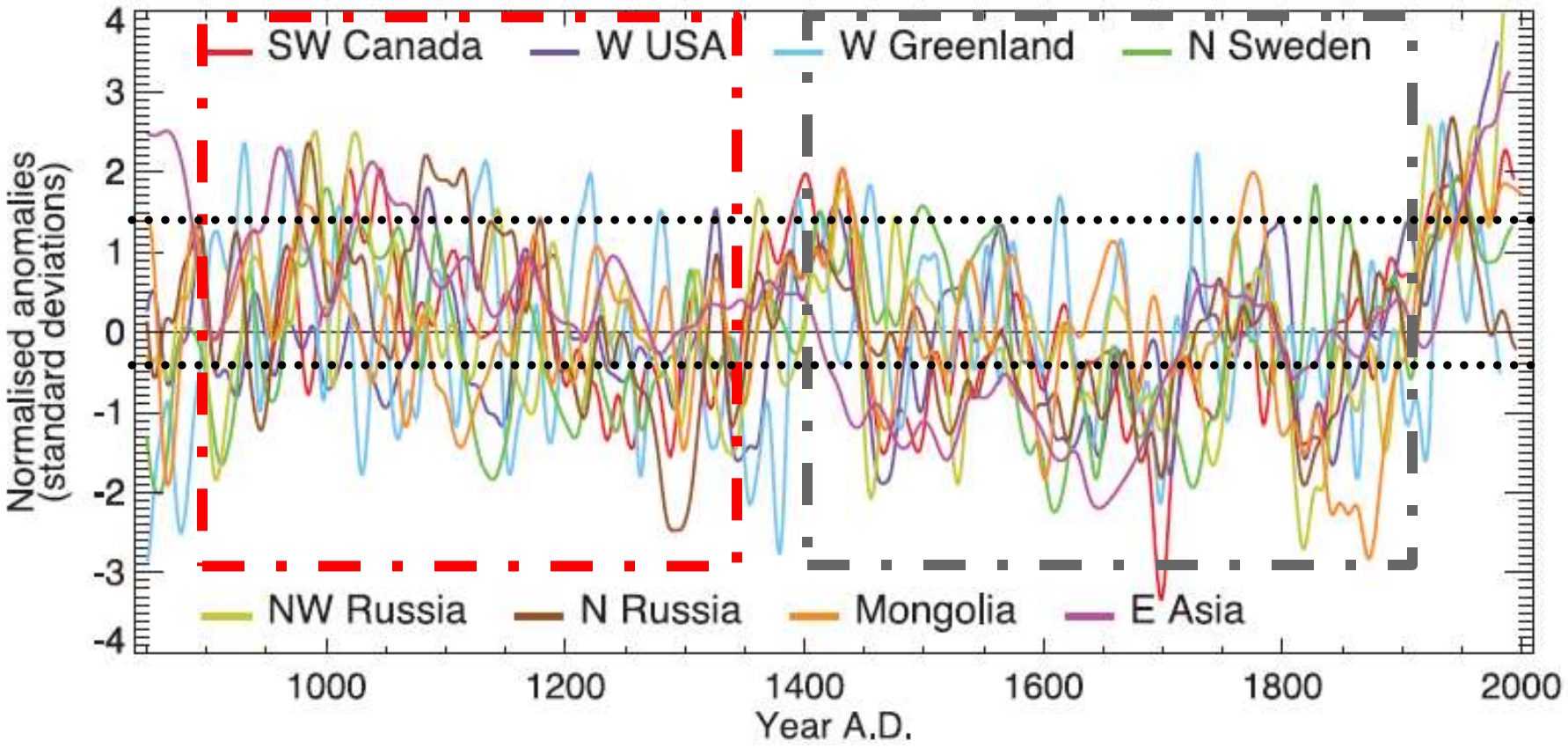
Low Solar Activity - LIA



The Little Ice Age (1400-1900)



Last 1500 years….



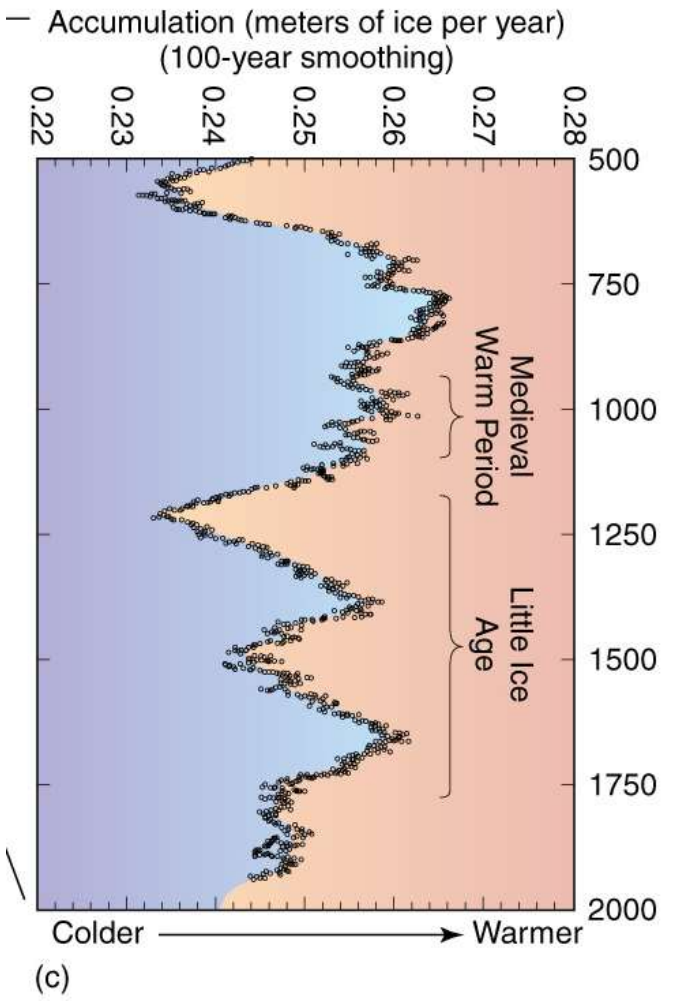
Northern Hemisphere

Image Credit: Robert A. Rohde, Global Warming Art

Data Credit: IPCC 2007

Medieval Warm Period (~800-1300)

- Scattered evidence exists in Europe and the high latitudes surrounding the North Atlantic.
  - Cultivation of Greenland & Iceland
  - Grapes in England?
  - Medieval temperatures were probably 1-2°C above early 20th century levels at various European locations
  - Evidence in Japan, Alaska
  - Regional in nature
    - There were both warmer and colder areas



- Drought was evident in western U.S. (Anasazi), Central America (Mayan) & Africa

Greenland

Farm Beneath the Sand
After three years of excavation, the Farm Beneath the Sand site began to take shape as rooms and passageways were revealed. It became clear that the front of the farm (to the right) had been eroded by the river; fortunately the river sands that covered the site had sealed it from the air and caused permafrost to preserve everything.

Greenland

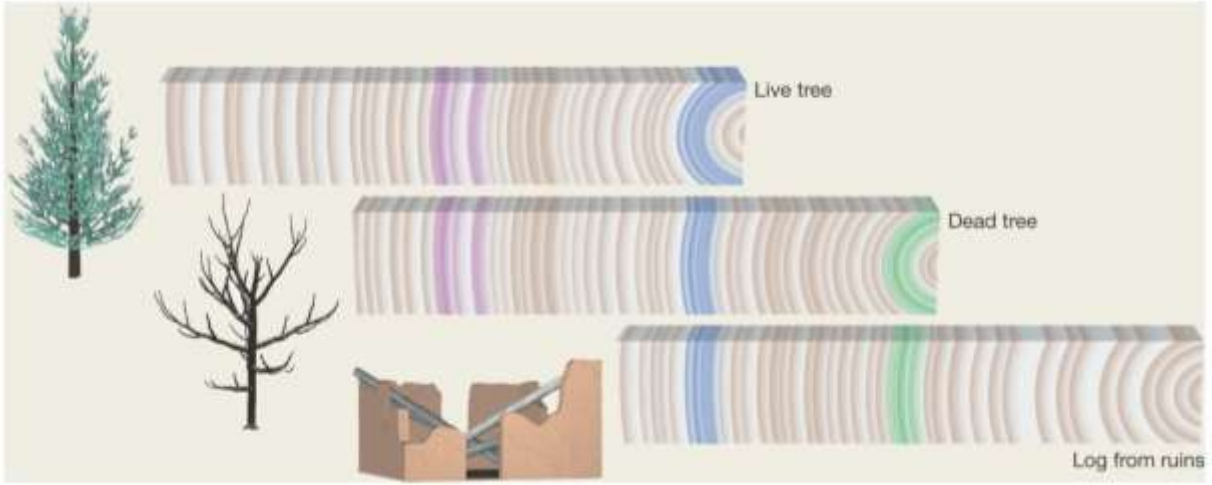
Thjodhildur's Church and Erik and Thjodhildur's Farmhouse.

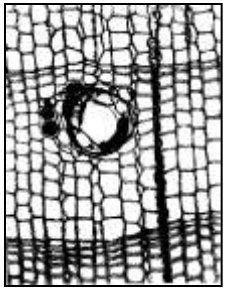
Hvalsey Church

Following the demise of the Western Settlement in the mid-fourteenth century, the Eastern Settlement continued for another one hundred years. In 1408 a wedding was recorded at the Hvalsey Church, but that was the last word to come from Greenland; after that was silence. The church stands today as a reminder of the perils of living too close to the edge in an unpredictable world. .

Tree-rings:

- annual layers of growth





http://web.utk.edu/~grissino/gallery.htm

Tree-Rings & US Drought

Cooke et al., 2007

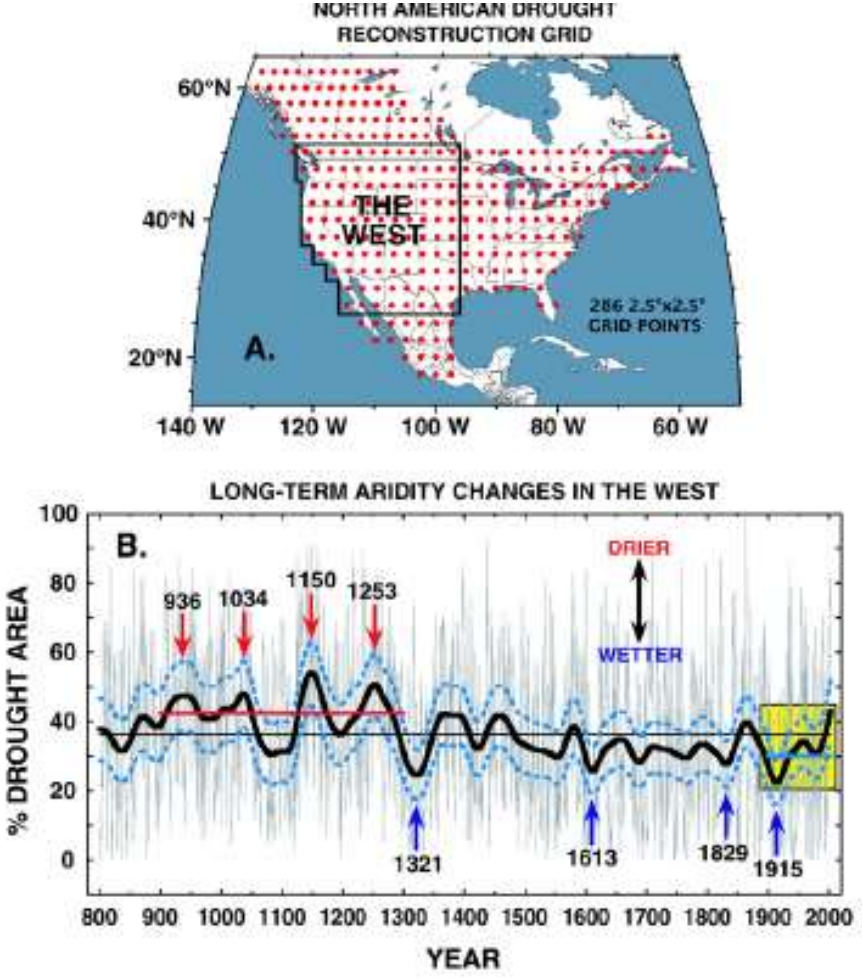


Fig. 10. Long-term aridity changes in the West (A) as measured by the percent area affected by drought (PDSI < −1) each year (B) (redrawn from Cook et al., 2004). The four most significant ($p < 0.05$) dry and wet epochs since AD 800 are indicated by arrows. The 20th century, up through 2003, is highlighted by the yellow box. The average drought area during that time, and that for the AD 900–1300 interval, are indicated by the thick blue and red lines, respectively. The difference between these two means is highly significant ($p < 0.001$).

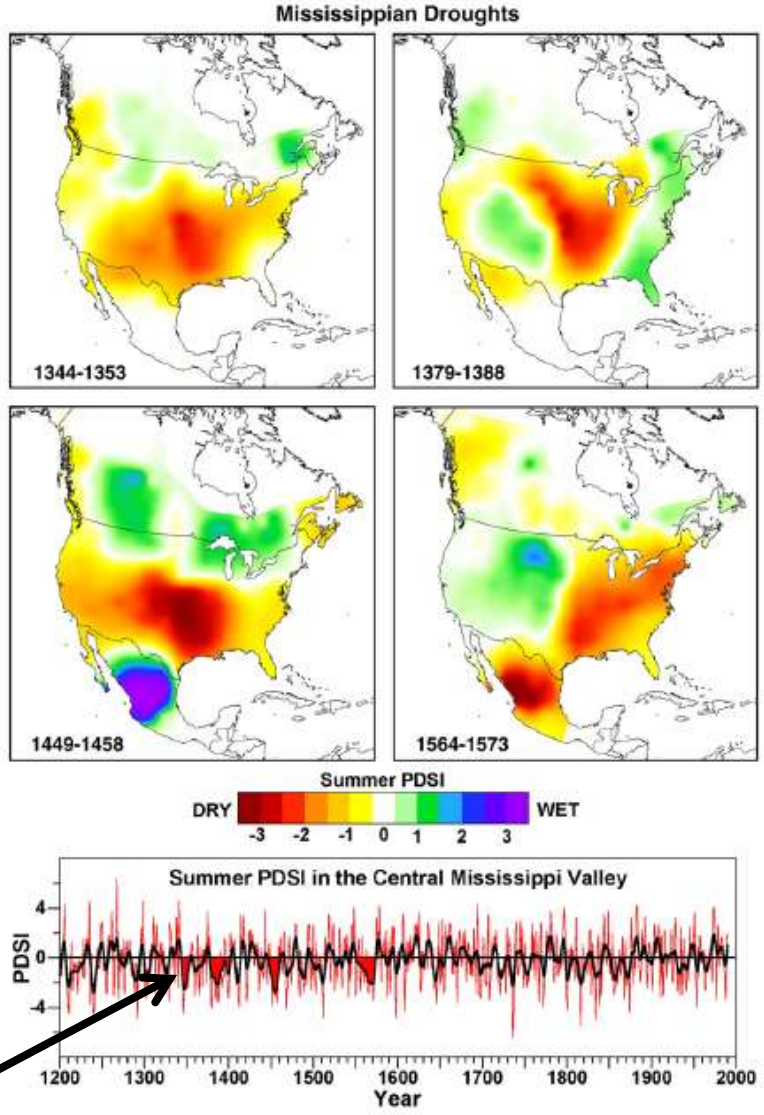


Fig. 12. Four intense decadal droughts over the central United States may have contributed to the syndrome of social and environmental change that resulted in the decline of complex Mississippian chiefdoms in the 14th and 15th centuries. The impacts of the 16th century drought (1564–1573) on native agriculturalists in South Carolina was mentioned by Spanish colonists at Santa Elena and may be relevant to earlier prehistoric drought impacts. The PDSI reconstructions for the central Mississippi Valley (time series for 37.5° N–90.0° W) indicate that the Mississippian droughts of the 14th, 15th and 16th centuries (red shading) may have been the most severe and sustained in 700 yr.

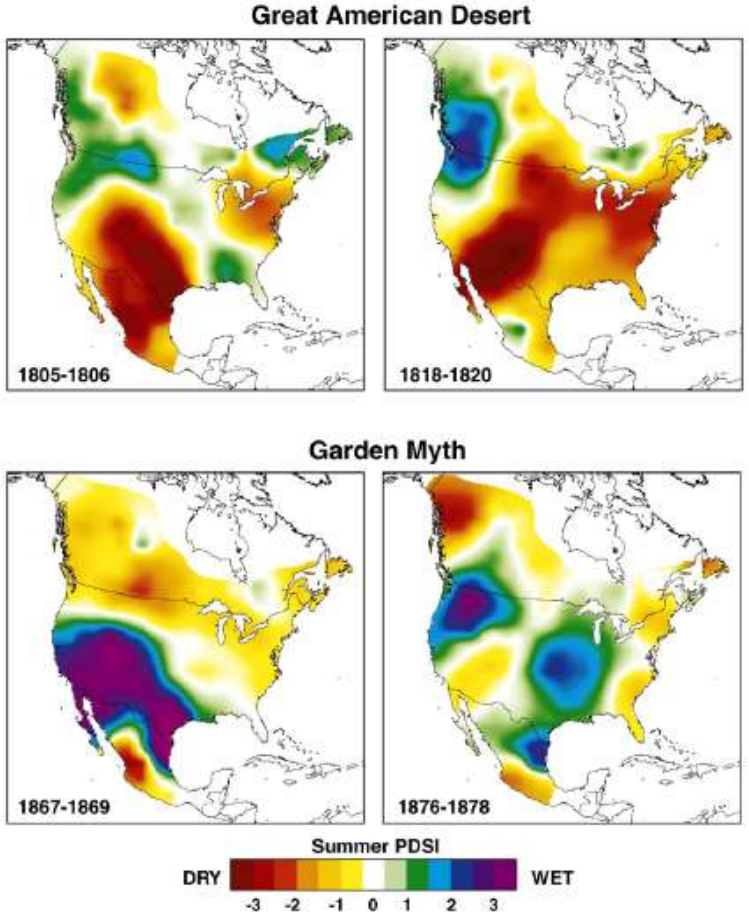
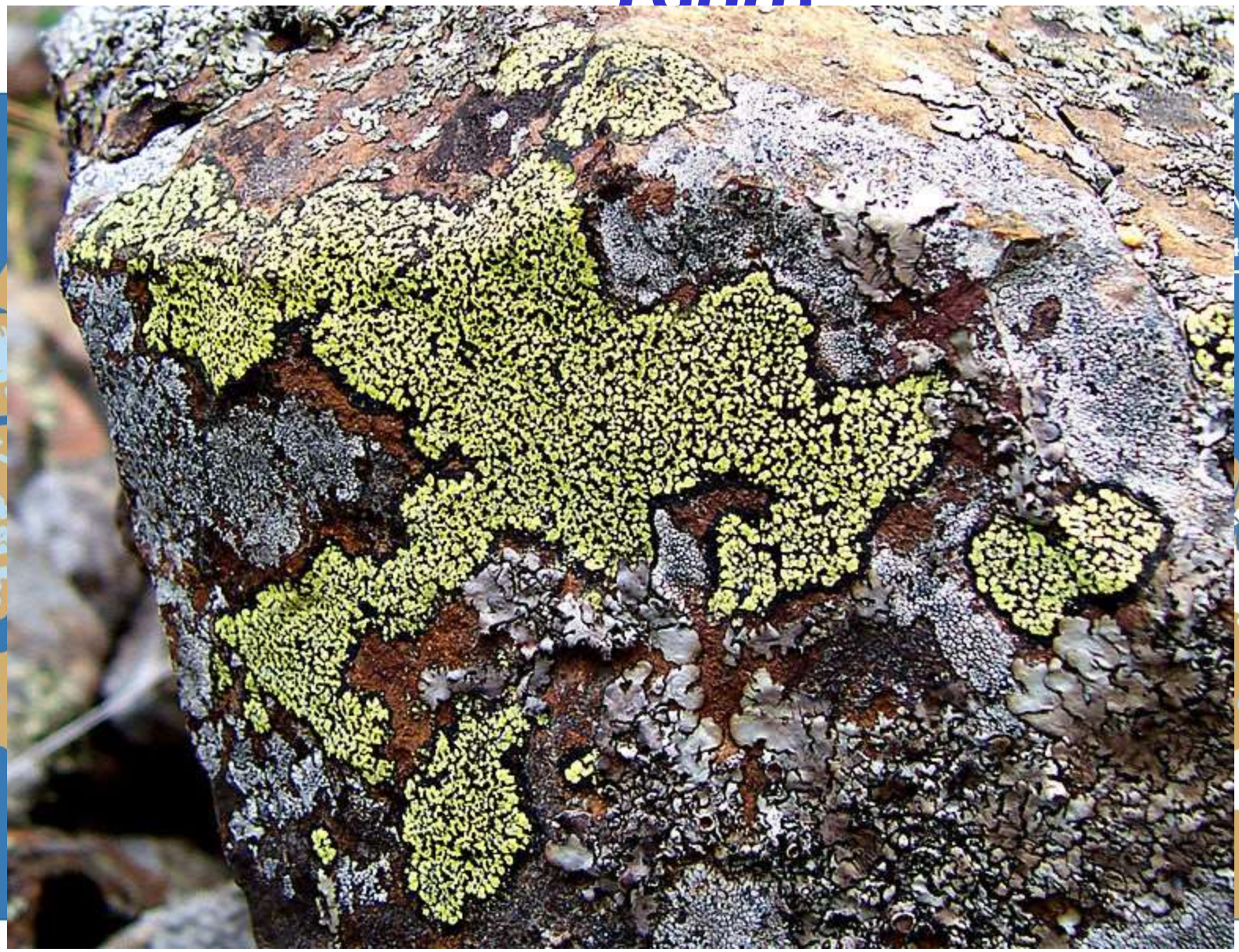


Fig. 13. Perceptions of the agricultural potential of the American West were influenced by prevailing climatic conditions (Lawson and Stockton 1981). The Pike expedition of 1806–1807 and the Long expedition of 1819–1820 both encountered extreme drought conditions which must have contributed to their descriptions of the "Great American Desert." Episodes of above average wetness in the 1860s and 1870s may also have helped boosters briefly promote the "Garden Myth of the Great Plains," before the return of drought to the Plains in the 1880s and 1890s.

Medieval Warm Period (~800-1300)

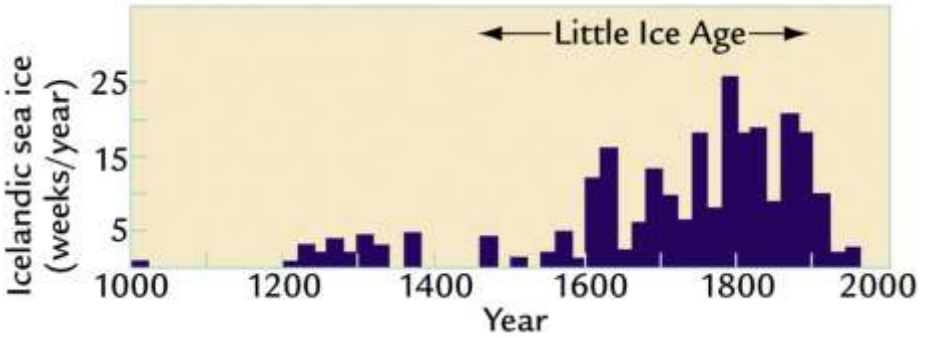
"Evidence is not sufficient to support a conclusion that hemispheric mean temperatures were as warm, or the extent of warm regions as expansive, as those in the 20th century as a whole, during any period in medieval times." (IPCC 2007)

The Little Ice Age (1400-1900)



Little Ice Age (1400-1900)

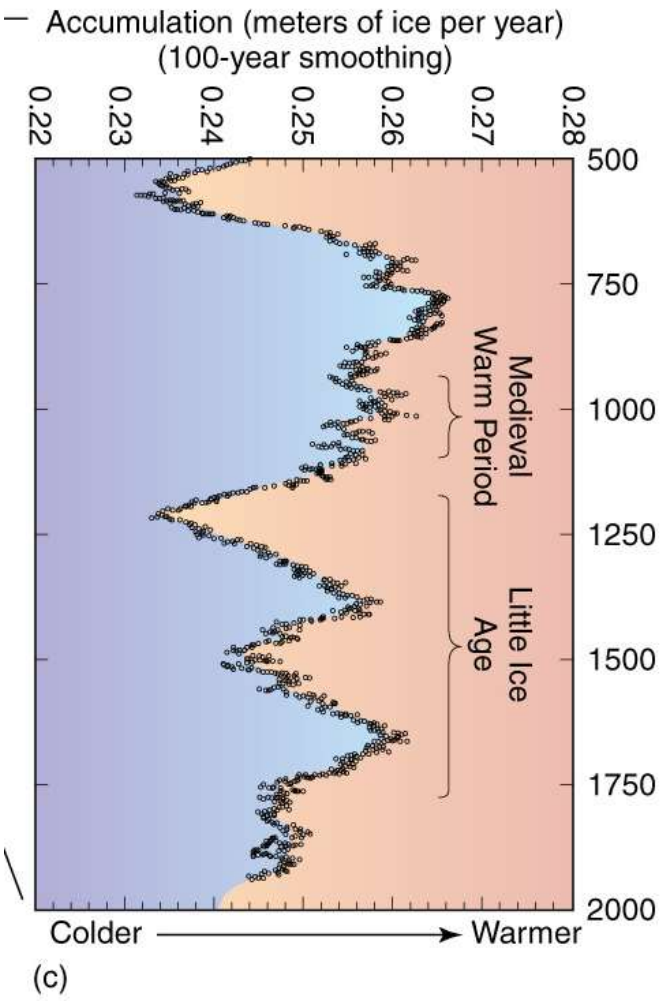
- A modest cooling of the Northern Hemisphere of less than 1°C
  - Glaciers grew in Europe (1000 m lower than in 1850s)
  - Sea ice expansion
- **Not** a **"true"** ice age: major ice sheets did not form
- Three minima, each separated by slight warming intervals beginning
  - About 1650
  - About 1770
  - About 1850



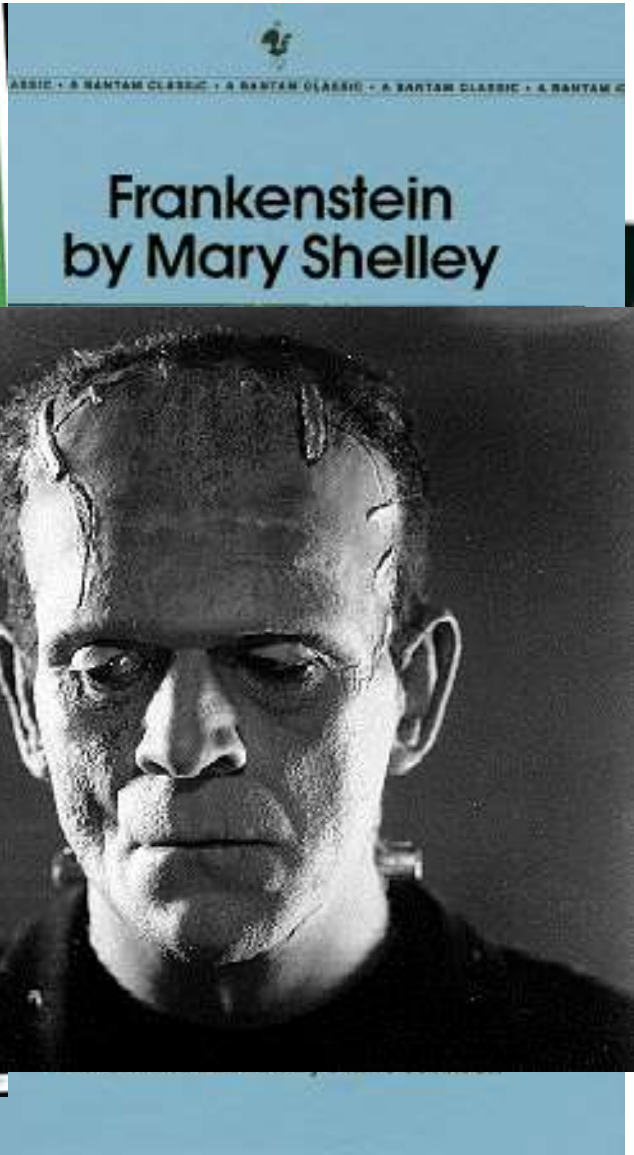
- Initially believed to be a global phenomenon; now less clear

Little Ice Age (1400-1900)

- Colder winters & shorter growing season meant crop failure and localized famine in northern regions of Europe
  - Great Famine of 1315-1317 (full recovery in 1322)
  - By the 1700s, cultivated land (MWP) in Iceland was covered by ice
  - 1816 – "the Year without a Summer"
- Settlements in Greenland were abandoned
  - Marginal climate?
  - Conflicts with native peoples?



816, Shelley, his wife & their friend Lord
, go to Lake Geneva for a summer holiday…

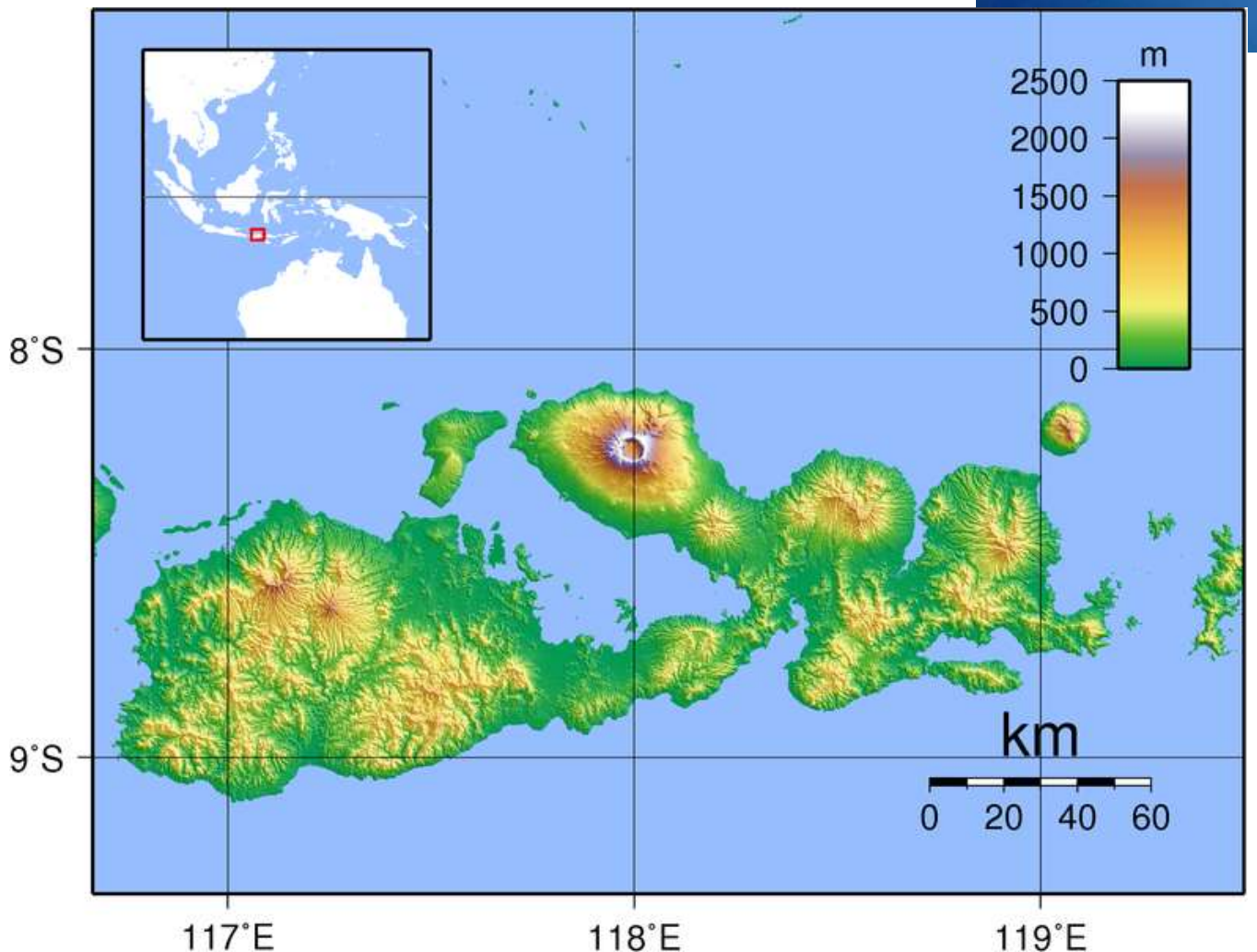


"Year Without a Summer" (1816)

"Darkness" by Byron

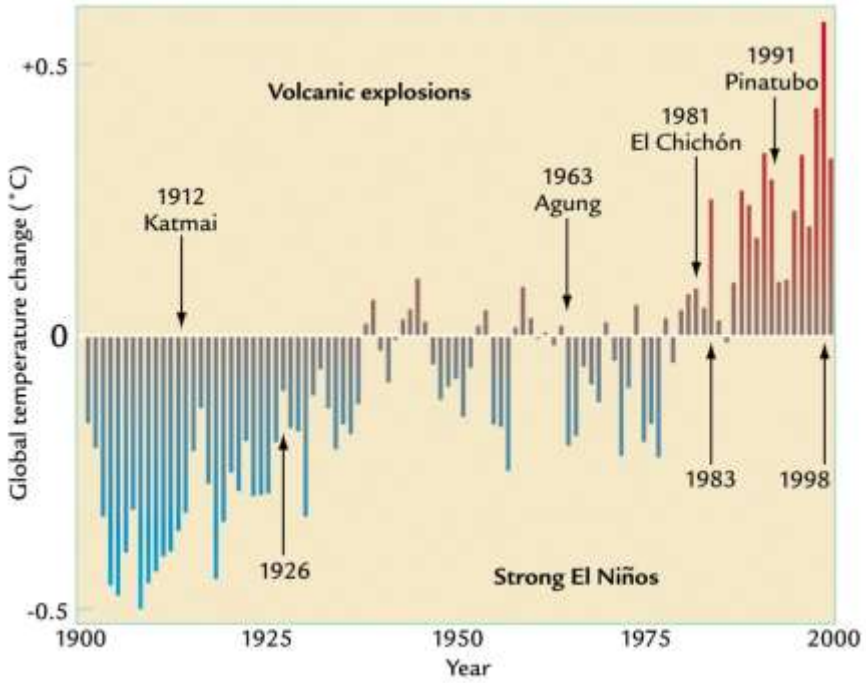
I had a dream, which was not all a dream.
The bright sun was extinguish'd, and the stars
Did wander darkling in the eternal space,
Rayless, and pathless, and the icy earth
Swung blind and blackening in the moonless air;
Morn came and went—and came, and brought no day,
And men forgot their passions in the dread
Of this their desolation; and all hearts
Were chill'd into a selfish prayer for light:
And they did live by watchfires—and the thrones,
The palaces of crowned kings—the huts,
The habitations of all things which dwell,
Were burnt for beacons; cities were consumed,
And men were gather'd round their blazing homes
To look once more into each other's face; . . .

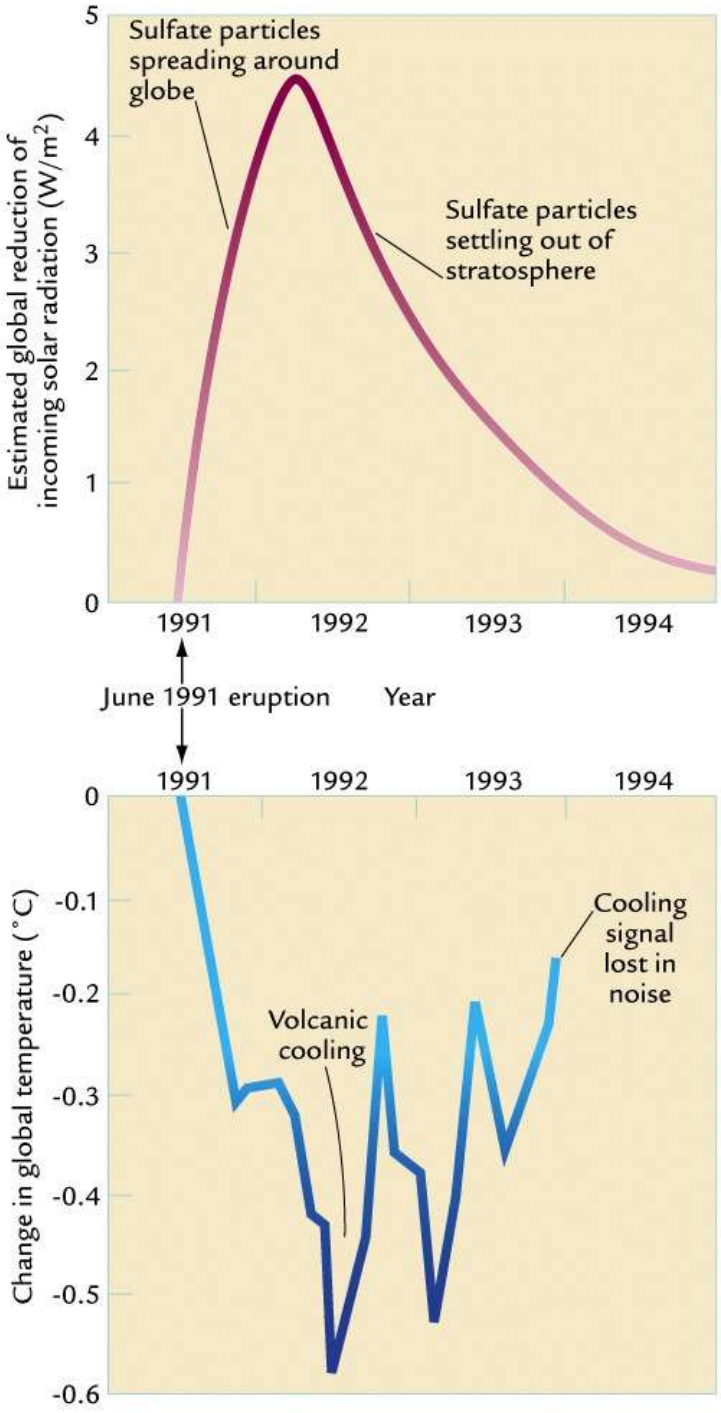
Tambora in 1815, together with an eruption from an unknown volcano in 1809, produced the "Year Without a Summer" (1816)



Volcanoes

- Eruptions:
  - Climate effects depend upon particle size, amount ejected, sulfur content & height materials reach
  - How does this cool climate?





Proposed causes of climate change from 1000-1850

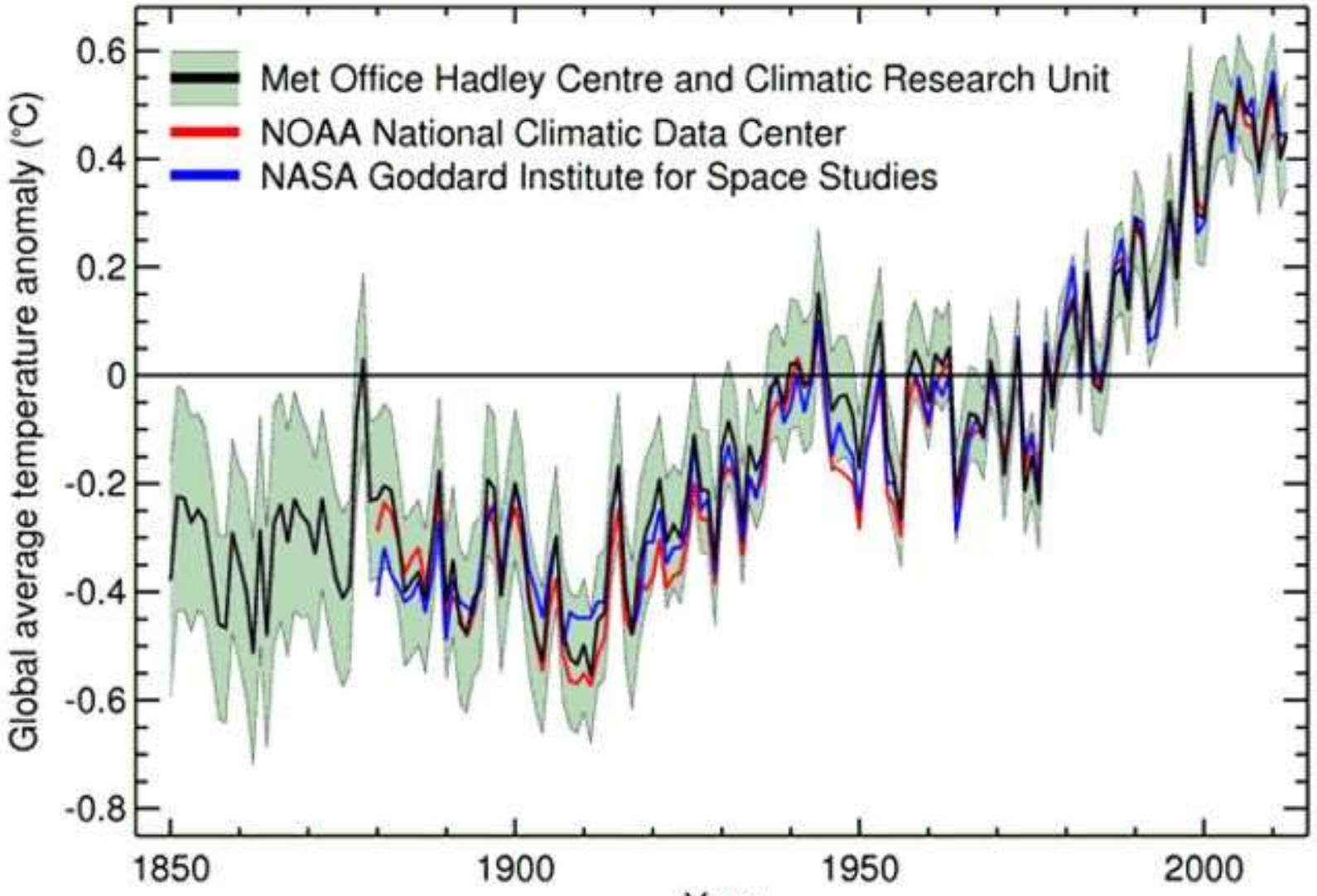
- Any or all of several factors could have played a causal role

- Far greater geographic coverage is needed to define the *global* climatic response
  - Notion of MWA & LIA is valid for trends across eastern Canada, Greenland, Iceland, northern Europe – what about rest of earth's surface (90-95%)?

- **<u>No such ambiguity</u> exists about the large, rapid and global warming since 1850**

Global Average Temperature, 1850-2012

(relative to the baseline of 1961-1990)

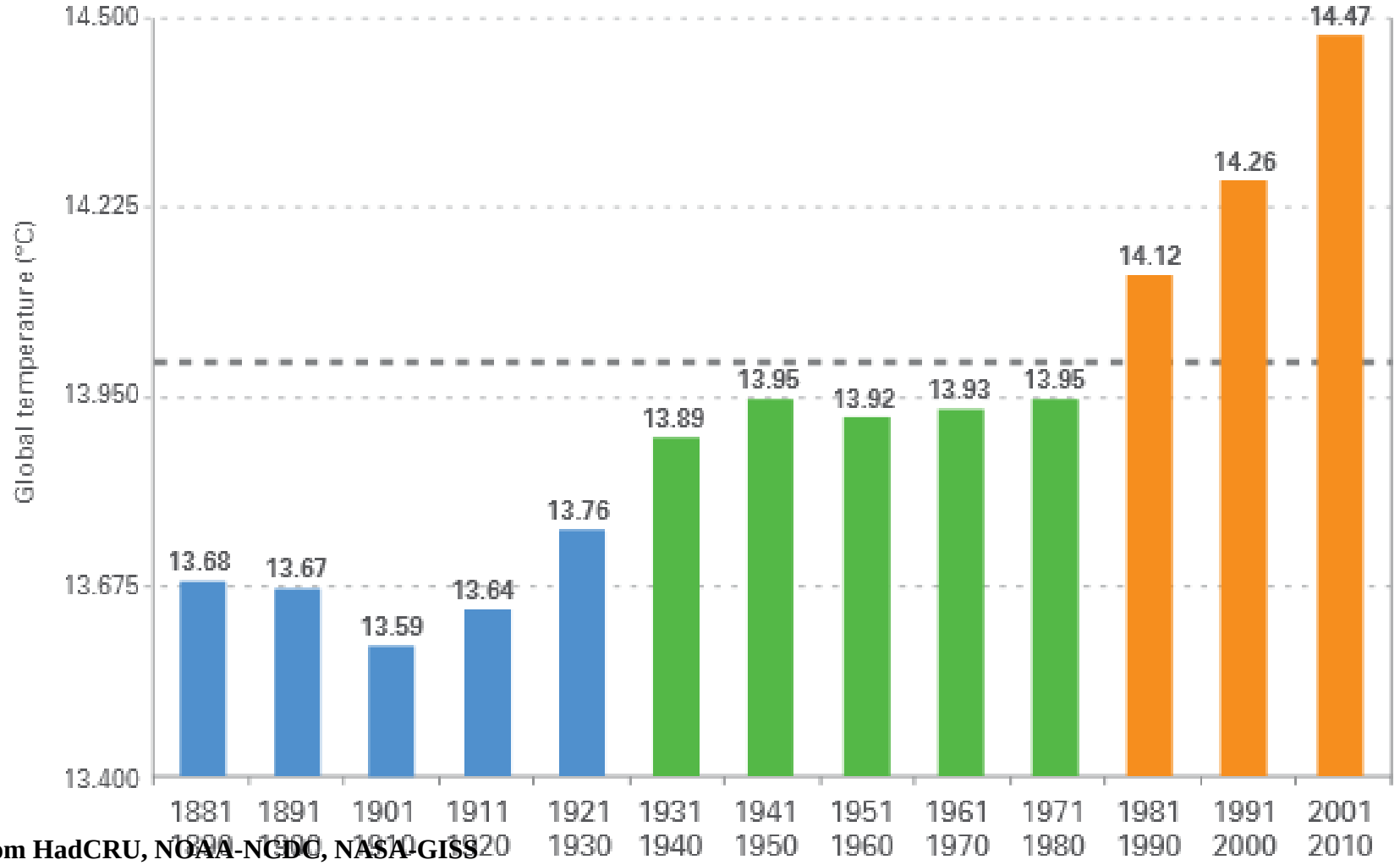


Source: *Met Office, United Kingdom*

1961-1990 had global mean average temperature of 14.0°C

Global Average Temperature, 1880-2010

(relative to the baseline of 1961-1990)

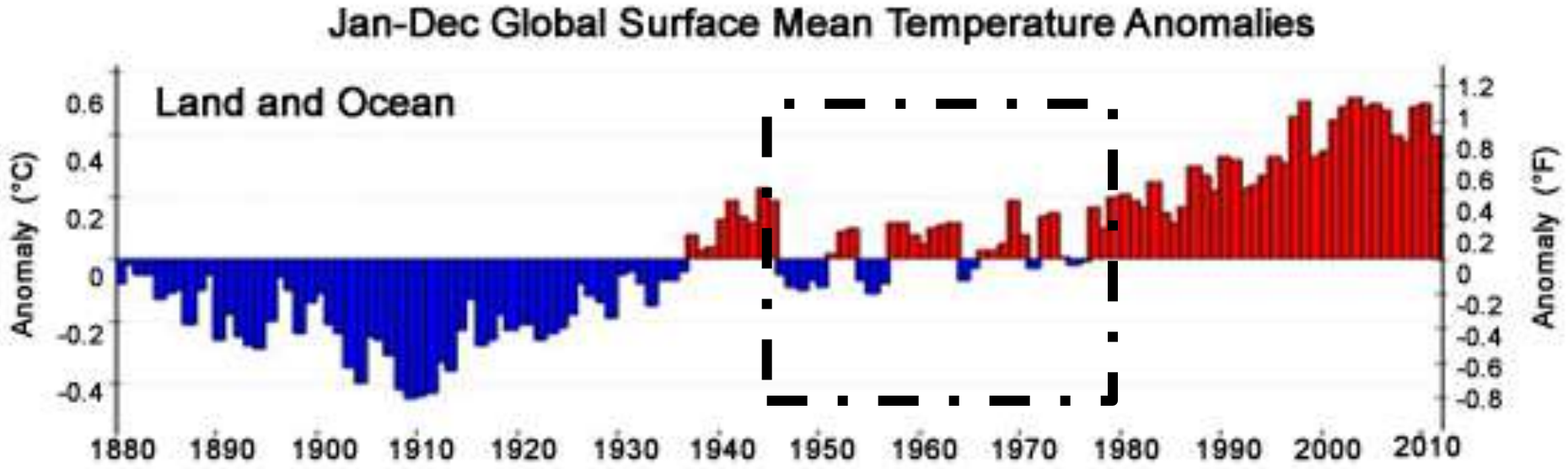


Data from HadCRU, NOAA-NCDC, NASA-GISS

Source: ***World Meteorological Organization, 2013***

1961-1990 had global mean average temperature of 14.0ºC

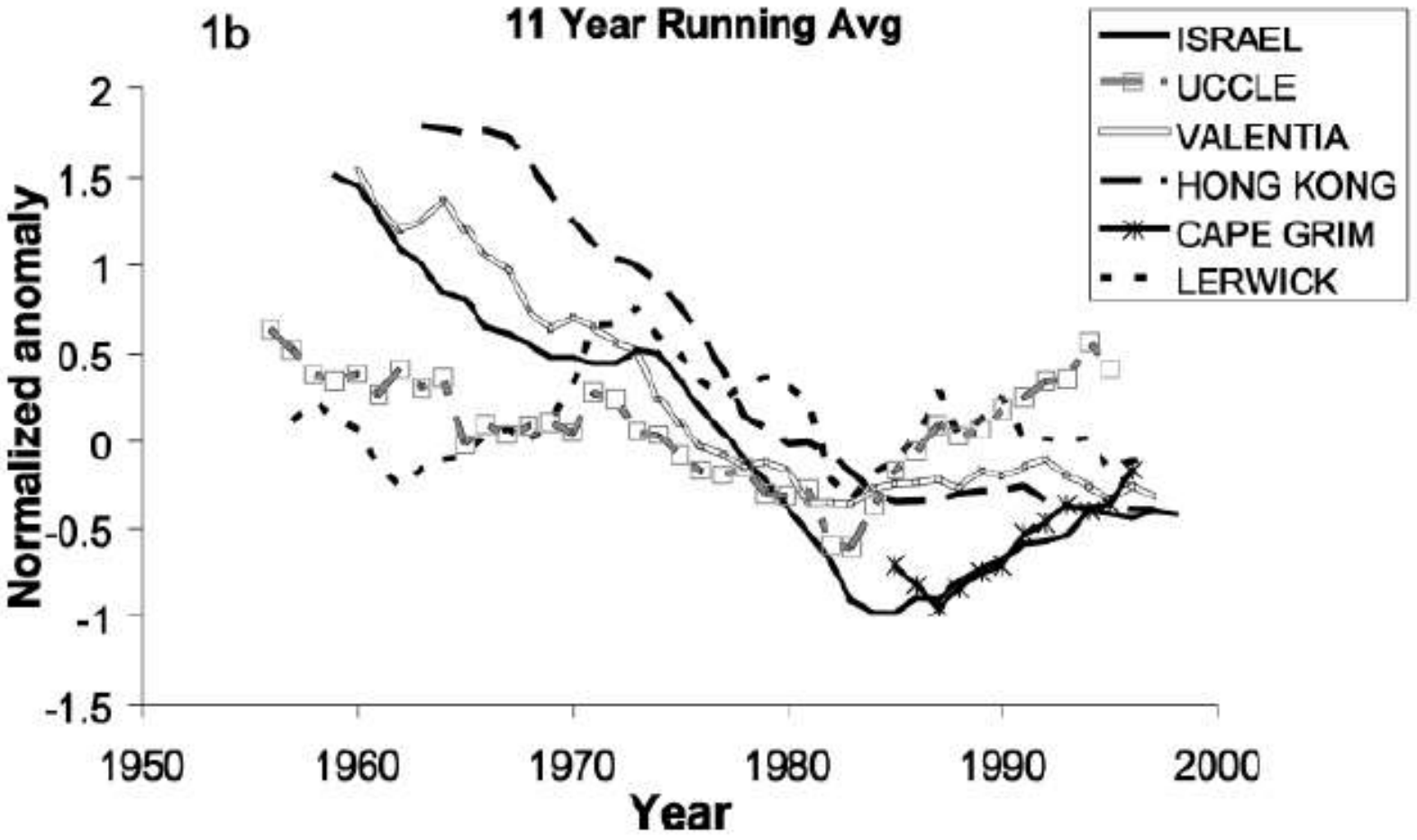
What about the cool temperatures from ~1945 to ~1980?



Global Dimming?

- **Global dimming** is the gradual reduction in the amount of global direct *irradiance* at the Earth's surface.
  - Measurements began in the 1950s.
    - Most data are from NH, and all taken on land
    - Data quality?
- Effect varies by location
  - Worldwide: ~4% reduction during 1960–1990

Anomalies in Annual Mean Incoming Shortwave Radiation

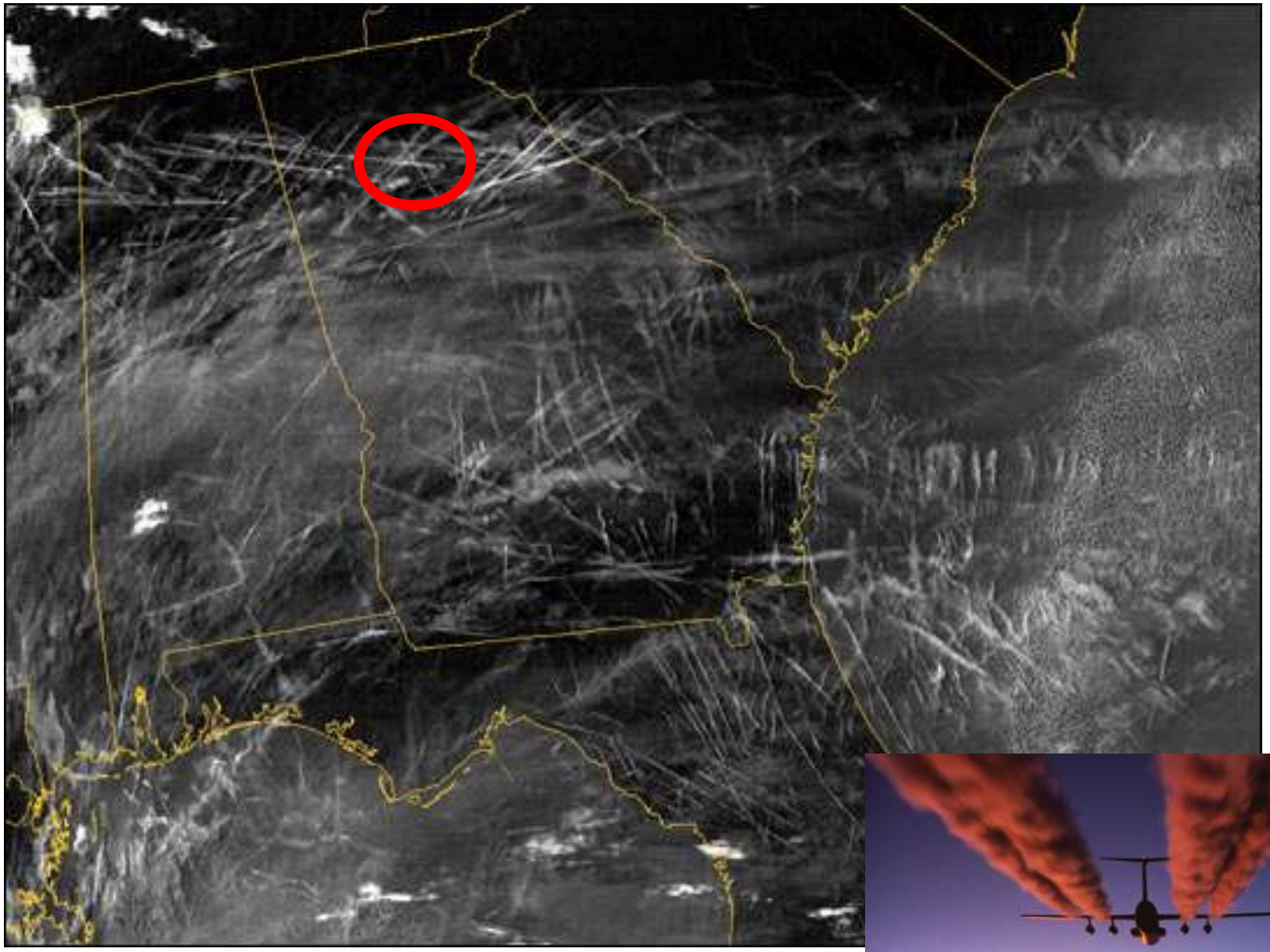


Where does it come from?

- Effect of global dimming is probably due *in part* to the increased presence of aerosol particles in the atmosphere.
  - Aerosol particles and other particulate pollutants reflect sunlight back into space.
  - Increased pollution, resulting in more particulates, creates clouds with a greater number of **smaller** droplets, making them more reflective.
- With global warming, there is a similar effect.
  - Water vapor and cloud feedback
    - Same effect as aerosols, but different cause

For more information: http://www.climate.noaa.gov/pdf/Aerosol_Factsheet_Sept_2009_FINAL.pdf

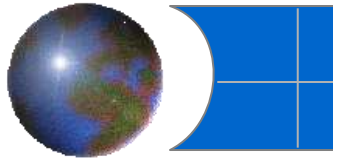
Aircraft Contrails, Jan 29 2004 MODIS

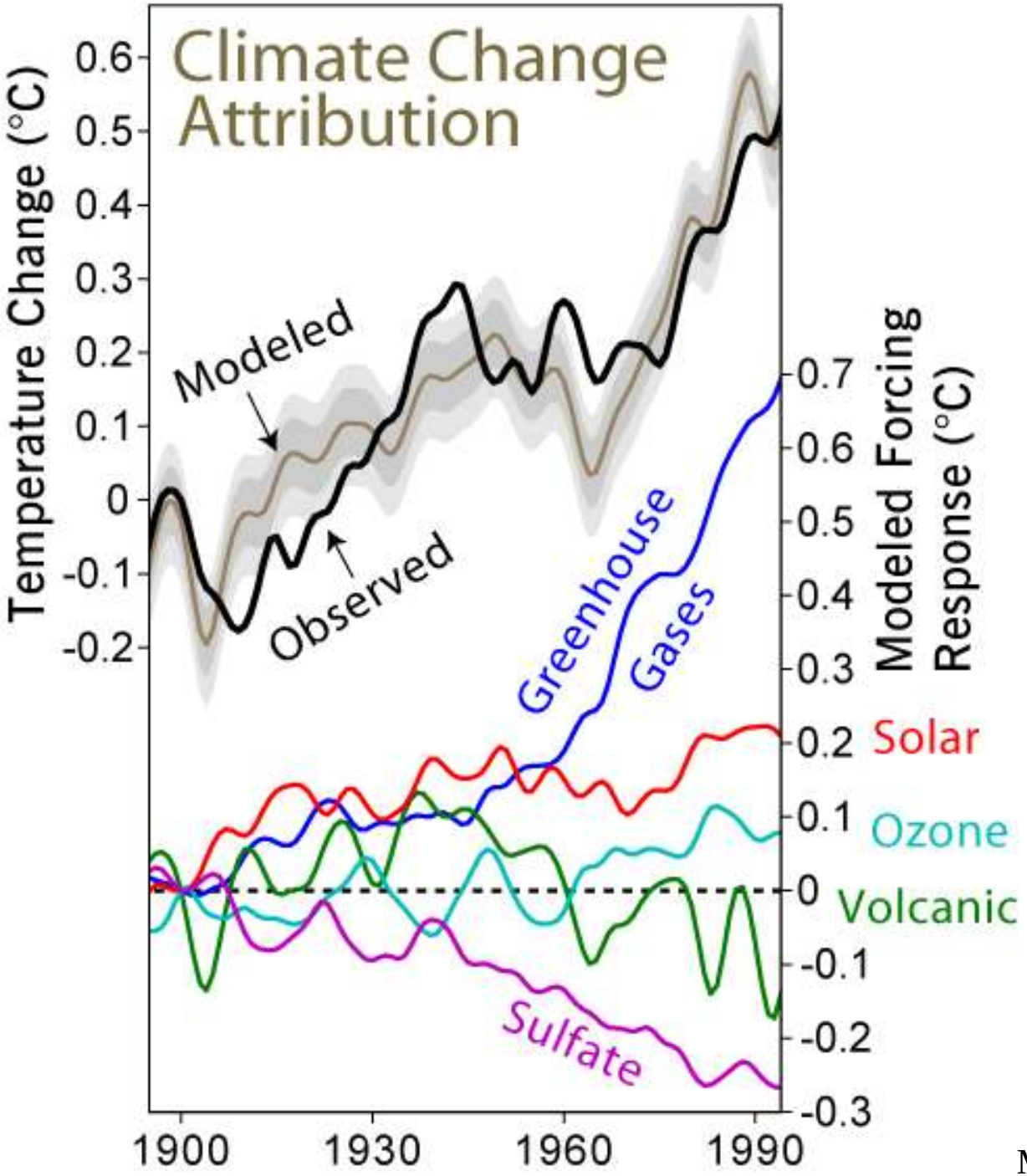


Aircraft Contrails over Europe

Effects are mostly regional

- Regions that are <u>downwind</u> from major sources of air pollution (specifically sulfur dioxide emissions) have generally cooled.
  - *may* help explain the cooling of the Eastern U.S. relative to the warming Western U.S.
  - examined effects in the Maldives
- *Extreme* regional effect
  - the Sahel

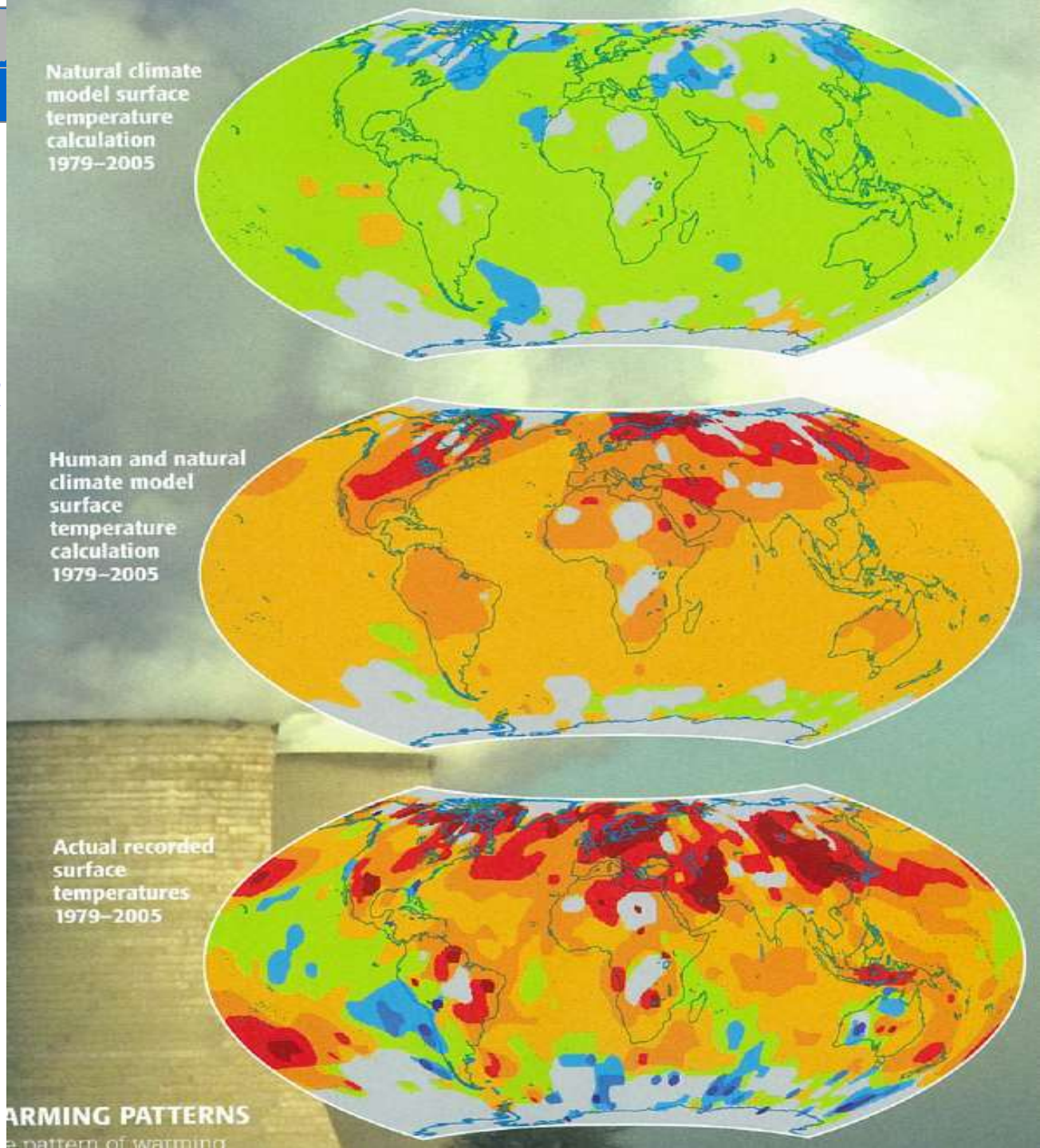


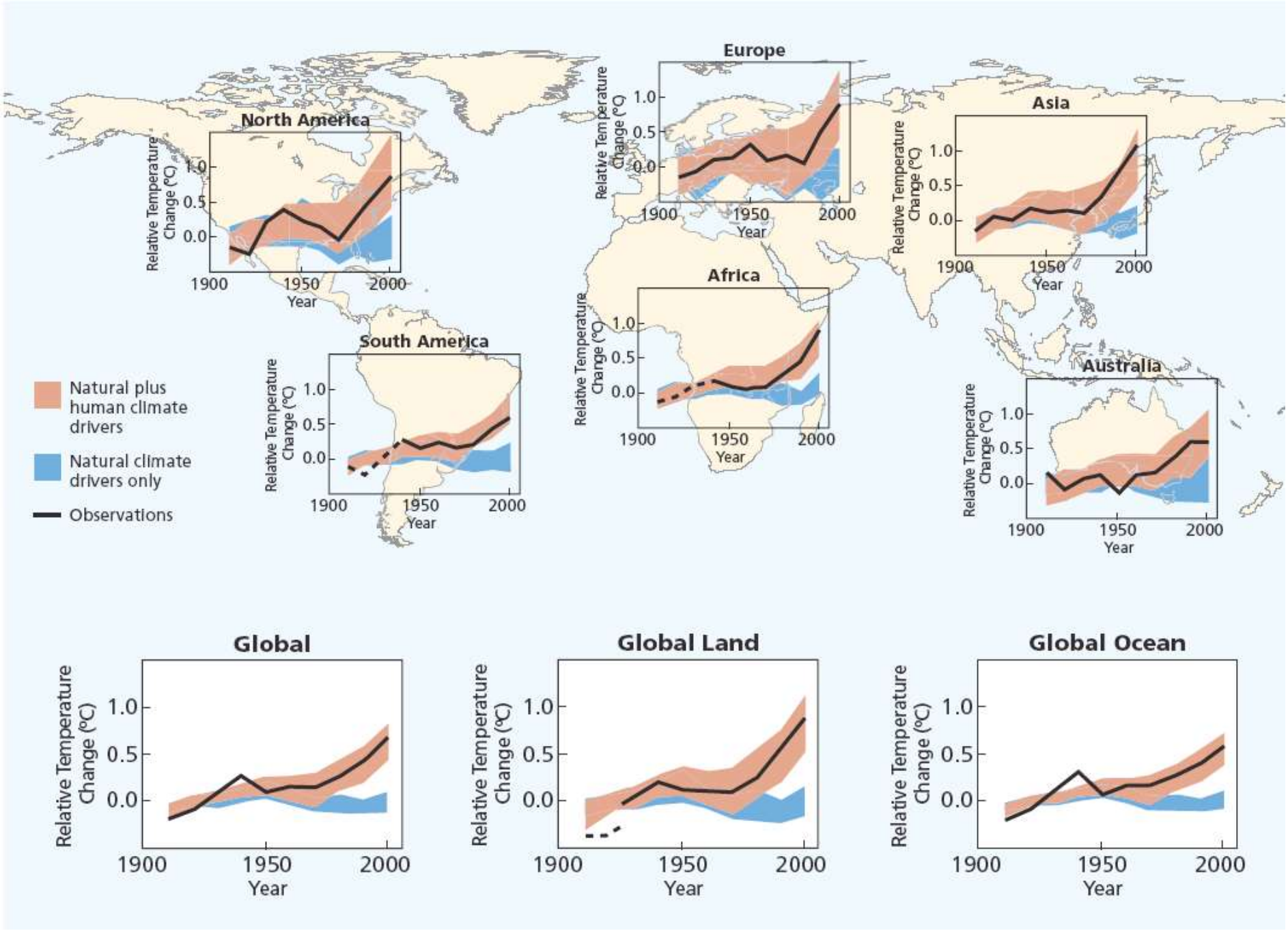


Meehl et al., 2004

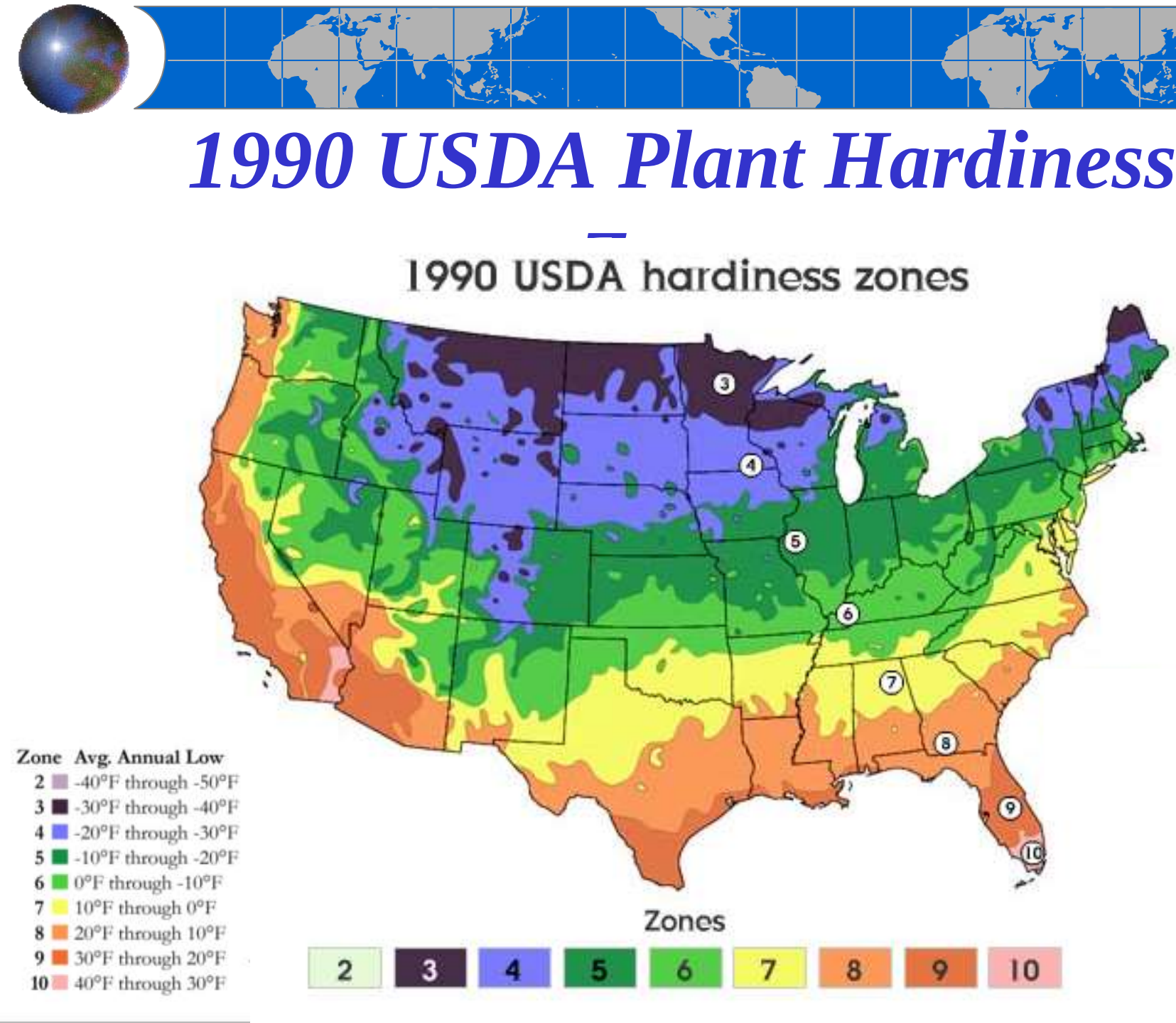
"Fingerprints"

Human and Natural Impacts on Climate, 1975-2005



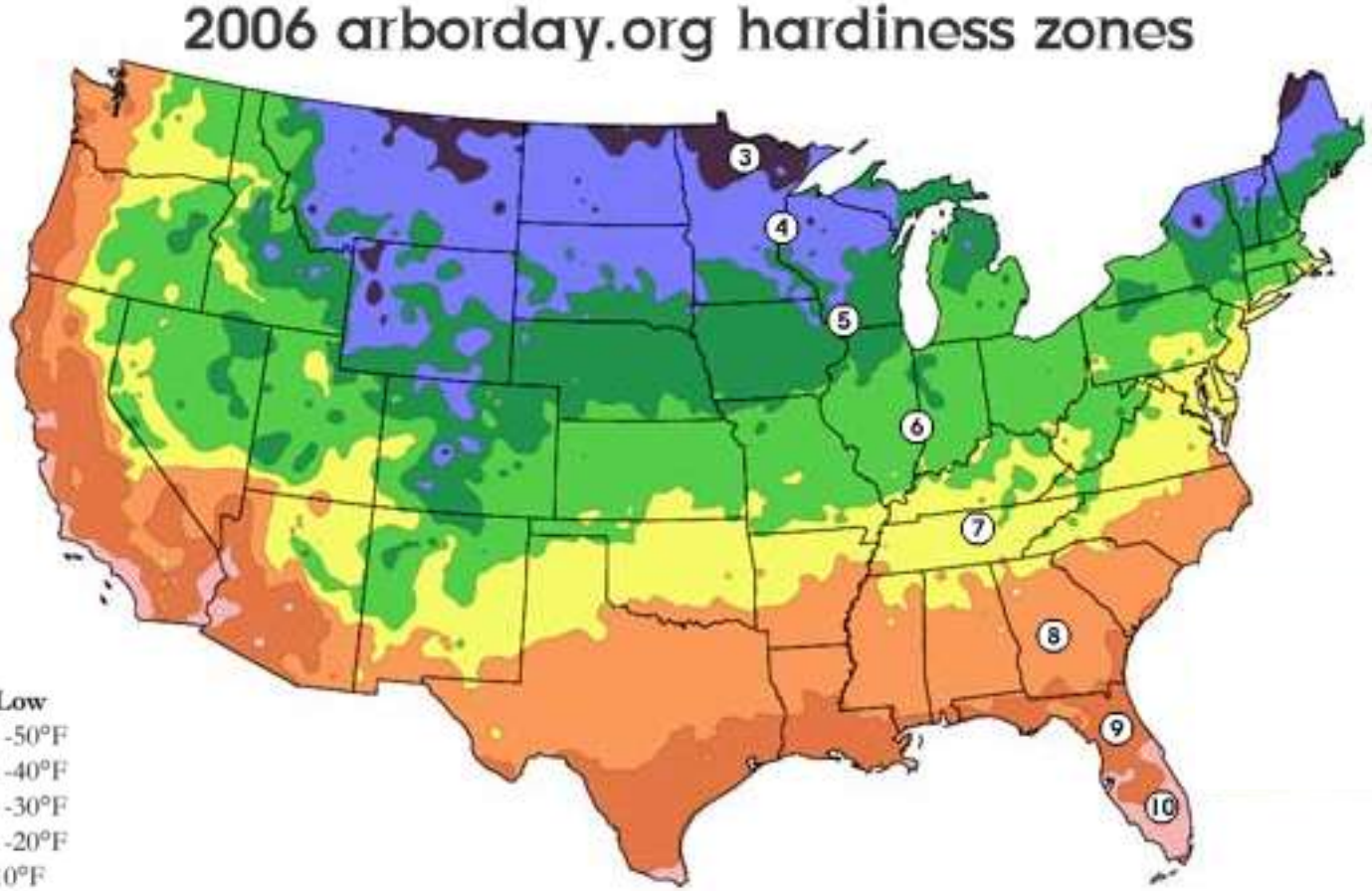

North America
Europe
Asia
Africa
South America
Australia
Relative Temperature Change (°C)
1.0
0.5
0.0
1900
1950
2000
Year
Natural plus human climate drivers
Natural climate drivers only
Observations
Global
Global Land
Global Ocean

1990 USDA Plant Hardiness



Zone	Avg. Annual Low
2	-40°F through -50°F
3	-30°F through -40°F
4	-20°F through -30°F
5	-10°F through -20°F
6	0°F through -10°F
7	10°F through 0°F
8	20°F through 10°F
9	30°F through 20°F
10	40°F through 30°F

2006 Arbor Day Foundation



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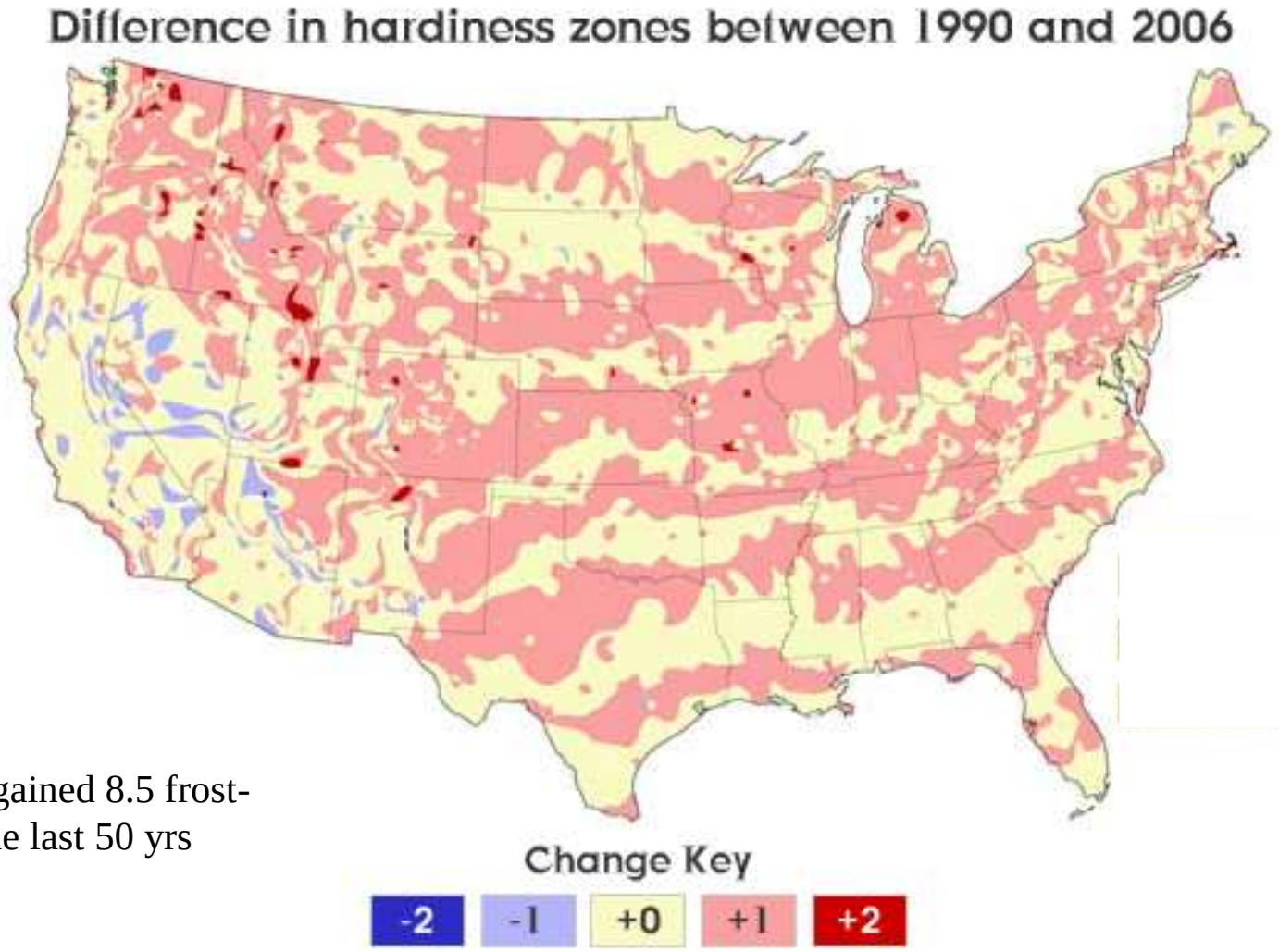
Change between 1990 and 2006

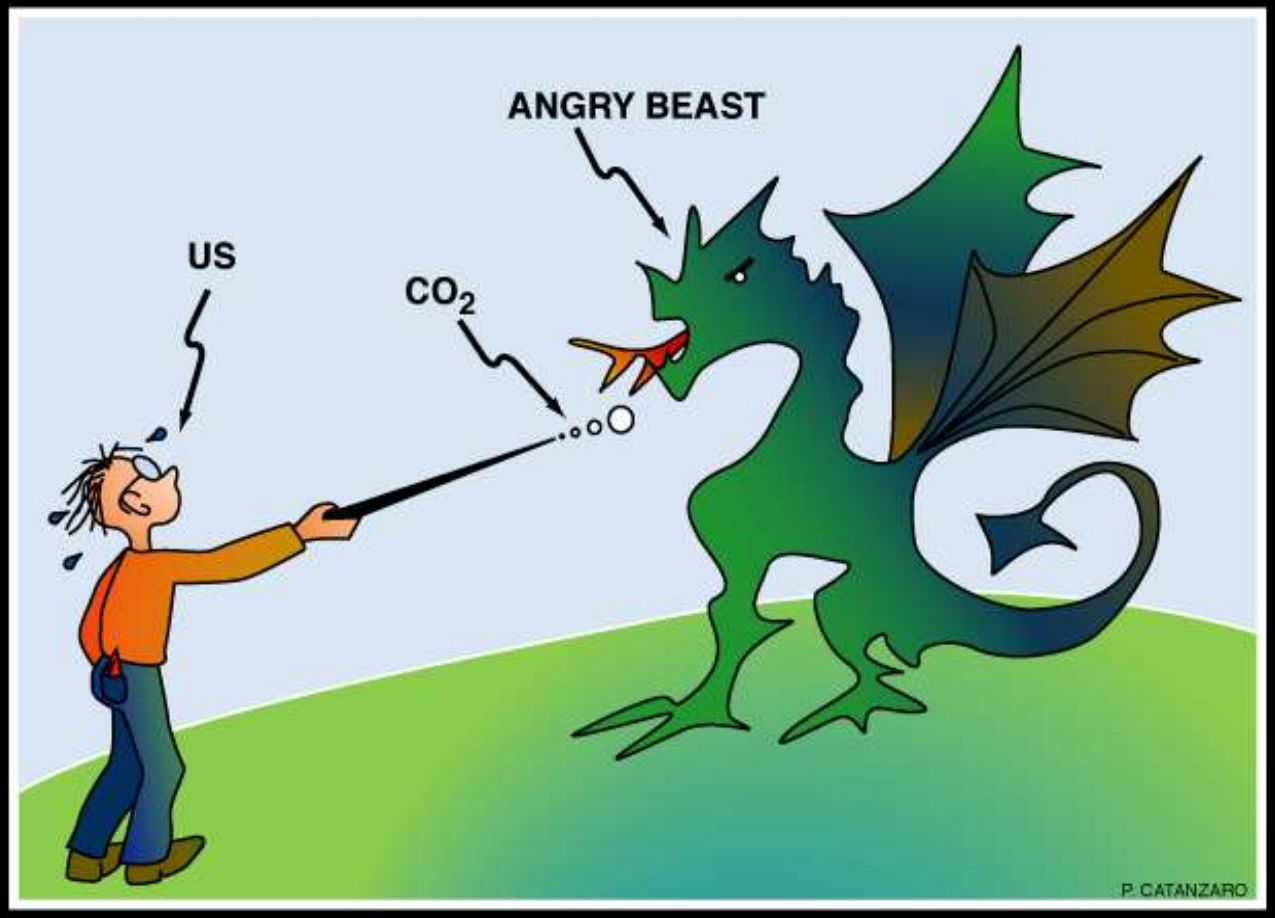


Montana has gained 8.5 frost-free days in the last 50 yrs

Take Home

- Proxy data is very important to our understanding of climate.
- We are improving our ability to read these signals and what they tell us about the Earth's past.
- They are revealing a complicated but fascinating story about our Earth's climatic evolution.
- We still have a great deal to learn.

FOSSIL FUEL CO_2 AND THE ANGRY CLIMATE BEAST



W.S. BROECKER

Additional Courses

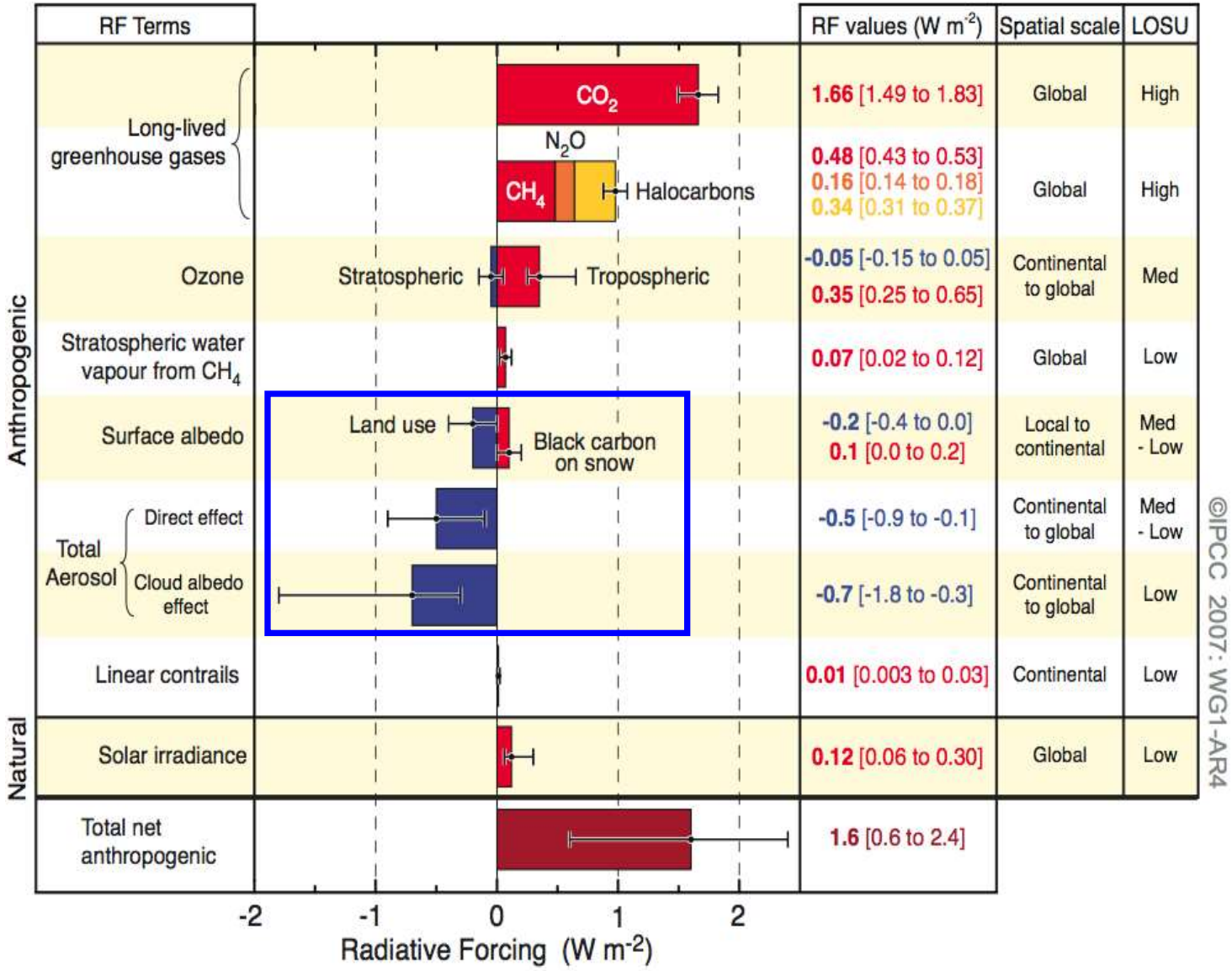
- GEOS 108N – Climate Change: Past & Future
- ERTH 303N – Weather & Climate
- GEOS 382 – Global Change
- FOR 407 – Biogeochemistry
- GPHY 550 – Seminar in Paleoclimate & Global Change

Resources

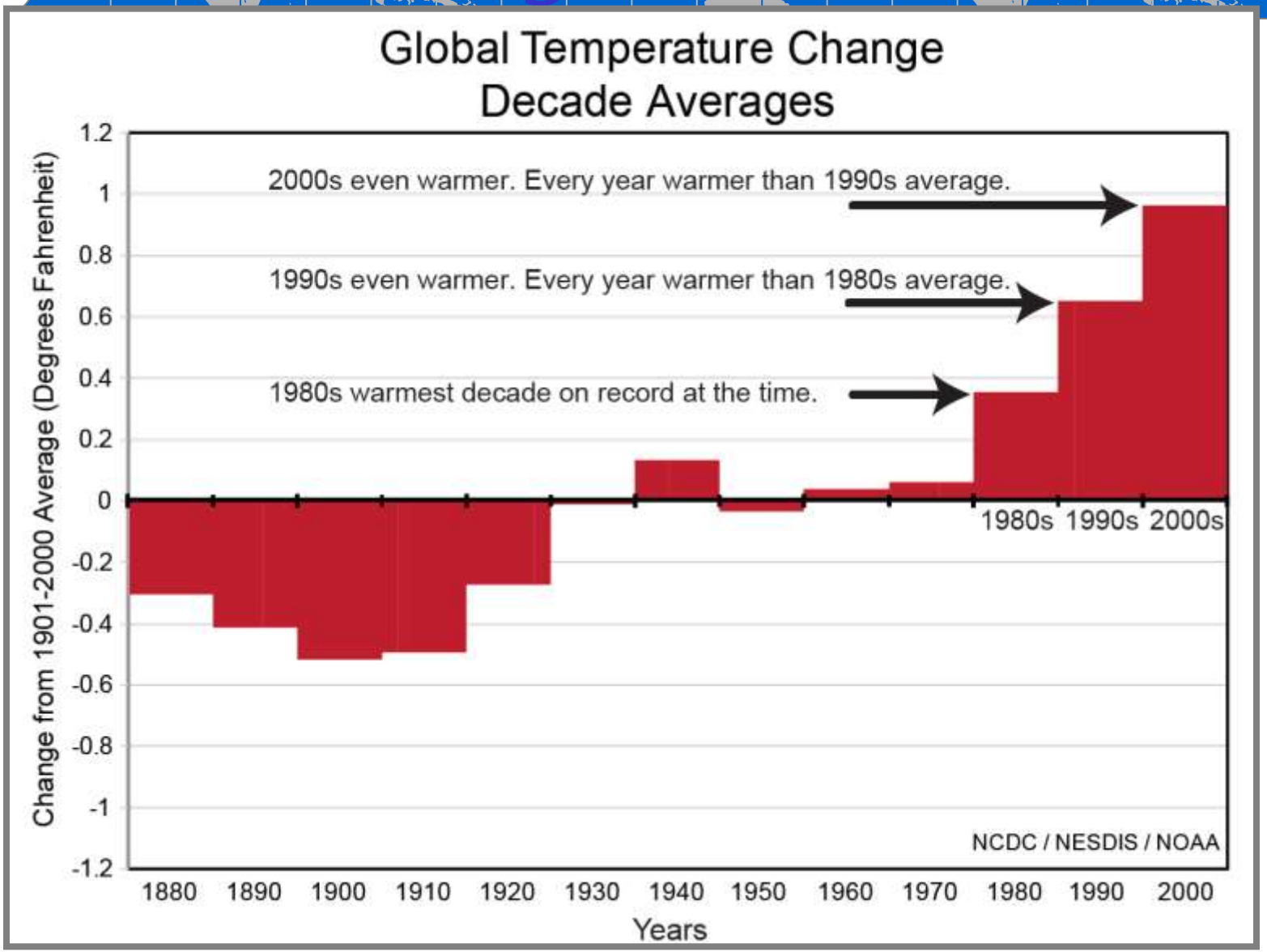
- W. Ruddiman. *Earth's Climate: Past and Future*. 2008. W.H. Freeman.
- E.C. Pielou. *After the Ice Age: The Return of Life to Glaciated North America*. 1992. University of Chicago Press.
- Broecker & Kunzig. *Fixing Climate*. 2008. Hill & Wang.

Human and Natural Drivers of Climate Change

Radiative Forcing Components



Setting Records?

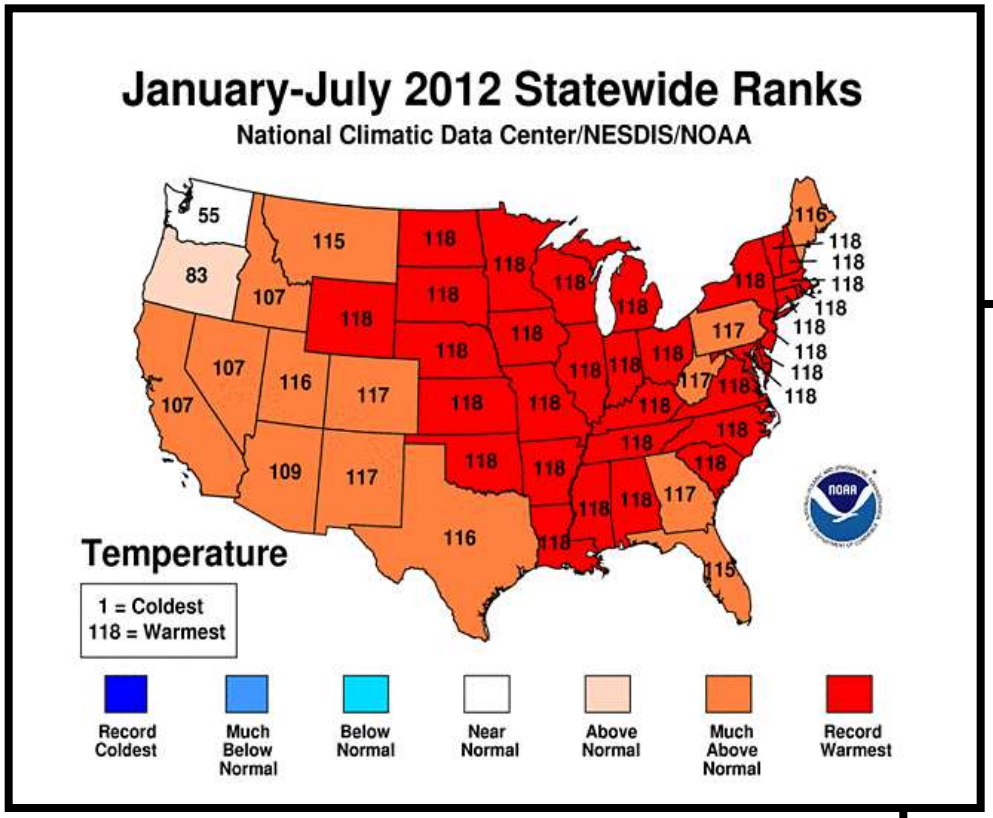


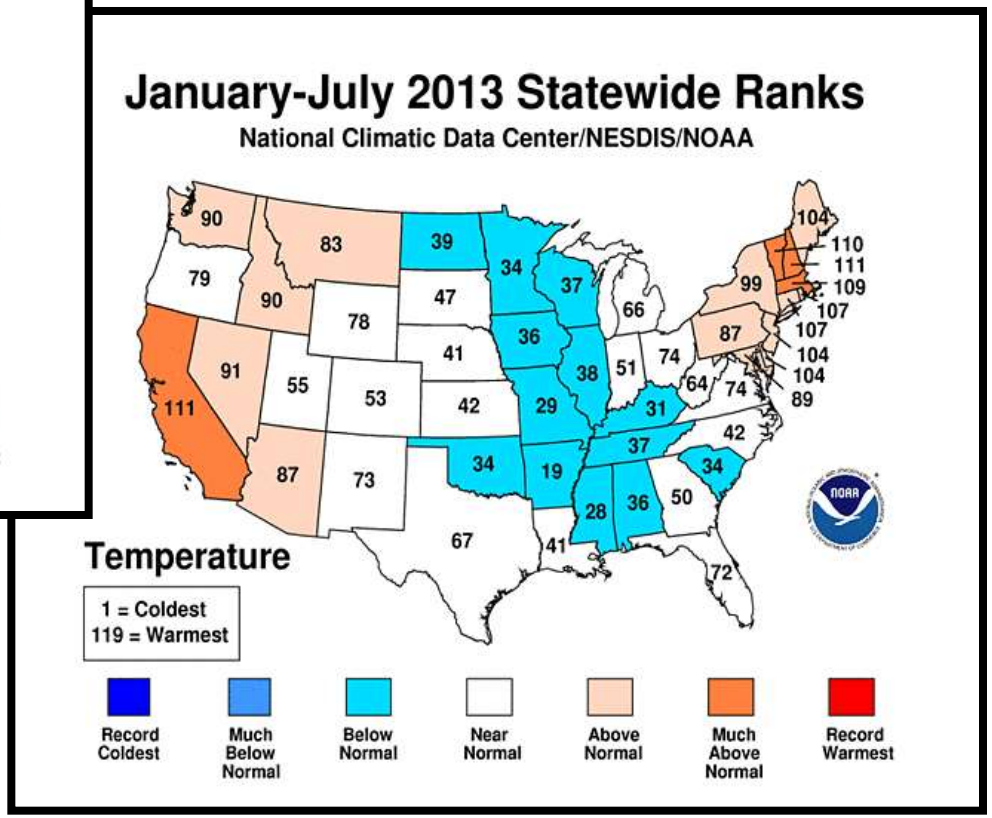
NOAA NCDC, State of the Climate *http://www.ncdc.noaa.gov/climate-monitoring/*

Interannual Variation

Oh what a difference a year makes….or does it?

Setting Records?





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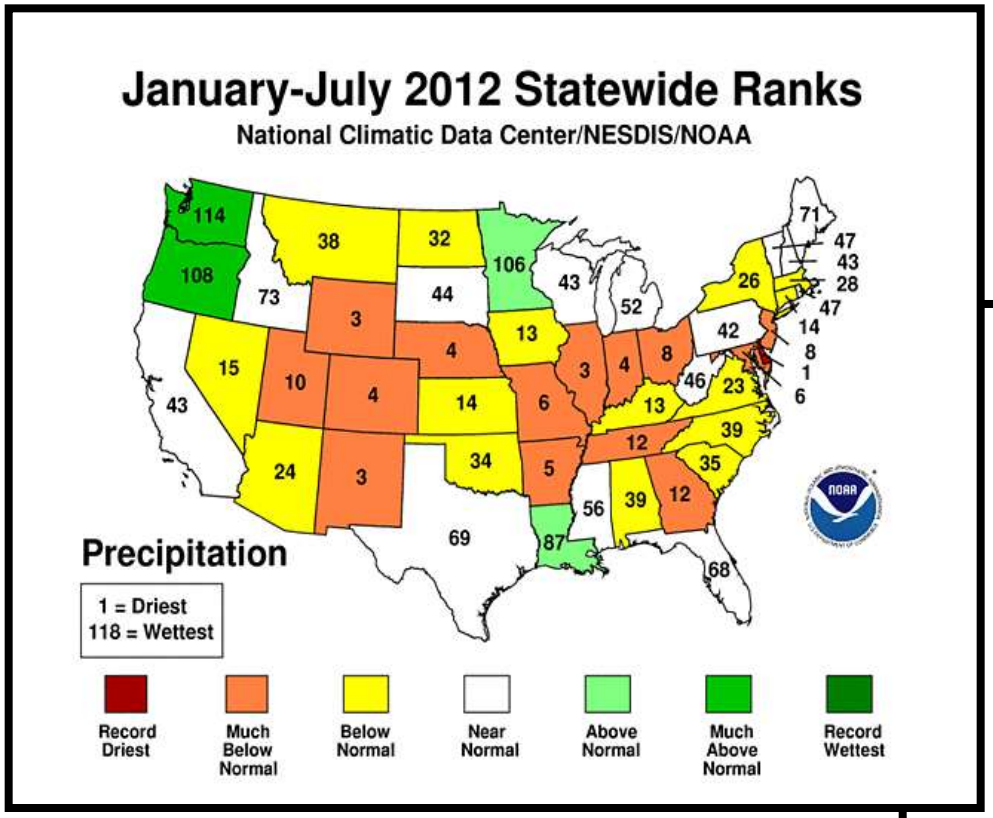

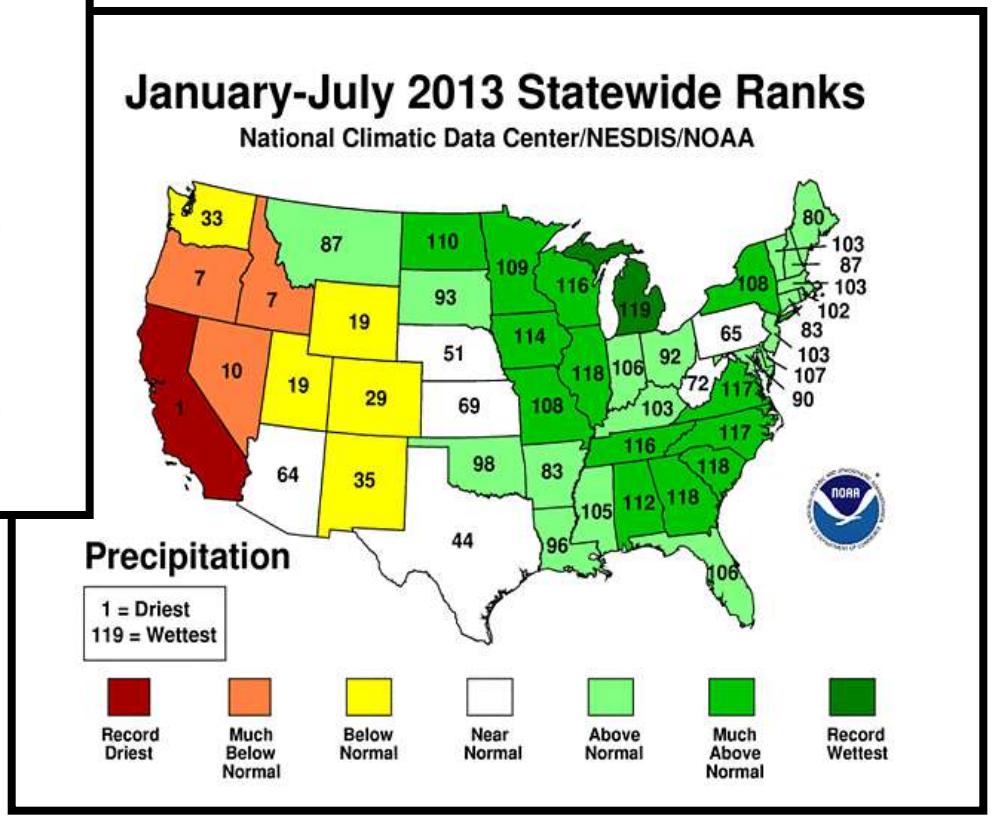

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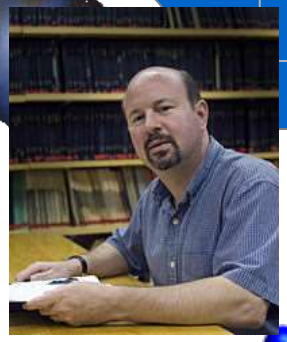


Scientists hopeful despite climate signs

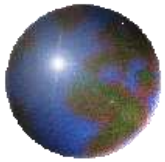
By SETH BORENSTEIN, AP Science Writer
Sun Sep 23, 2007, 7:31 PM ET

- *Michael Mann, Penn State U.:* "Sometimes we fear that we are delivering too morose a message and not conveying enough that there is reason for optimism.“

- *Andrew Weaver, U. of Victoria:* "It's hard at times….You can't give up hope because what else is there in life if you give up hope? When you give up hope, that's quitting and scientists don't like to quit."

- *James Hansen, NASA:* "I am always surprised when people get depressed rather than energized to do something. It's not too late to stabilize climate.…I am not about to give up”

- *David Myers, Hope College (psychologist):* "Human beings are remarkably resilient….To do what climate researchers are doing takes enough optimism to sustain their hope and enough realism to create their concern."



The Earth's Climate History

1. Over the last century, the earth's surface temperature has increased by about 0.75°C (about 1.35°F).
2. Little Ice Age = Cooling during 1,400 A.D. – 1,900 A.D. (N.H. temperature was lower by 0.5°C, alpine glaciers increased; few sunspots, low solar output)
3. Medieval Climate Optimum (Warm Period) = Warming during 1,000 A.D. – 1,300 A.D. in Europe and the high-latitudes of North Atlantic (N.H. warm and dry, Nordic people or Vikings colonized Iceland & Greenland)
4. Holocene Maximum = 5,000-6,000 ybp (1°C warmer than now, warmest of the current interglacial period)
5. Younger-Dryas Event = 12,000 ybp (sudden drop in temperature and portions of N.H. reverted back to glacial conditions)
6. Last Glacial Maximum = 21,000 ybp (maximum North American continental glaciers, lower sea level exposed *Bering land bridge* allowing human migration from Asia to North America)
7. We are presently living in a long-term Icehouse climate period, which is comprised of shorter-term *glacial* (e.g., 21,000 ybp) and *interglacial* (e.g., today) periods. There were four periods of Icehouse prior to the current one.
8. For most of the earth's history, the climate was much warmer than today.