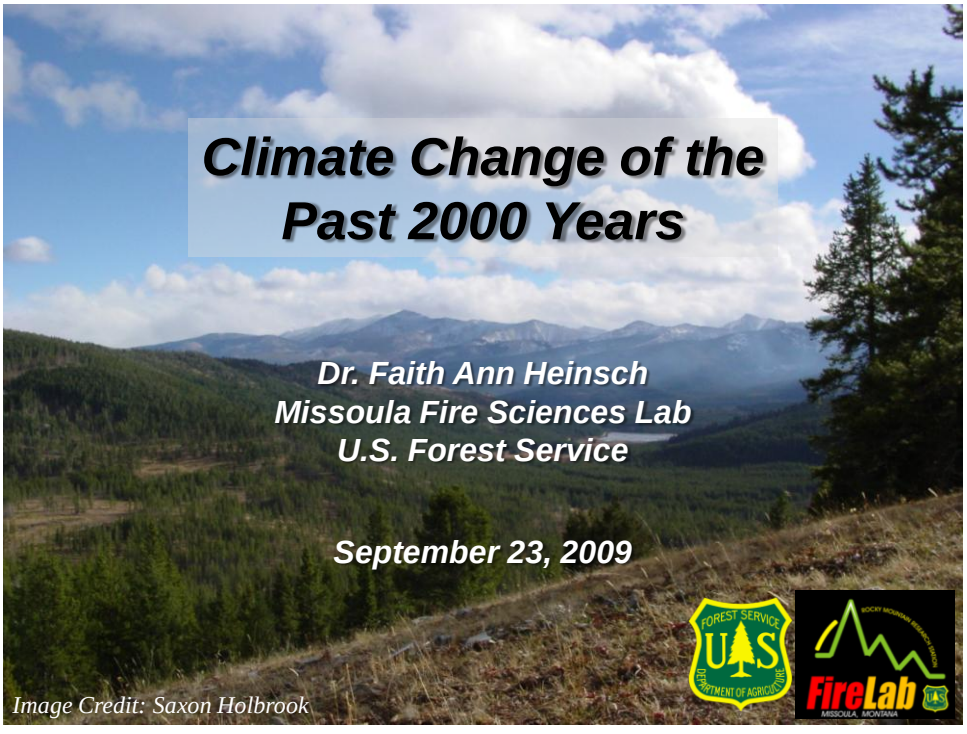
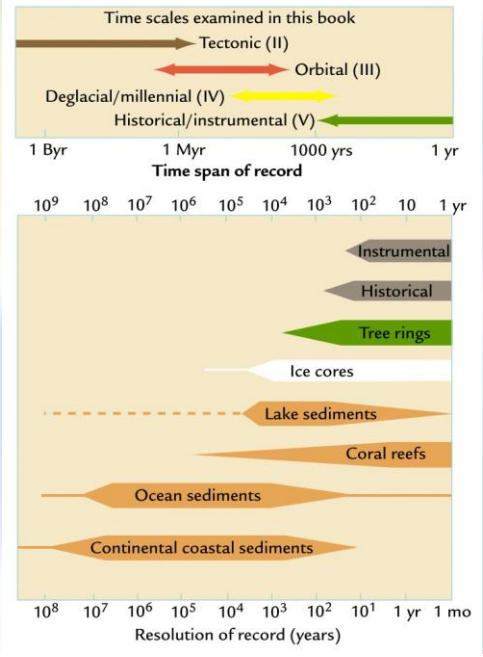
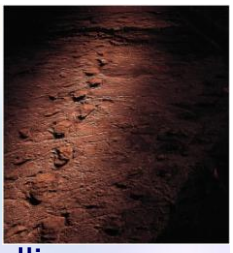
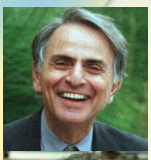


Time scales for Proxy Data



Anthropocene

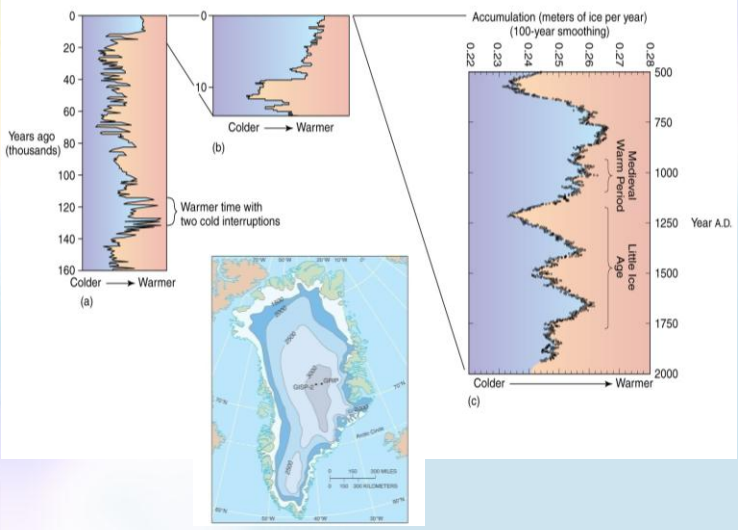


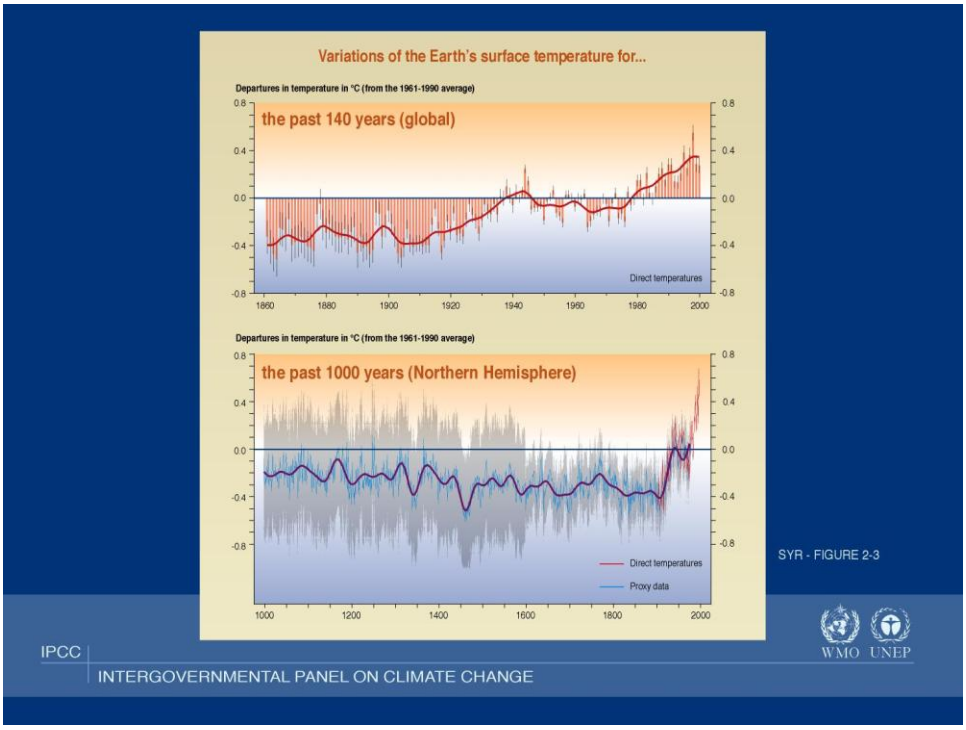


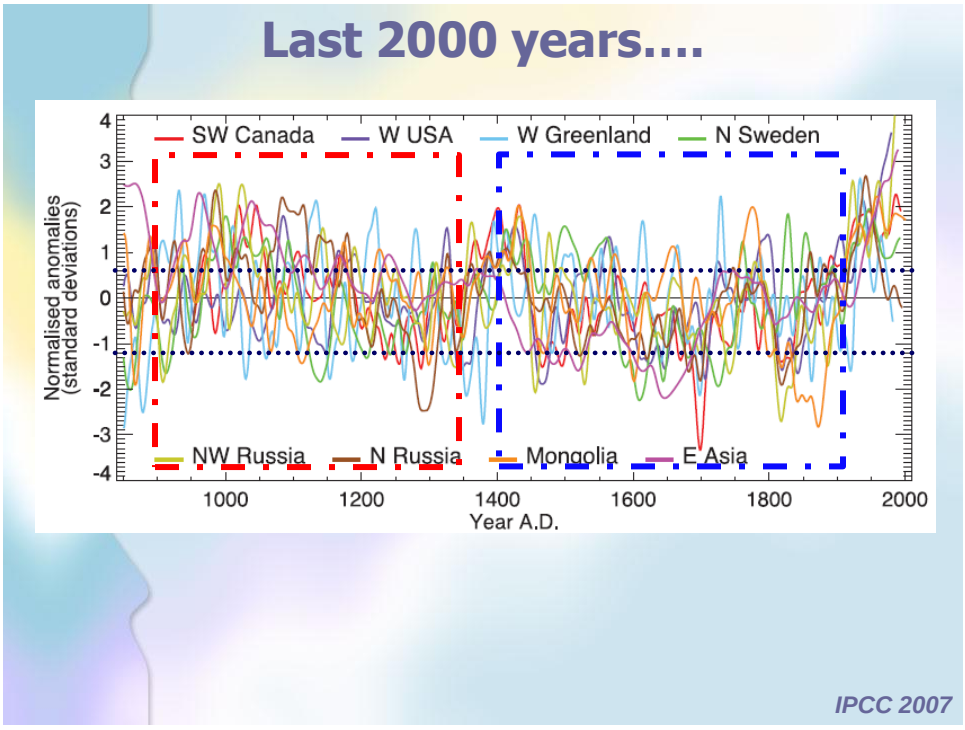
- Term used for climate where humans are the dominate controlling mechanism…
  - Concept first proposed in 1979 by Sagan
  - Phrase coined by Crutzen in 2000
    - Nobel prize winning chemist for his work on ozone depletion
  - No precise start date.
  - May be considered to start in late 18th century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

Last 2000 years….

- Greenland Ice Cores:
  - High resolution record of temps near Europe…




Variations of the Earth's surface temperature for...
Departures in temperature in °C (from the 1961-1990 average)
the past 140 years (global)
Direct temperatures
Departures in temperature in °C (from the 1961-1990 average)
the past 1000 years (Northern Hemisphere)
Direct temperatures
Proxy data
SYR - FIGURE 2-3
IPCC
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
WMO UNEP


Last 2000 years....
SW Canada
W USA
W Greenland
N Sweden
NW Russia
N Russia
Mongolia
E Asia
Normalised anomalies (standard deviations)
Year A.D.
IPCC 2007

Last 2000 years….

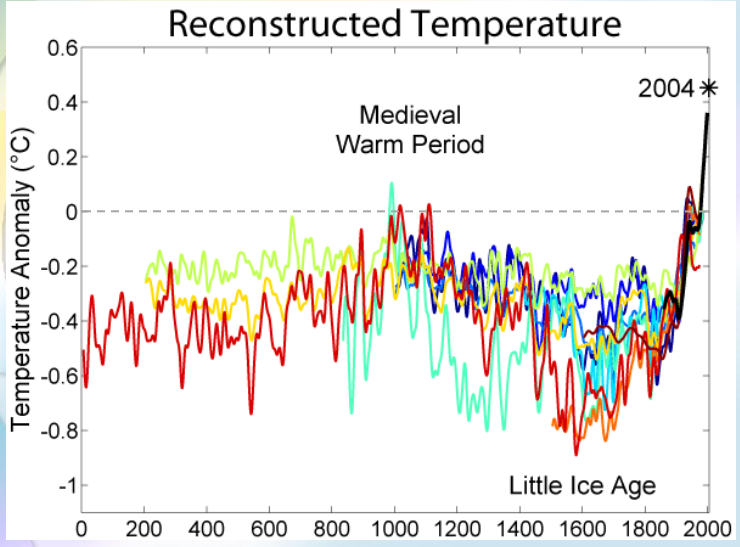
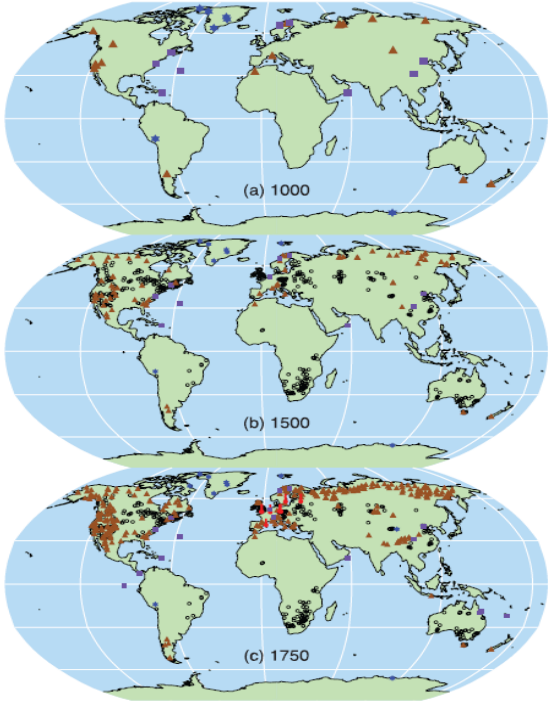


Image Credit: Robert A. Rohde, Global Warming Art

Proxy Records – Where do they come from?

- Instrumental record
- Tree rings
- Boreholes
- Ice core/ice borehole
- Other

IPCC 2007



Medieval Warm Period (~800-1300)
(a.k.a. Medieval Climate Optimum)

Medieval Warm Period (~800-1300)

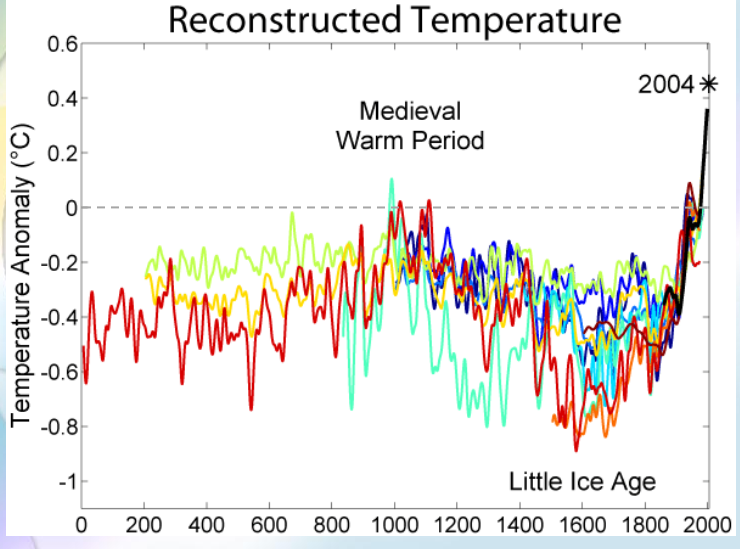
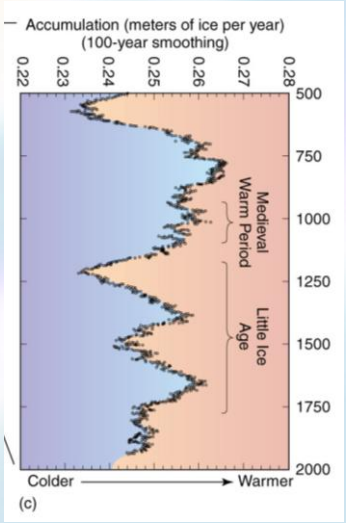


Image Credit: Robert A. Rohde, Global Warming Art

Medieval Warm Period (~800-1300)

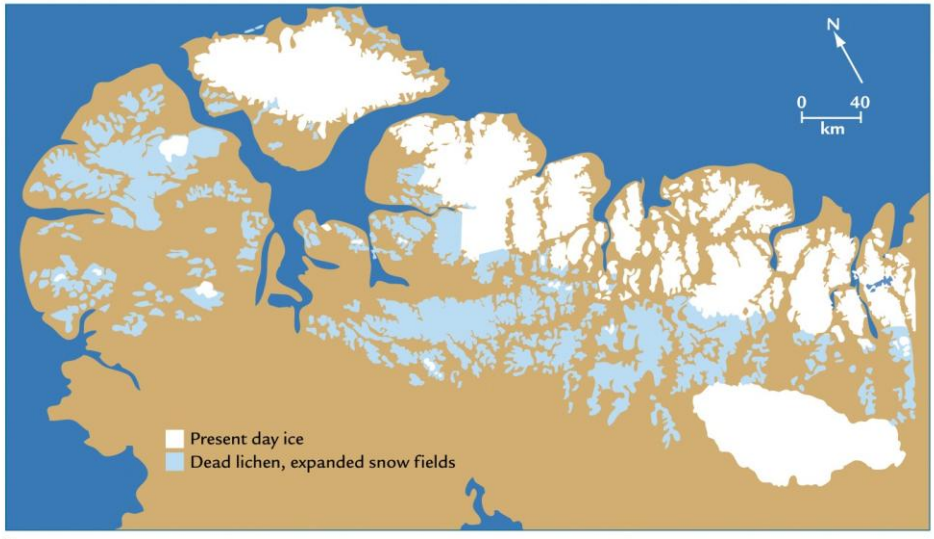
- Scattered evidence exists in Europe and the high latitudes surrounding the North Atlantic.
  - Cultivation of Greenland & Iceland
  - Grapes in England?
  - Medieval temperatures were probably 1-2°C above early 20th century levels at various European locations
  - Evidence in Japan, Alaska
  - Regional in nature
    - There were both warmer and colder areas
- Drought was evident in western U.S. (Anasazi), Central America (Mayan) & Africa



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)



C

The Little Ice Age (1400-1900)

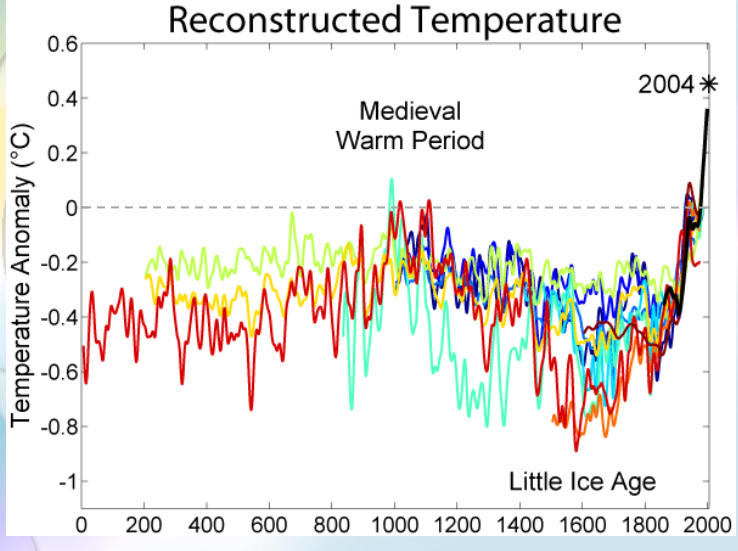
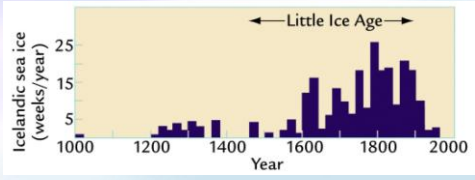


Image Credit: Robert A. Rohde, Global Warming Art

Little Ice Age (1400-1900)

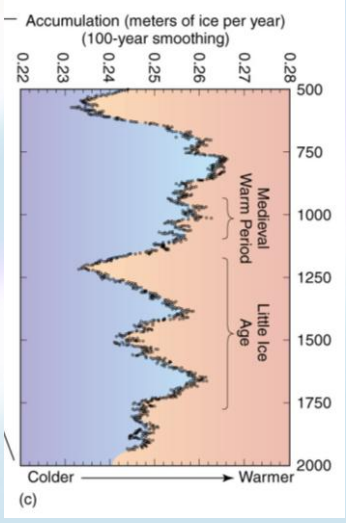
- A modest cooling of the Northern Hemisphere of less than 1°C
  - Glaciers grew in Europe (1000 m lower than in 1850s)
  - Sea ice expansion
- Three minima, each separated by slight warming intervals beginning
  - About 1650
  - About 1770
  - About 1850



- 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
- Settlements in Greenland were abandoned
  - Marginal climate?
  - Conflicts with native peoples?
- Large-scale advances of glaciers
- **Not a "true" ice age** since major ice sheets did not form

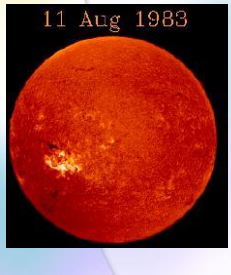


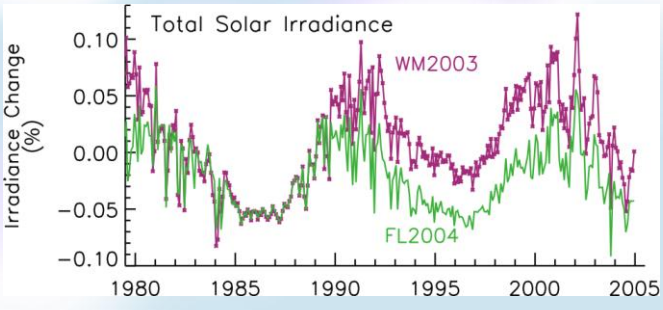
Proposed causes of climate change from 1000-1850

- Orbital forcing
  - Decreasing summer insolation (tilt and precession cycles)
  - Only explains about half the amount observed in reconstruction for northern hemisphere (0.1°C)
- Millennial bipolar seesaw
  - Antarctica warm when Greenland is cold
    - Typical of large glacial-age oscillation
  - Insufficient proxy data in southern hemisphere to test

Proposed causes of climate change from 1000-1850

- Solar variability
  - Maunder Minimum
  - 11-year Sunspot cycle
  - Recent research minimizes this effect





Proposed causes of climate change from 1000-1850

- Volcanic eruptions
  - Sulfate aerosols
  - The more frequent clusters of eruptions after 1300 could have constributed to the small cooling trend in the LIA
- Greenhouse-Gases
  - Drop in CO_2 concentration by 7-8 ppm from 100-1200 to 1600-1800
    - Solar-volcanic changes
    - Anthropogenic hypothesis
      - Reforestation of agricultural land
      - The "Black Death" (bubonic plague)
      - The American Pandemic (host of diseases)

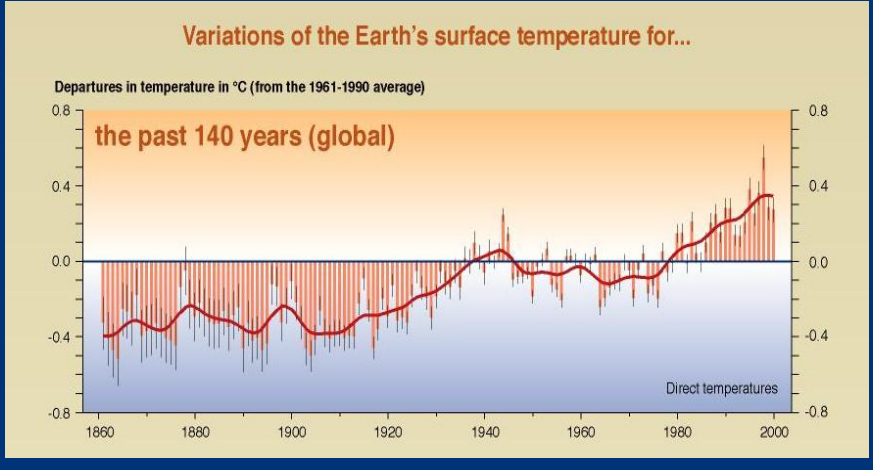
CO_2

Proposed causes of climate change from 1000-1850

- Evidence for MWP is uncertain
  - Fewer records; larger uncertainties
- Estimated cooling from 1000 years ago into the LIA is small

Proposed causes of climate change from 1000-1850

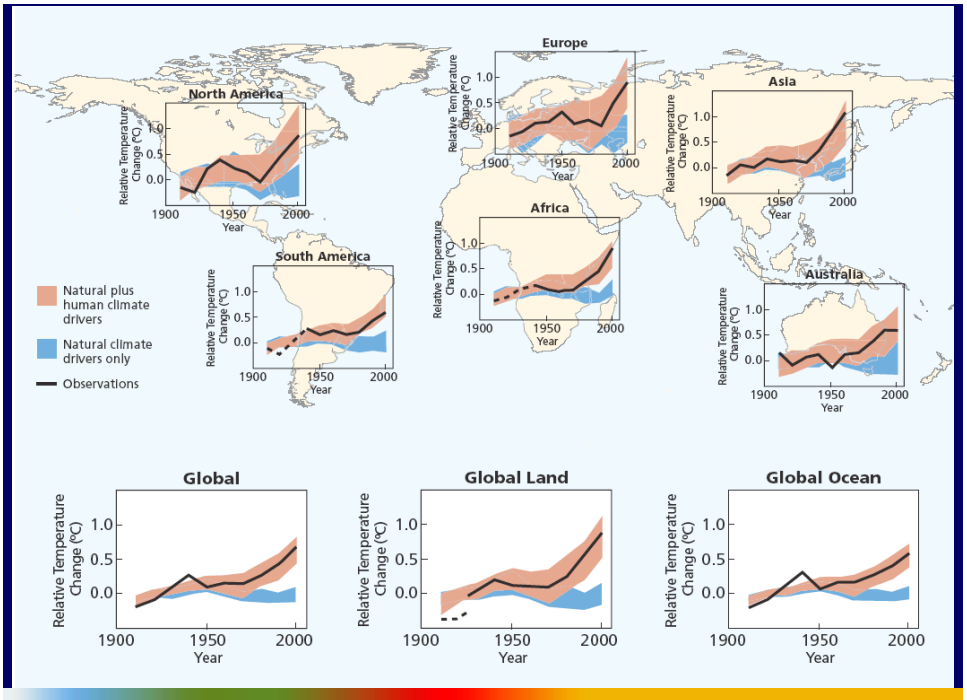
- Any or all of several factors could have played a causal role
- Far greater geographic coverage is needed to define the *global* climatic response
  - Notion of MWA & LIA is valid for trends across eastern Canada, Greenland, Iceland, northern Europe – what about rest of earth's surface (90-95%)?
- No such ambiguity exists about the large, rapid and global warming since 1850



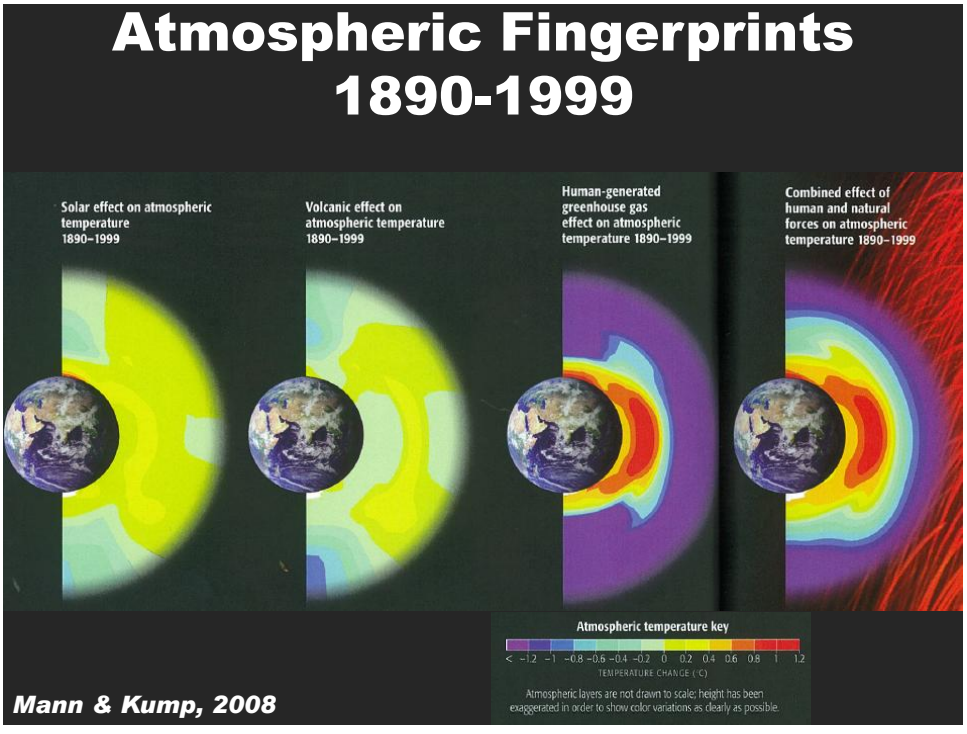
SYR - FIGURE 2-3a

IPCC | INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

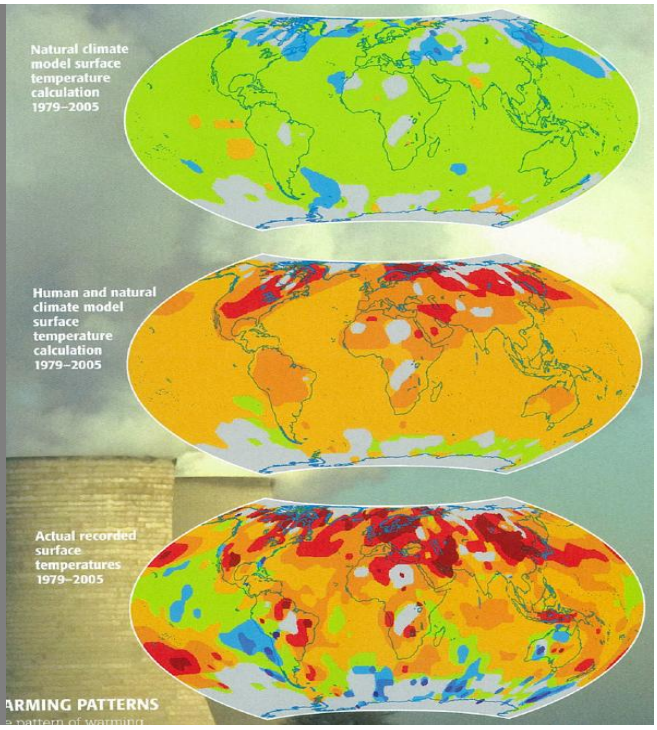


Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.



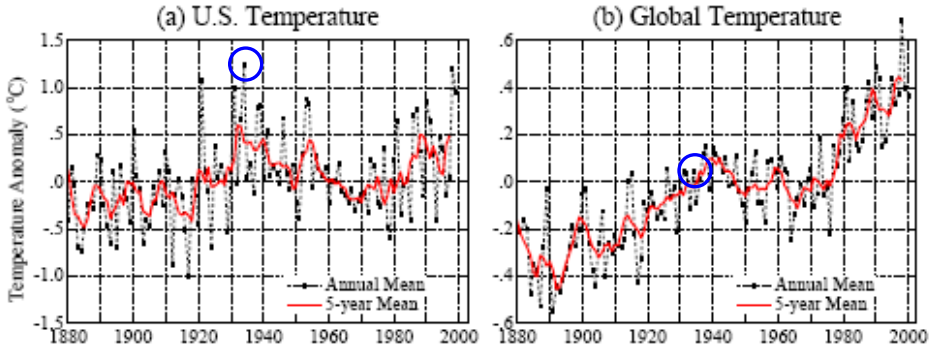
"Fingerprints"

Human and Natural Impacts on Climate, 1975-2005



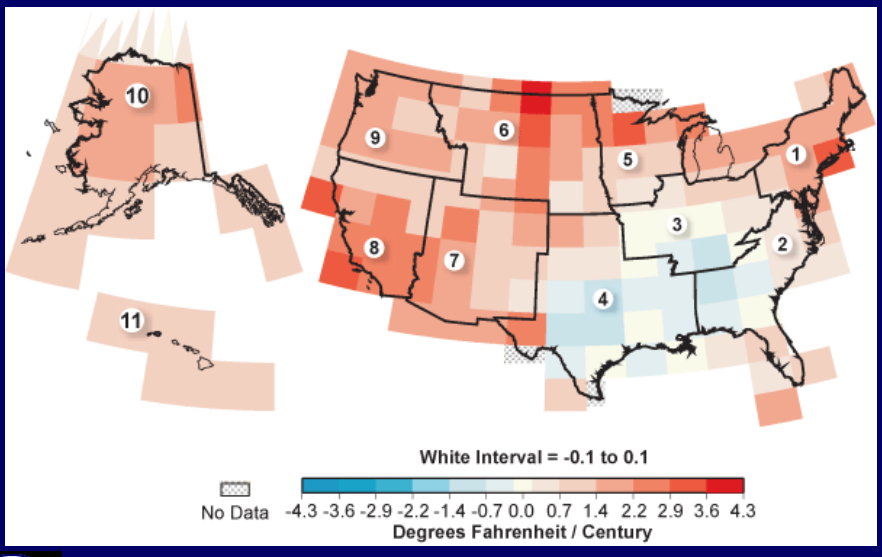
Mann & Kump, 2008

Temperature Trends: 1880 to 2000



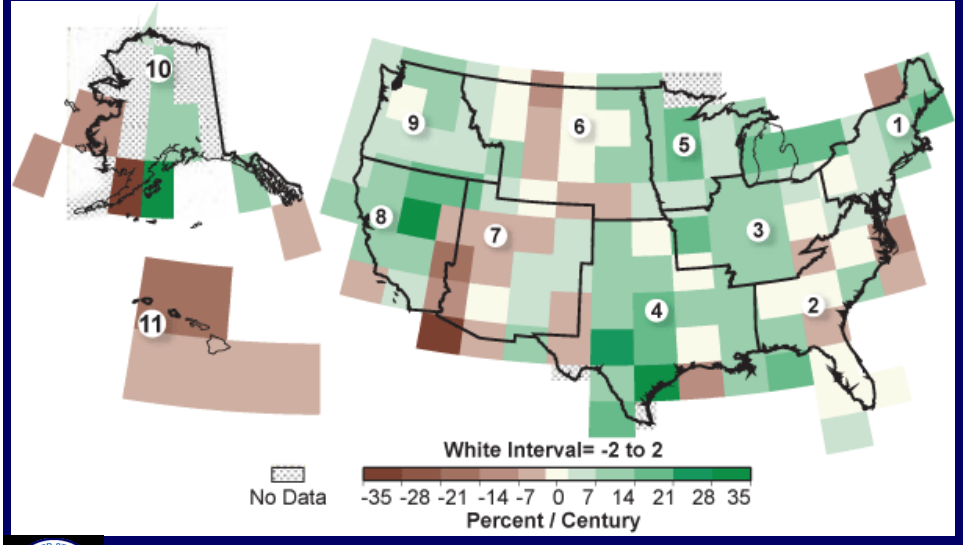
(Hansen et al., Journal of Geophysical Research, 2001)

U.S. Mean Temperature Trends: 1901 - 2003



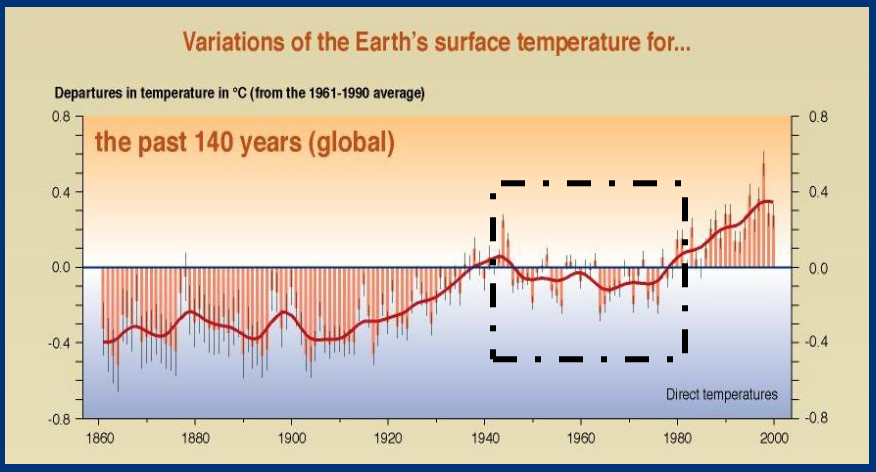
Data courtesy NOAA's National Climatic Data Center

U.S. Precipitation Trends: 1895 - 2003



Data courtesy NOAA's National Climatic Data Center

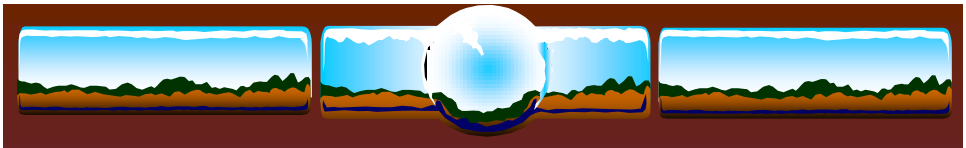
What about the cool temperatures from ~1945 to ~1980?



SYR - FIGURE 2-3a

IPCC | INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

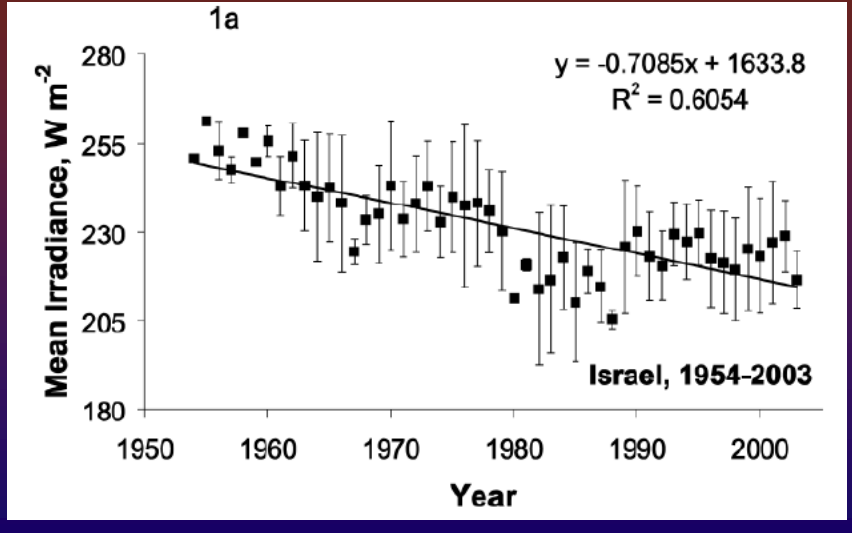


Global Dimming
or
"Long Term Trends in Solar Radiation"

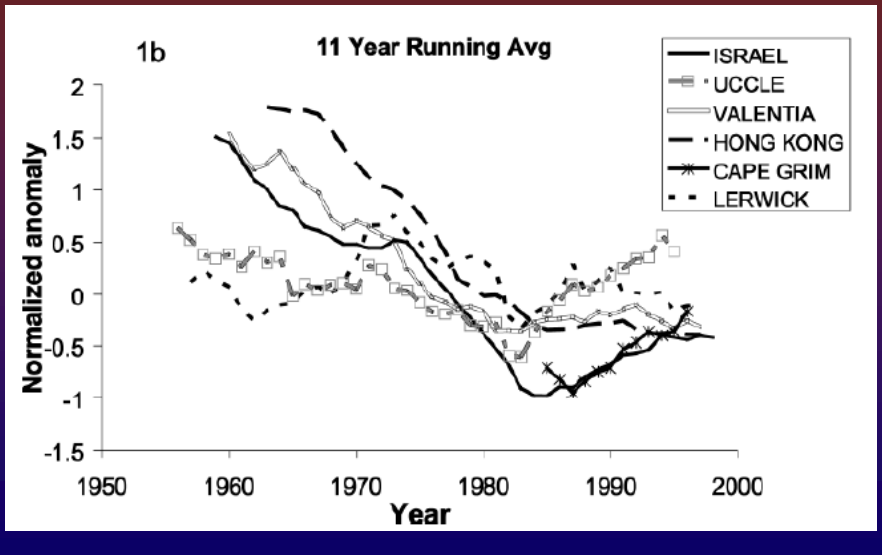
What is global dimming?

- **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

50 years of Radiation Data - Israel



Incoming Shortwave Radiation
Anomalies in the annual mean



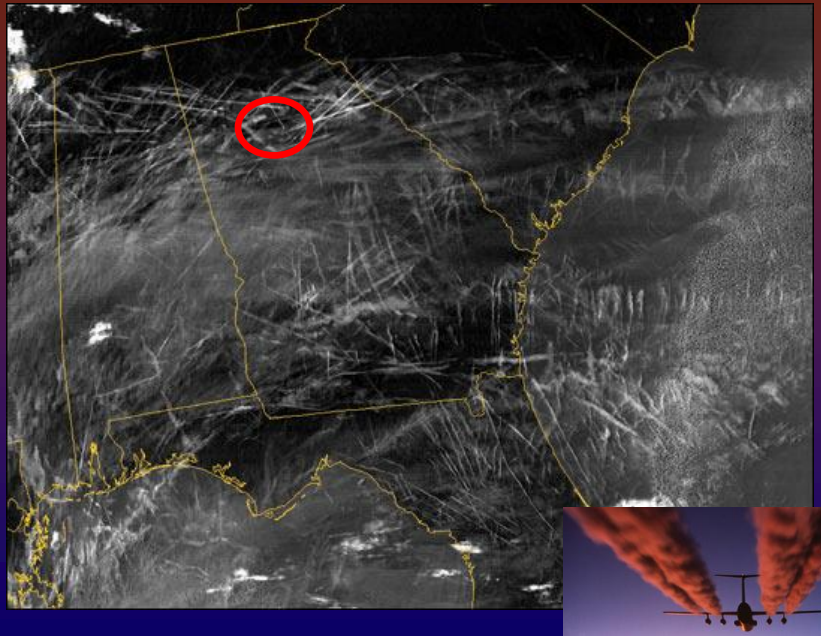
Supporting Evidence

- Worldwide decline in the "pan evaporation rate."
  - Sunlight, humidity, and wind are dominant factors

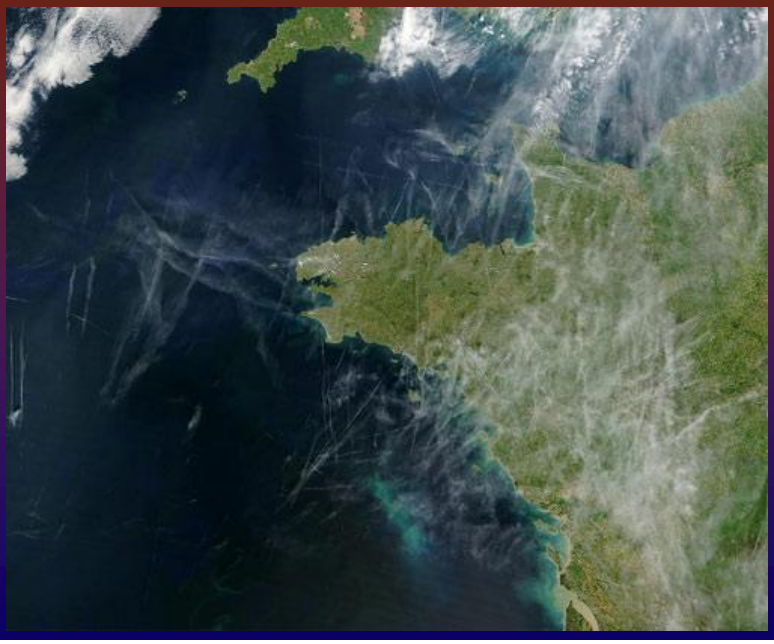
Where does it come from?

- 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 absorb solar energy and 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

Aircraft Contrails, Jan 29 2004 MODIS



Aircraft Contrails over Europe



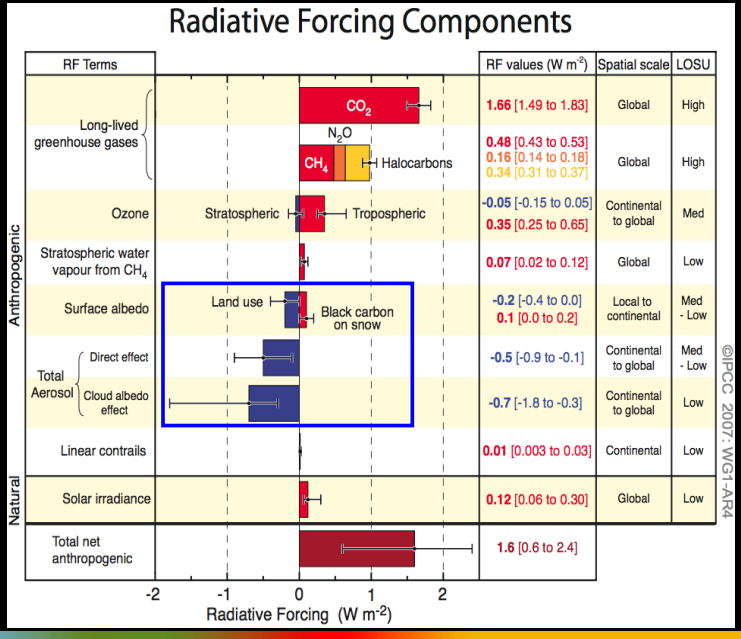
Effects are mostly regional

- 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.
- *Extreme* regional effect
  - the Sahel

Trend Reversal – 1990-2006

- The "dimming" trend reversed
  - part of this change is due to decreases in pollution.
    - particularly over Europe
- Most developed nations have done more to reduce aerosols released into the atmosphere than to reduce CO_2 emissions.

Human and Natural Drivers of Climate Change



IPCC - WGI

Effects on Climate Systems

- Climate change, to the current date, appears to have been a tug of war, really, between two manmade pollutants.
  - greenhouse gases are pulling the system towards a warmer state (+2.6-3.0 W m^{-2})
  - particles from pollution that are cooling it down (-1.5 W m^{-2})

- **JAMES HANSEN: "**If the particle forcing is what we estimate, that would imply that removing that forcing would cause a **global warming of more than 1°C**. That's more than the warming that we've seen already, so this is a huge factor."