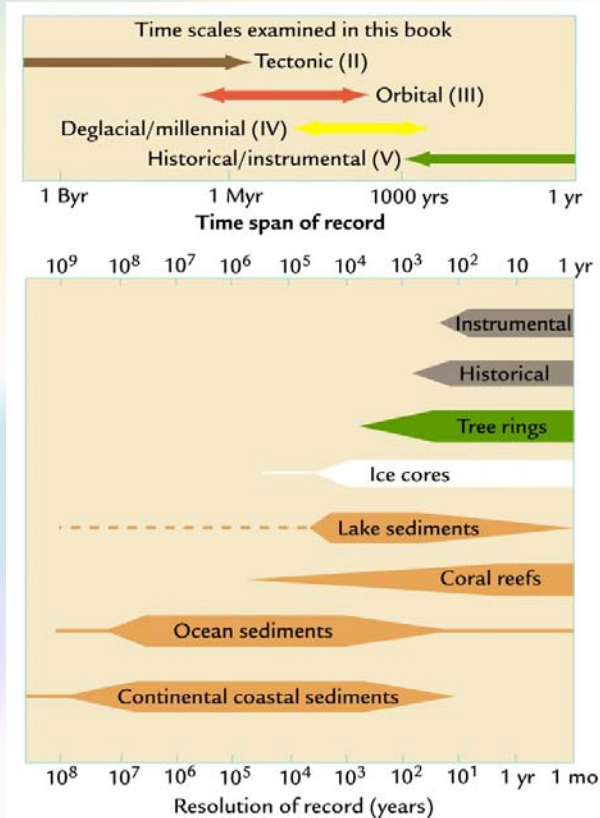


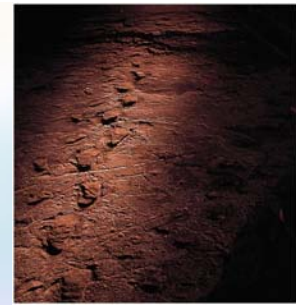
Climate Change of the Last 2000 Years

Dr. Faith Ann Heinsch
U.S. Forest Service,
Missoula Fire Sciences Lab
February 12, 2009

Time scales for Proxy Data



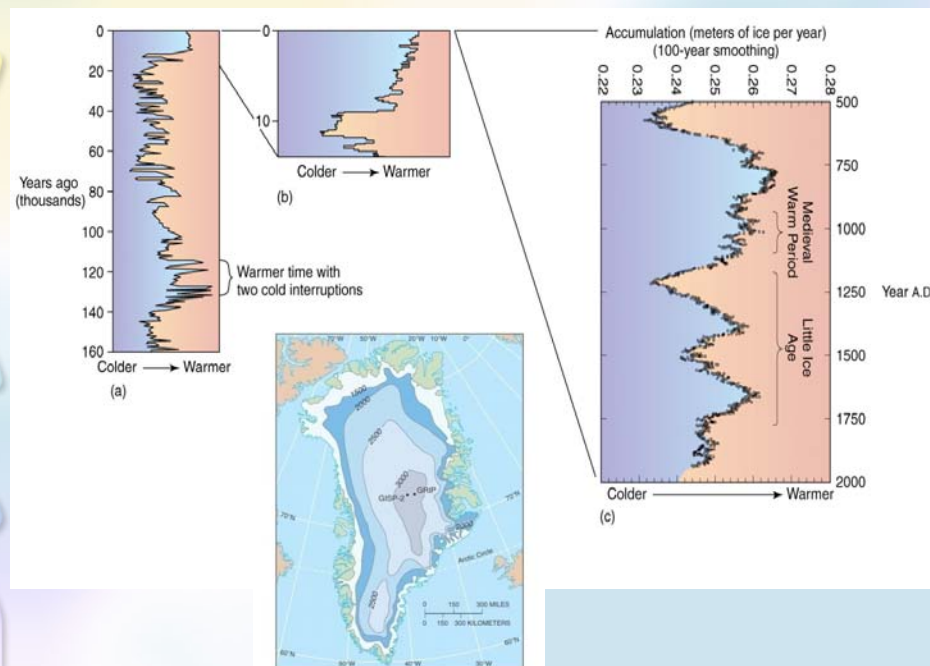
Anthropocene



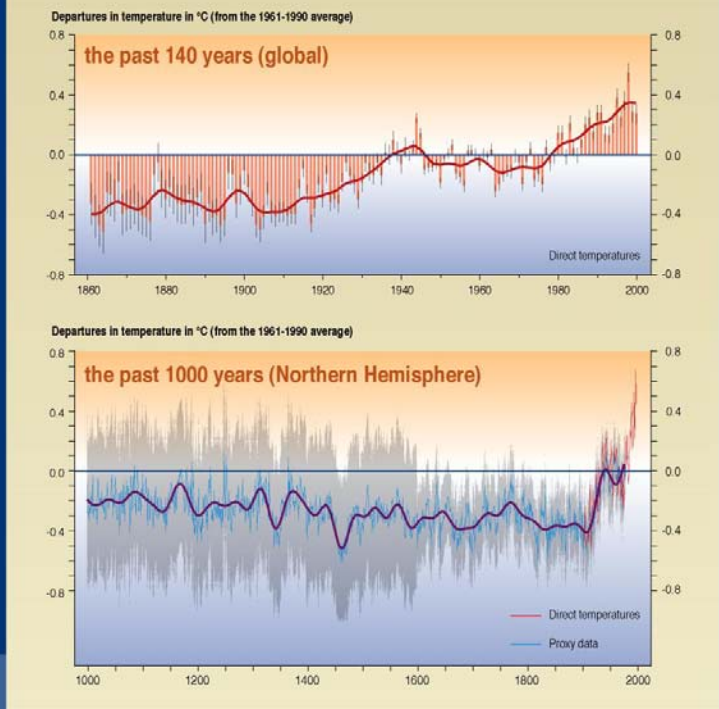
- Term used for climate where humans are the dominate controlling mechanism...
 - Concept first proposed in 1979 by Sagan
 - Phrase coined by Crutzen in 2000
 - Nobel prize winning chemist for his work on ozone depletion
 - No precise start date.
 - May be considered to start in late 18th century
 - “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...



SYR - FIGURE 2-3



Last 2000 years....

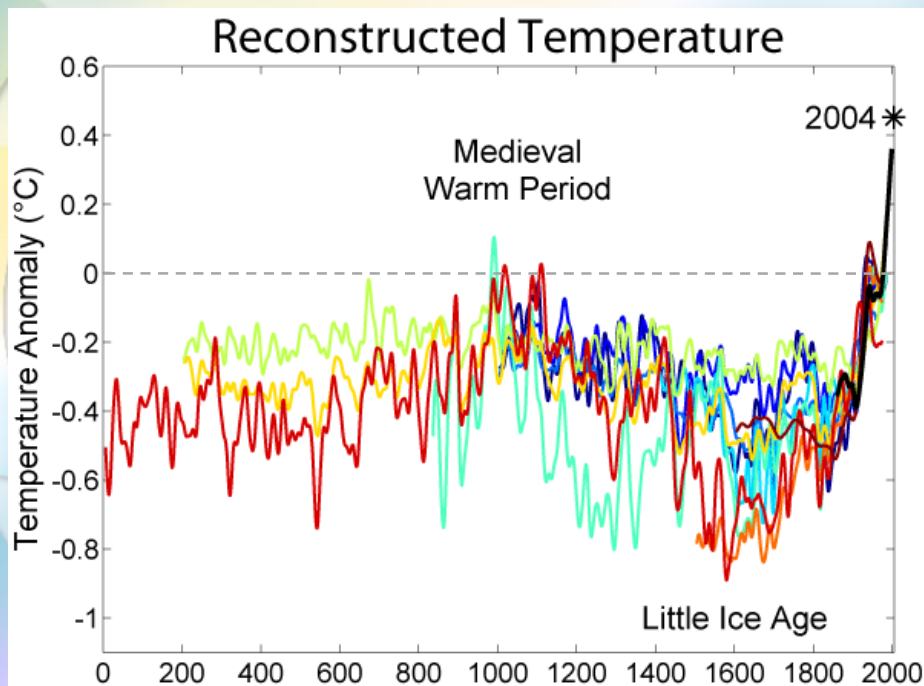
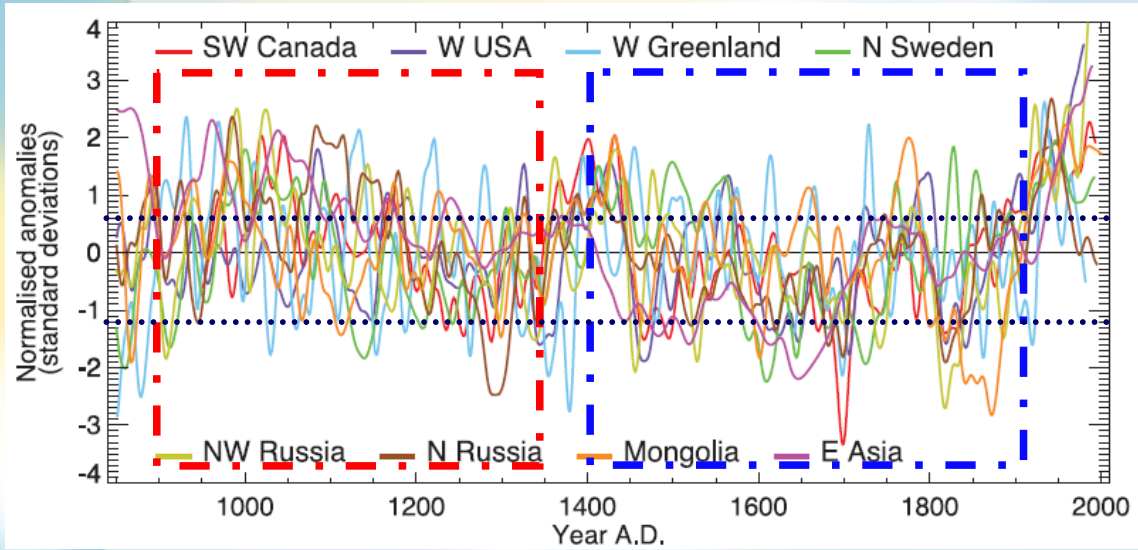


Image Credit: Robert A. Rohde,
Global Warming Art

Last 2000 years....

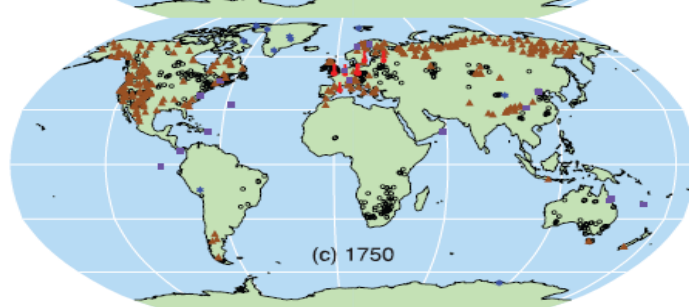
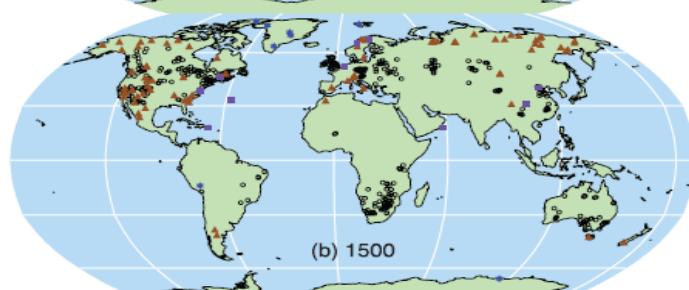
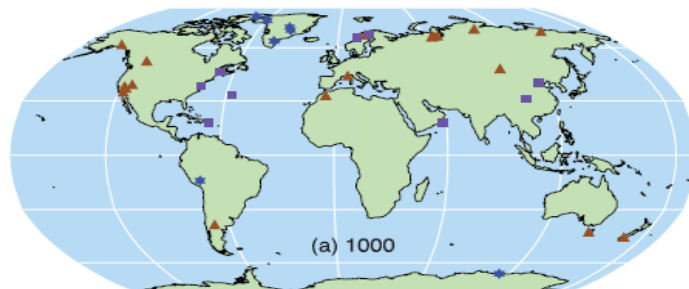


IPCC 2007

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)

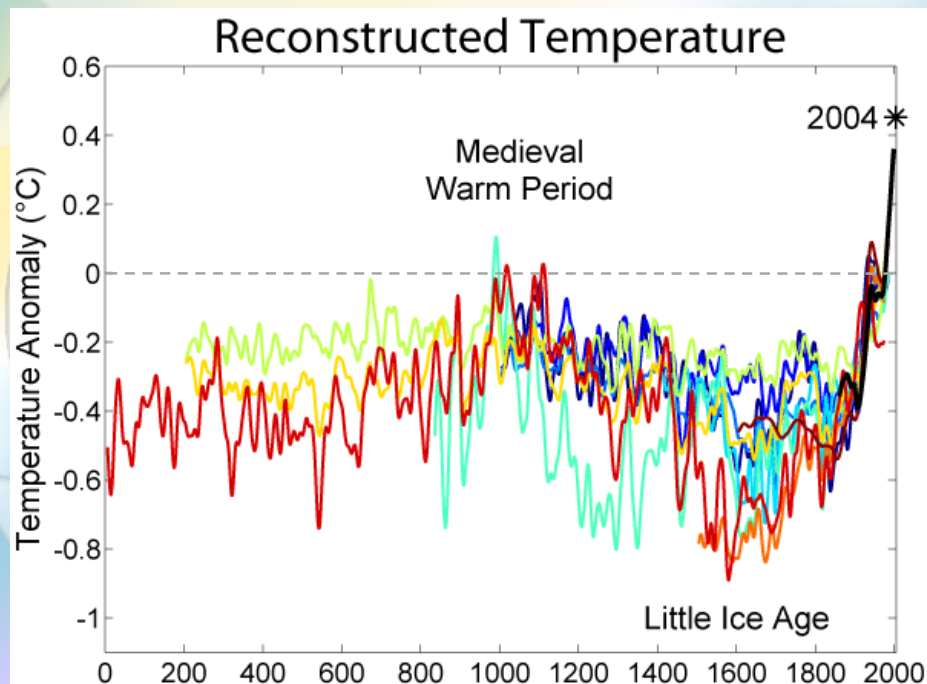
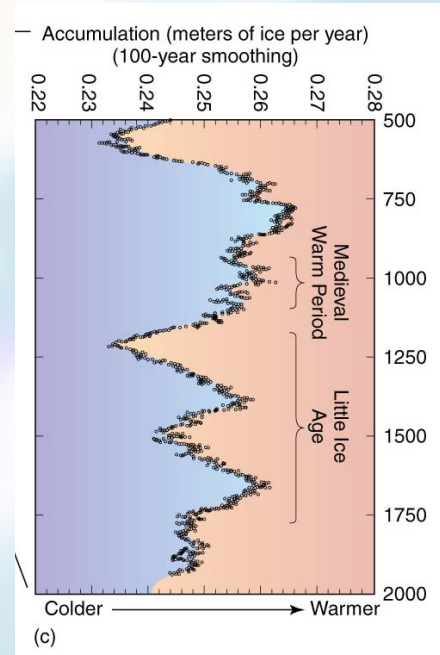


Image Credit: Robert A. Rohde,
Global Warming Art

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

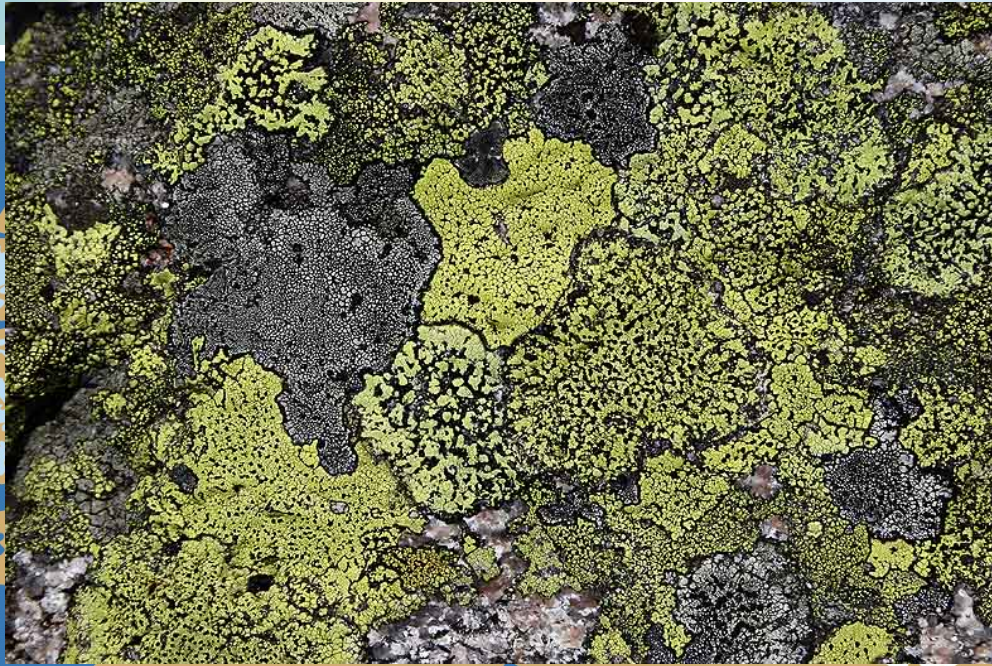


Medieval Warm Period (~800-1300)

“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)

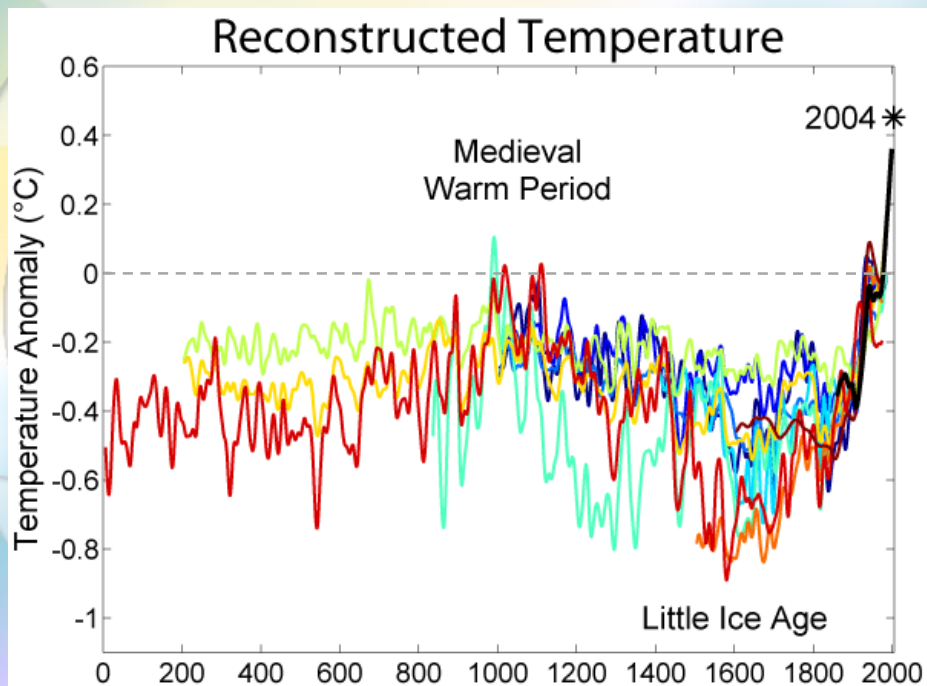
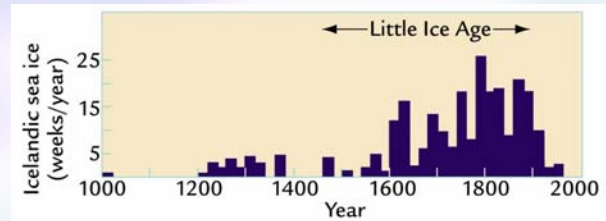


Image Credit: Robert A. Rohde,
Global Warming Art

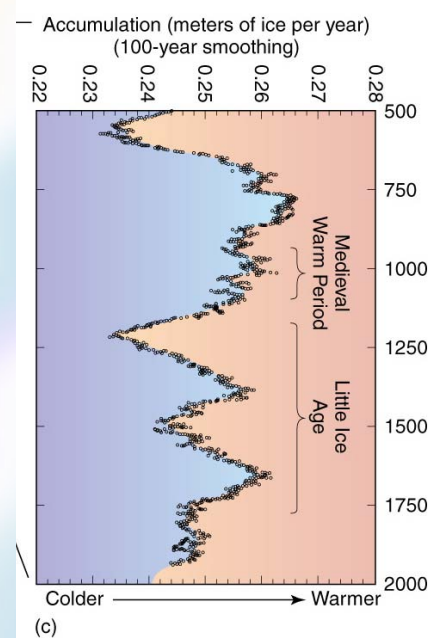
Little Ice Age (1400-1900)

- 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

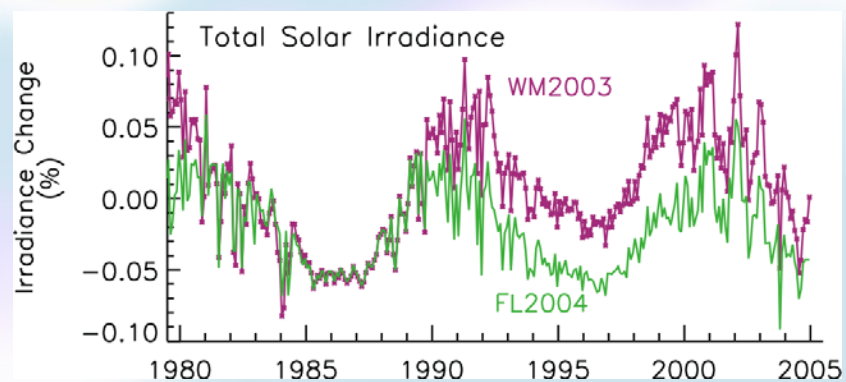


Proposed causes of climate change from 1000-1850

- 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 contributed to the small cooling trend in the LIA

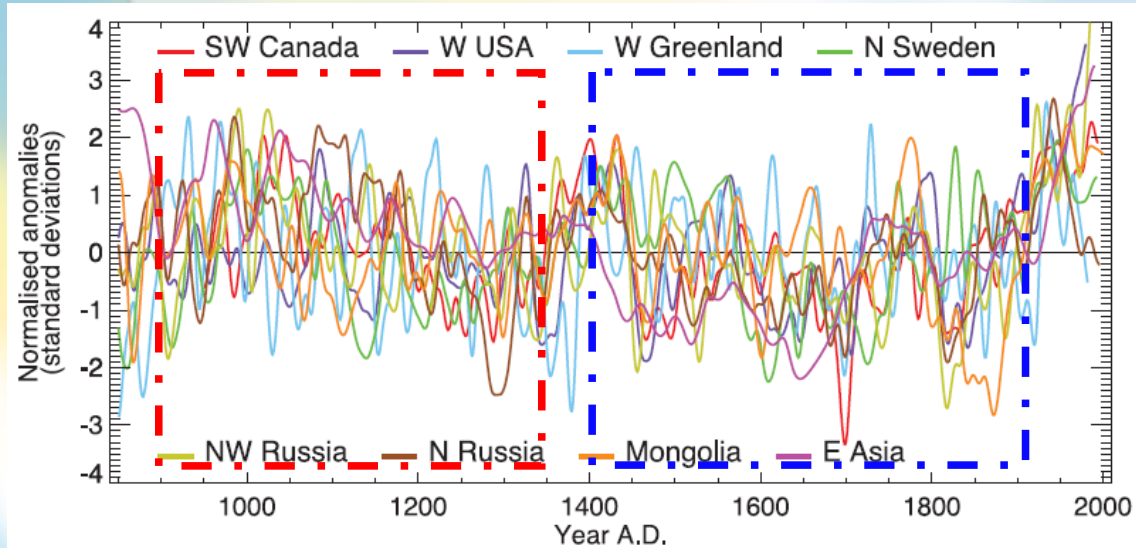
- Greenhouse-Gases

- Drop in CO₂ 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)

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

Medieval Warm Period (~800-1300)



IPCC 2007

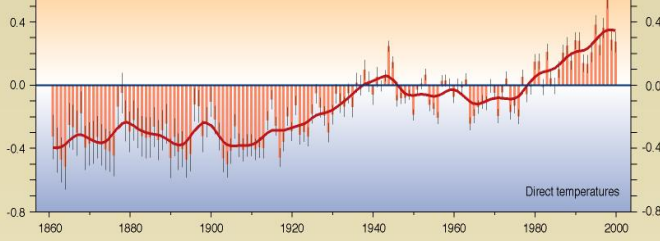
Proposed causes of climate change from 1000-1850

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

Variations of the Earth's surface temperature for...

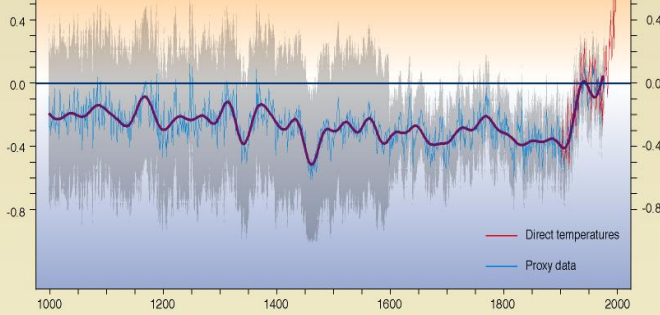
Departures in temperature in °C (from the 1961-1990 average)

the past 140 years (global)



Departures in temperature in °C (from the 1961-1990 average)

the past 1000 years (Northern Hemisphere)

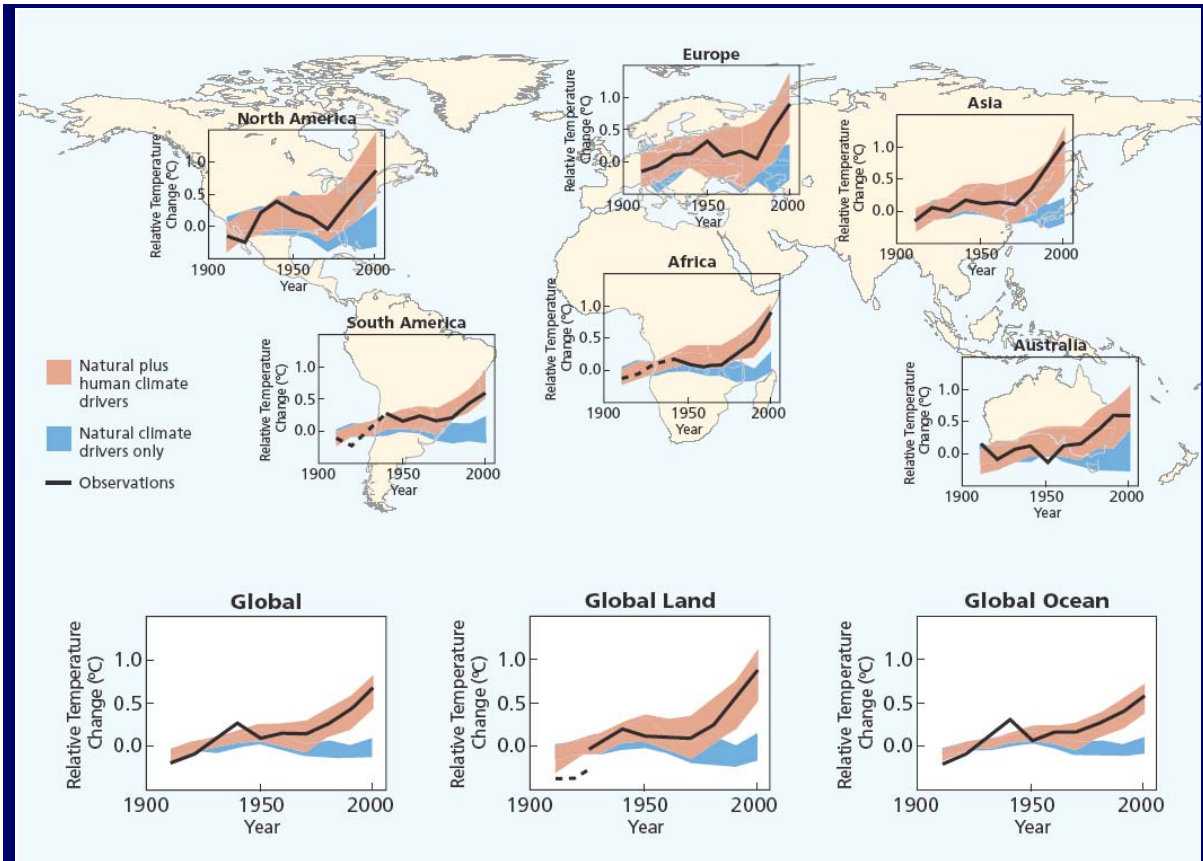


SYR - FIGURE 2-3



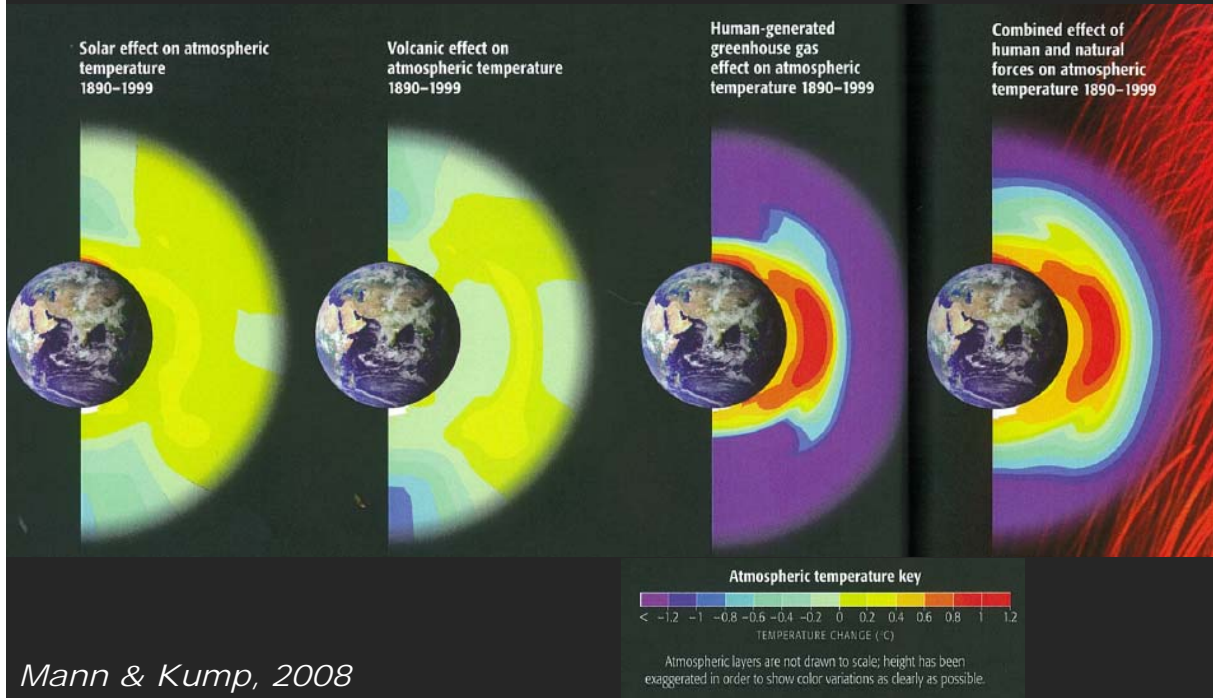
IPCC

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



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

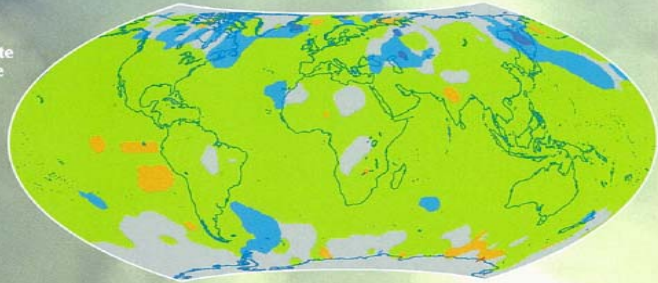
Atmospheric Fingerprints 1890-1999



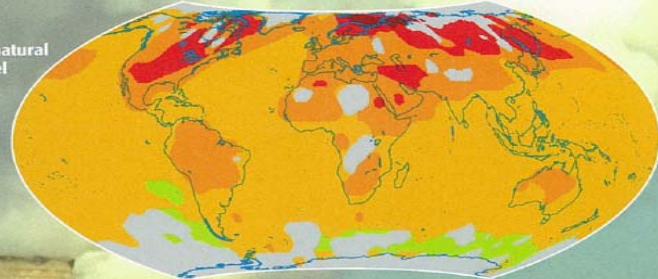
"Fingerprints"

Human and Natural Impacts on Climate, 1975-2005

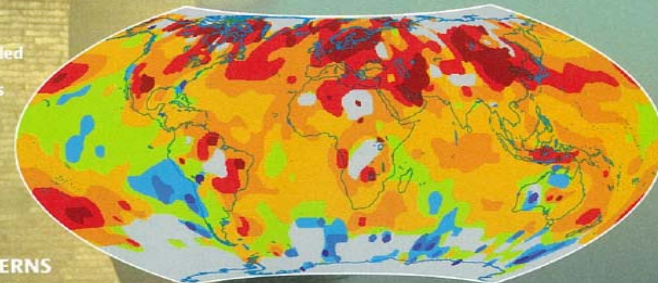
Natural climate model surface temperature calculation 1979-2005



Human and natural climate model surface temperature calculation 1979-2005



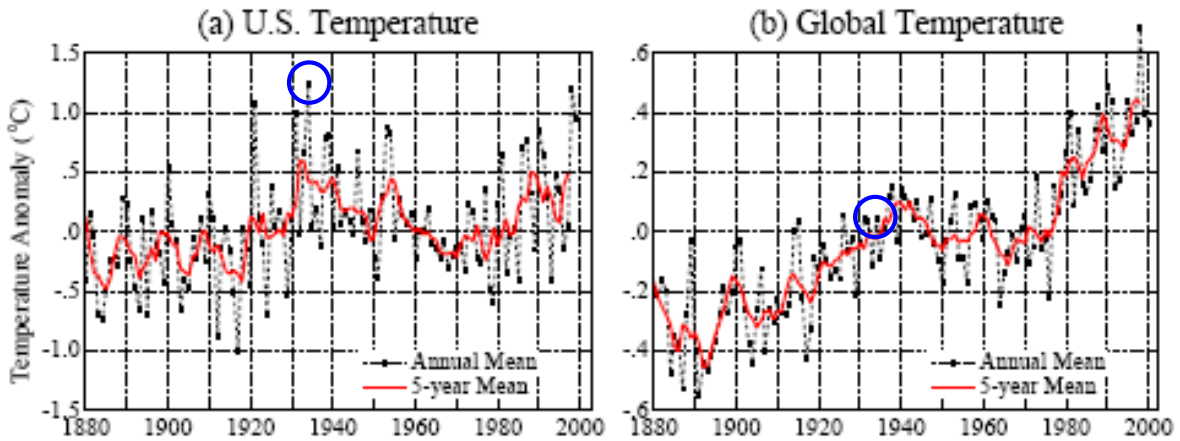
Actual recorded surface temperatures 1979-2005



Mann & Kump, 2008

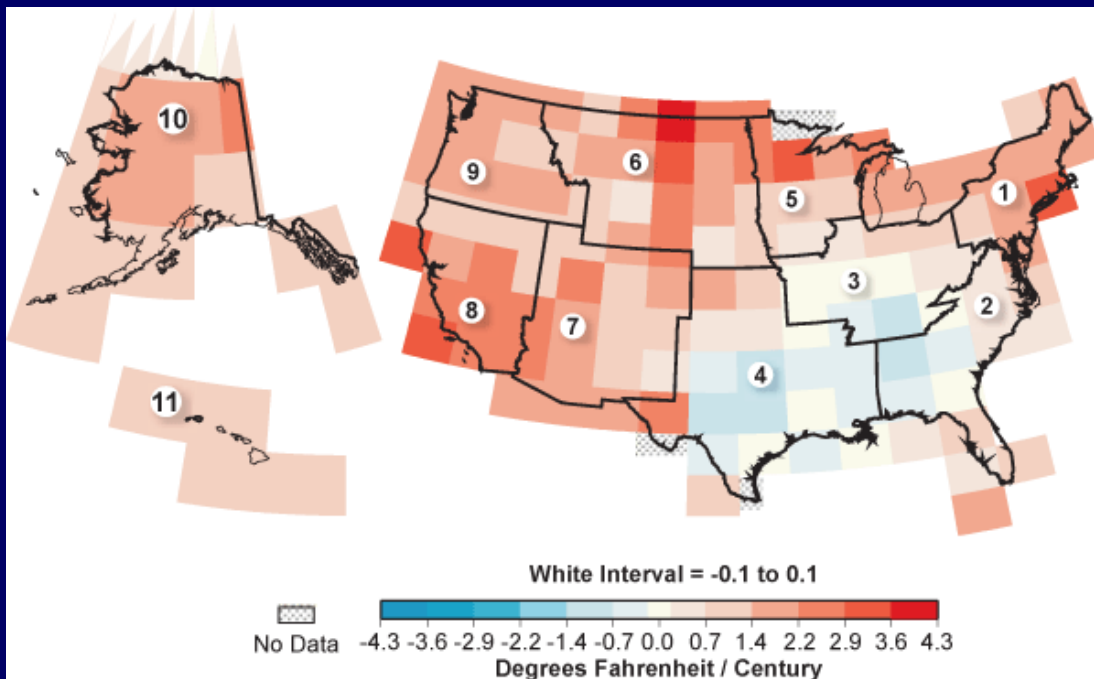
ARMING PATTERNS
a pattern of warming

Temperature Trends: 1880 to 2000



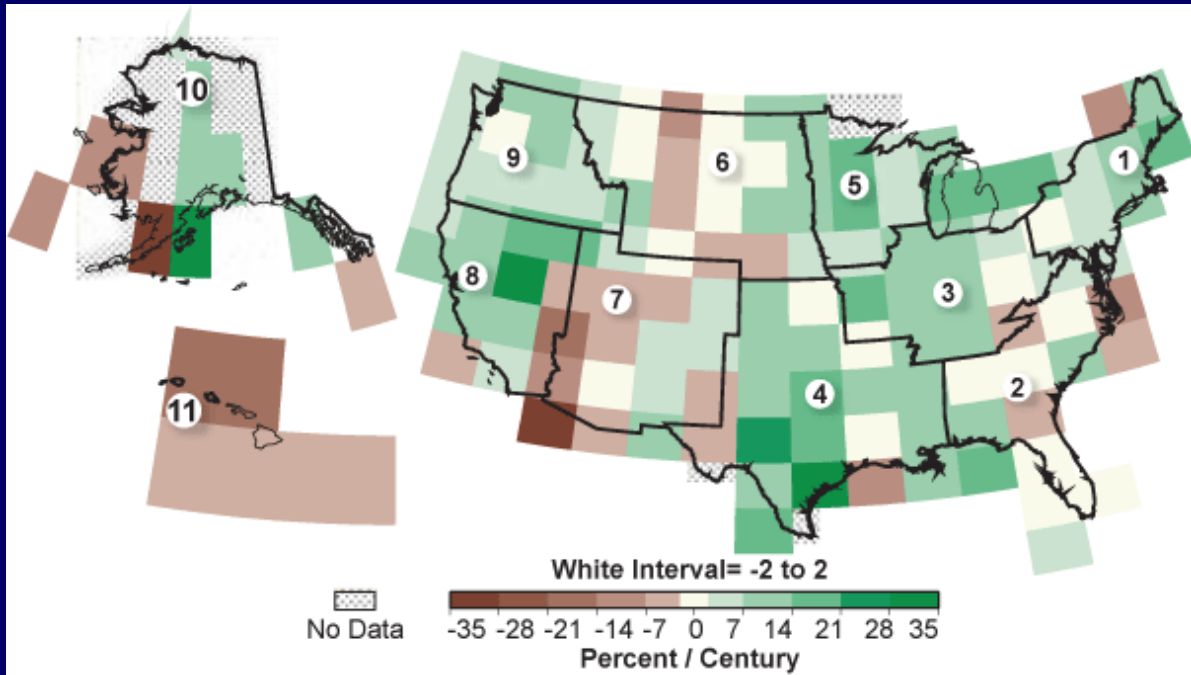
(Hansen et al., Journal of Geophysical Research, 2001)

U.S. Mean Temperature Trends: 1901 - 2003



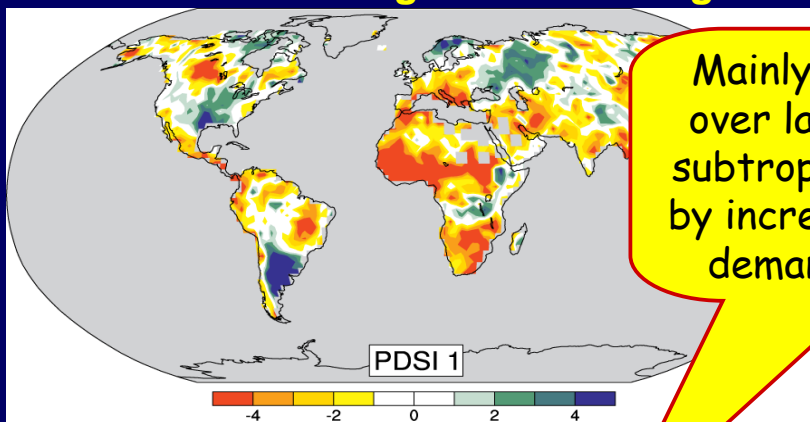
Data courtesy NOAA's National Climatic Data Center

U.S. Precipitation Trends: 1895 - 2003



Data courtesy NOAA's National Climatic Data Center

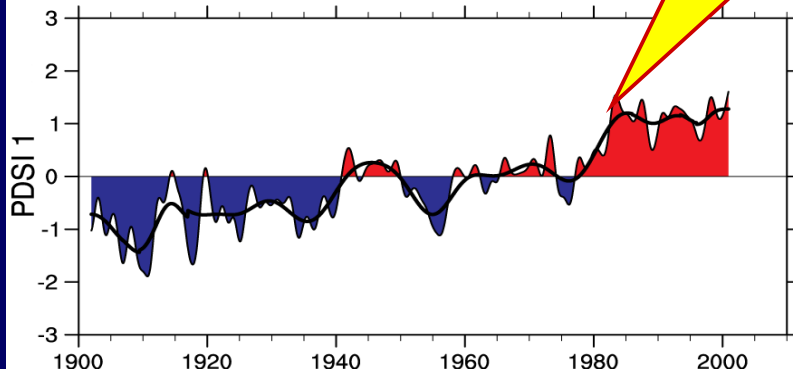
Drought is increasing most places

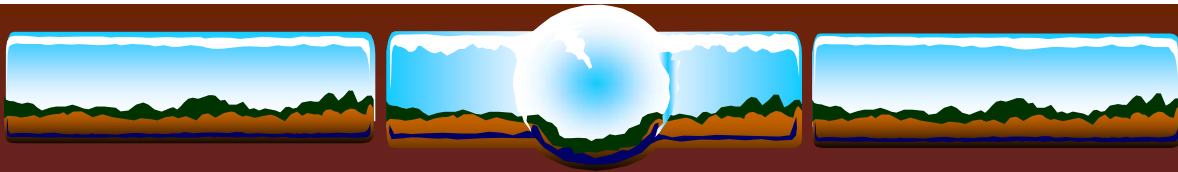


Mainly decrease in rain over land in tropics and subtropics, but enhanced by increased atmospheric demand with warming

Severity Index (PDSI) for 1900 to 2002.

The time series (below) accounts for most of the trend in PDSI.





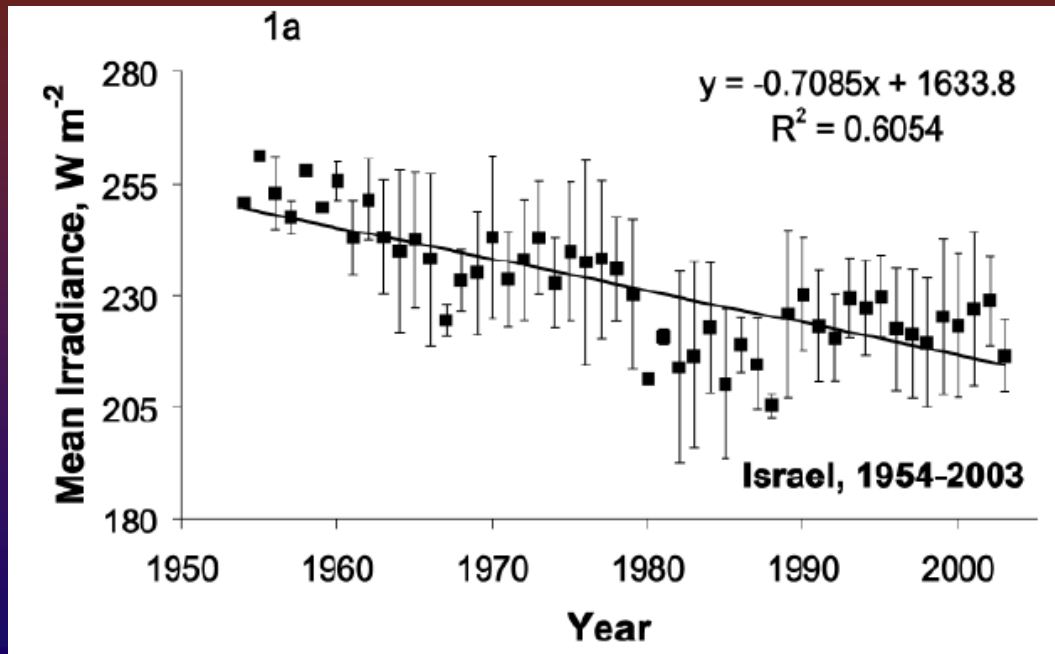
Global Dimming or “Long Term Trends in Solar Radiation”



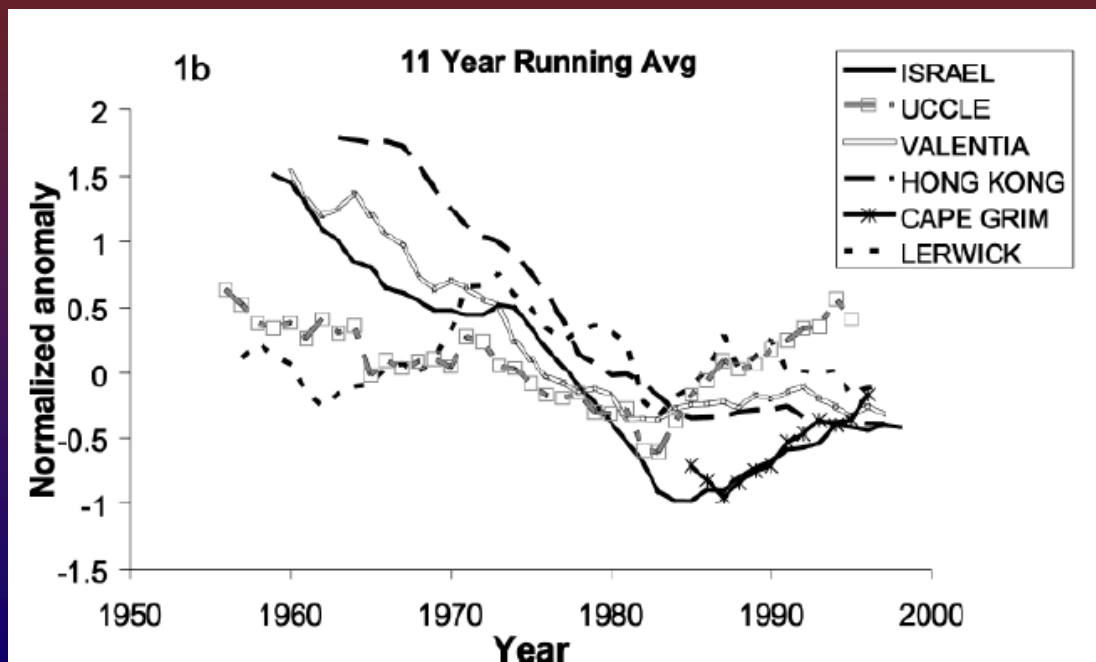
What is global dimming?

- **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

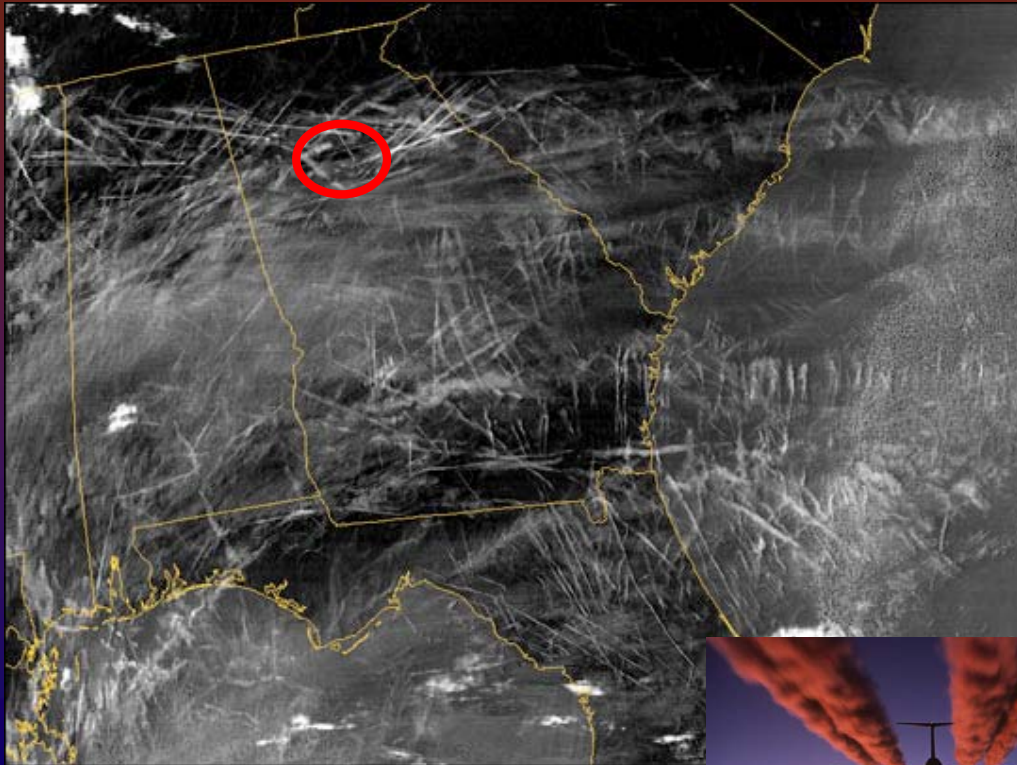
- Worldwide decline in the “pan evaporation rate.”
 - Sunlight, humidity, and wind are dominant factors



Where does it come from?

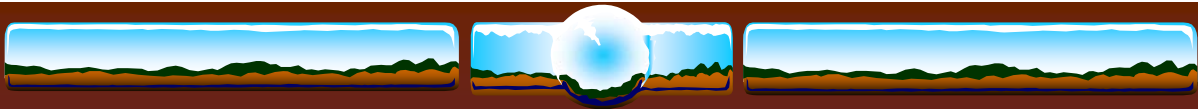
- Effect of global dimming is probably due *in part* to the increased presence of aerosol particles in the atmosphere.
 - Aerosol particles and other particulate pollutants absorb solar energy and reflect sunlight back into space.
 - Increased pollution, resulting in more particulates, creates clouds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

Aircraft Contrails, Jan 29 2004 MODIS



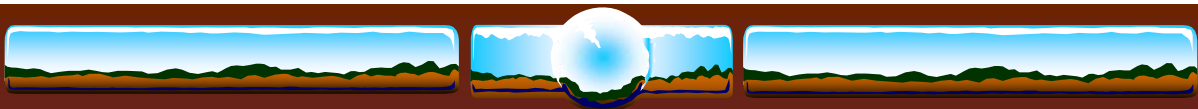
Aircraft Contrails over Europe





Effects are mostly regional

- Regions that are downwind 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

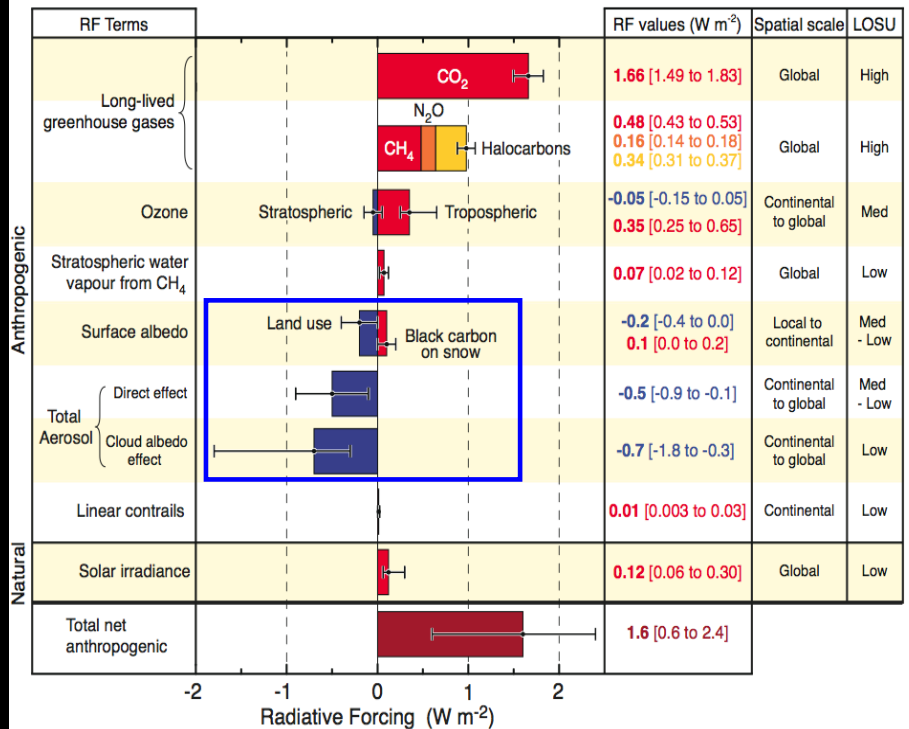


Trend Reversal – 1990-2006

- The “dimming” trend had reversed
 - likely that part of this change, particularly over Europe, is due to decreases in pollution.
- Most developed nations have done more to reduce aerosols released into the atmosphere than to reduce CO₂ emissions.

Human and Natural Drivers of Climate Change

Radiative Forcing Components



IPCC - WGI

©IPCC 2007: WG1-AR4

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 $1^{\circ}C$. That's more than the warming that we've seen already, so this is a huge factor."

