Climate Dynamics (PCC 587): Climate Records

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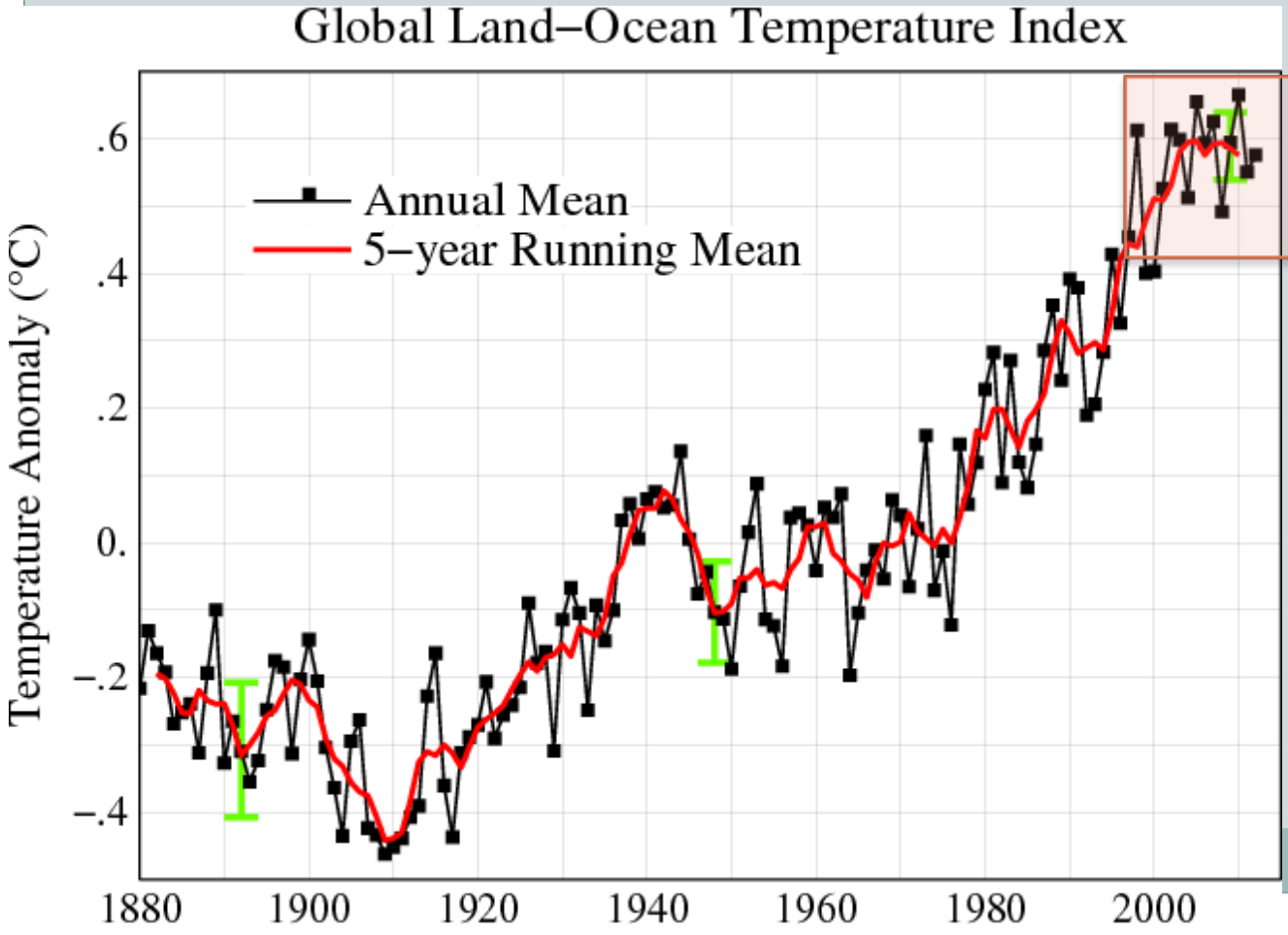
DAY 8: 10/21/2013

The Instrumental Record from NASA

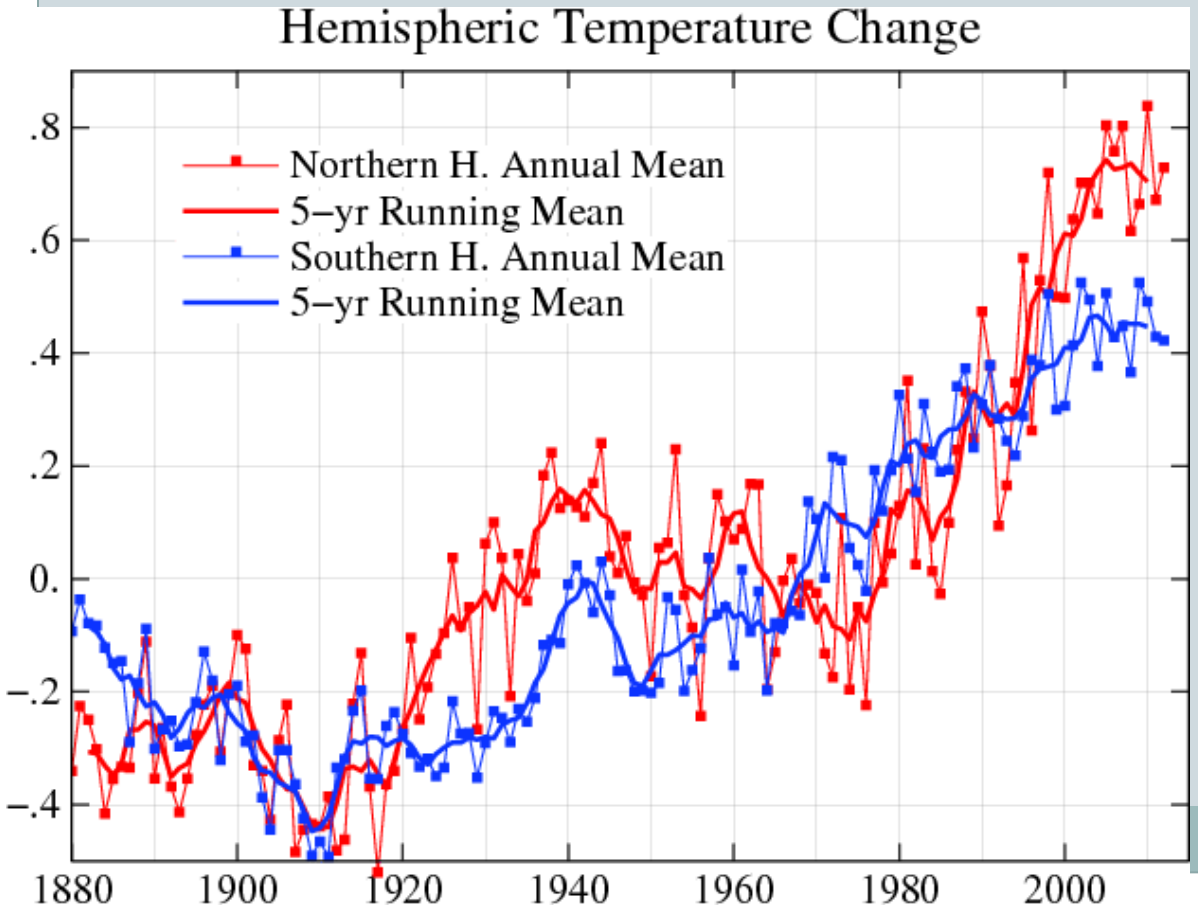
- Global temperature since 1880



13 warmest years: 2001-2012 and 1998 (biggest El Niño ever)

Separation into Northern/Southern Hemispheres

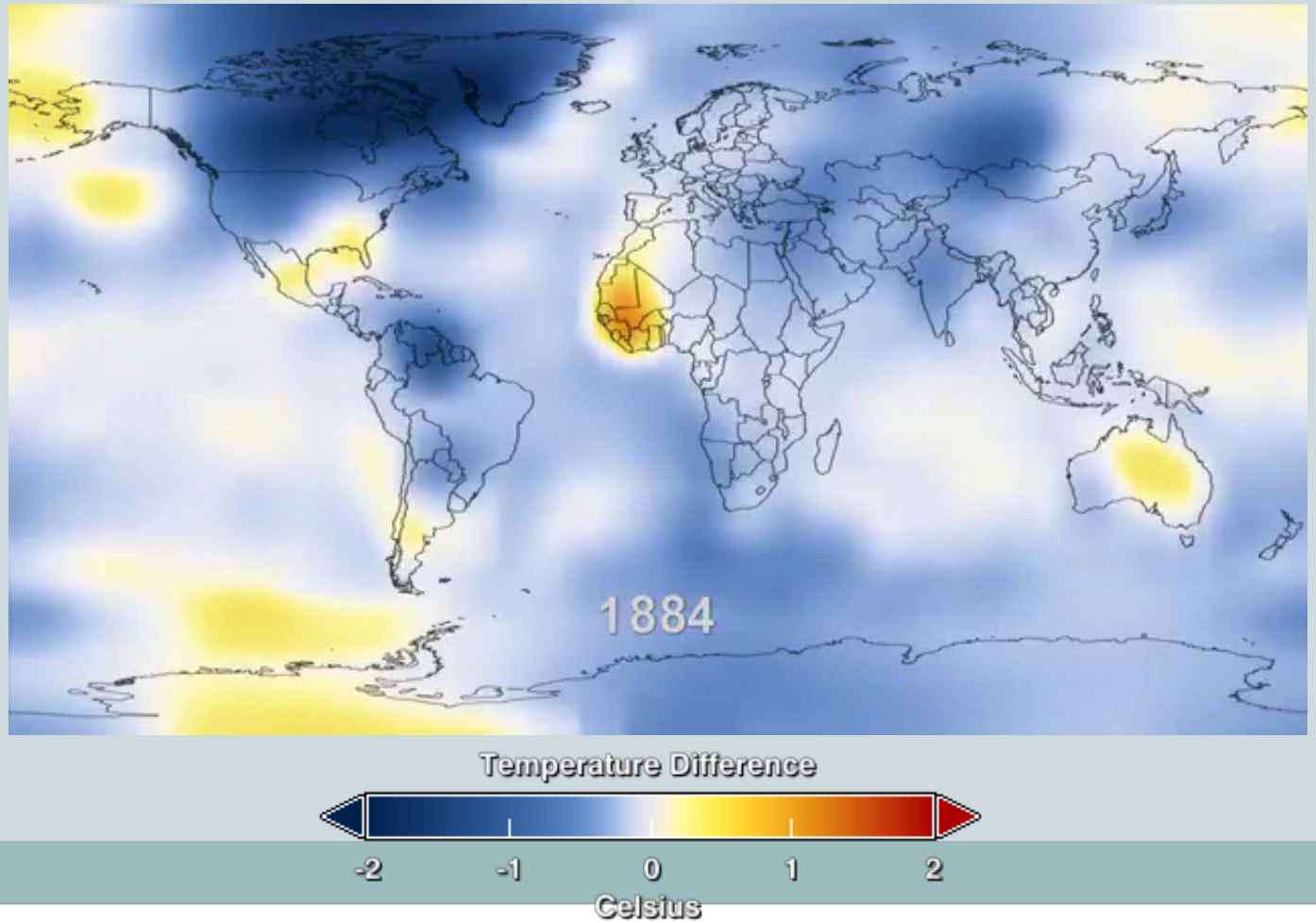
- N. Hem. has warmed more (1° C vs 0.8° C globally)
- S. Hem. has warmed more steadily though



Cooling from 1940-1975 only in the N. Hem. (likely due in part to "global dimming" from aerosols)

Spatial Structure of the Warming

- NASA temperature record, 5 yr averages



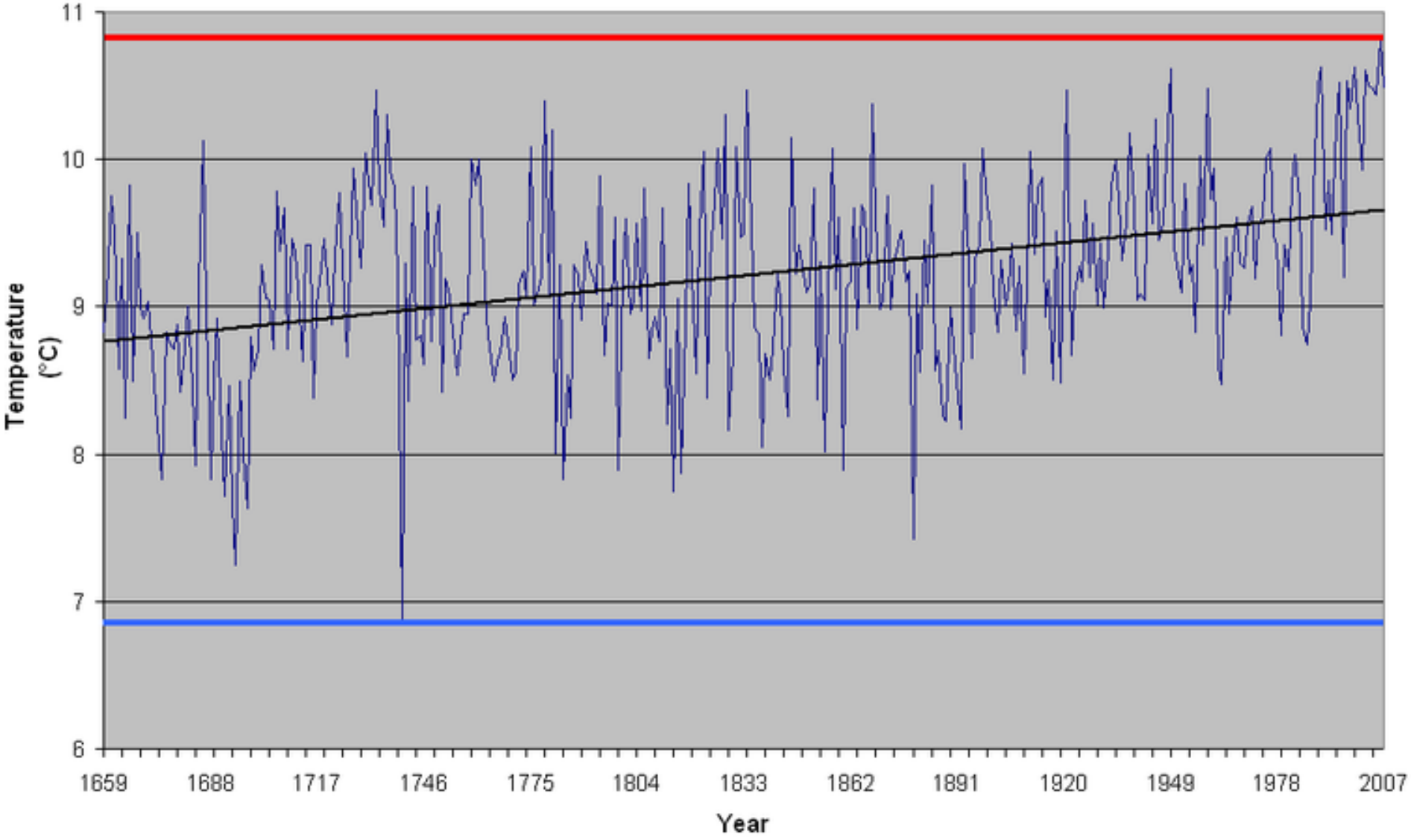
Thermometers

- Temperature is easy to measure
- Some history:
  - Ancient Greeks knew that gases/liquids expand when heated
  - Galileo played around with thermometer-type devices (1592)
  - Ferdinand II de Medici, Grand Duke of Tuscany, invented sealed glass thermometer (much more accurate) around 1650
    - Measured temperatures within artificial incubators to hatch chicks
    - Established the first international network of weather stations
      - 7 stations in Italy, also Warsaw, Paris, Innsbruck, Osnabruck

Temperature Scales

- Daniel Gabriel Fahrenheit invented his scale in 1724
  - Also invented the mercury thermometer (1714)
  - Scale based on three points:
    - Freezing point (32^0)
    - Cold temperature of an ice/salt/water mixture (0^0)
    - Underarm body temperature (96^0)
  - Later redefined slightly to just depend on 32^0 and 212^0…
- Anders Celsius (1742)
  - Based on 0^0 for **boiling** and 100^0 for **freezing**!
  - Switched by Linnaeus in 1745

Central England temperature record (since 1659!)



Weather Observations

- Meteorological Society of Mannheim (1780):
  - 37 stations in Europe, 2 in North America
  - Very rigorous procedures for making measurements, calibrating instruments
- Invention of telegraph allowed for quick construction of weather maps by 1850
- First International Meteorological Conference (August 1853)
  - US Navy Lieutenant Matthew Fontaine Maury developed standard procedure for meteorological observations on ships

Surface temperature measurement protocol

Thermometer between 1.25-2 m (4-6.5 ft) above ground

White colored to reflect away direct sunlight

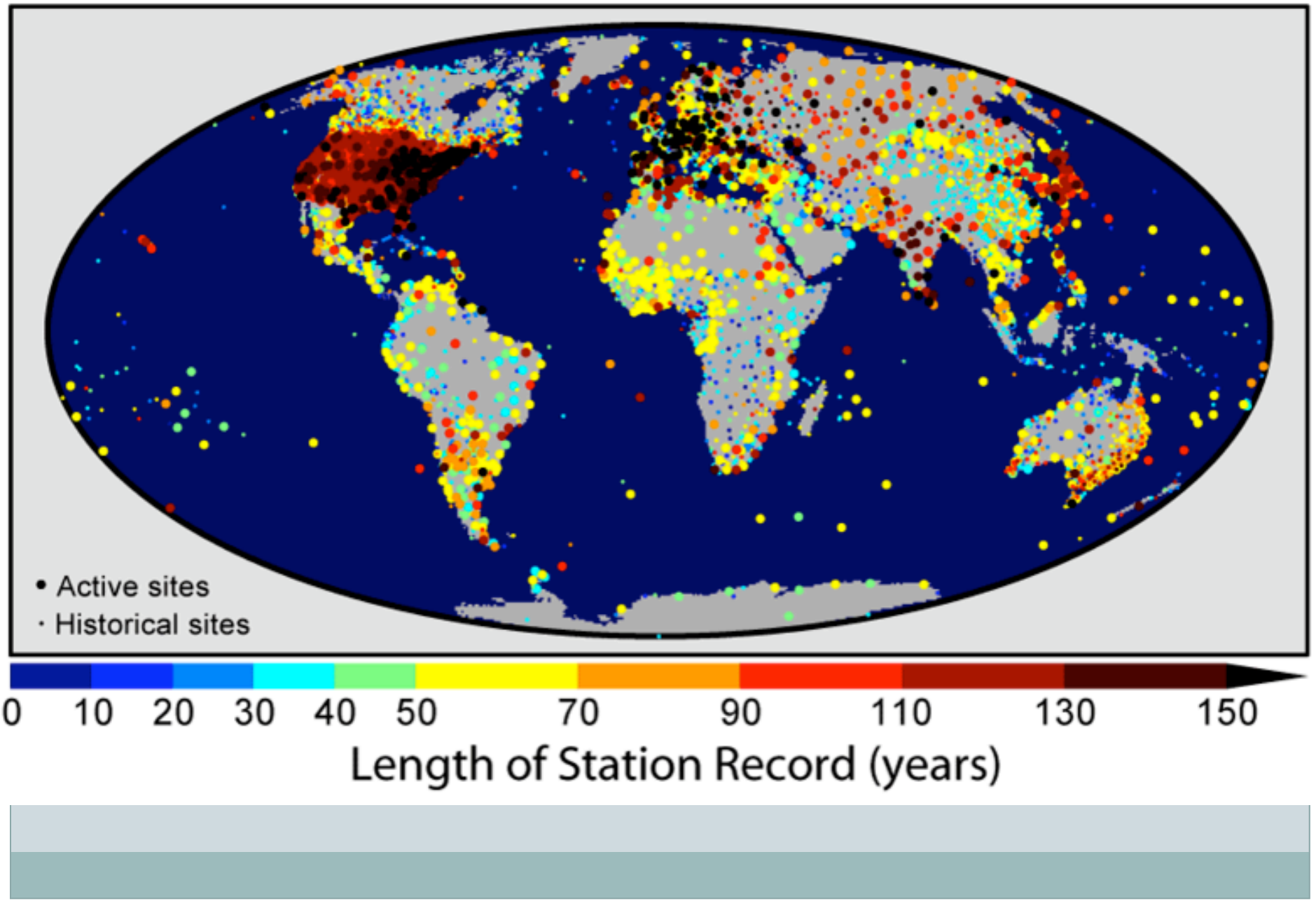
Slats to ensure fresh air circulation

"Stevenson screen": invented by Robert Louis Stevenson's dad Thomas

Thermometer Measurements

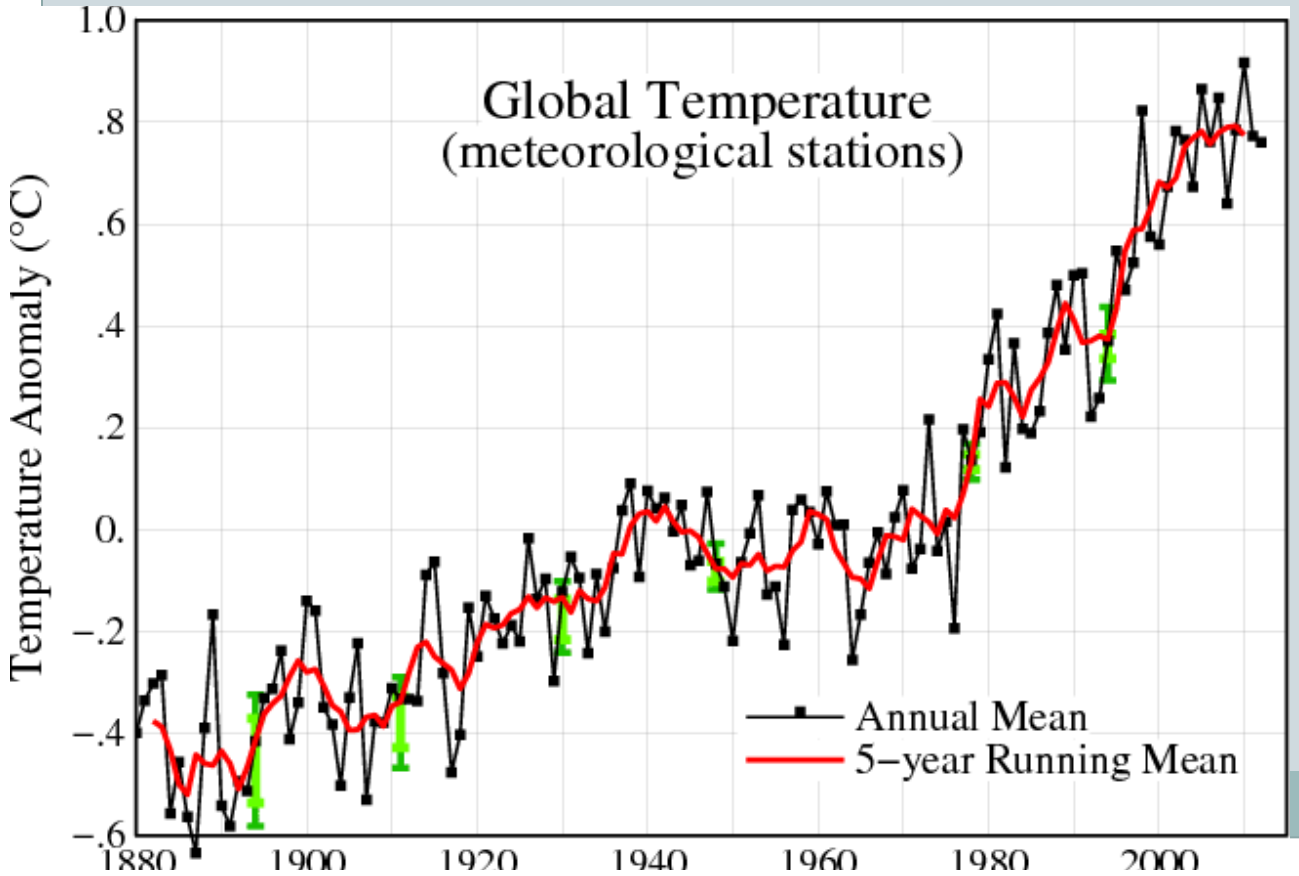
- Bank thermometers make me LOL
  - Often poorly sited, read high

Global Climate Network Temperature Stations



Temperatures over Land Only

- NASA keeps track of land-only measurements separately



Warming in the station data record is larger than in the full record (1.1° C as opposed to 0.8° C)

Sea surface temperature measurements

Standard bucket (~1891)

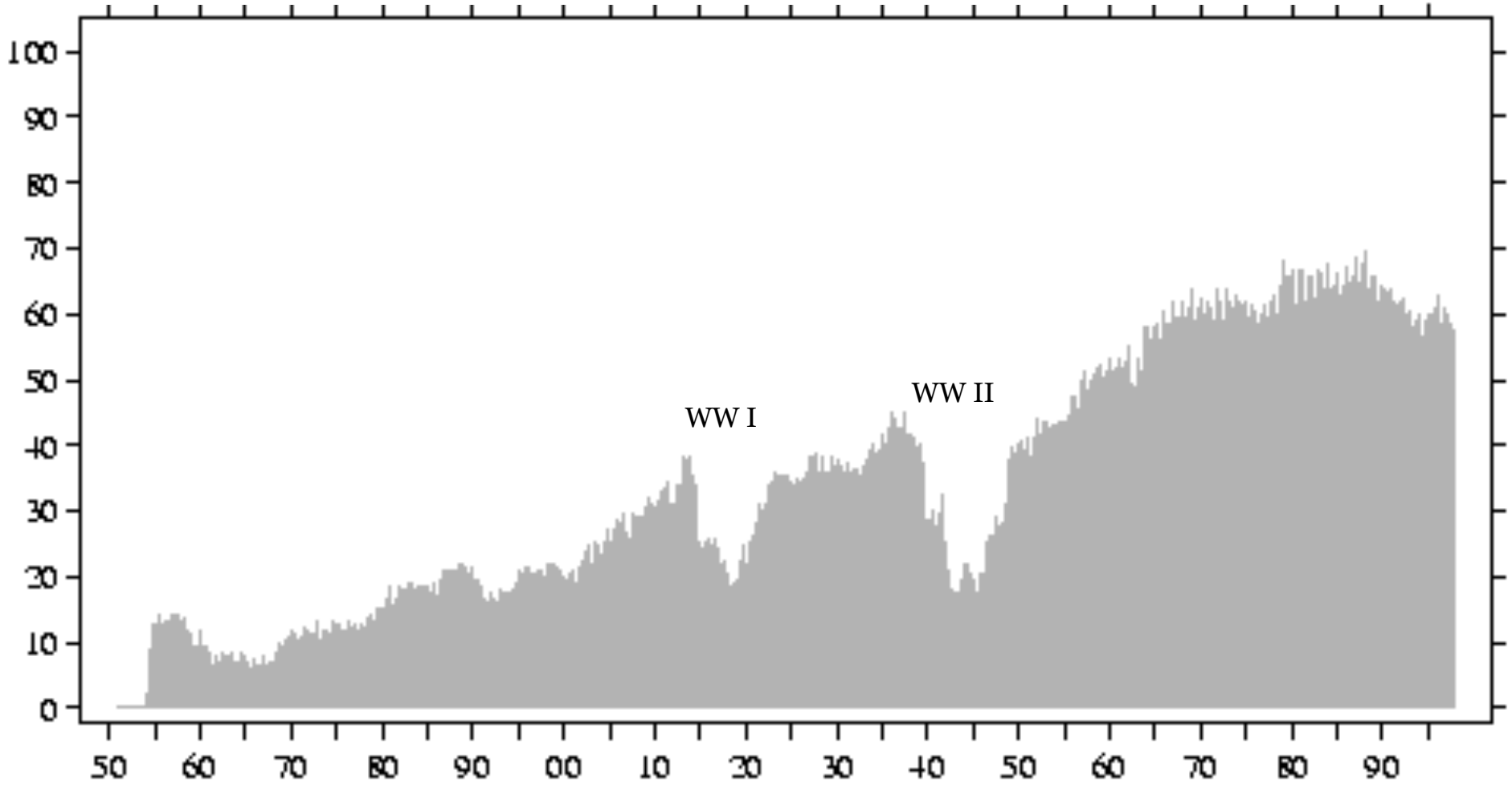
Canvas bucket (pre WWII)

Insulated bucket (now)

"Bucket" temperature: older style subject to some cooling by evaporation

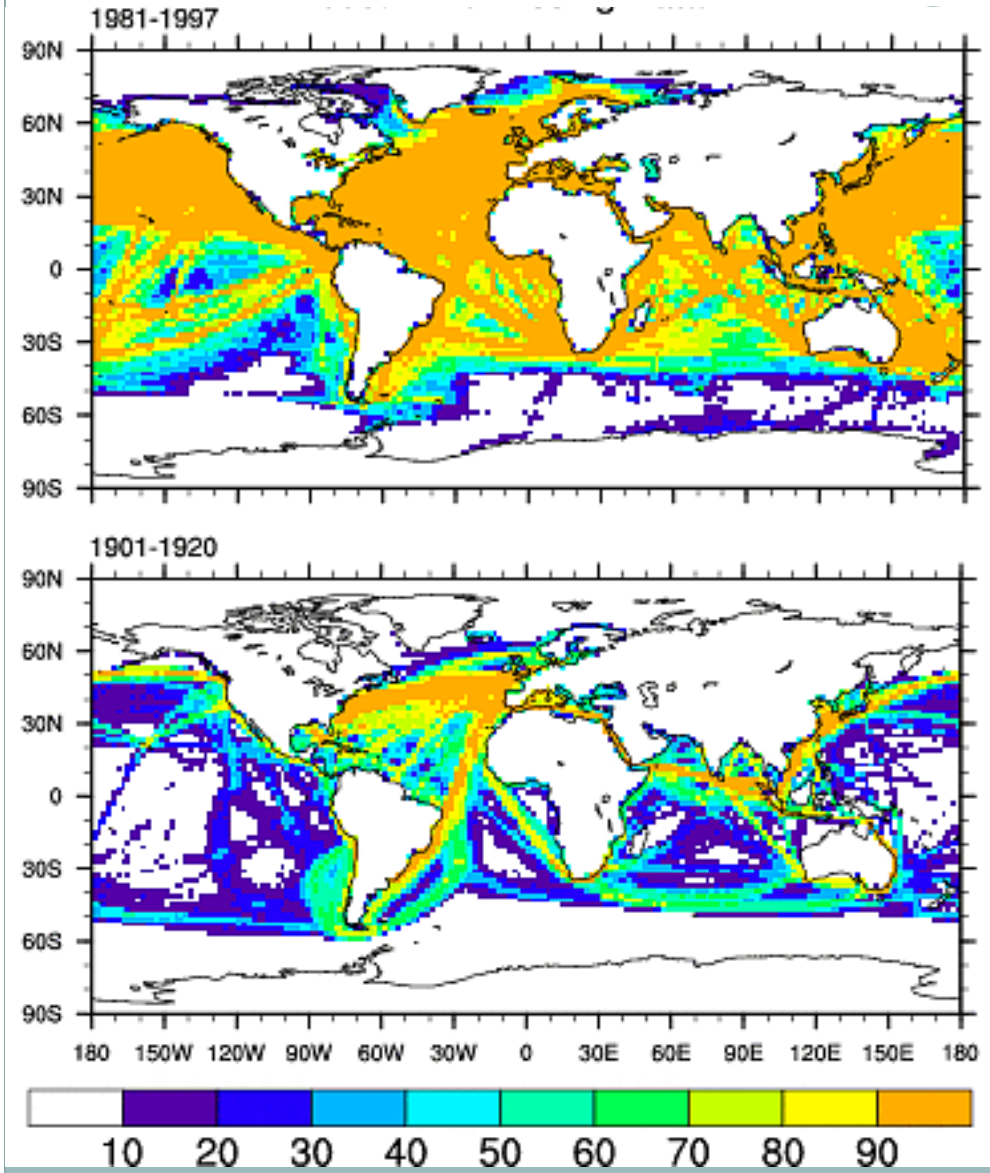
Starting around WWII, many measurements taken from **condenser intake pipe** instead of from buckets

Percent coverage of ocean by year



1850 **1900** **1950** **1990**

Percent coverage of ocean



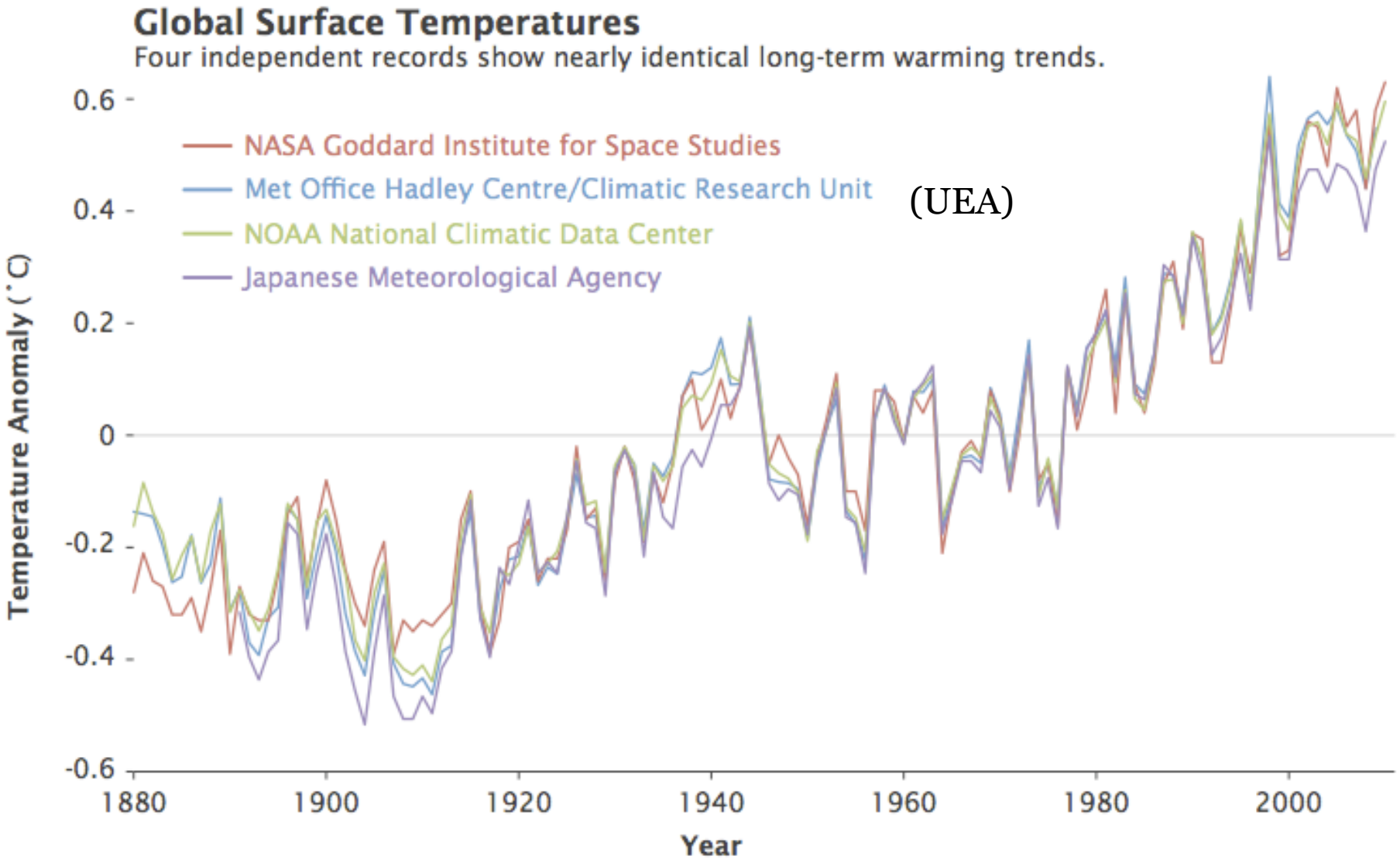
1981-1997

1901-1920

10% = 1 in 10 months had a ship measurement

Constructing the Global Temperature Record

- Groups construct global temperature based on data that follows these procedures
- Decent enough global coverage started around 1880-1890


Global Surface Temperatures
Four independent records show nearly identical long-term warming trends.
NASA Goddard Institute for Space Studies
Met Office Hadley Centre/Climatic Research Unit
NOAA National Climatic Data Center
Japanese Meteorological Agency
(UEA)
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1880
1900
1920
1940
1960
1980
2000
Year
Credit: NASA Earth Observatory/Robert Simmon
Data Sources: NASA Goddard Institute for Space Studies, NOAA National Climatic Data Center, Met Office Hadley Centre/Climatic Research Unit, and the Japanese Meteorological Agency.

Climate Data Groups

- National Climatic Data Center (NOAA)
  - Asheville, NC

Climate Data Groups

- University of East Anglia Climate Research Unit (CRU)
  - Norwich, England
- Hadley Centre
  - Exeter, England

Climate Data Groups

- Goddard Institute for Space Studies (NASA)
  - New York, NY

Raw Weather Station Data

```
#
#       This data is from: ATG rooftop, U. of Wash. (stn. code uwa)
#
#
```

Atmospheric Sciences Rooftop Site and Instrument specifications

University of Washington
Seattle, WA

Established: July 1999

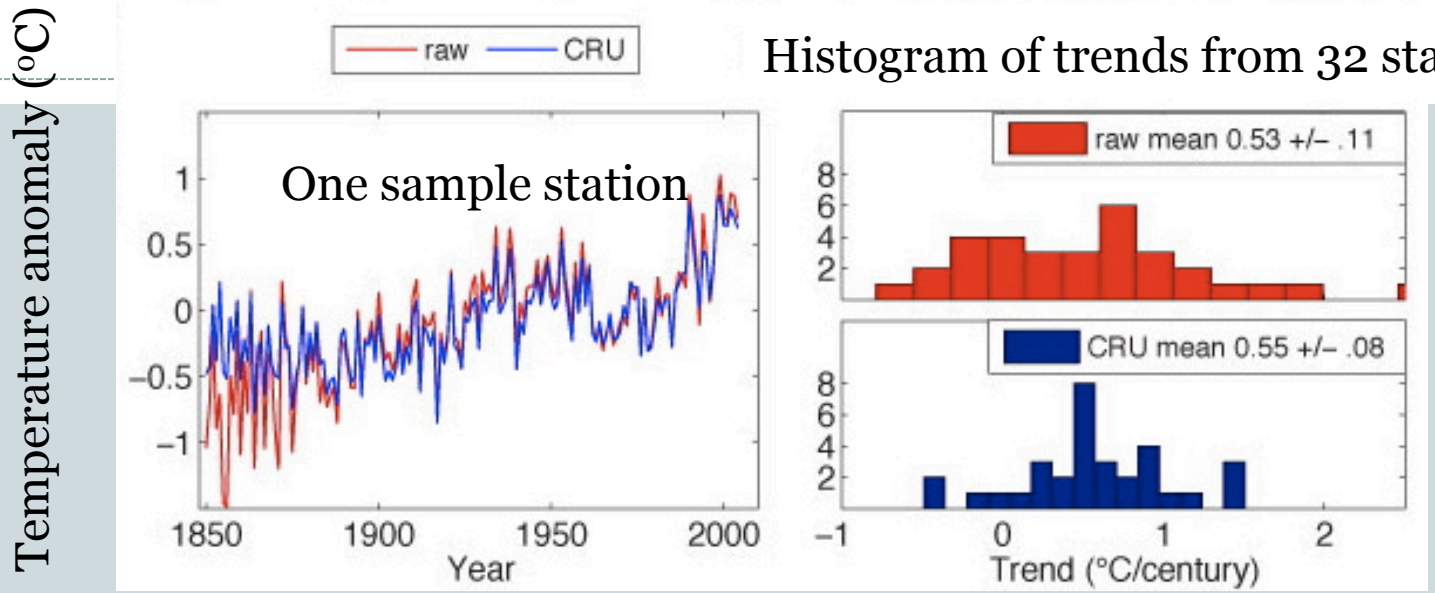
```
#  Rain Gauge (inches) ------------------------------------------------------------*
#  Relative humidity (%) ---------------------------------------------------------*  |
#  Solar irradiance (W/m^2) ------------------------------------------------*  |  |
#  Visibility (miles) ------------------------------------------------------*  |  |
#  Cloud height (100's of feet) --------------------------------------*  |  |  |
#  Cloud cover (1/8ths of sky) ---------------------------------*  |  |  |  |
#  Wind peak (nautical miles per hour) ----------------------*  |  |  |  |  |
#  Wind speed (nautical miles per hour) -----------------*  |  |  |  |  |  |
#  Wind direction (clockwise degrees from North) --*  |  |  |  |  |  |  |  |
#  Dewpoint temperature (F) -------------------*  |  |  |  |  |  |  |  |  |
#  Air temperature (F) -------------------*  |  |  |  |  |  |  |  |  |  |
#  Pressure (millibars) -----------*  |  |  |  |  |  |  |  |  |  |  |  |
#                                  |  |  |  |  |  |  |  |  |  |  |  |
#                                  |  |  |  |  |  |  |  |  |  |  |  |
#    Date(GMT)     Julian date    Pres  Tair Tdew Dir Spd  Peak  Cc Cht Vis  Radn   RelH Rain
# -------------  -------------- ------ ---- ---- --- ---- ---- --- --- --- ------ ----- ----
#
2010-02-07 04:34 2455235.1902778 1010.8 49.7 38.7 132  6.6  8.7   X  M   M     0.0  65.8 0.00
2010-02-07 04:35 2455235.1909722 1010.8 49.7 39.0 125  6.0  7.1   X  M   M     0.0  66.4 0.00
2010-02-07 04:36 2455235.1916667 1010.5 49.8 38.9 136  6.8  7.6   X  M   M     0.0  66.1 0.00
2010-02-07 04:37 2455235.1923611 1010.7 49.7 38.9 137  6.5  7.6   X  M   M     0.0  66.2 0.00
2010-02-07 04:38 2455235.1930556 1010.7 49.7 39.0 128  6.5  8.7   X  M   M     0.0  66.4 0.00
2010-02-07 04:39 2455235.1937500 1010.8 49.6 38.9 143  6.4  7.5   X  M   M     0.0  66.3 0.00
2010-02-07 04:40 2455235.1944444 1010.6 49.6 39.0 131  6.9  7.5   X  M   M     0.0  66.6 0.00
2010-02-07 04:41 2455235.1951389 1010.7 49.6 39.0 134  6.1  7.5   X  M   M     0.0  66.7 0.00
2010-02-07 04:42 2455235.1958333 1010.7 49.6 38.9 131  6.7  8.8   X  M   M     0.0  66.7 0.00
```

Constructing Global Temperature

- Groups like NASA, NOAA, CRU have two steps:
  - **Remove inhomogeneities** in individual stations due to **changes in observing practices**, **station environment**, or other non-meteorological factors
    - E.g., urban stations are removed
  - They also have well-documented procedures for **combining fragmented record**.

*You can download **raw** weather station data from the "World Monthly Surface Station Climatology"*
http://rda.ucar.edu/datasets/ds570.0

Step 1

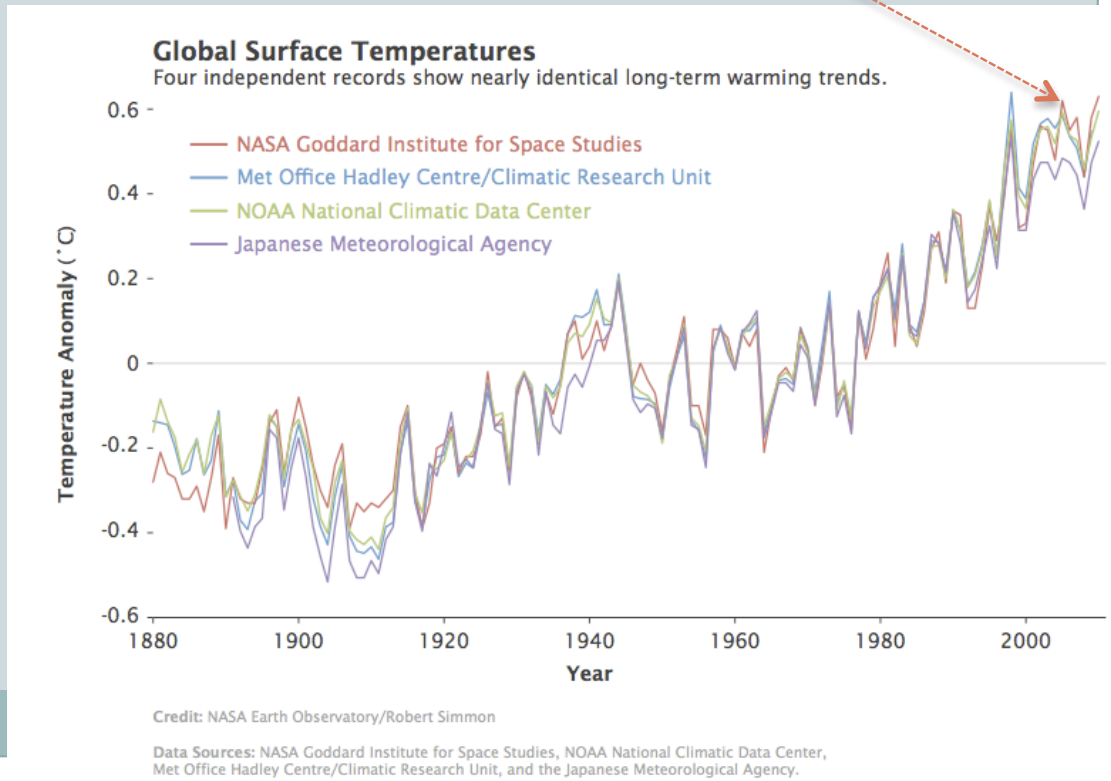


UW researchers Kevin Wood & Eric Steig took random sets of 32 stations and compared the raw data to the CRU analysis.

CRU weeded out some extremes but didn't change the average much

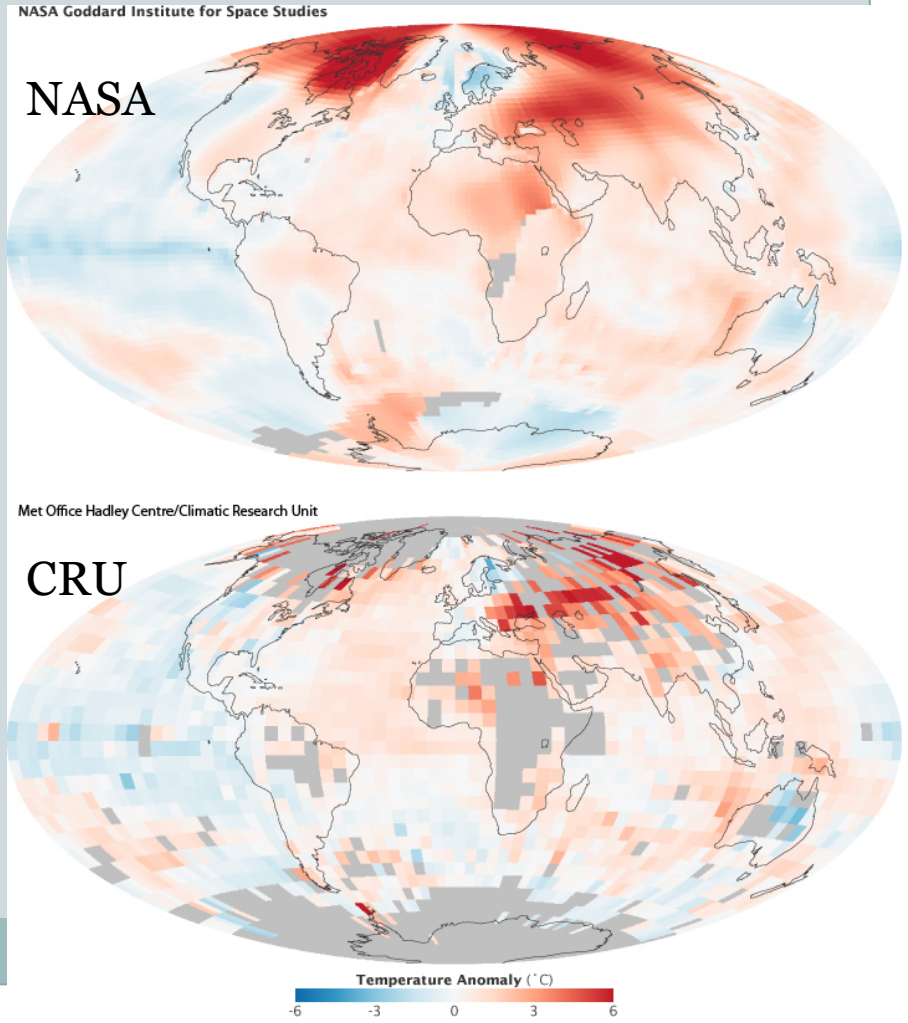
Constructing Global Temperature

- Centers have different procedures for **filling in gaps** where there's no data
- Notice how there is differences among centers recently?
  - Let's discuss why…



Constructing Global Temperature

- CRU and NOAA **don't include** the Arctic Ocean where there's no data
- NASA **fills** these points with the nearest station
- So CRU and NOAA are not including one of the locations that's clearly warming the fastest!
  - But that's their procedure & they're sticking to it…



Pitfalls of temperature measurements

incomplete spatial sampling

short and “gappy” records

instrument changes

changes in station site, sometimes undocumented

changes in exposure of station site

changes in observing protocol

transcription errors

invalid data (faulty instruments, unreliable observers)

“urban heat island” effect

Virtue of the temperature measurements:

Redundancy

Many different stations

Three different data sets (land, ocean, upper air)

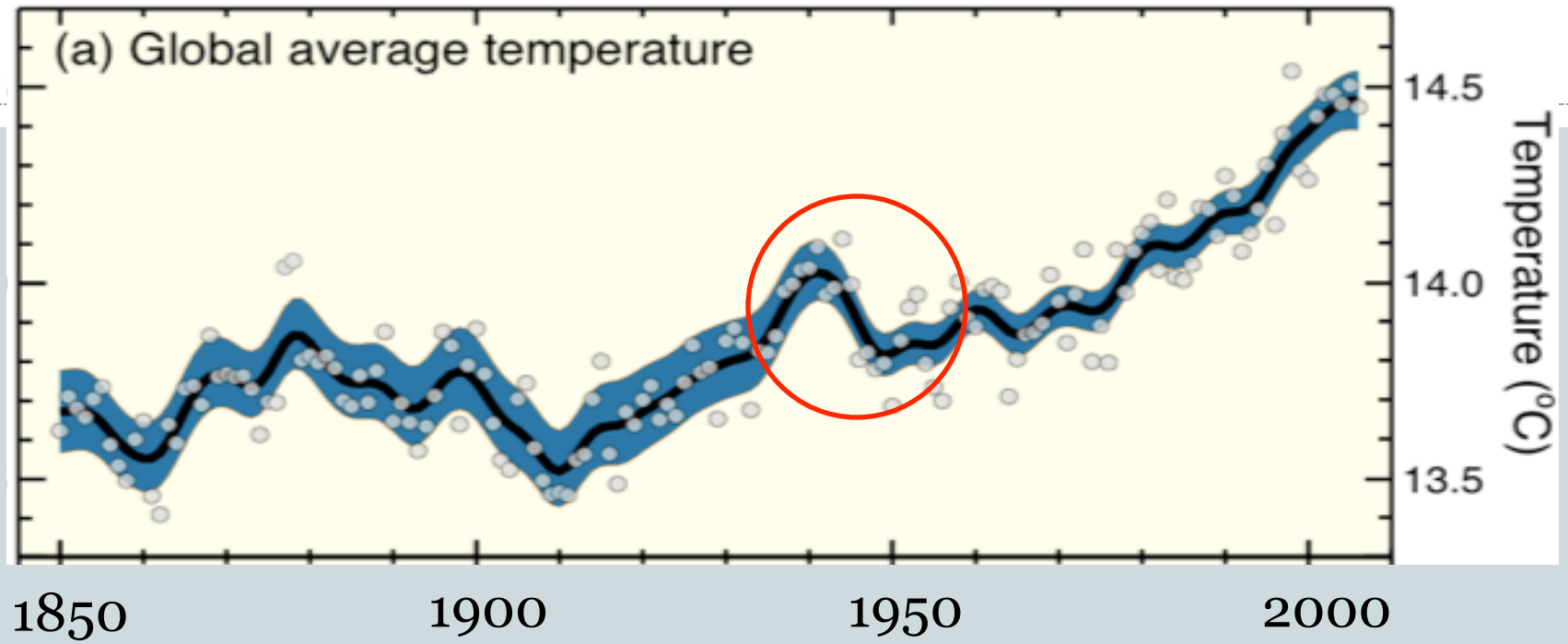
Multiple analysis methods by different groups

Random errors tend to average out

Systematic errors can be removed by calibration

Estimated **uncertainty** with global temperature measurements: currently **0.1º C** (and more in the past).

Case study 1



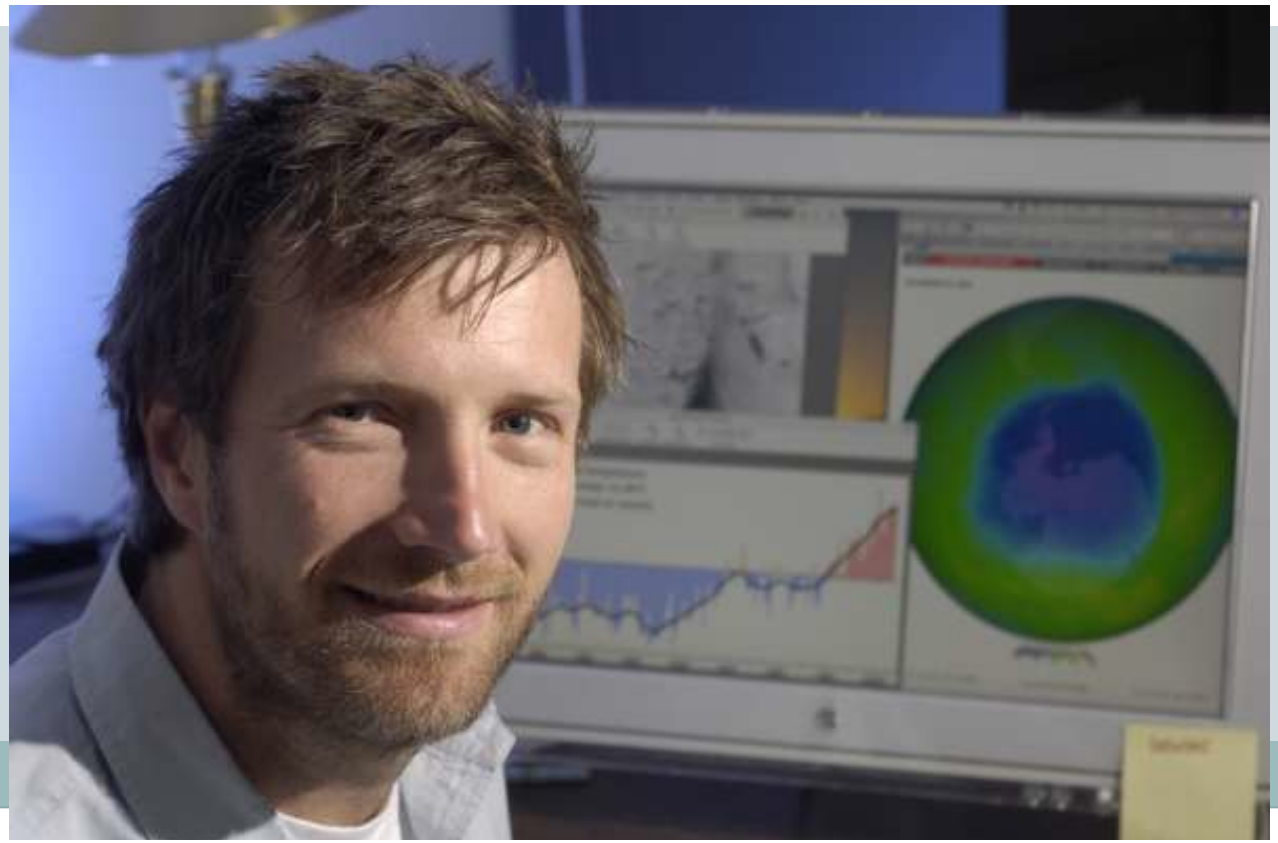
Is this feature real?
The accidental discovery that it isn't?

nature Vol 453|29 May 2008|doi:10.1038/nature06982

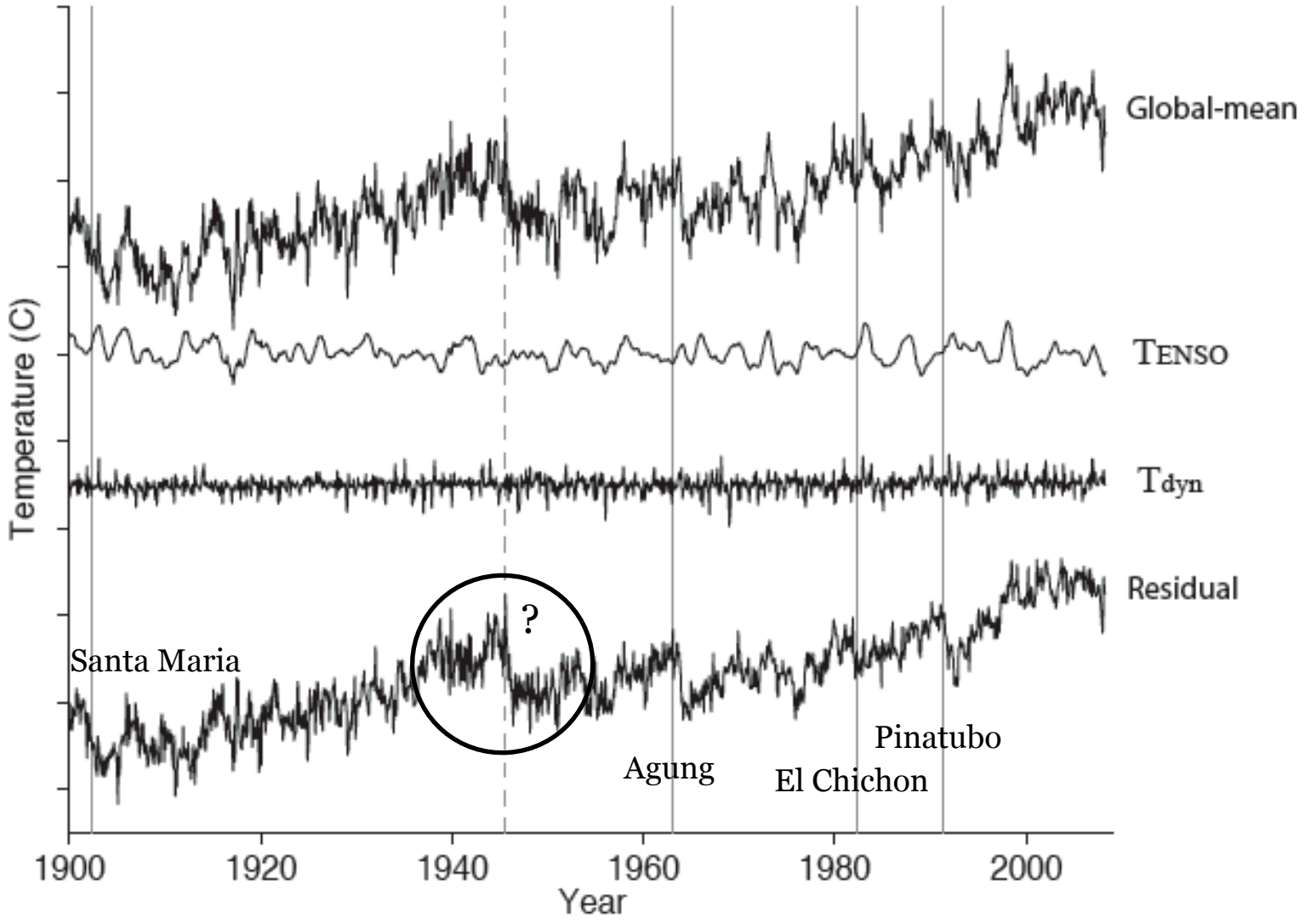
LETTERS

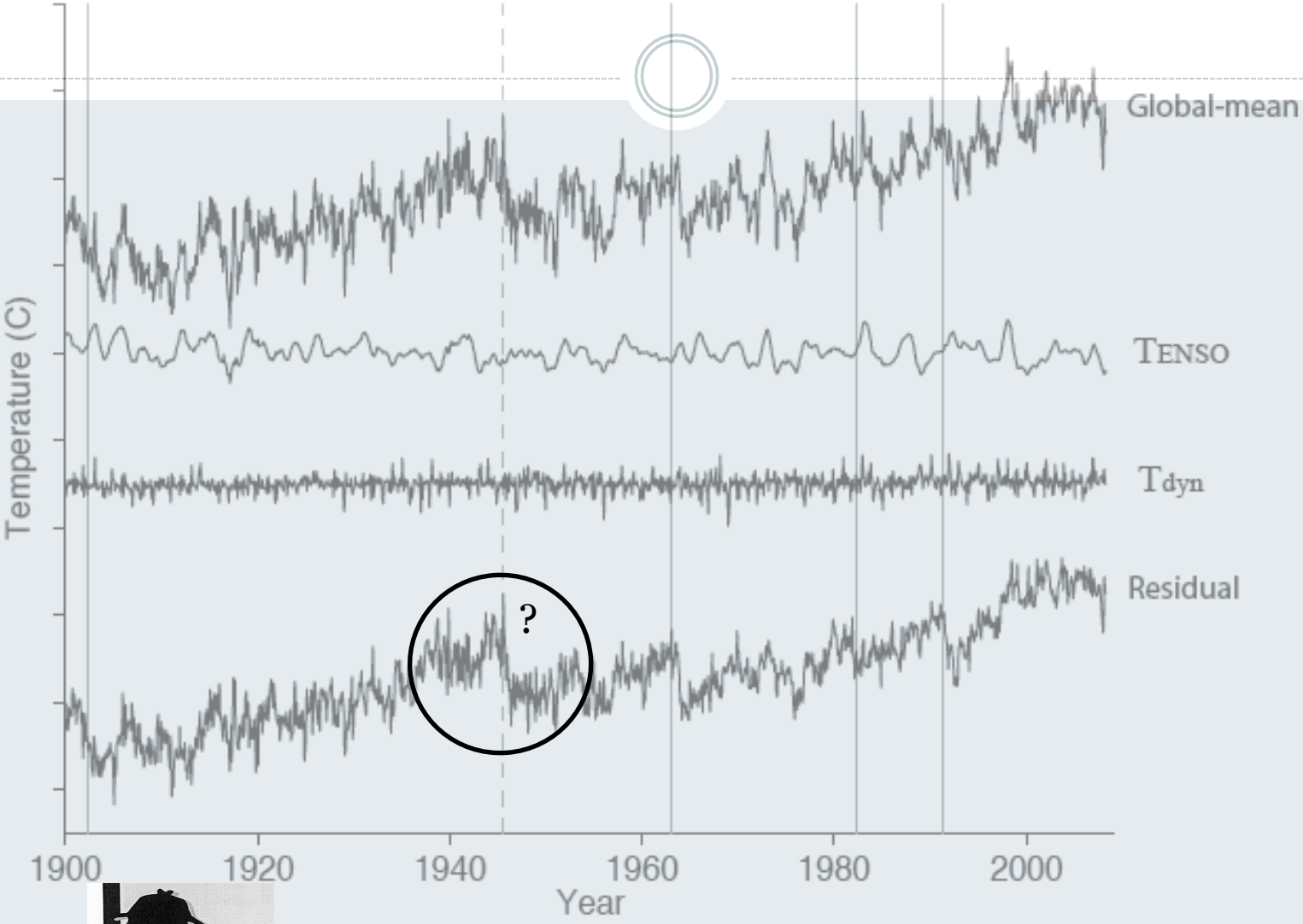
A large discontinuity in the mid-twentieth century in observed global-mean surface temperature

David W. J. Thompson[1], John J. Kennedy[2], John M. Wallace[3] & Phil D. Jones[4]

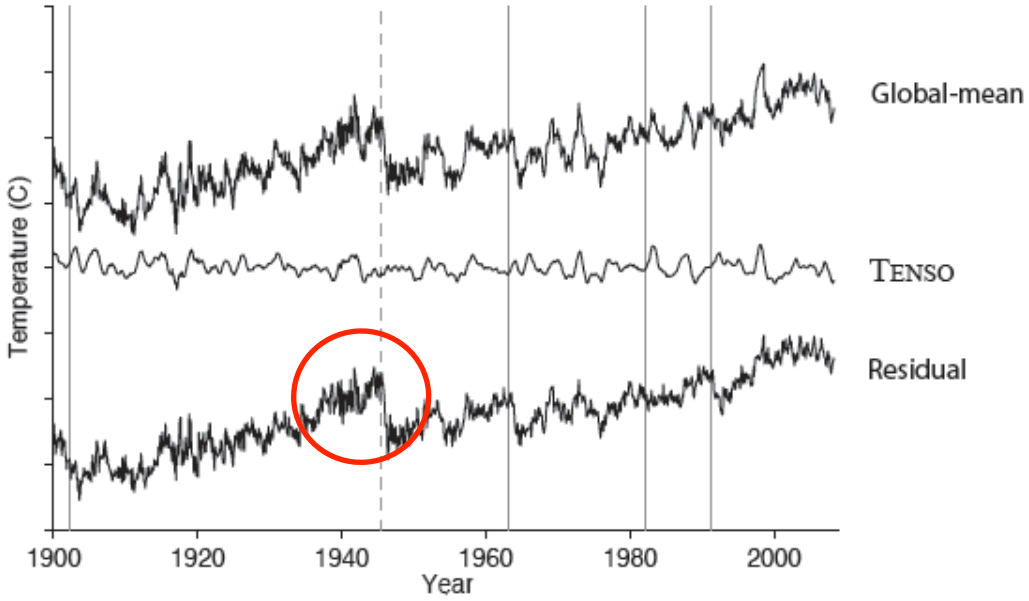


Former UW grad student (with Wallace)

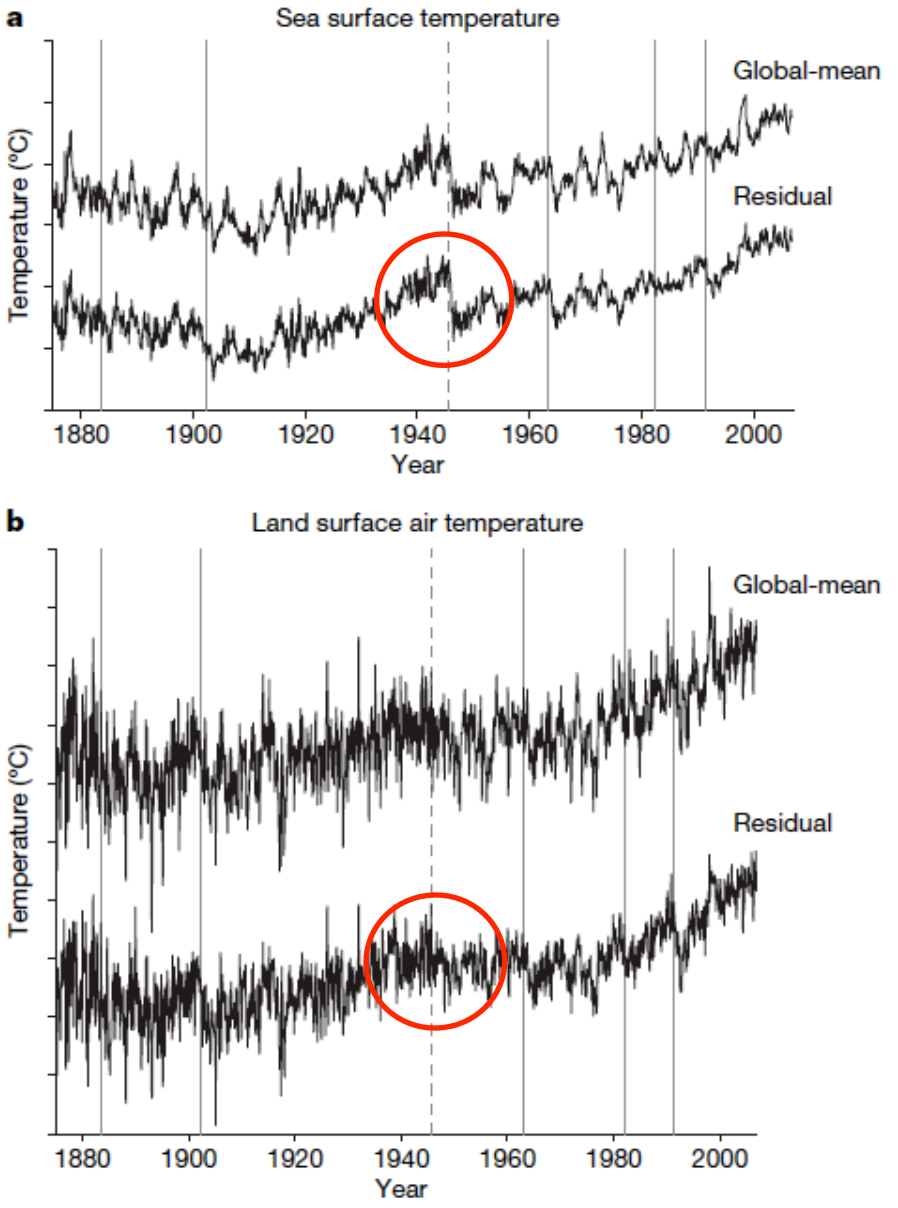

Global-mean
TENSO
Tdyn
Residual
Temperature (C)
?
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year



1945: Could it be the effect of the atomic bombs?

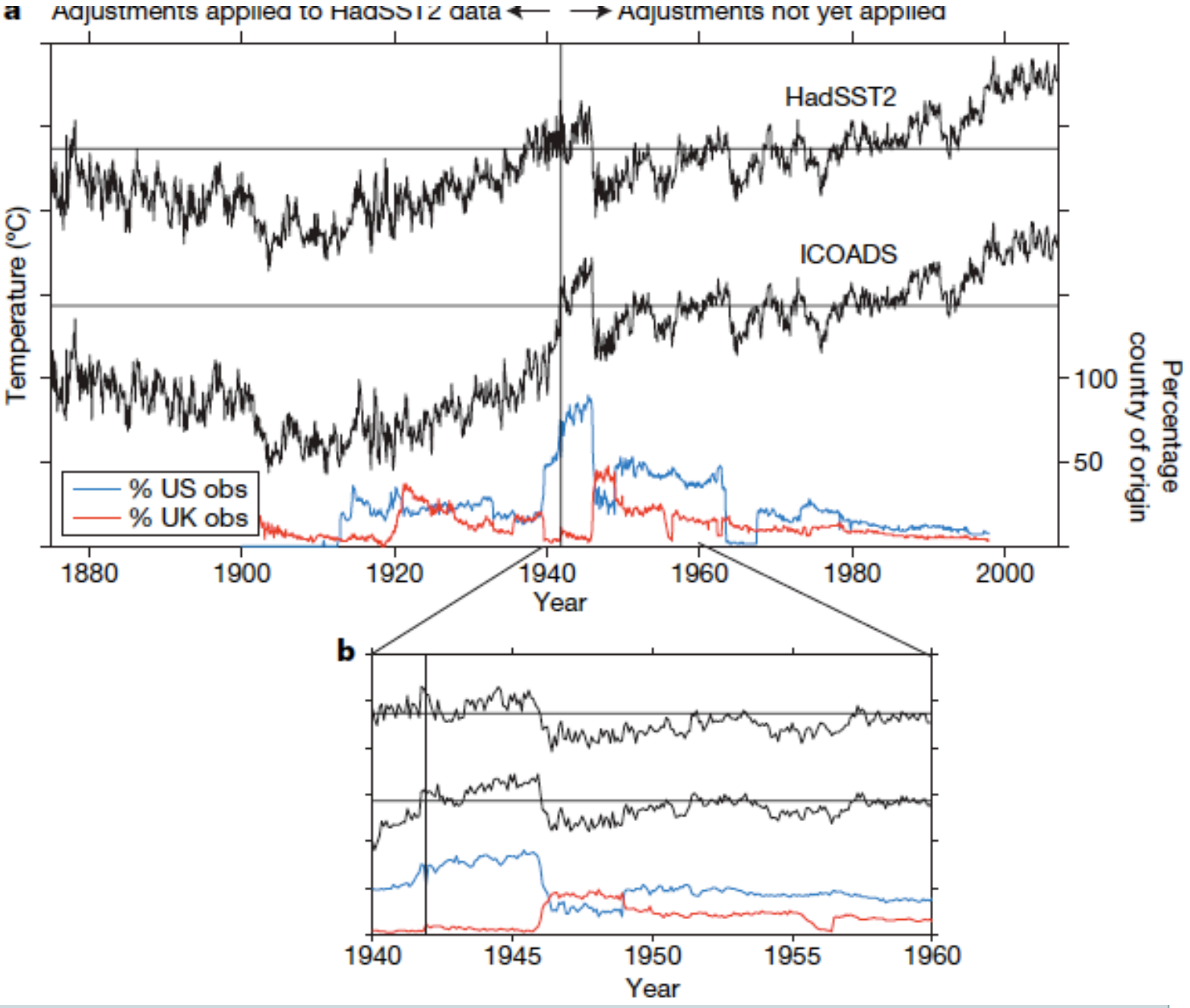


Sea surface temperature:
Now you see it!



Sea surface temperature:
Now you see it!

Land surface air temperature:
Now you don't!

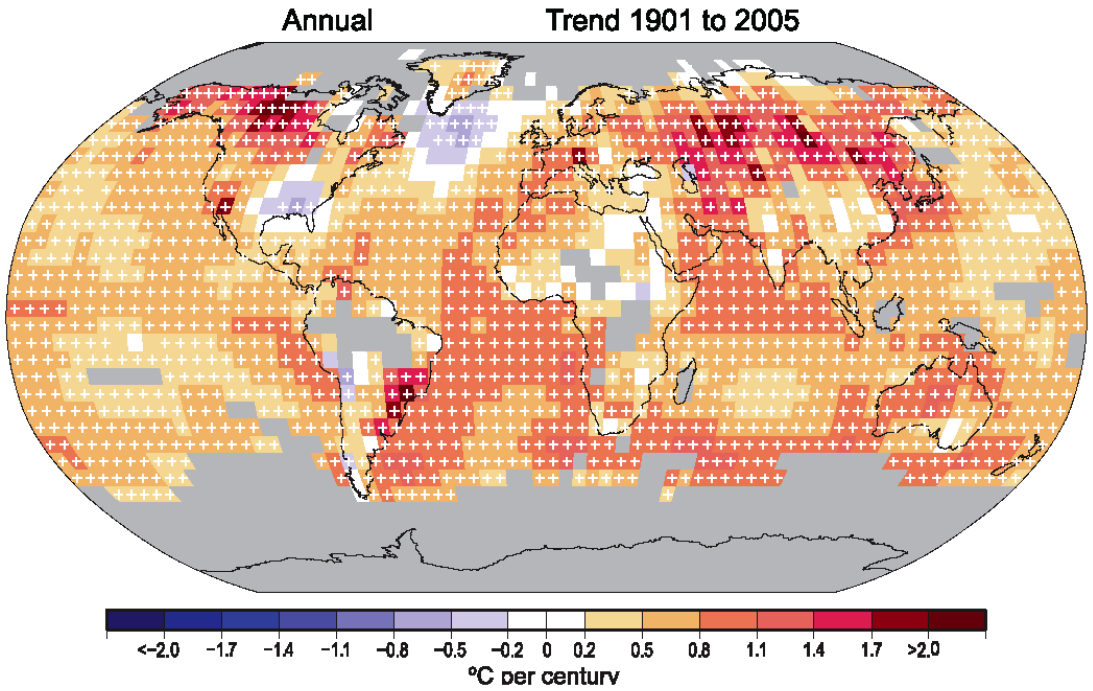

a
Adjustments applied to HadSST2 data
Adjustments not yet applied
HadSST2
ICOADS
Temperature (°C)
% US obs
% UK obs
100
50
Percentage country of origin
1880
1900
1920
1940
1960
1980
2000
Year
b
1940
1945
1950
1955
1960
Year

Reason for Discontinuity

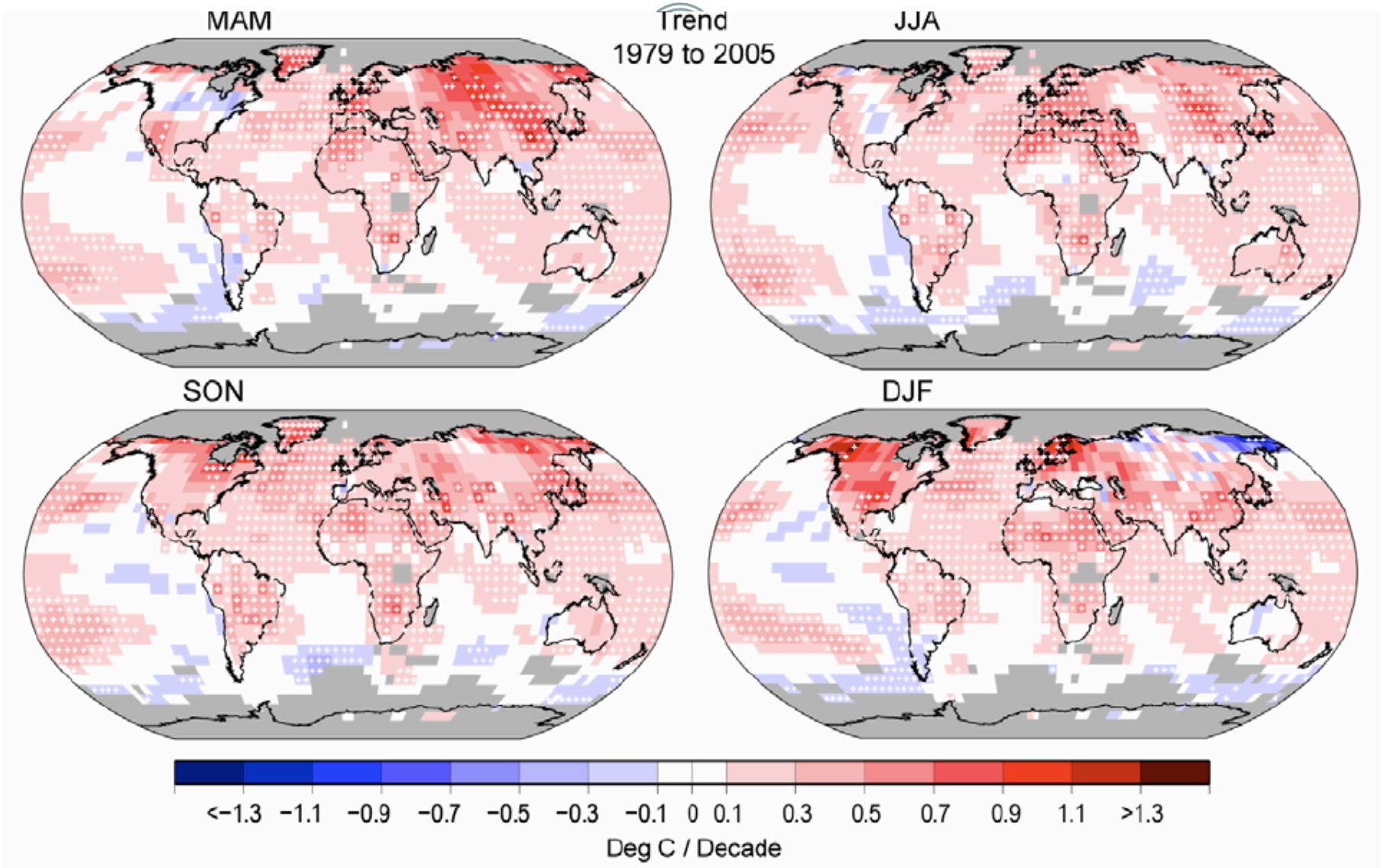
- US ships mostly used engine room intake measurements
  - These are biased slightly **warm**
- UK ships mostly used uninsulated bucket measurements
  - These are biased slightly **cold**
- Switch from mostly US ships during the war to a lot more UK ships after the war led to the false drop in temperature
  - Groups are working on correcting this now

Is the warming **Global**?

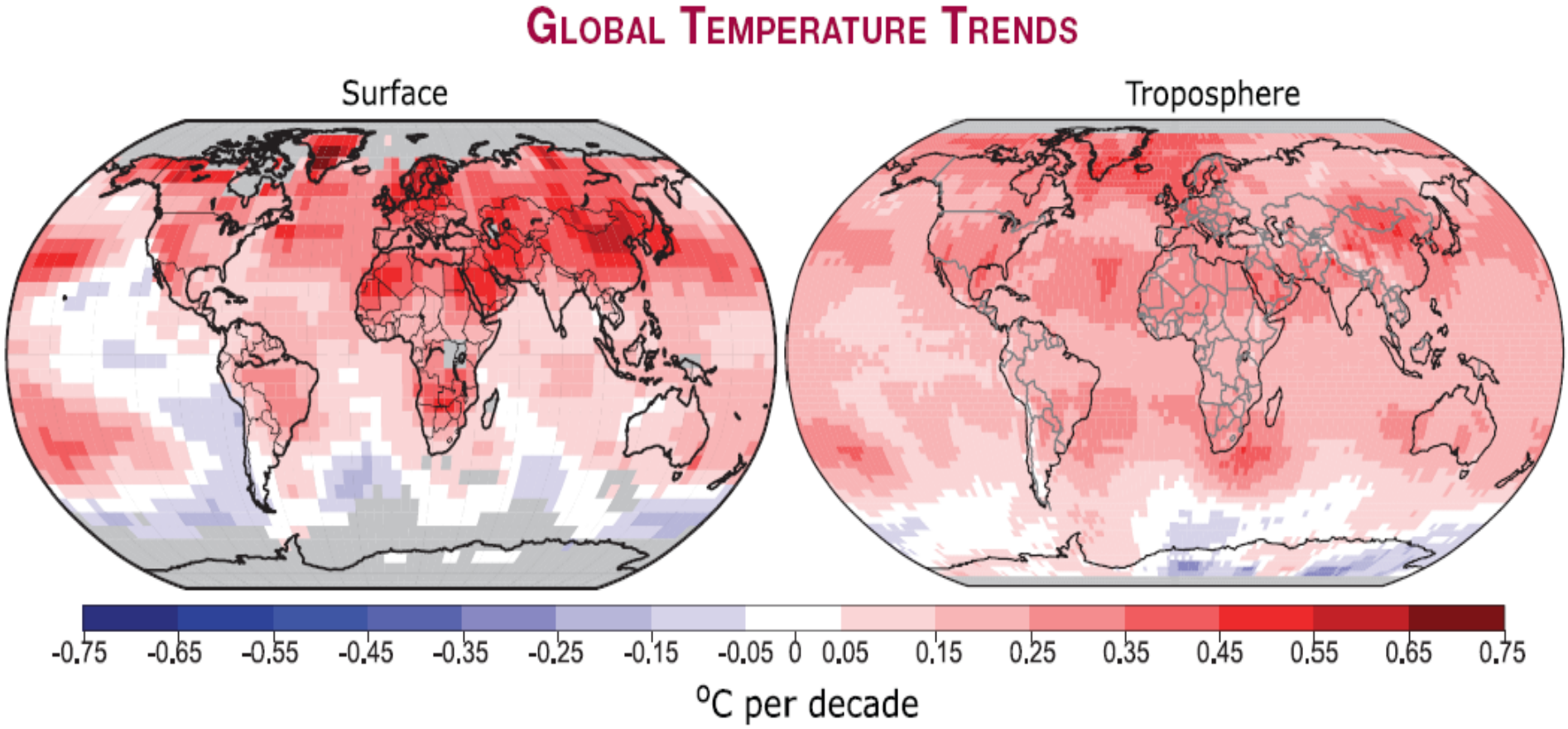
Yes, although enhanced over land at poles (as expected)



Consistency with season

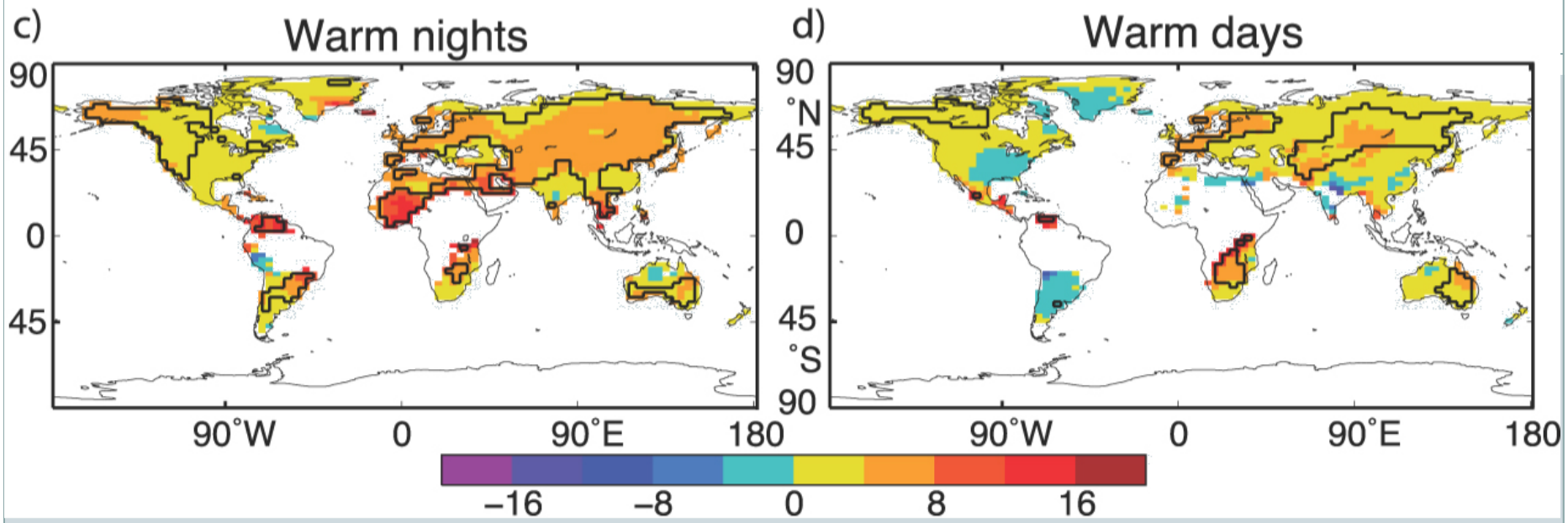


Warming extends above the surface



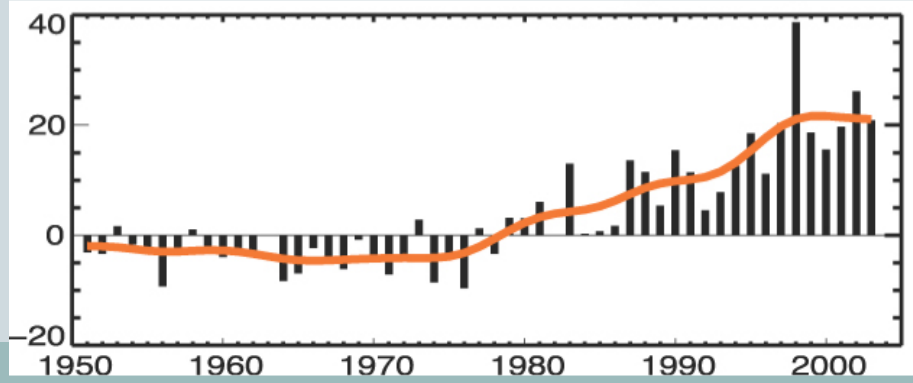
IPCC, 2007, WG I, Fig TS.6: Patterns of linear warming trends over the period 1979-2005 for the surface (right, from thermometers) and lower atmosphere (left, from satellite).

Increasing Warmth

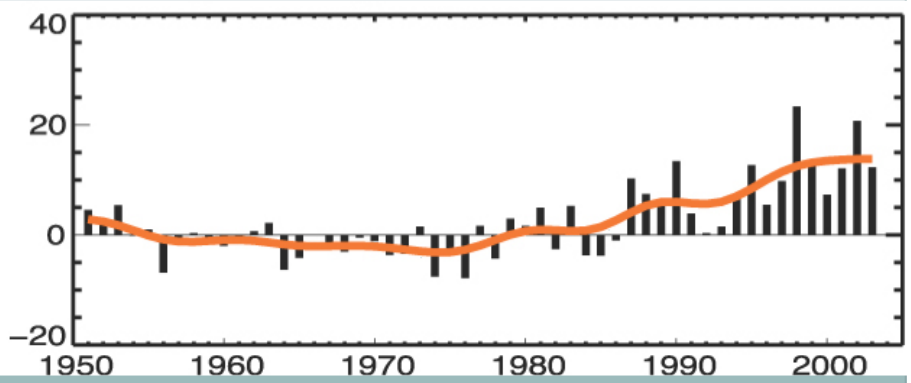


Trends (days per decade)

Global Annual **Warm Nights**

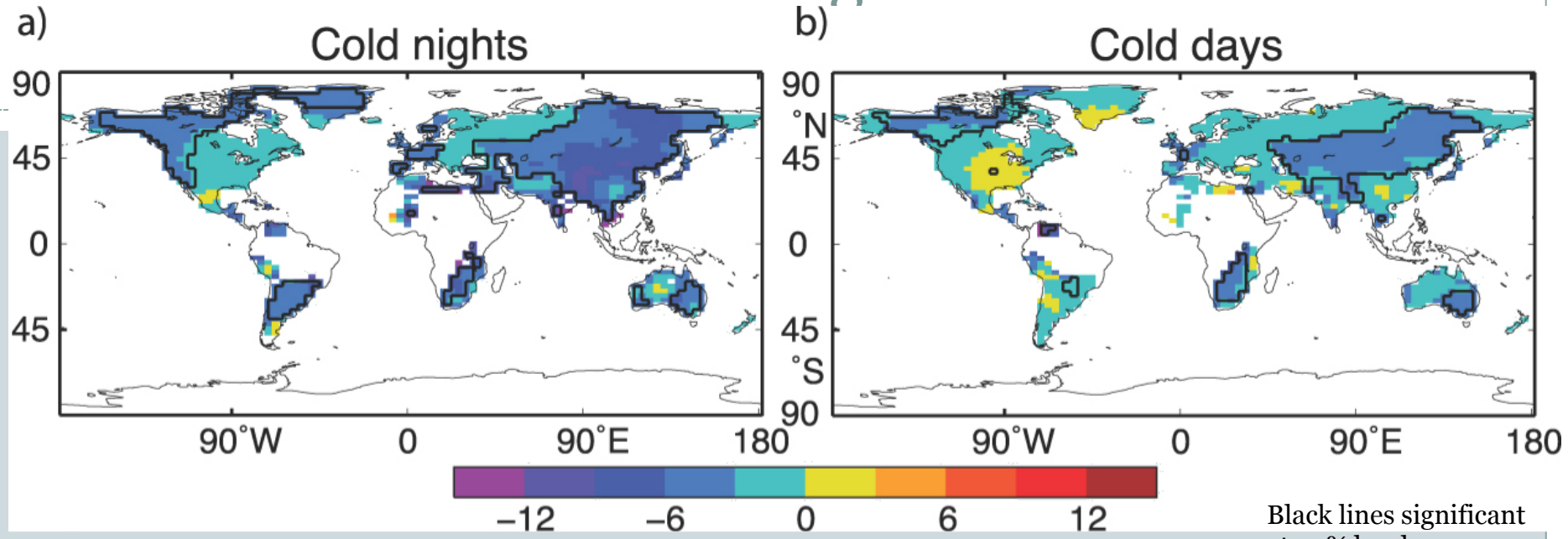


Global Annual **Warm Days**



IPCC WG1 2009; FAQ 3.3, Figure 1.

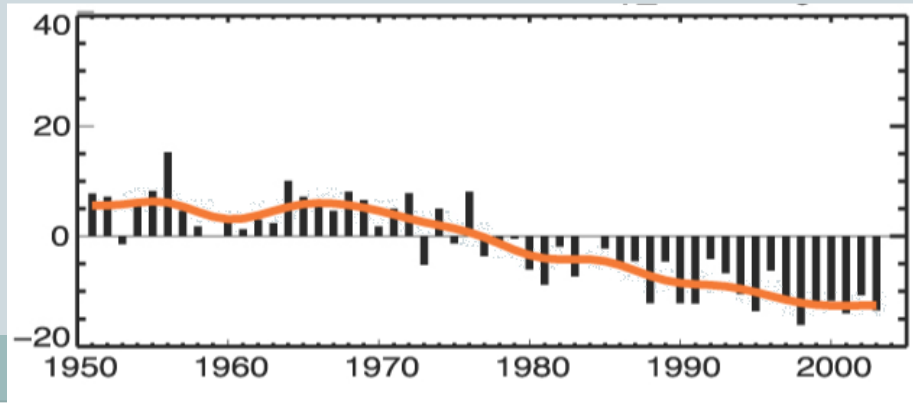
Decreasing Cold



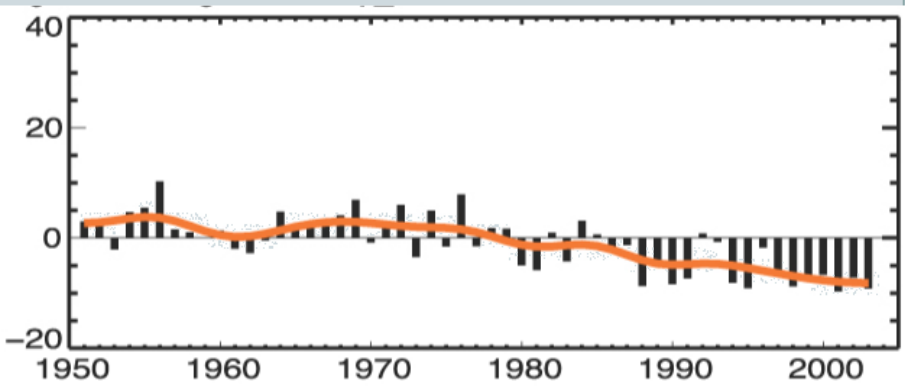
Black lines significant at 95% level

Trends (days per decade)

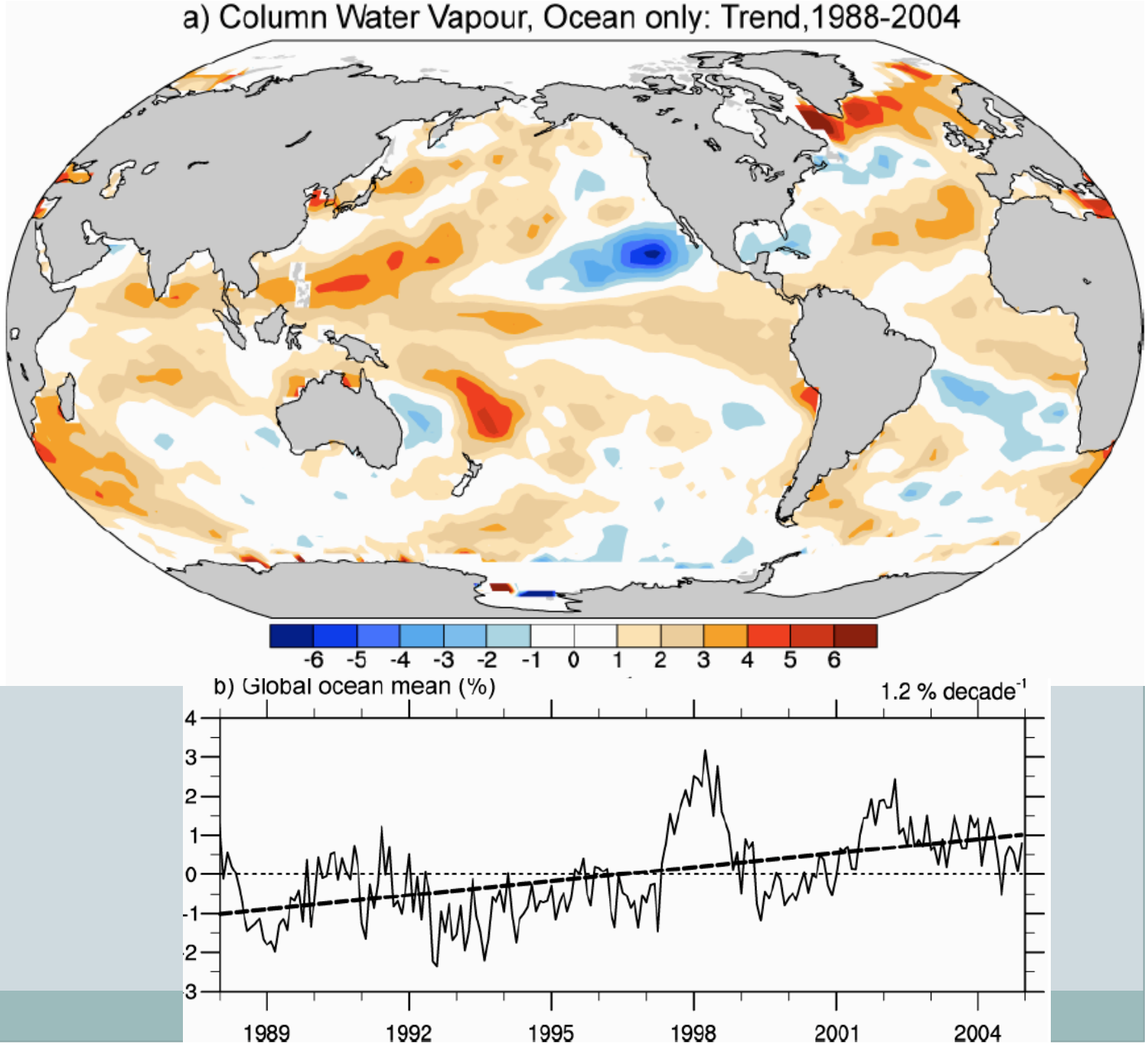
Global Annual **Cold Nights**



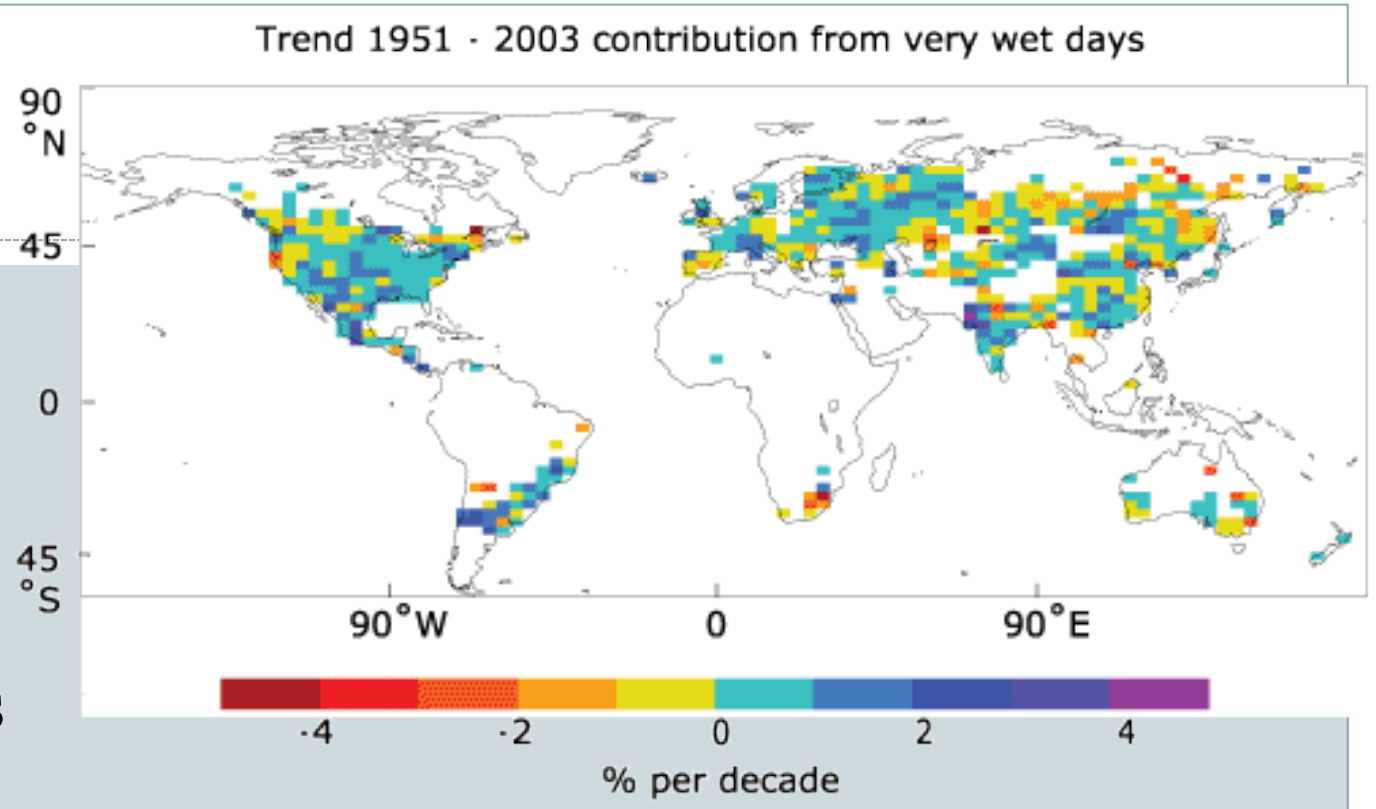
Global Annual **Cold Days**

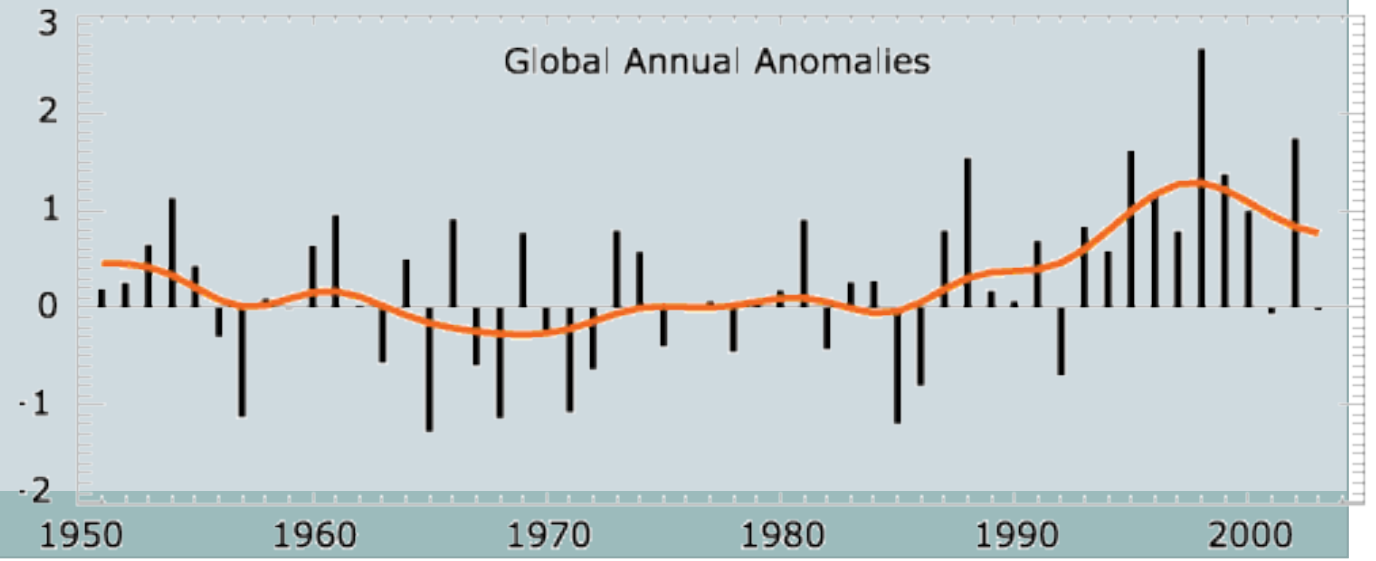


Water vapor concentration is increasing

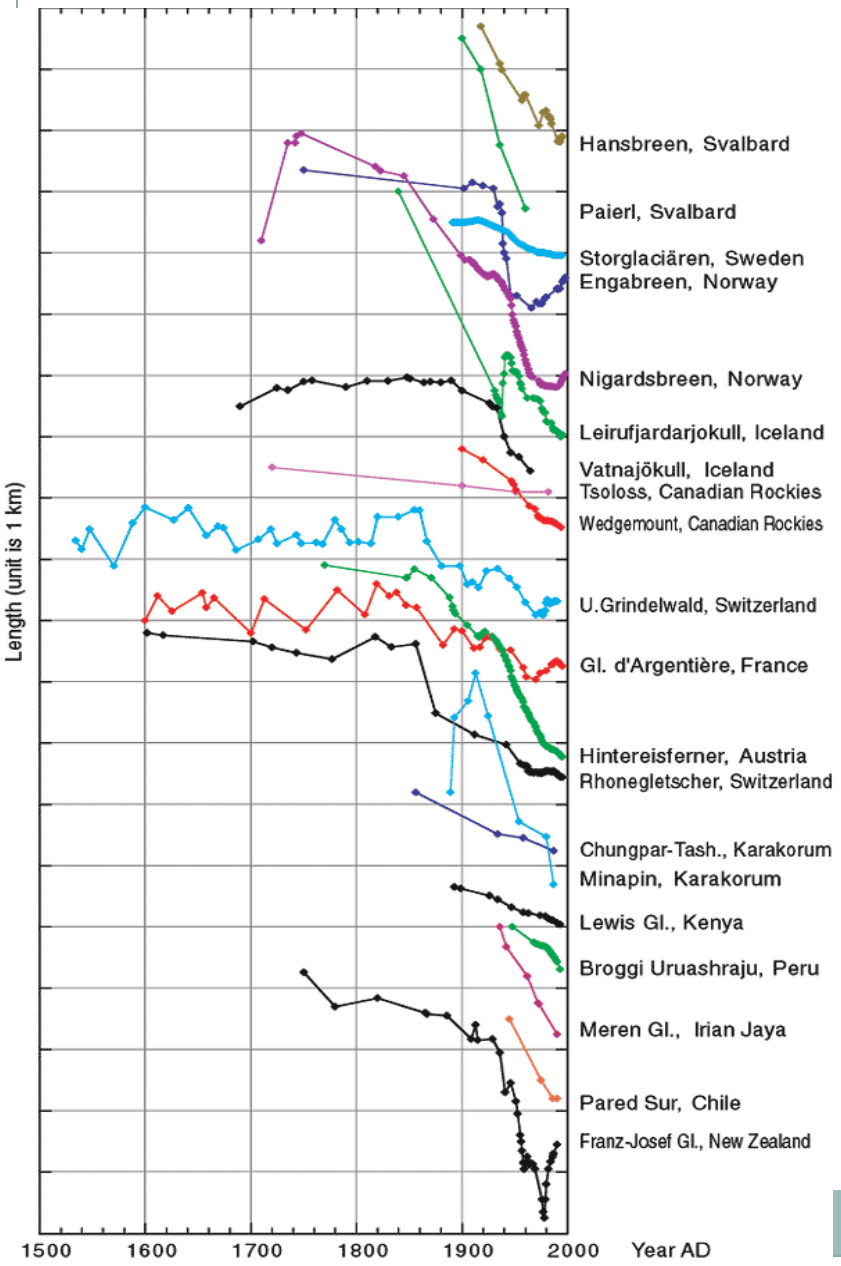


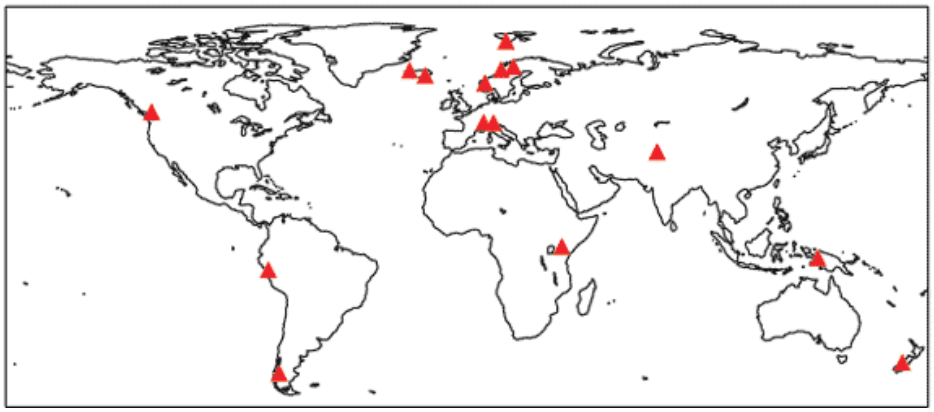
A larger % of the annual rainfall is falling on the wettest days



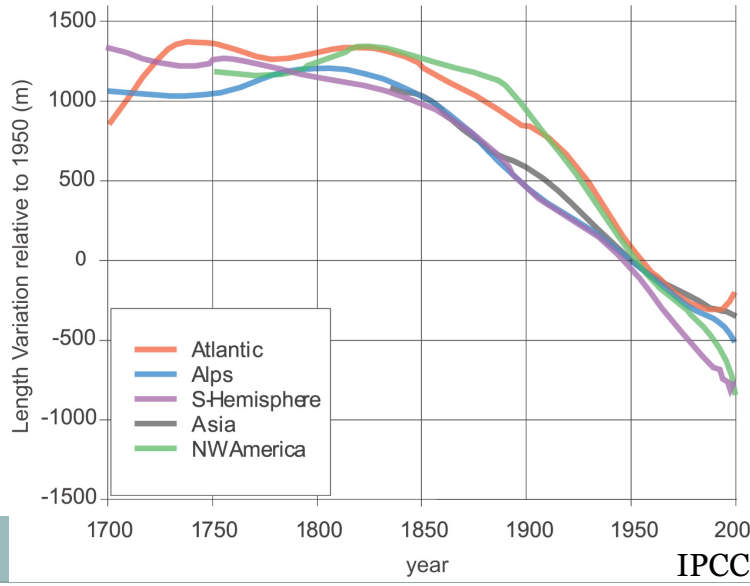


Changes in Glacier Length 1500-2000



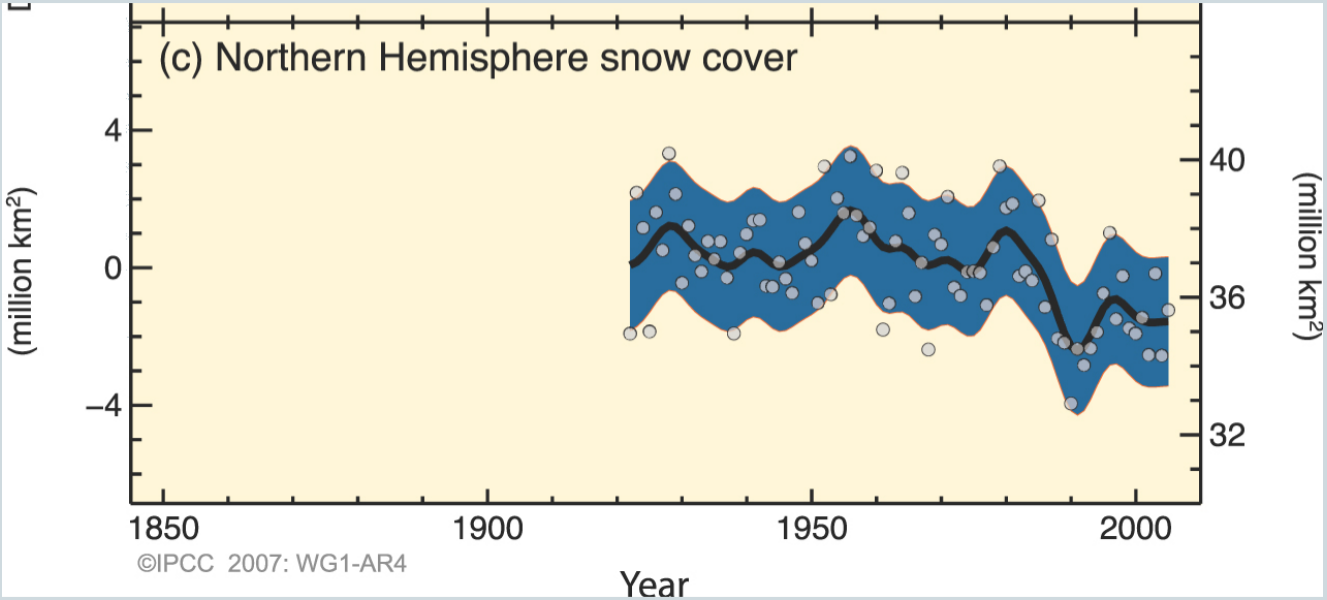


Most glaciers around the world are receding



IPCC 2007 Fig4.13

Northern Hemisphere Snow Cover



Snow cover has decreased by 7.5% since 1922.

Shaded areas show 95% uncertainty levels.
Zero represents the 1961-1990 average.

IPCC Fig SPM3

Other signs of (global) warming

- melting mountain glaciers
- decrease in winter snow cover
- increasing atmospheric water vapor
- warming of global oceans
- rising sea level (due to warming and ice-melt)
- timing of seasonal events
  e.g. earlier thaws, later frosts
- thinning and disappearing Arctic sea ice
- species range shifts (poleward and upward)

Every one of these data sets can be questioned to some extent.
Taken together, the totality of evidence of global warming is quite convincing.

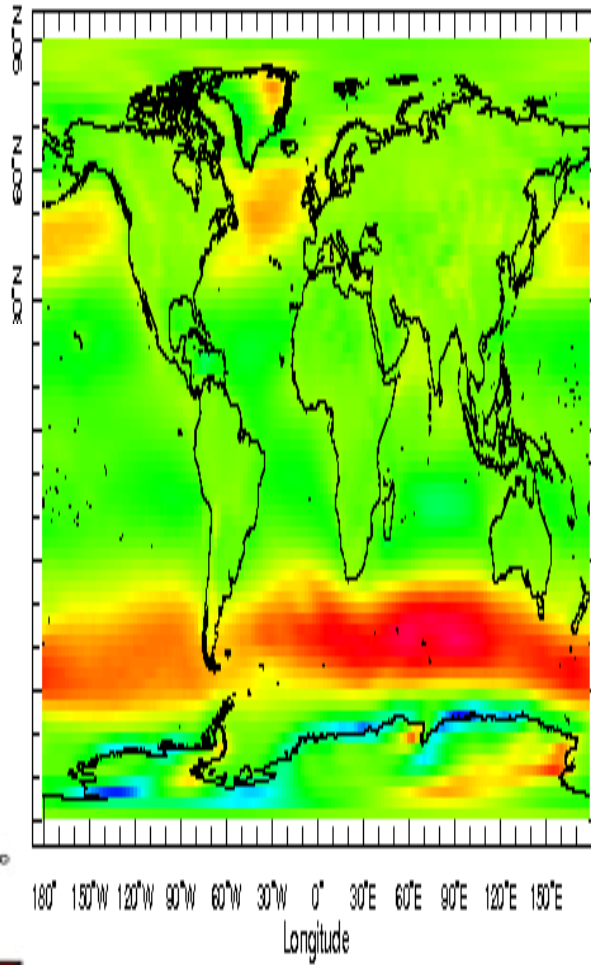
Summary of Instrumental Temperature Records

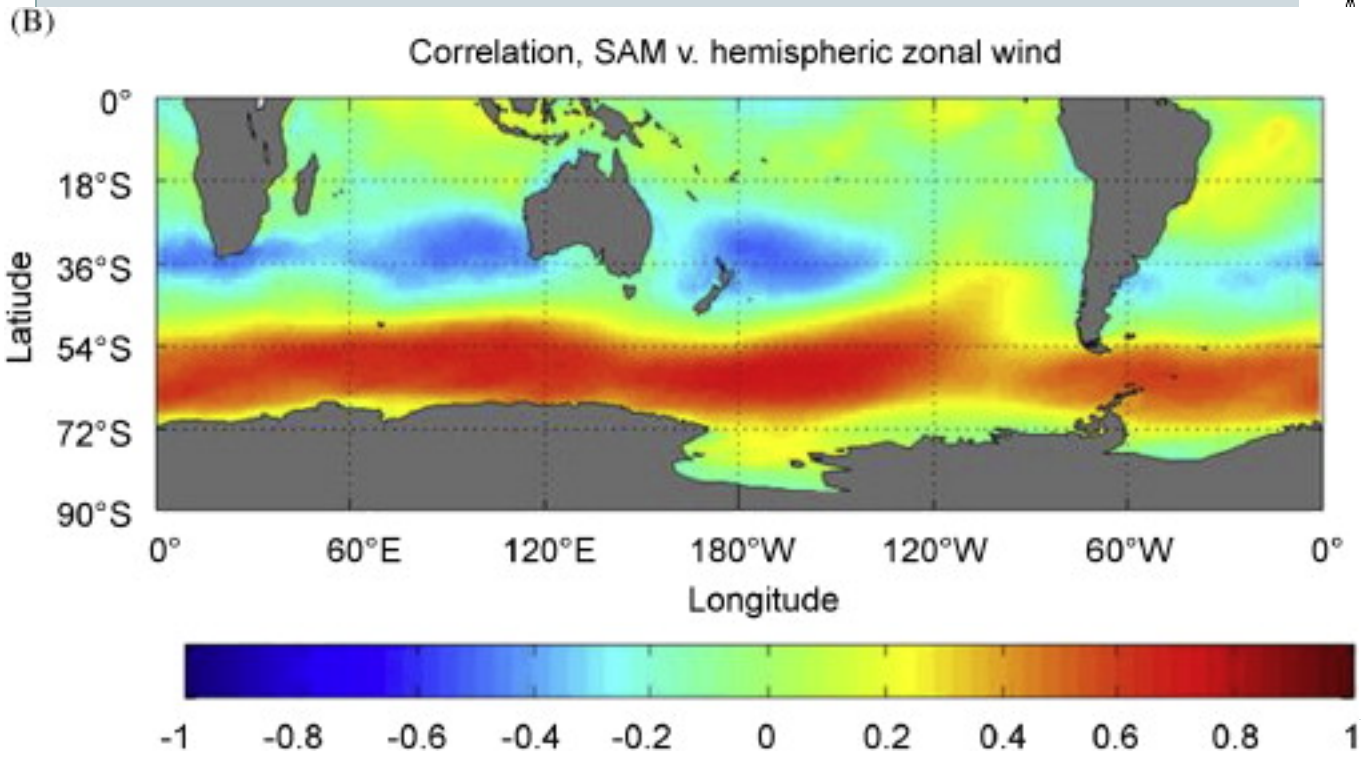
- Definitely **not perfect** data
  - Not fully global coverage (even now)
  - Changes in station sites in the past
  - Instrument changes (e.g., bucket vs intake on ships)
- On the other hand…
  - **Lots** of overlapping nearby stations
  - Data over land, ocean, upper air give different perspectives
    - We also discussed the apparent disagreement of upper air data trends with the surface (which have been resolved over the last 10 years)

Natural variability in the Southern Hemisphere

- The Southern Annular Mode (SAM) is the natural variability of the SH storm tracks
  - Learn about SAM

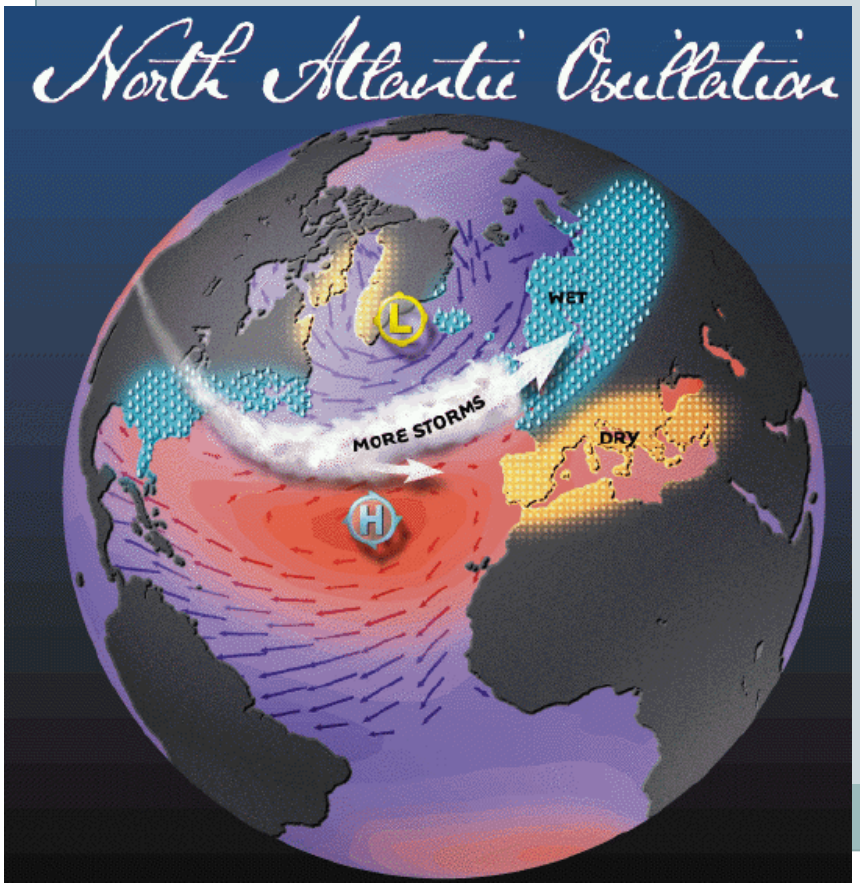
Average winds

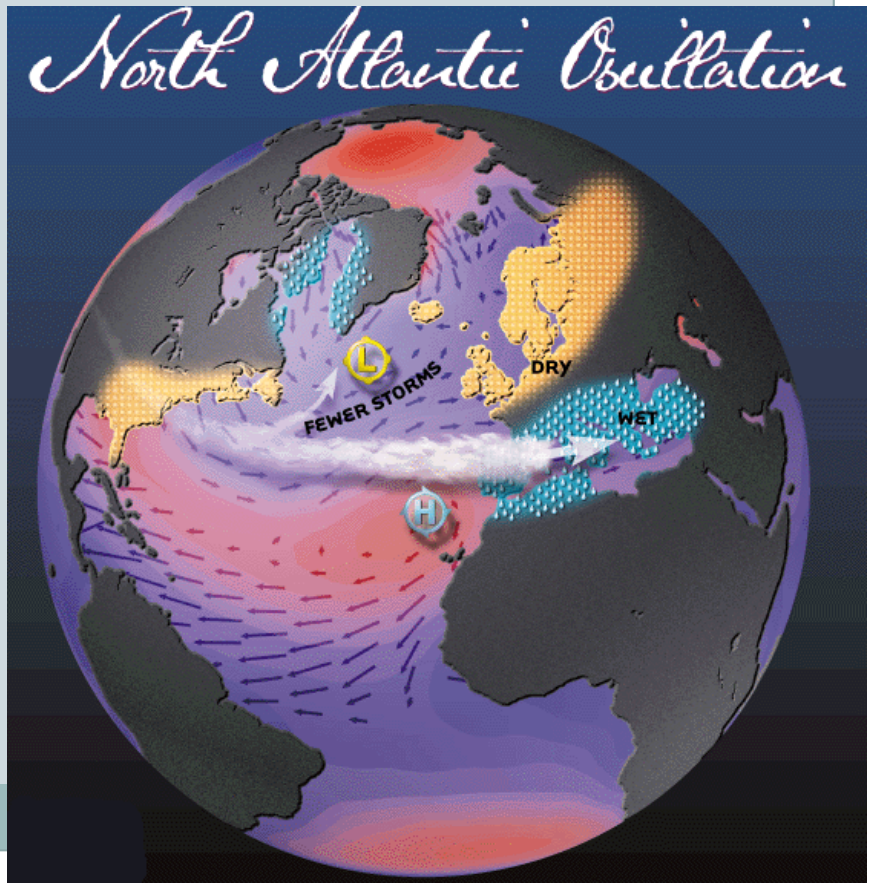




Northern Hemisphere Natural Variability

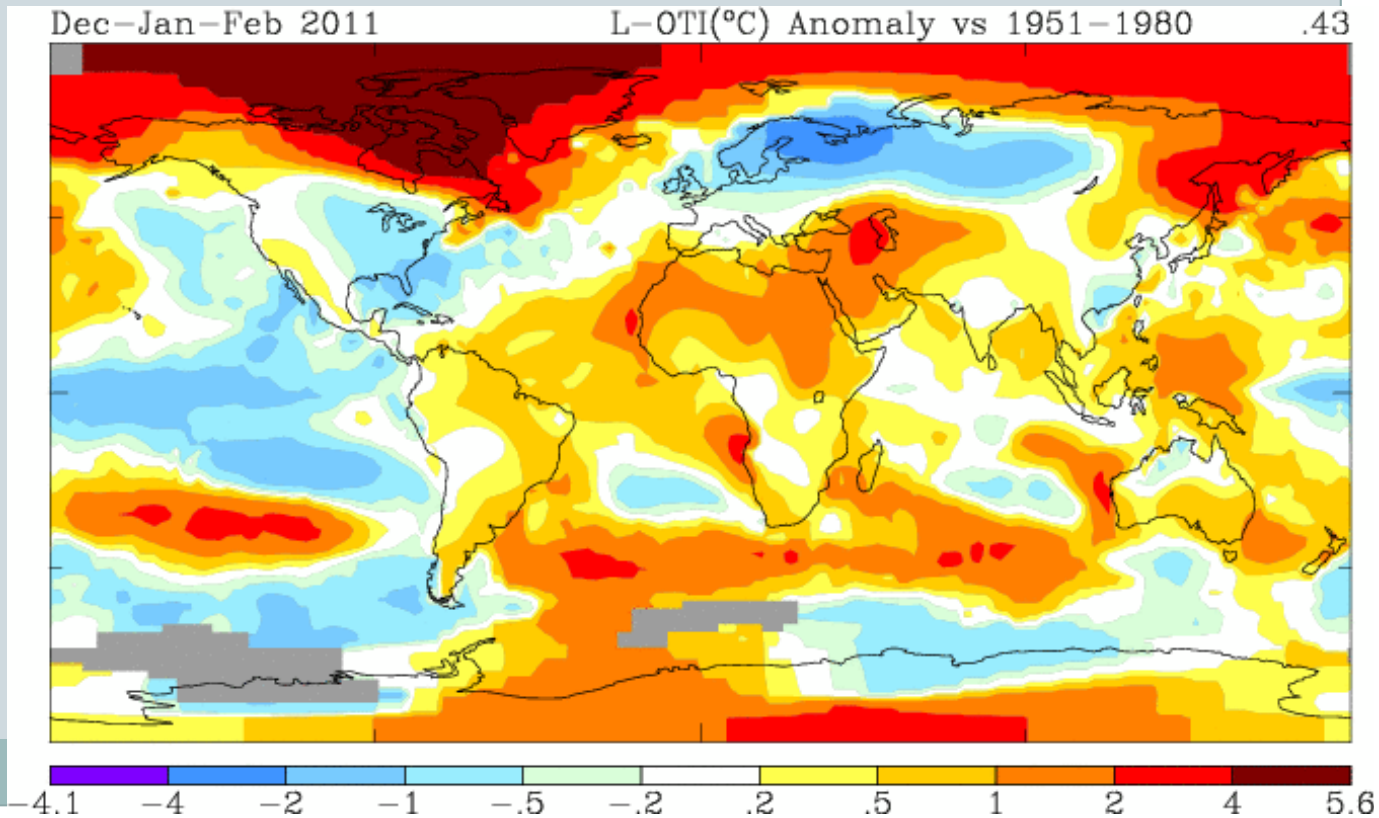
- Similar shifts occur in the NH, but the patterns are more regional (North Atlantic Oscillation)





Winter 2010-11's Temperature Anomalies

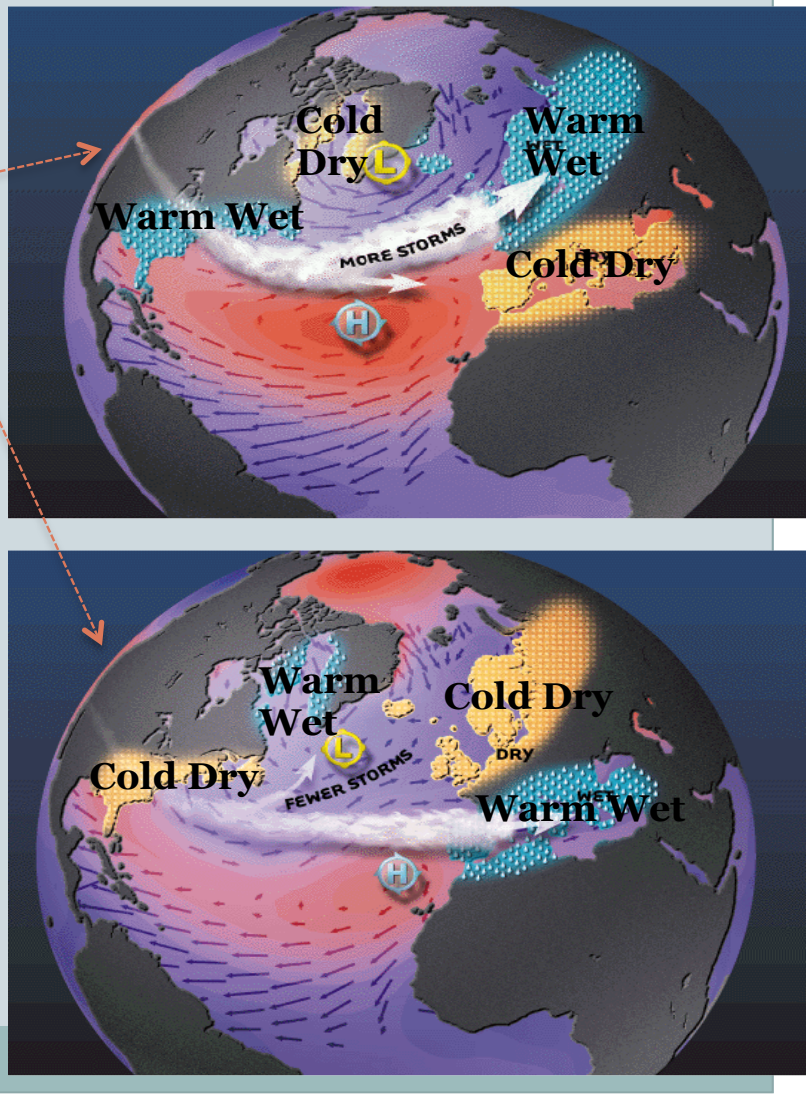
- Winter 2010-2011 temperatures
  - Very cold temperatures in N. Europe/East Coast of US
  - Surrounded by warm regions though



Is this proof of/disproof of/caused by global warming?

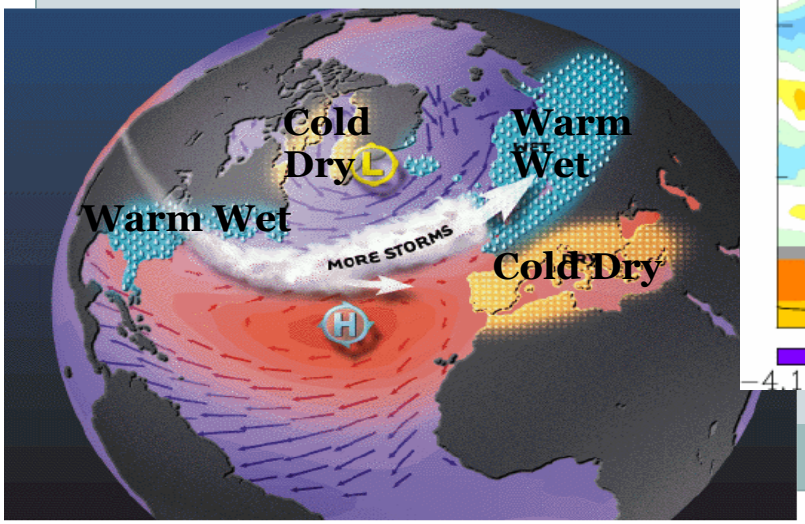
- Wobbling back and forth between these two patterns is common (due to the **North Atlantic Oscillation**)
- Much natural climate variability is just sloshing of heat like this
  - One warm/cold season is not proof/disproof of global warming

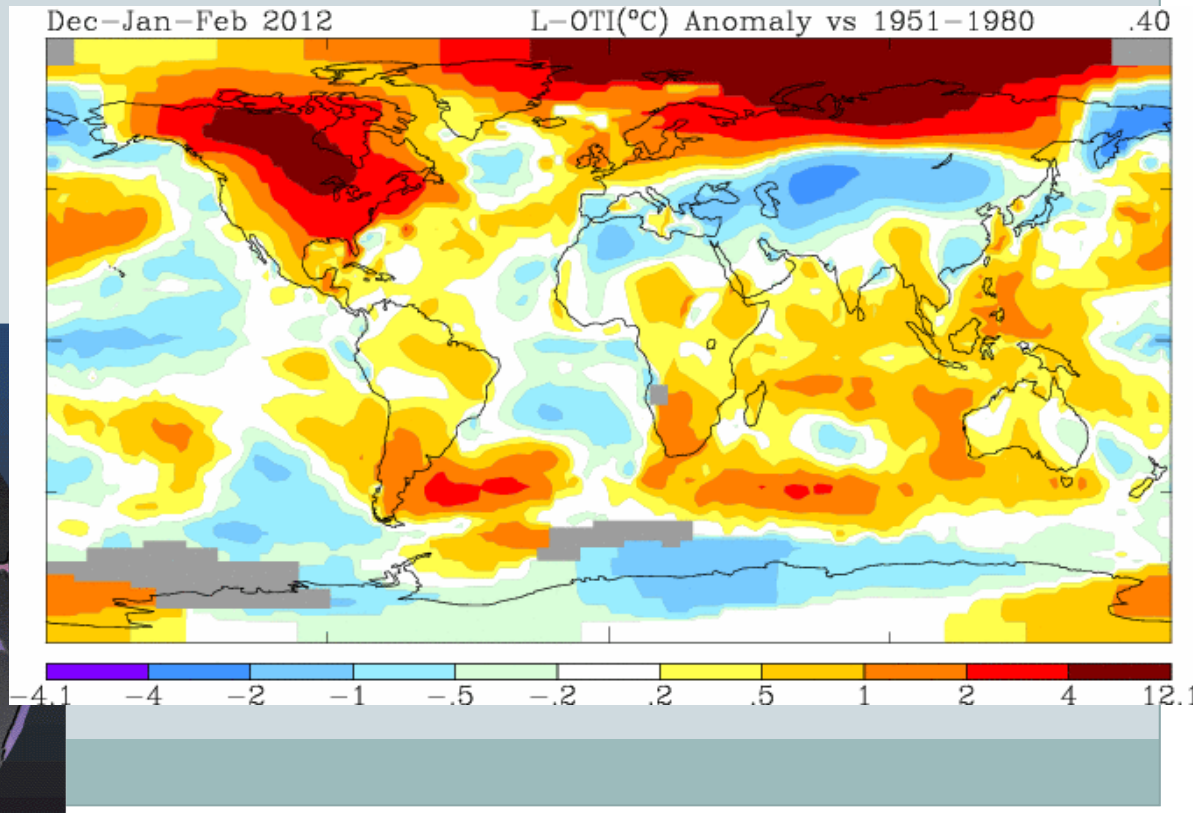
Winter 2010 was more like this → →



Winter 2011-2012

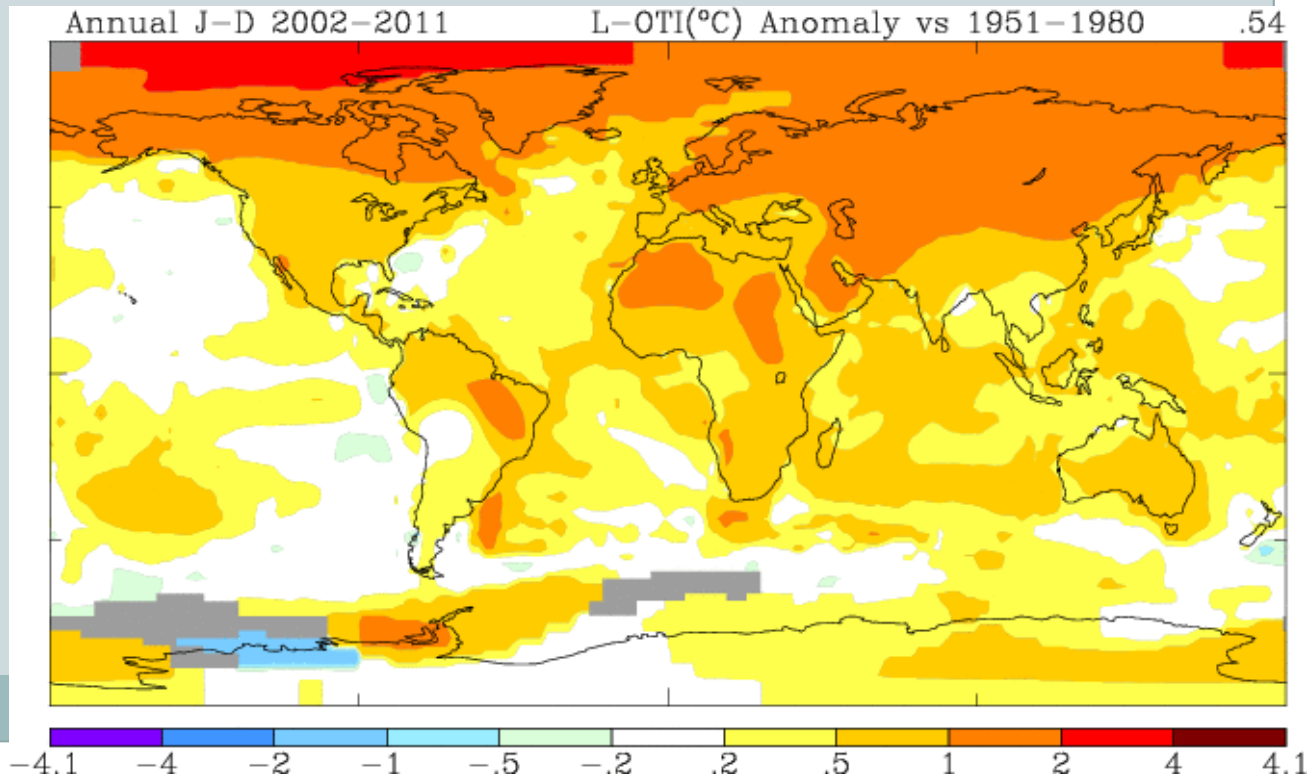
- Average temperatures from Dec 2011-Feb 2012
  - Just the opposite phase as winter 2010-11
  - Very warm US east coast/N. Europe & colder Mediterranean





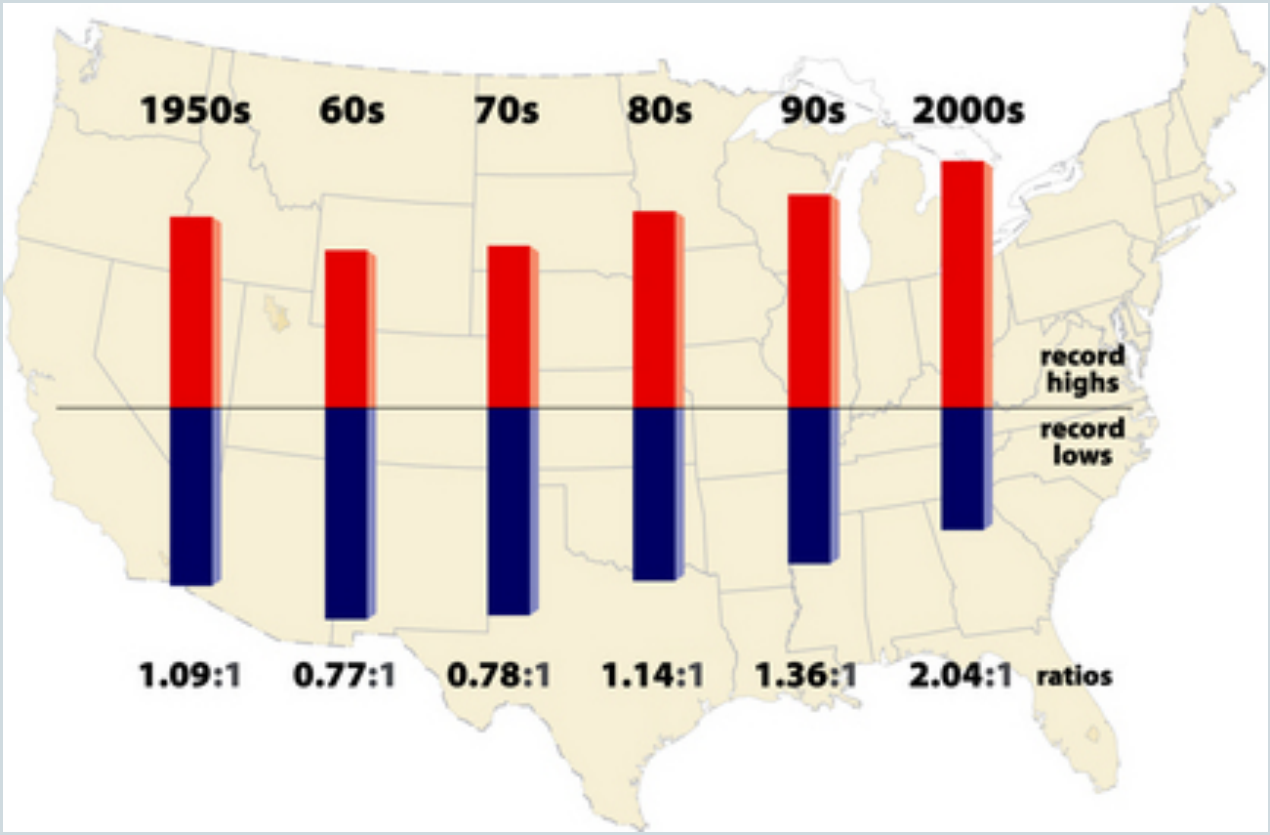
Longer Time Periods

- Natural climate variability like the North Atlantic Oscillation averages out after a few years
  - Slower, steadier global warming shows up clearly over a 10 year average



Record Highs vs Record Lows

- Have to look at longer periods of time to see a trend



In the US, record highs have been significantly outpacing record lows over the last two decades

From Meehl et al 2010

SAM trends

- SAM has been trending towards positive phase
  - Likely ozone depletion has been important for much of this
  - Even with large trends, there's still much natural variability