ATM S 111: Global Warming

Climate Records

Jennifer Fletcher

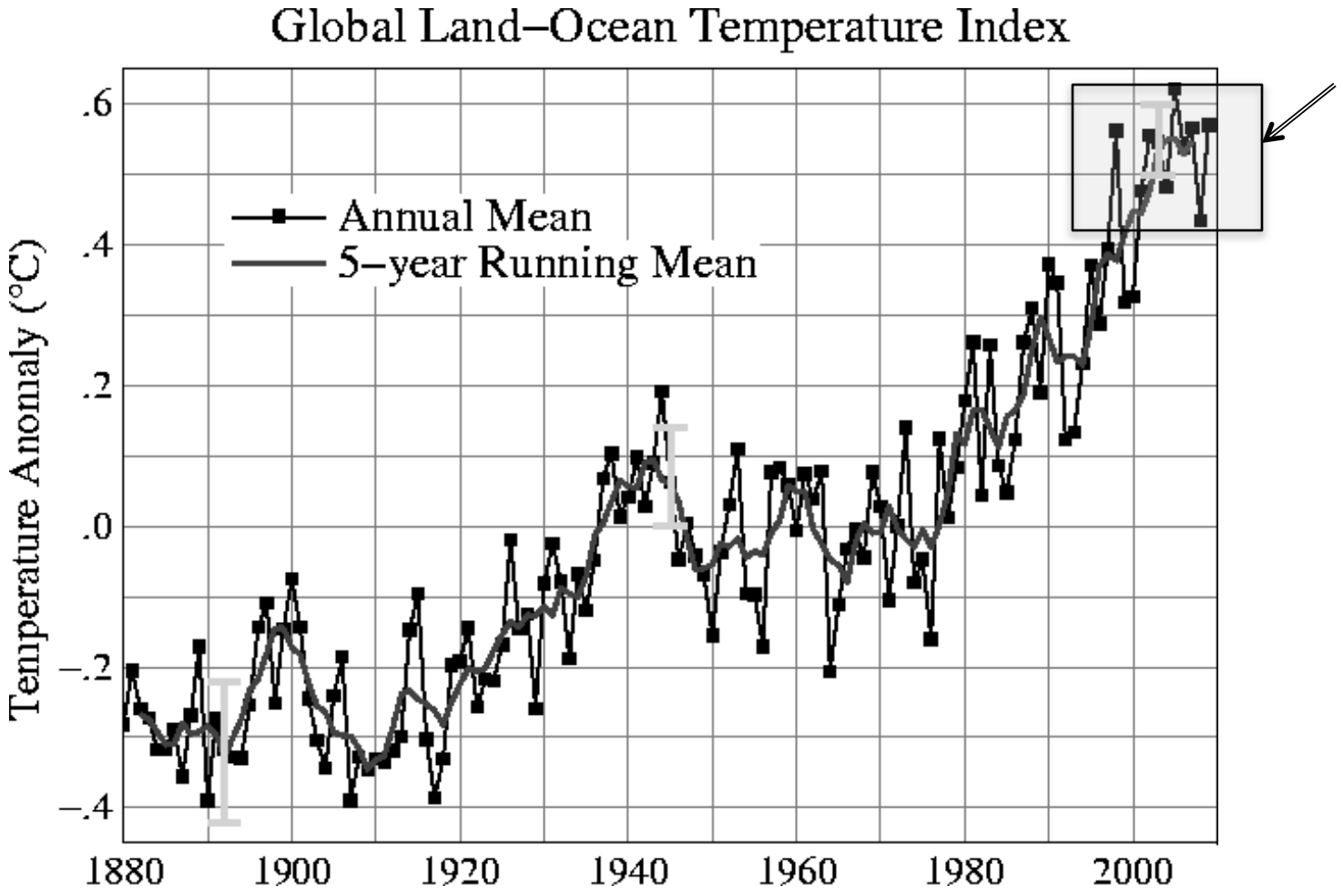
Day 24: July 26 2010

Reading

- For today: “Keeping Track” (Climate Records) pp. 171-192
- For tomorrow/Wednesday: “The Long View” (Paleoclimate) pp. 193-226.

The Instrumental Record from NASA

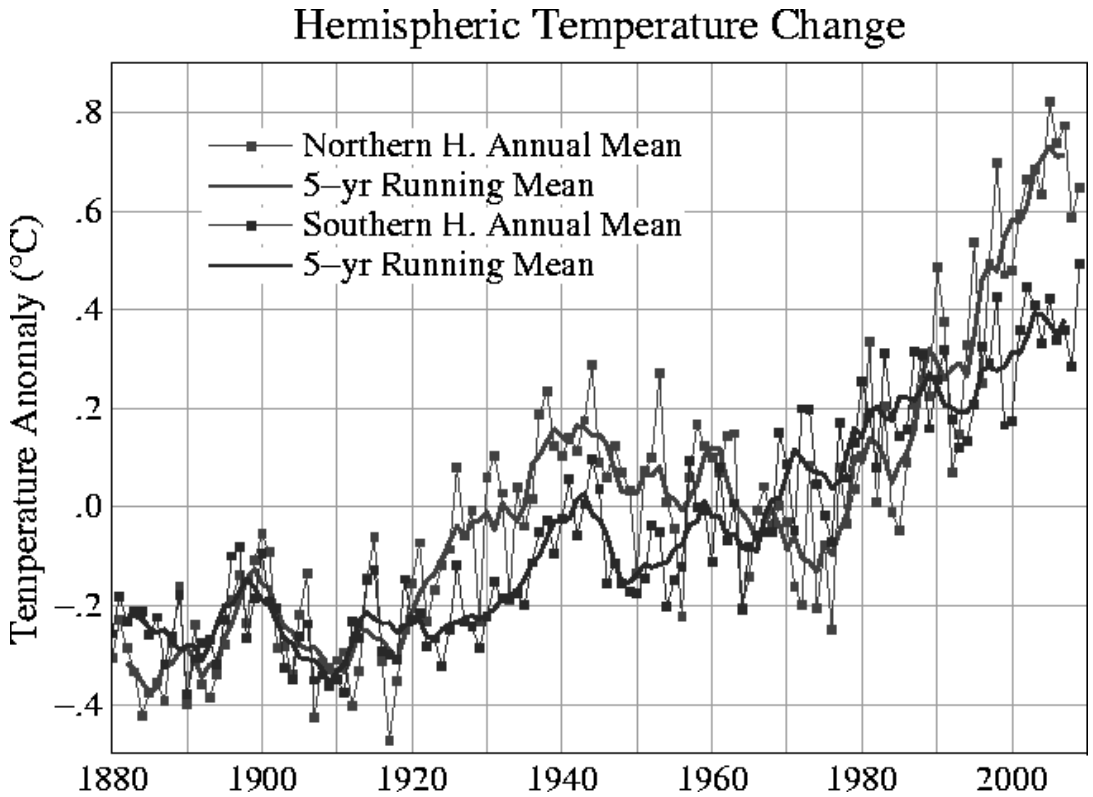
- Global temperature since 1880



Ten warmest years: 2001-2009 and 1998 (biggest El Niño ever)

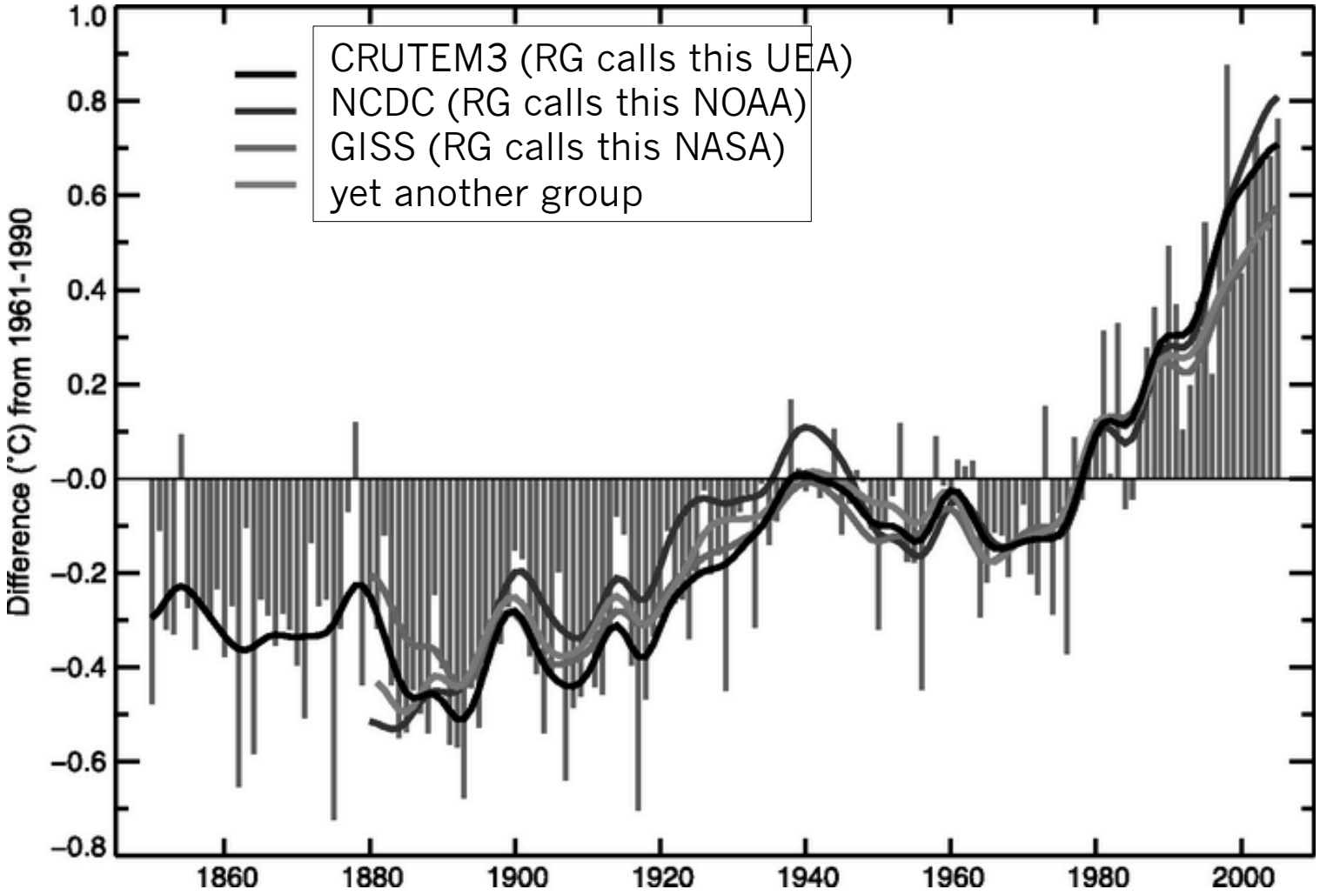
Separation into Northern/ Southern Hemispheres

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



Cooling in the record from 1940-1975 essentially only in the N. Hem. record (this is likely due to aerosol cooling)

Temperature estimates from other groups



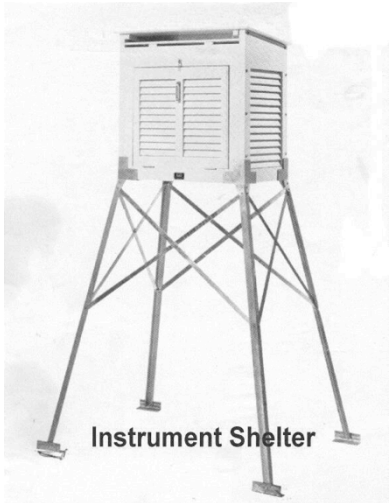
Surface air temperature over land

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

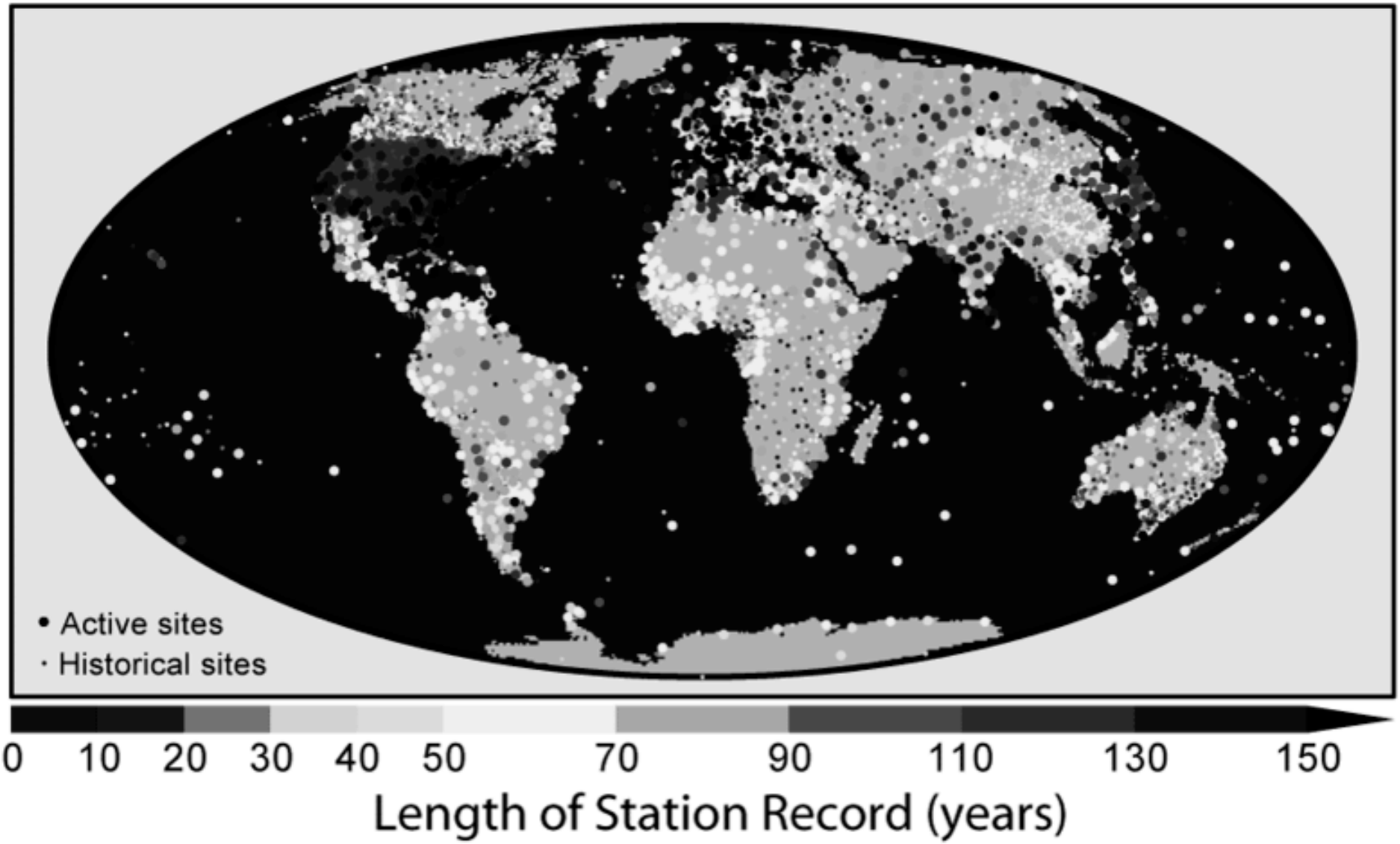
White colored to reflect away direct sunlight

Slats to ensure fresh air circulation

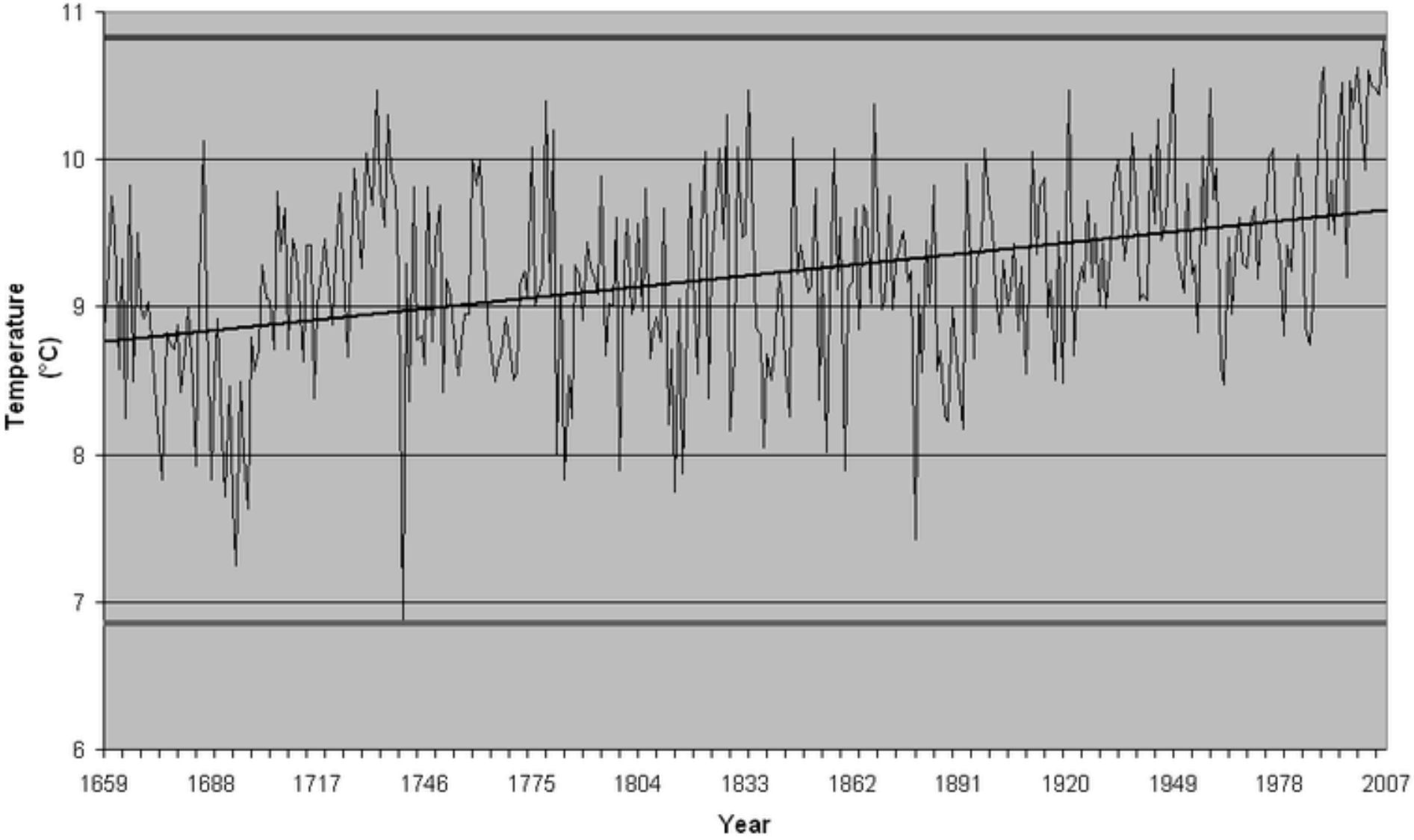
“Stevenson screen”: invented by Robert Louis Stevenson’s dad Thomas



Global Climate Network Temperature Stations

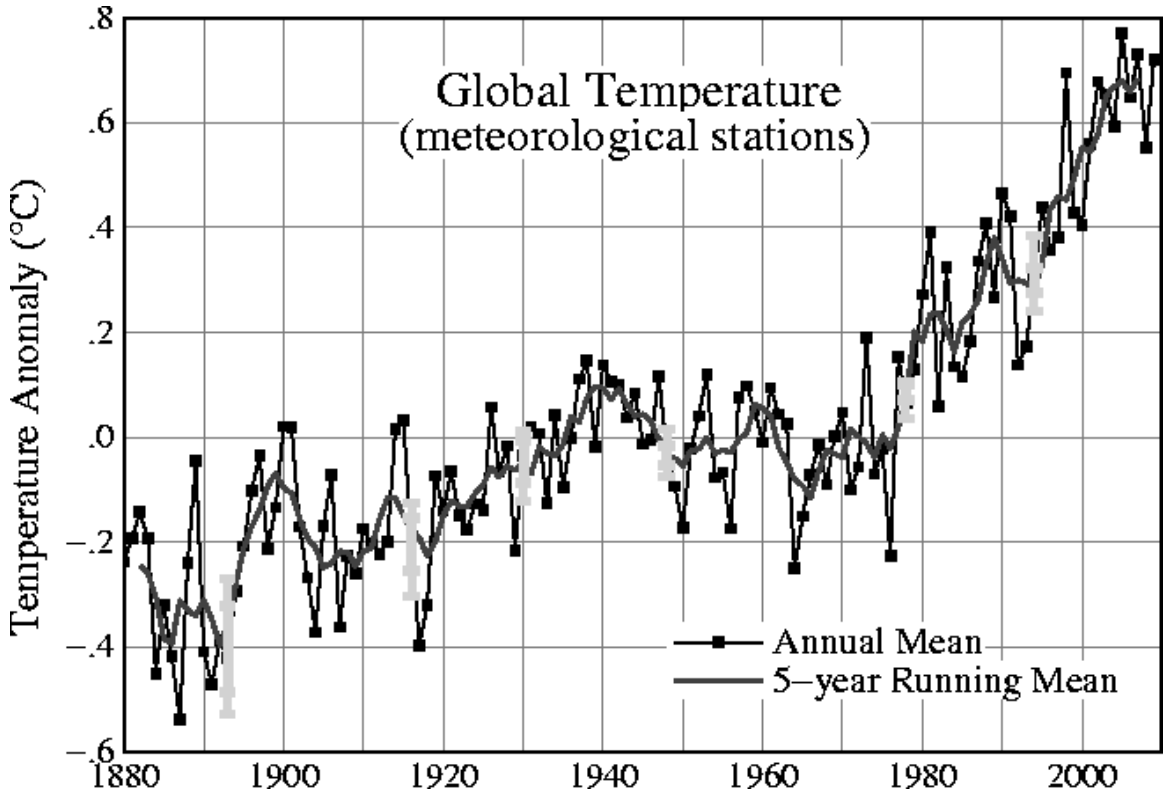


Yearly average Central England temperature record (since 1659)



Temperatures over Land Only

- NASA separates their analysis into land station data only (not including ship measurements)



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)

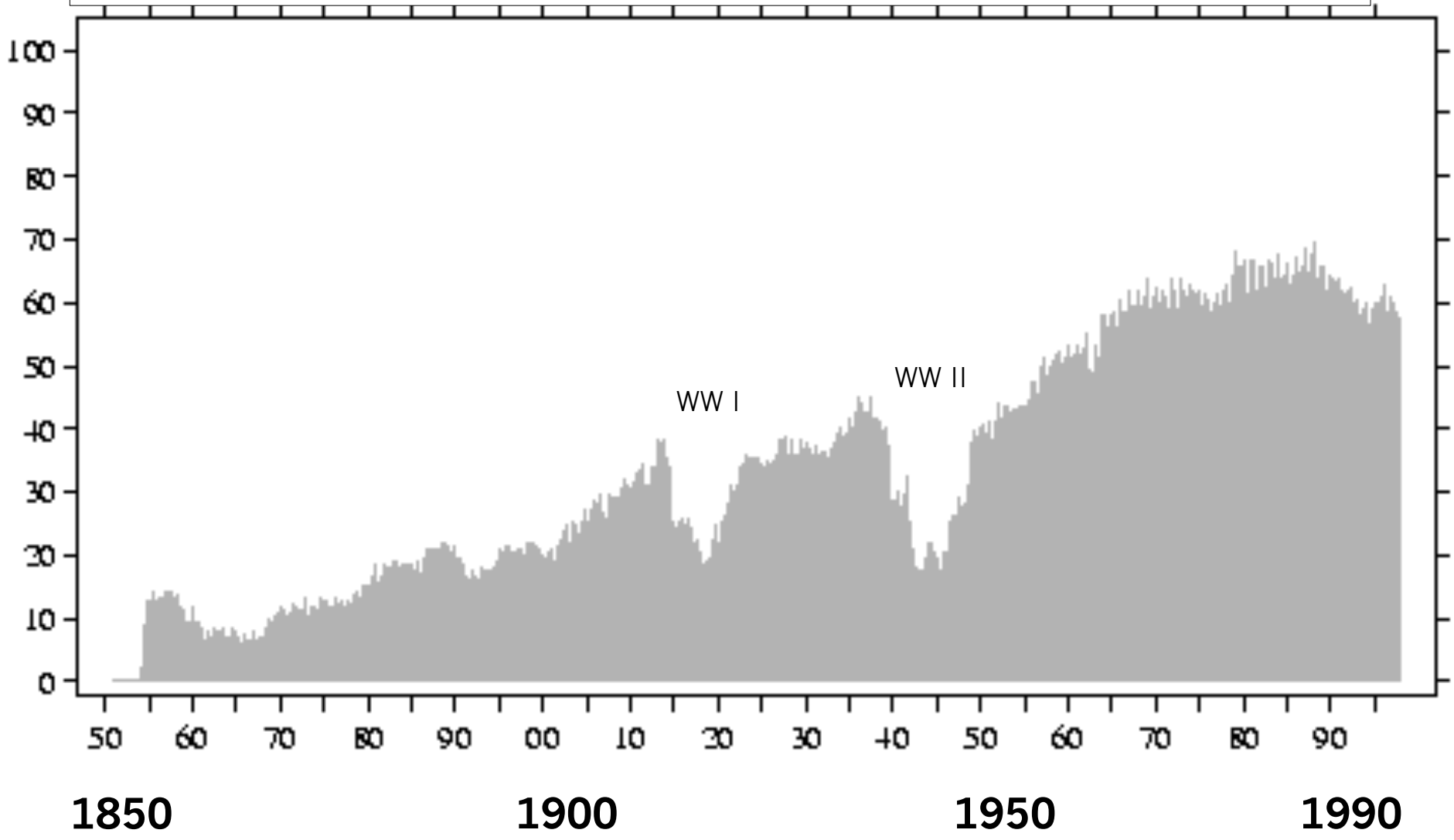
Canvas bucket (pre WWII)

Insulated bucket (now)

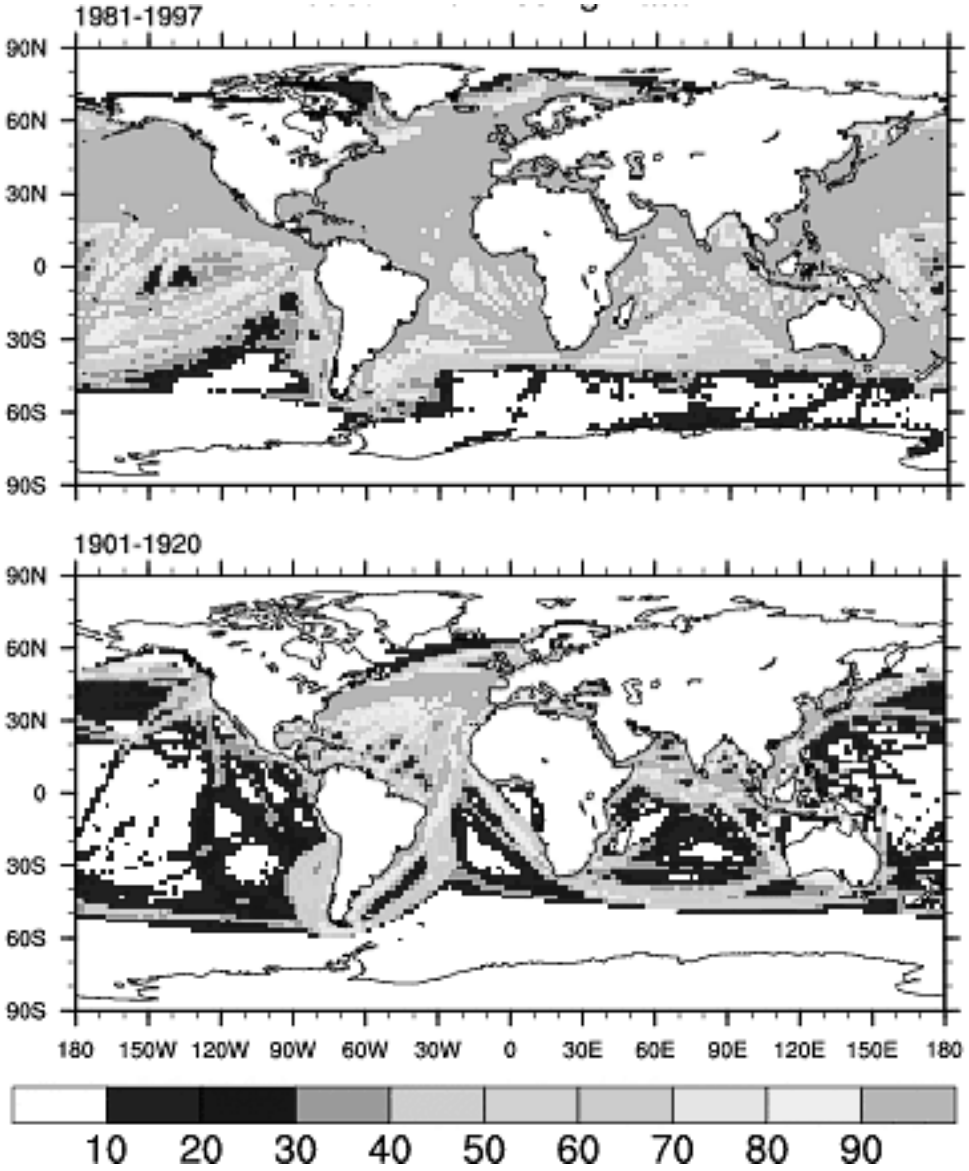
"Bucket" temperature: older style subject to evaporative cooling

Starting around WWII: many temperature measurements taken from **condenser intake pipe** instead of from buckets.
Typically 0.5 C warmer than old style buckets

Percent coverage of ocean by year



Percent coverage of ocean



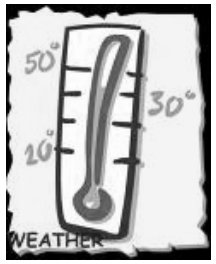
1981-1997

1901-1920

10% = 1 in 10 months had a ship measurement

Where are these data sets assembled?

And what do groups like NASA or UEA do to the raw data?



Climate Data Groups

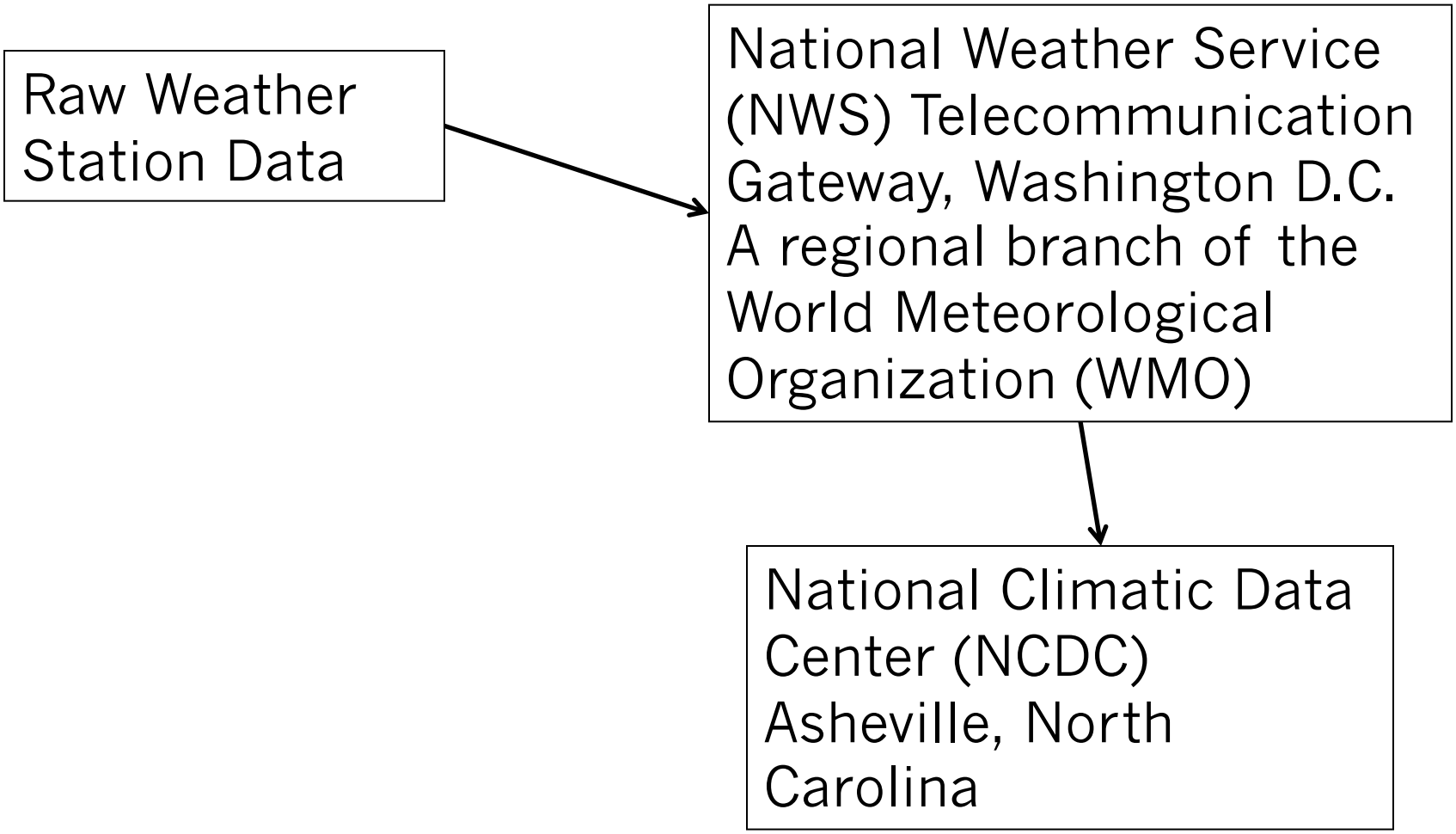
- National Climatic Data Center (NOAA)
  - Asheville, NC

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
National Weather Service (NWS) Telecommunication Gateway, Washington D.C. A regional branch of the World Meteorological Organization (WMO)
National Climatic Data Center (NCDC) Asheville, North Carolina

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

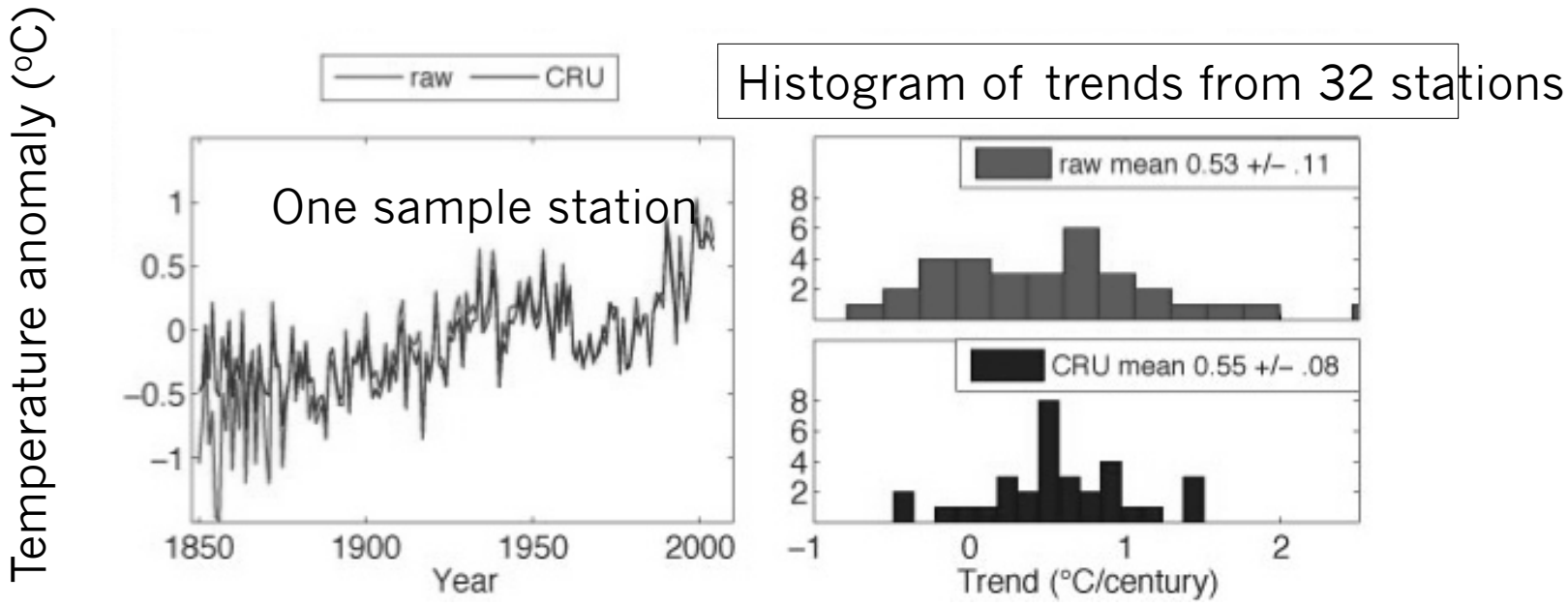
```
#  Rain Gauge (inches) ------------------------------------------------------------------*
#  Relative humidity (%) ---------------------------------------------------------------*     |
#  Solar irradiance (W/m^2) ------------------------------------------------------*     |     |
#  Visibility (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
2010-02-07 04:43 2455235.1965278 1010.8 49.6 38.9 134  7.7  8.8   X  M   M     0.0  66.6 0.00
2010-02-07 04:44 2455235.1972222 1010.9 49.5 39.1 137  6.5  7.8   X  M   M     0.0  67.0 0.00
2010-02-07 04:45 2455235.1979167 1010.8 49.6 39.2 138  5.8  6.8   X  M   M     0.0  67.2 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
  - They also have procedures for **combining fragmented record**. More about this in a minute...

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

Step 1



UW graduate student Kevin Wood took a random set of 32 stations and compared the raw data to the CRU analysis.

As expected CRU weeded out some extremes but didn't change the mean much at all

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 allows “sanity checks”

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).
Any years closer together than that are not worth arguing about!

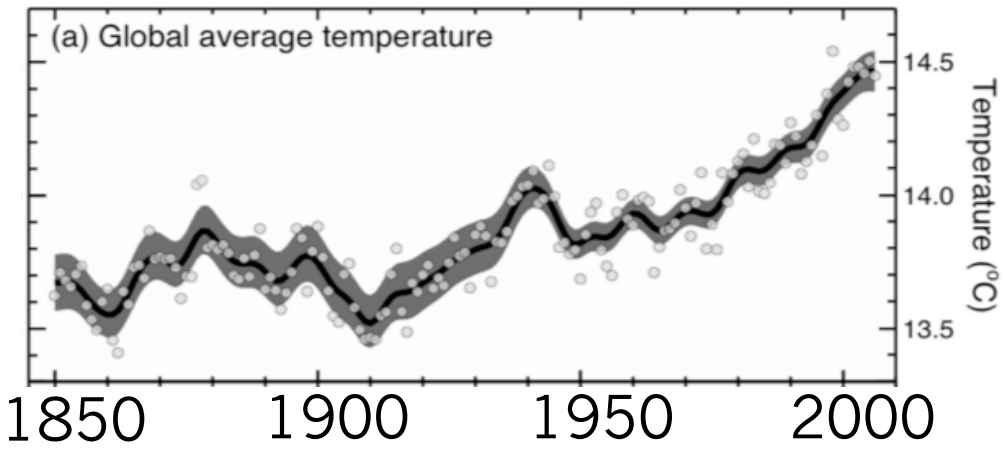
The benefits of evaluating global mean temperature is that it is global

Changes in instruments site exposure, etc. can be ignored so long as they are randomly distributed in time because we are averaging over many stations and random variations tend to average out.

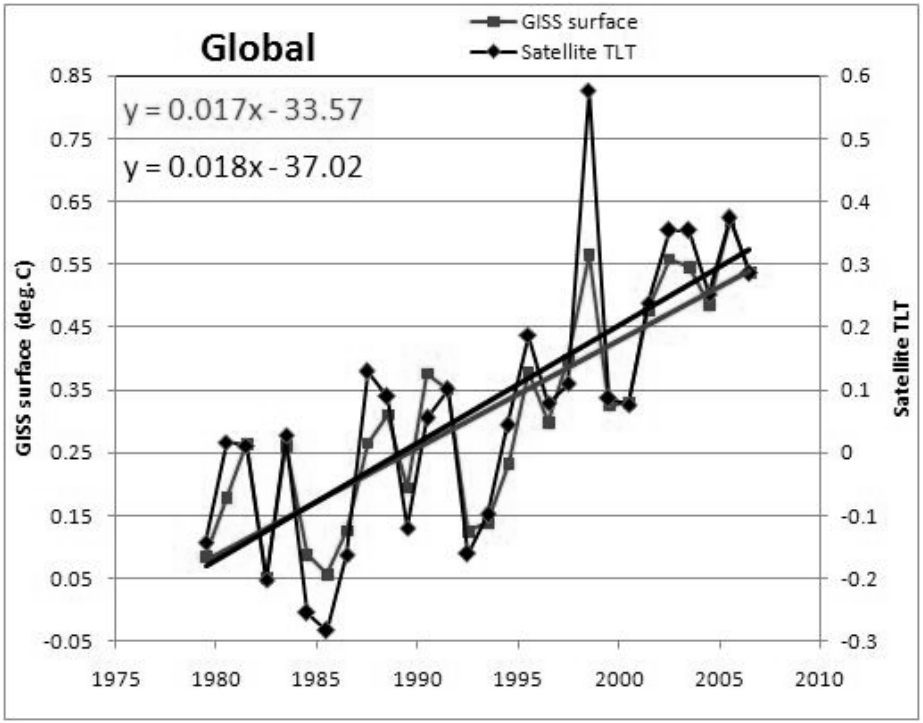
Similar long term temperature trends are seen in rural stations. Hence, urban sprawl evidently hasn't raised the global average temperature as much as one might think.

But adjustments are required if many stations experienced changes in instrumentation all around the same time.

Monitoring global temperatures
Two case studies

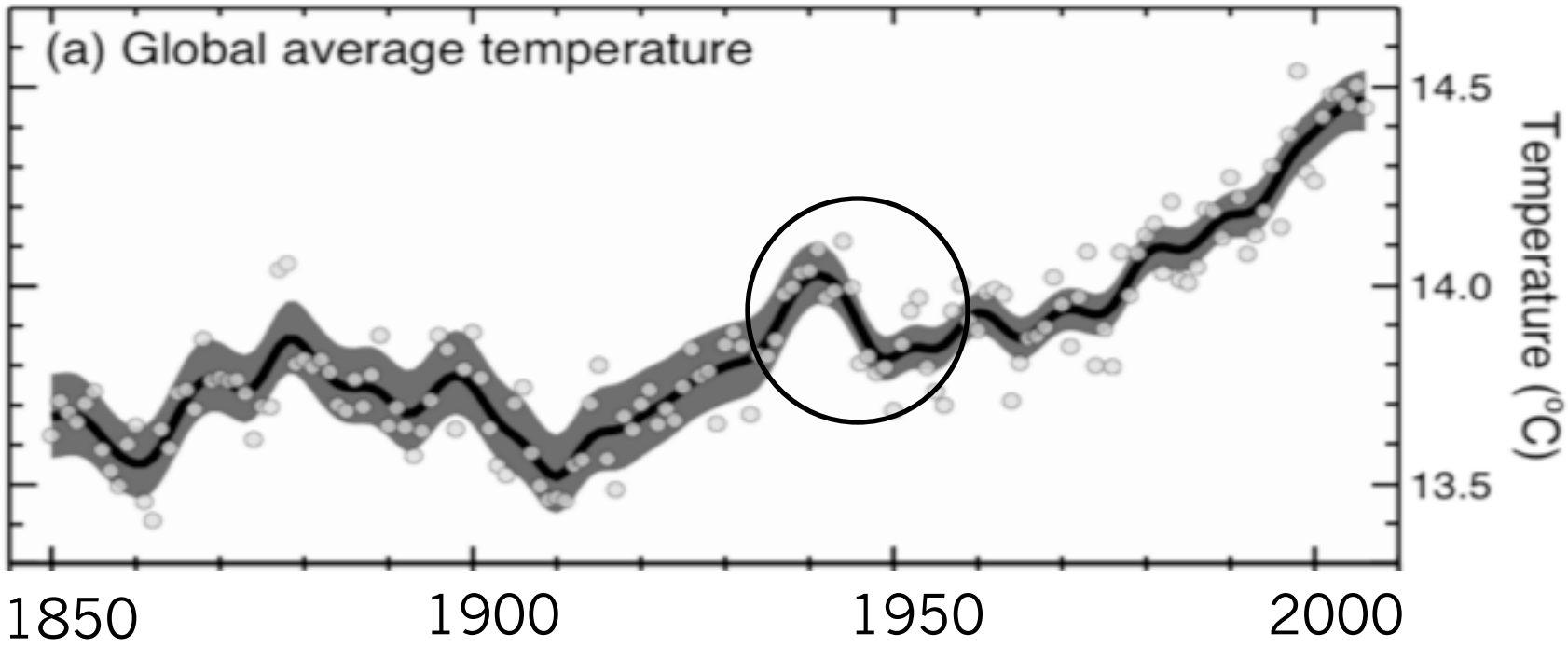


sea surface temperature



upper air temperature

Case study 1



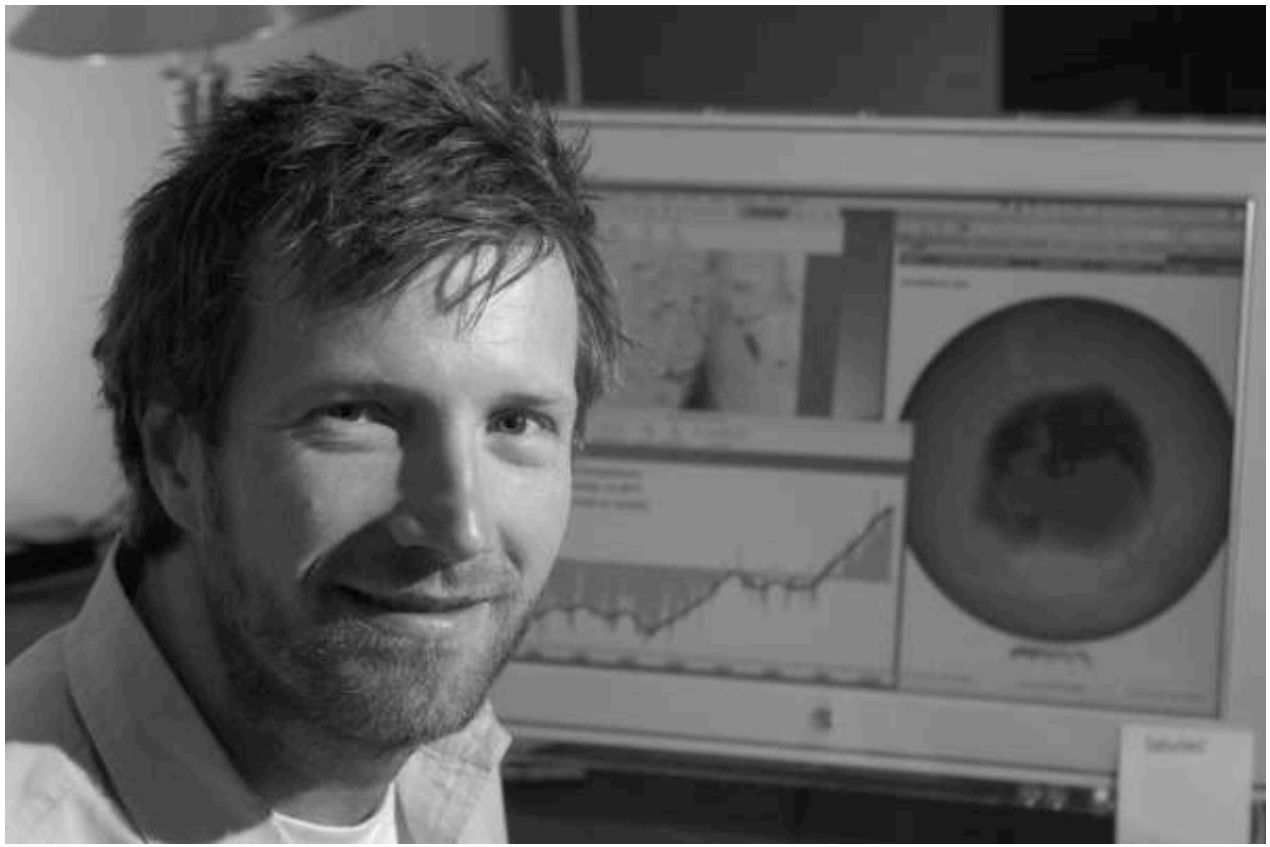
Is this feature real?
The accidental discovery that it isn't?

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

LETTERS

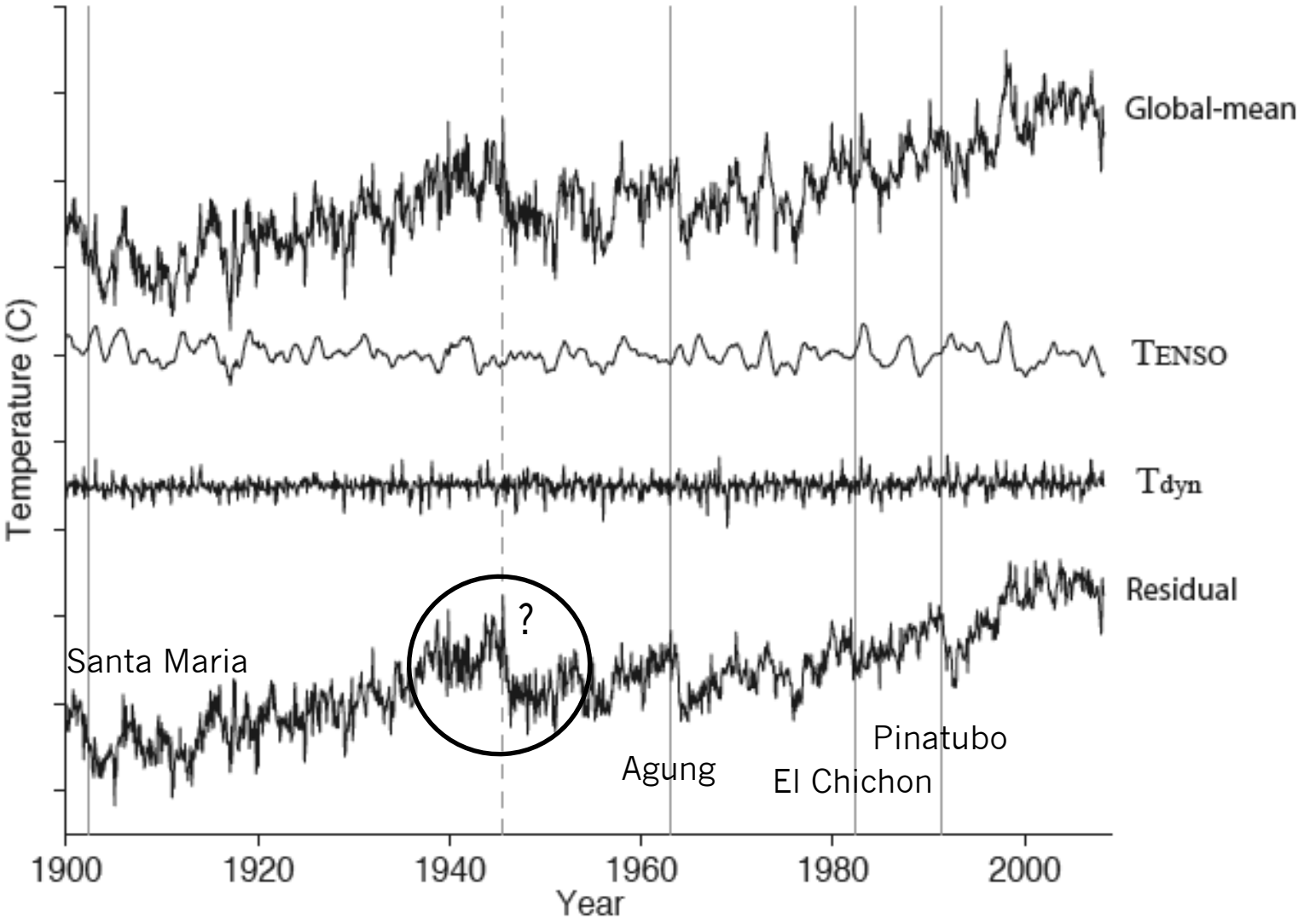
A large discontinuity in the mid-twentieth century in observed global-mean surface temperature

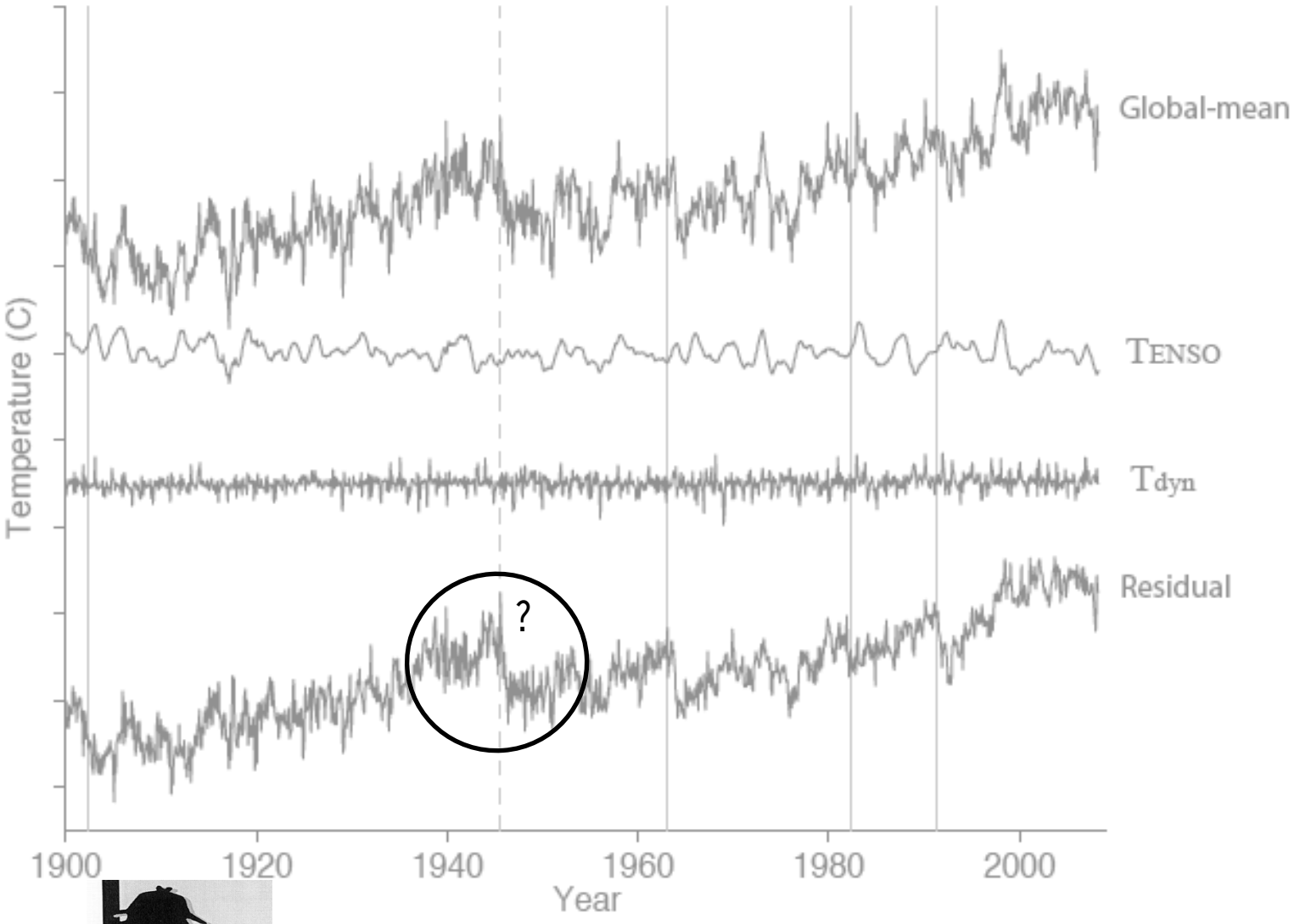
David W. J. Thompson[1], John J. Kennedy[2], John M. Wallace[3] & Phil D. Jones[4]



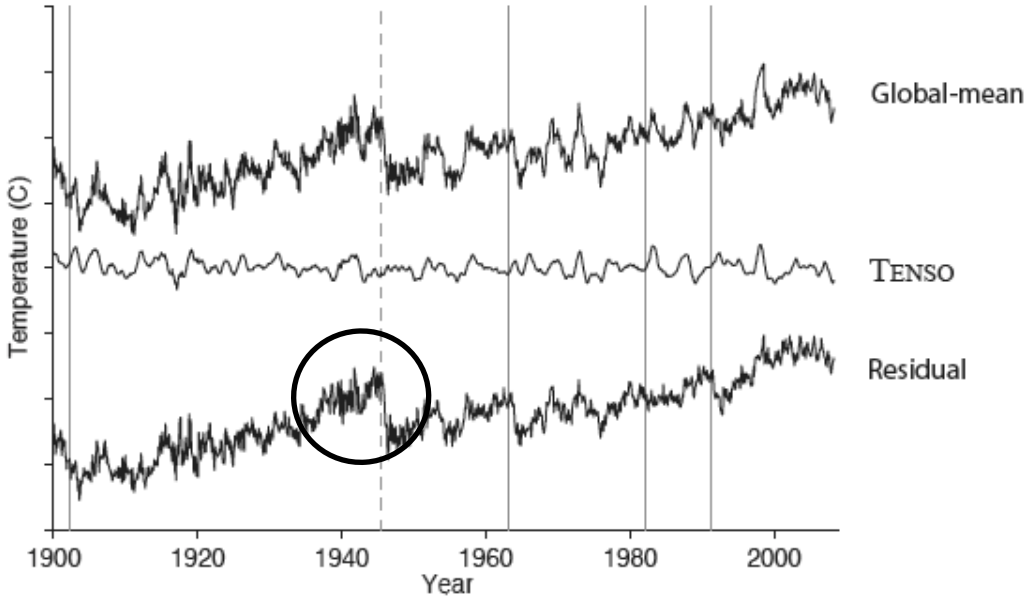
Former UW grad student (with Wallace)

One of Popular Science's "Brilliant 10" young scientists

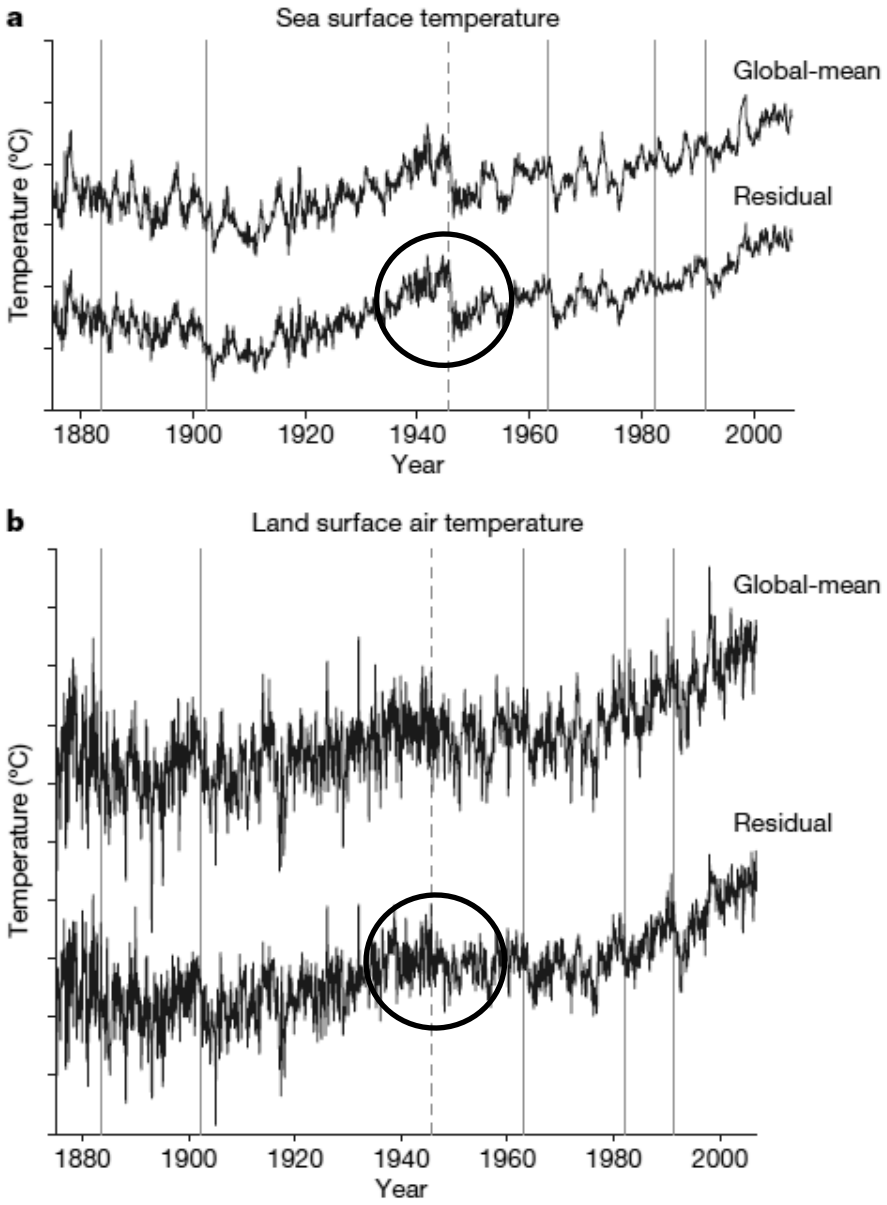

Temperature (C)
Global-mean
TENSO
Tdyn
Residual
?
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year



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

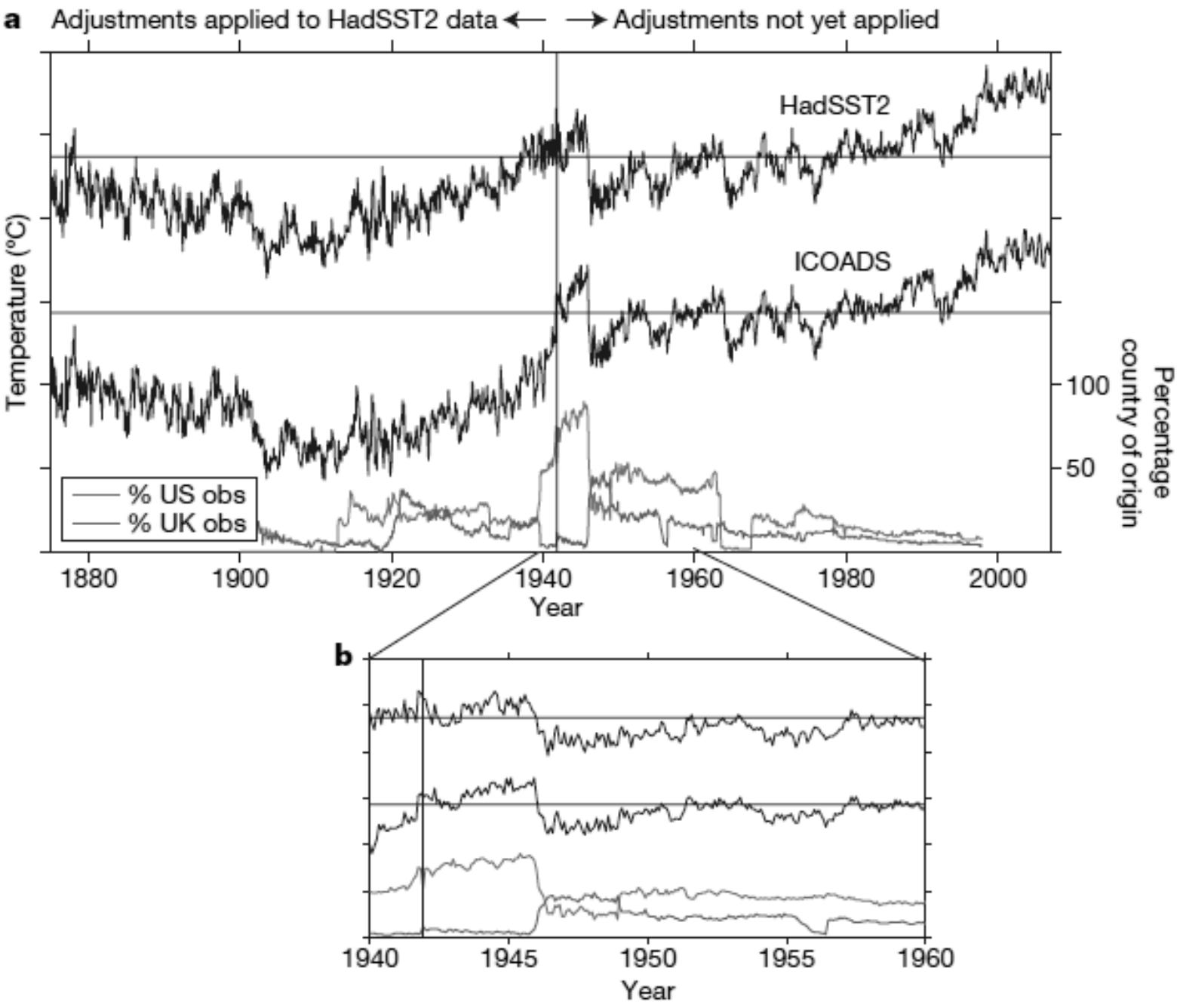


Sea surface temperature:
Now you see it!



Sea surface temperature:
Now you see it!

Land surface air temperature:
Now you don't!

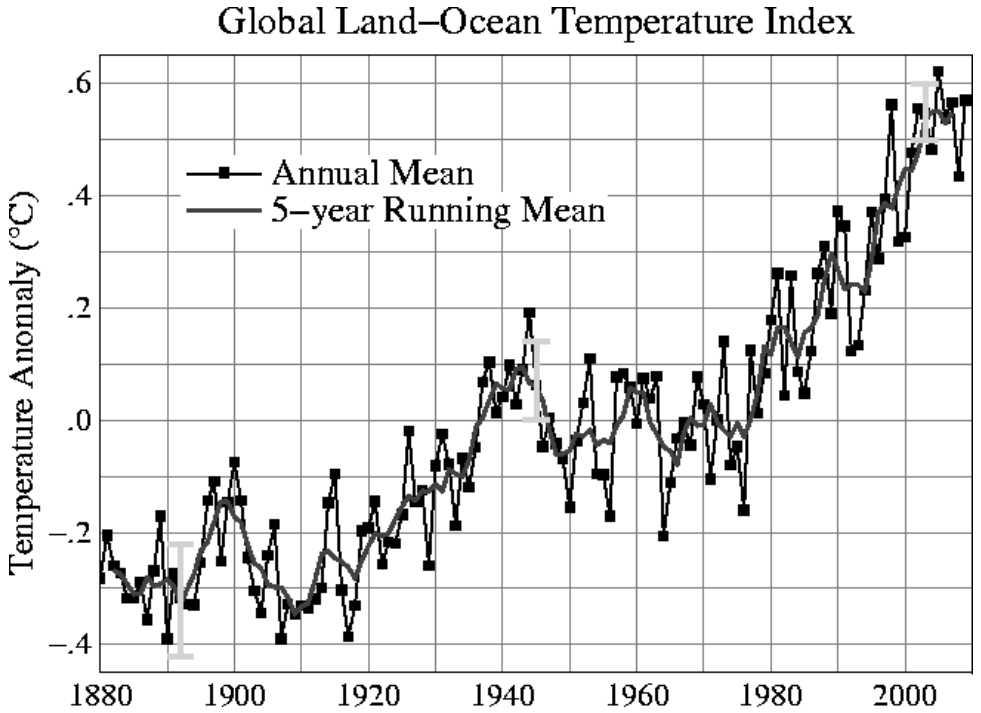

a
Adjustments applied to HadSST2 data
Adjustments not yet applied
HadSST2
ICOADS
Temperature (°C)
% US obs
% UK obs
Percentage country of origin
100
50
1880
1900
1920
1940
1960
1980
2000
Year
b
1940
1945
1950
1955
1960
Year

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

Last Time

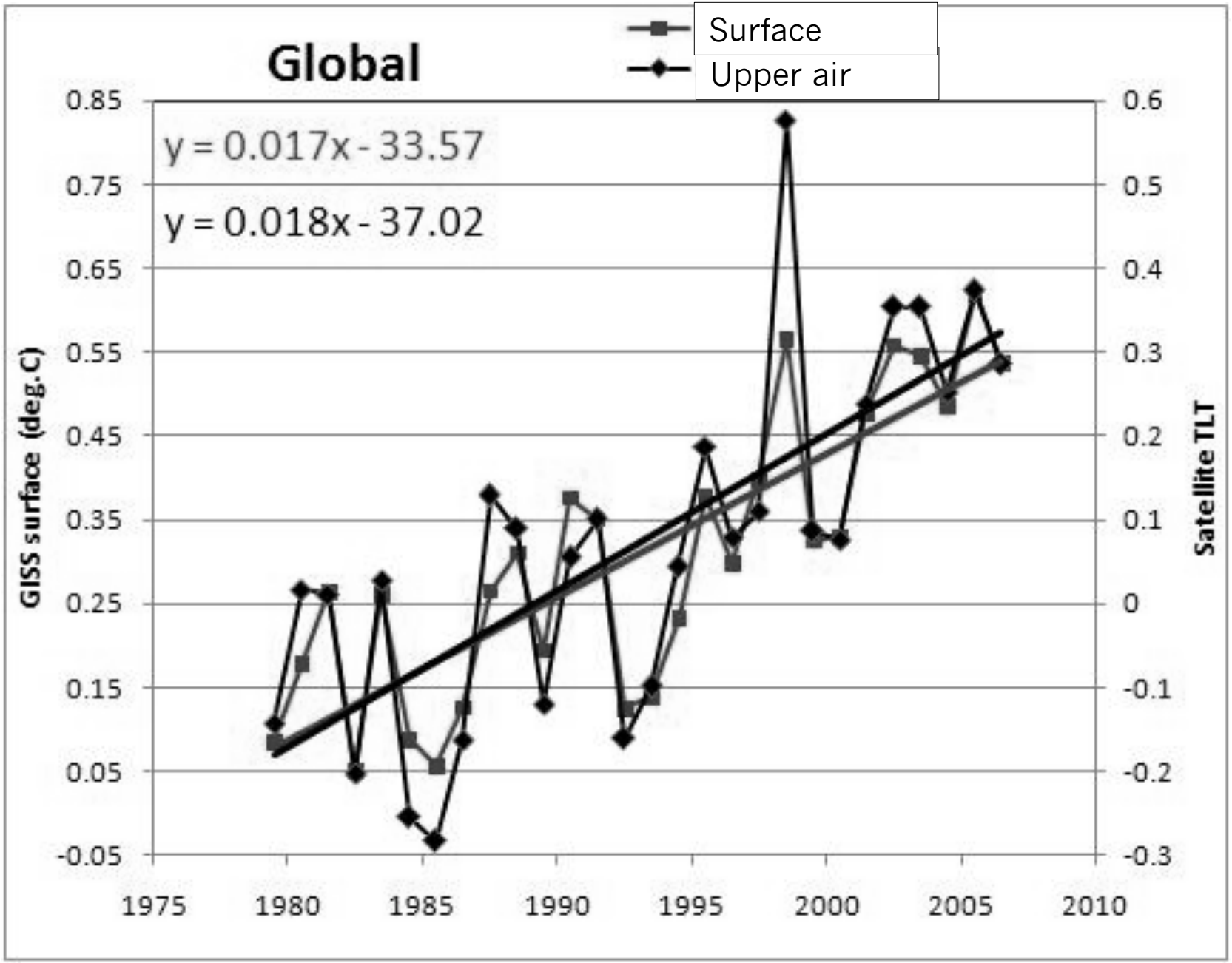
- Surface temperature is recorded at thousands of weather stations and on ships around the world.
- Climate data centers, run by NASA, NOAA, and the University of East Anglia in England, compile this data, attempt to account for errors, and compute the global average (accounting for differences in coverage).
- NASA surface record →



Last Time

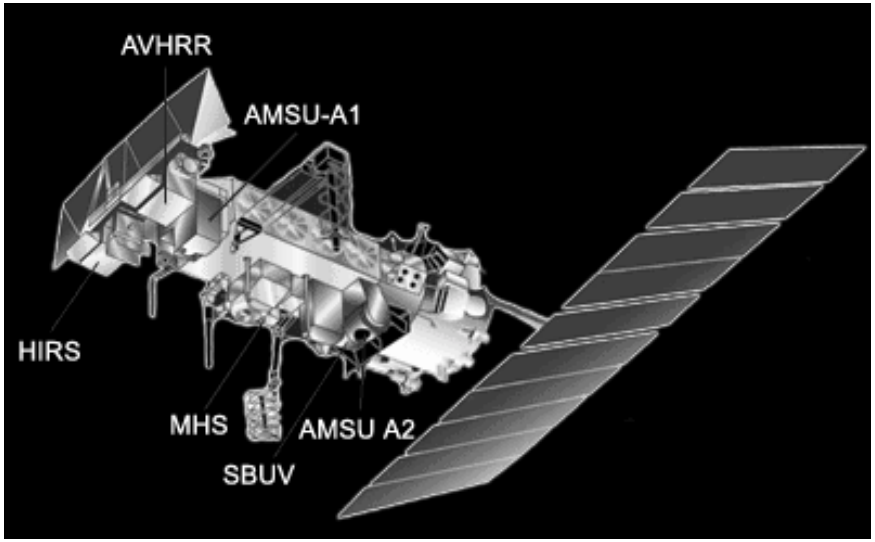
- Adjustments for errors and inconsistencies in weather records can be complicated and imperfect.
- However, three different groups, using different methods, give similar global mean surface temperature trends over the 20th Century.
- Some errors, such as the one leading to spurious cooling after WWII, have only recently been caught.
- In this case, the culprit was a shift from sea surface temperature records with a warm bias to those with a cold bias after 1945.
- Next – another example of a recently resolved discrepancy in climate records.

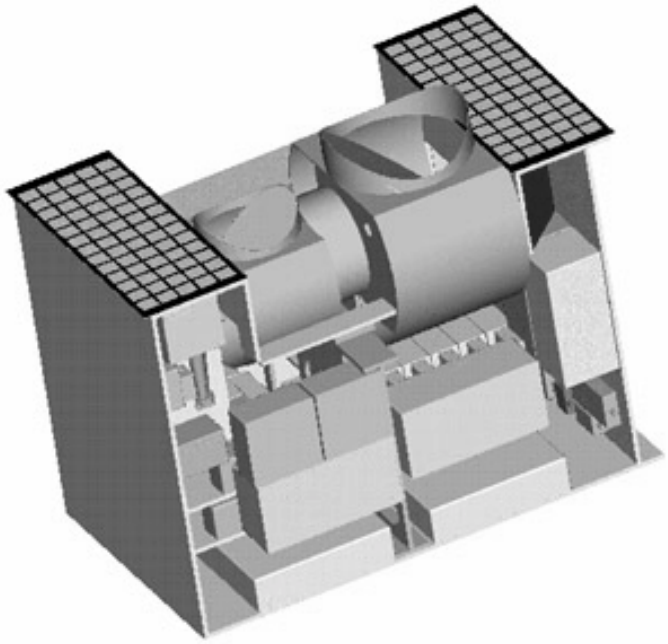
Case study 2: Heat at a Height



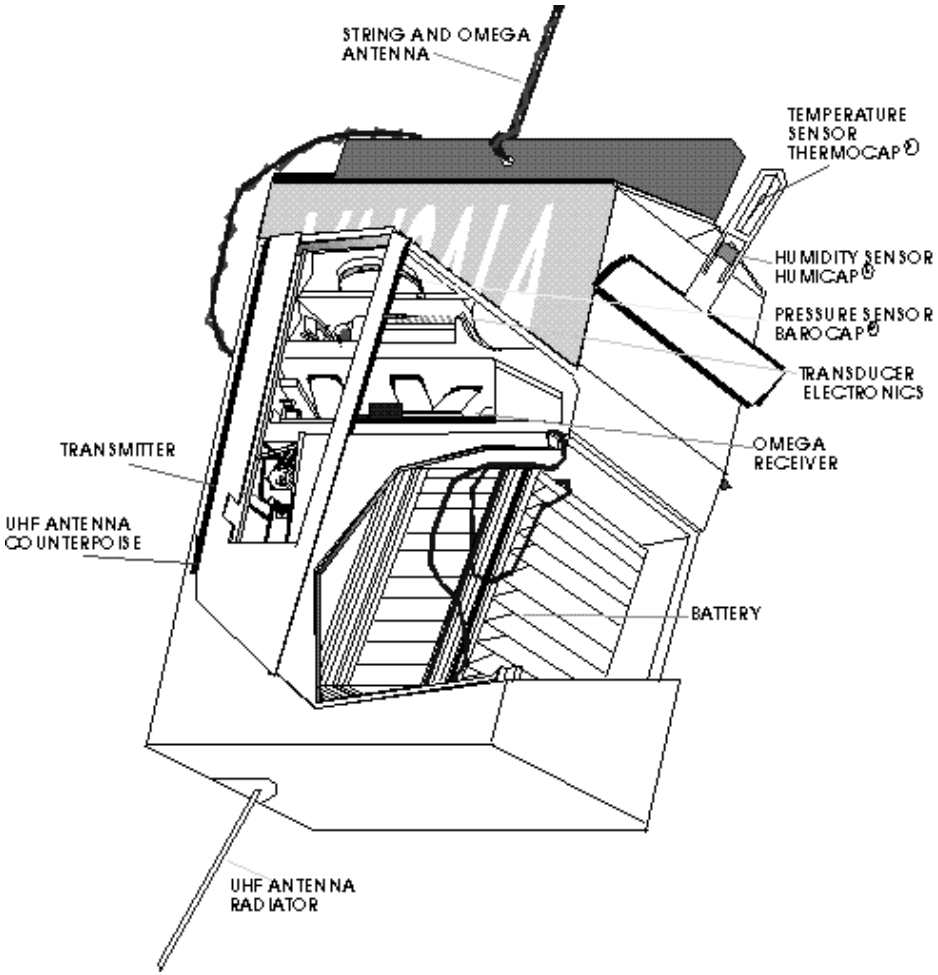
“Via Satellite” Temperatures

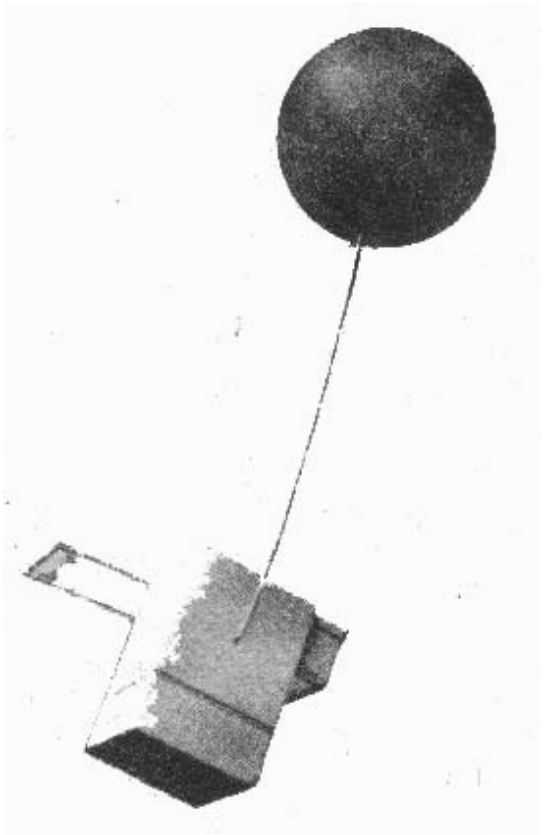
- Remote temperature sensing
  - The microwave sounding unit (MSU): since 1979
  - Works like infrared thermometer
  - Multiple wavelength channels give temperatures at different heights
  - Global coverage twice daily



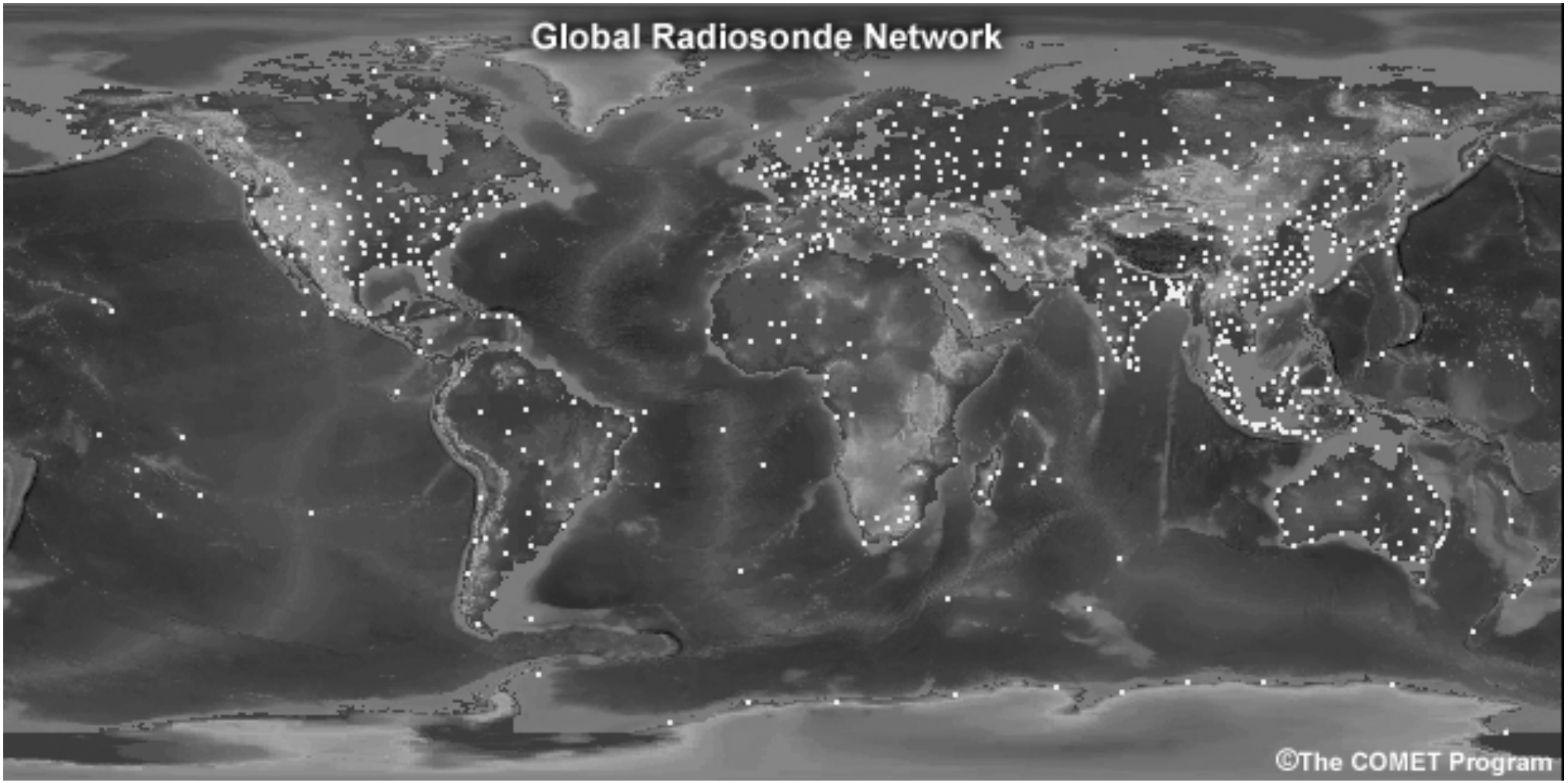


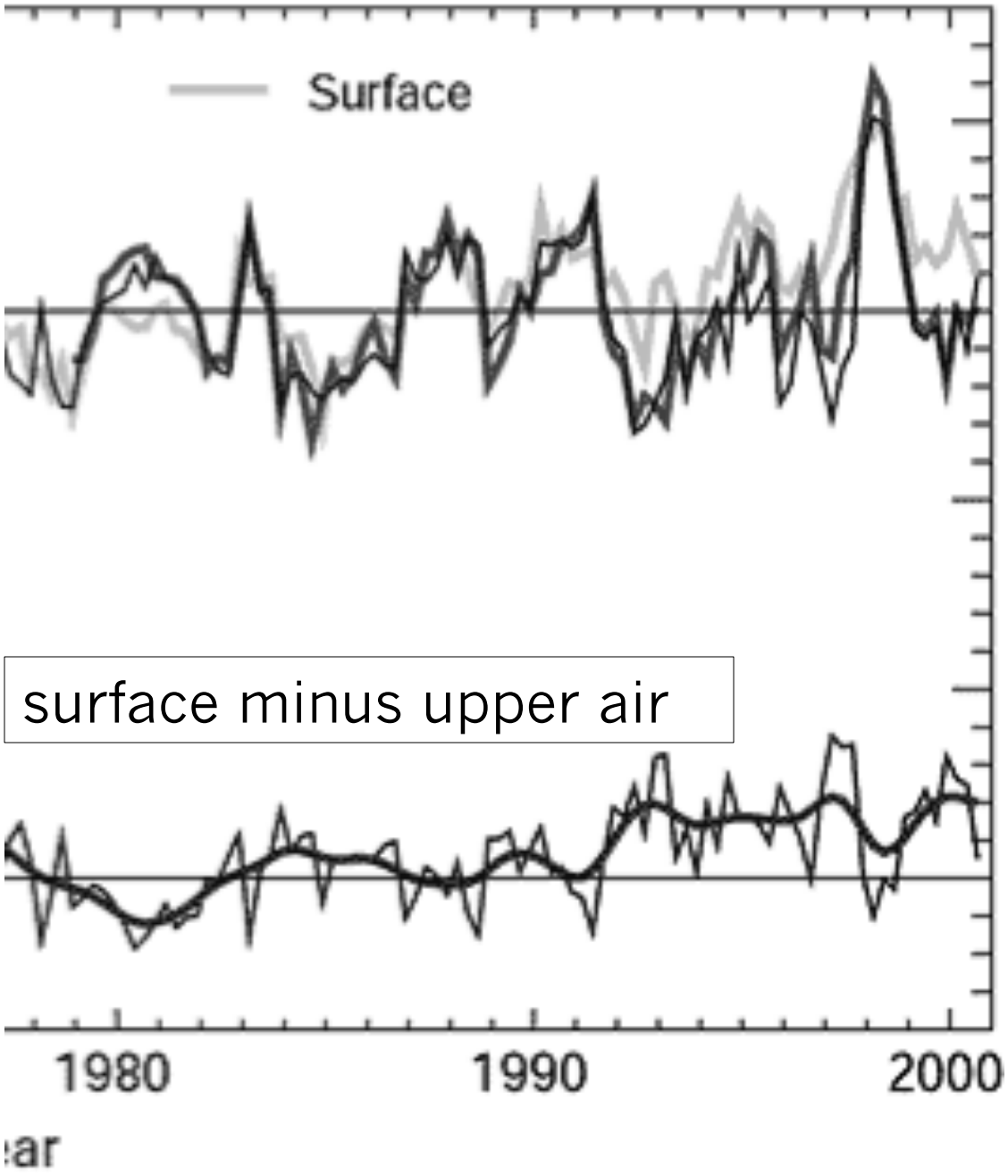
Upper air observations





Radiosondes (weather balloons): since 1946

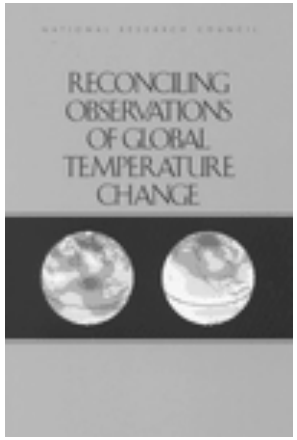

Global Radiosonde Network
©The COMET Program



Plots from the 2001 IPCC Report

At this time (2001), **we thought** the **surface warmed much faster** than upper atmosphere (black lines are balloons and MSU)

Yet: Both are supposed to heat up together. In the tropics, basic thermodynamics and models predict that the upper atmosphere should warm more than the surface.



In 2000 a panel convened by the National Academy of Sciences said:

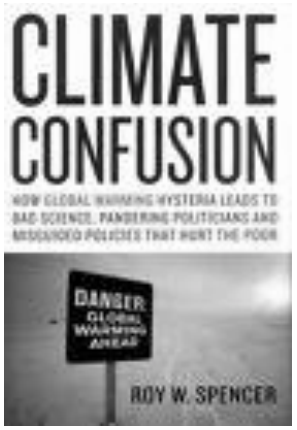
"Major advances in the ability to interpret and model the subtle variations in the vertical temperature profile of the lower atmosphere" are needed…

paraphrased from panel chair J. M. Wallace

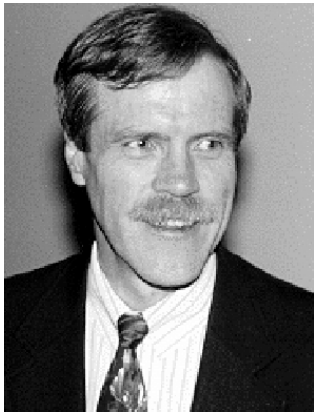
In other words, in 2000 we needed to figure out how the earth's surface can be heating up while the middle layers of the atmosphere are not.

Skeptics said: The satellite data are more comprehensive and more accurate than the surface data. Those who claim that the earth is overheating are just blowing hot air. If the global warming modelers admitted that, their gravy train would derail.

Prior to 2001, global warming skeptics Spencer and Christy and the University of Alabama Huntsville (UAH) team were the sole producers of the MSU satellite estimates



Roy Spencer, NASA



John Christy, UAH

Contribution of stratospheric cooling to satellite-inferred tropospheric temperature trends

Qiang Fu[1], Celeste M. Johanson[1], Stephen G. Warren[1] & Dian J. Seidel[2]

[1]*Department of Atmospheric Sciences, University of Washington, Seattle, Washington 98195, USA*
[2]*NOAA Air Resources Laboratory, Silver Spring, Maryland 20910, USA*

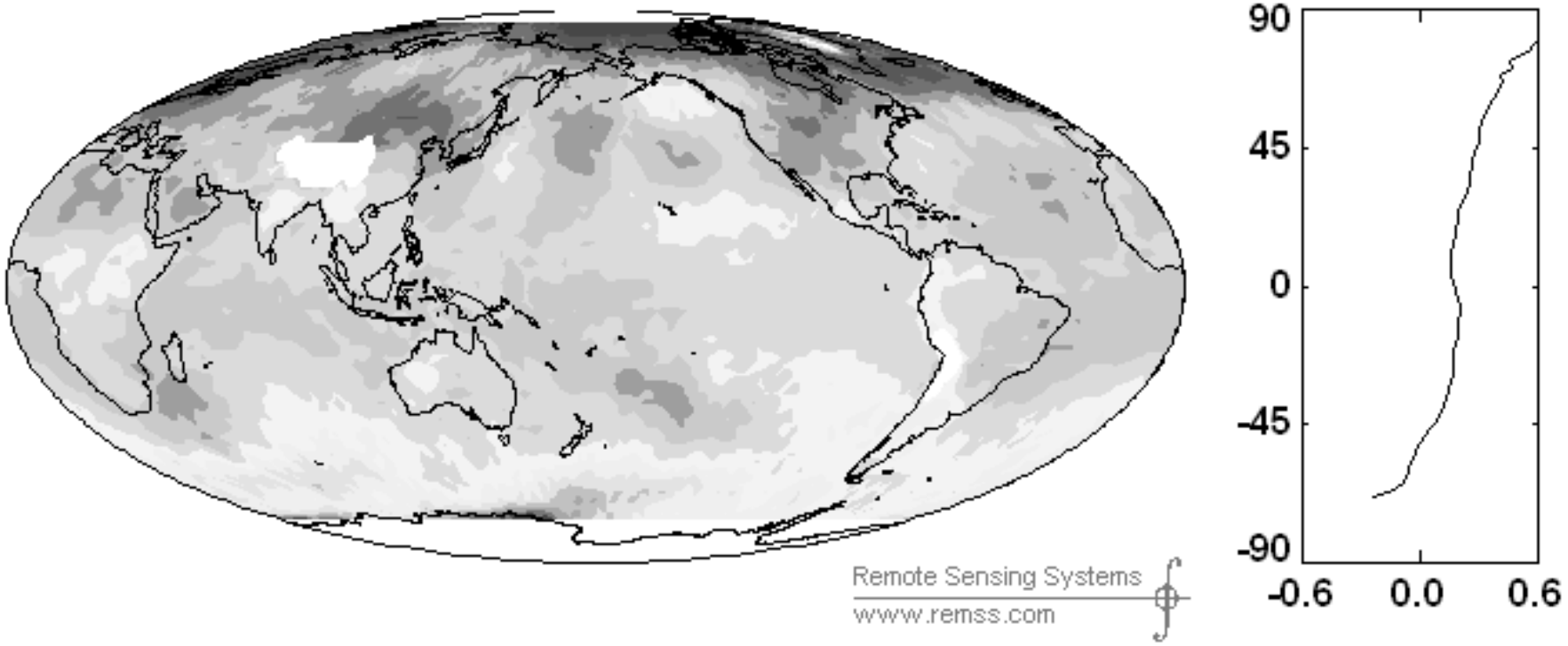
Prof. Q. Fu

Dr. Celeste Johanson

The RSS team now offers an independent estimates of trends and shows much more significant warming. The group identified an error in the algorithm used by Spencer and Christy. Spencer and Christy have acknowledged the error in their algorithm

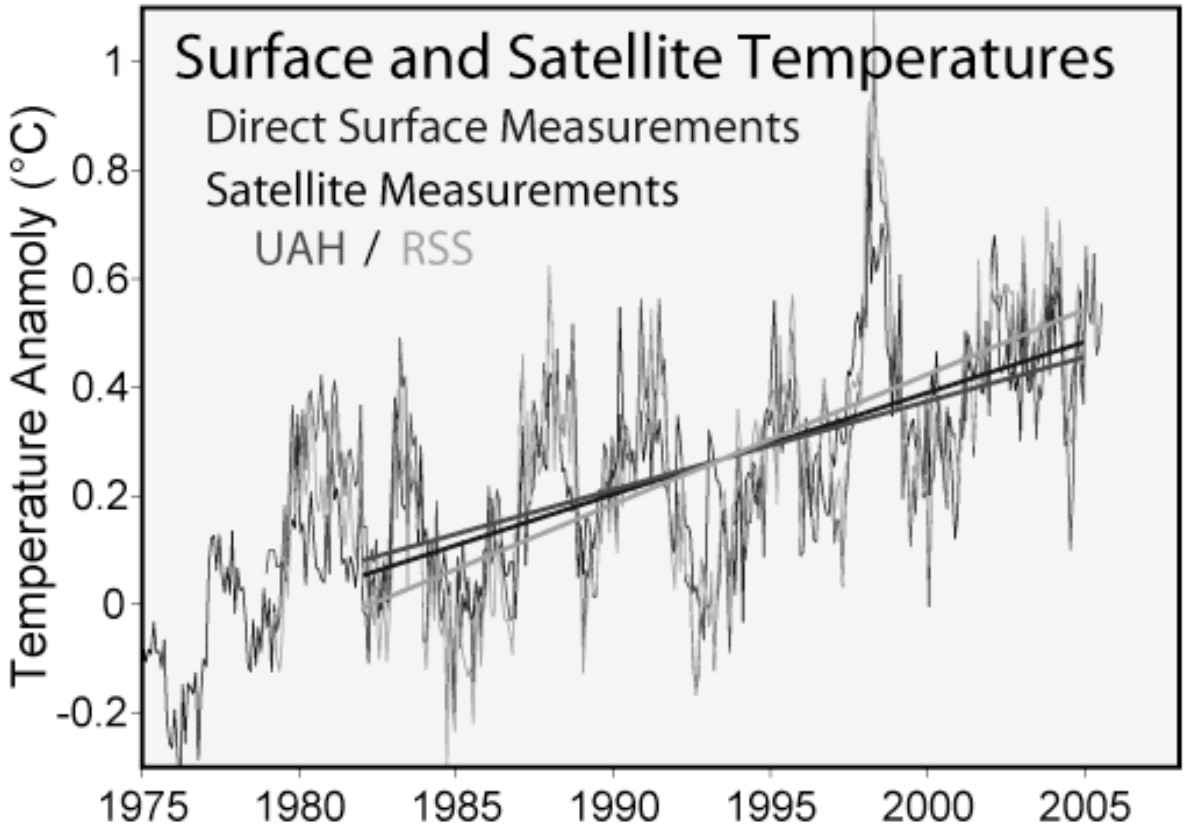
The RSS team in fact show substantial upper air warming

1979-2007 trend



deg C in 29 years

The surface and (satellite derived) atmospheric temperature trends are now consistent with what is expected with human forced global warming

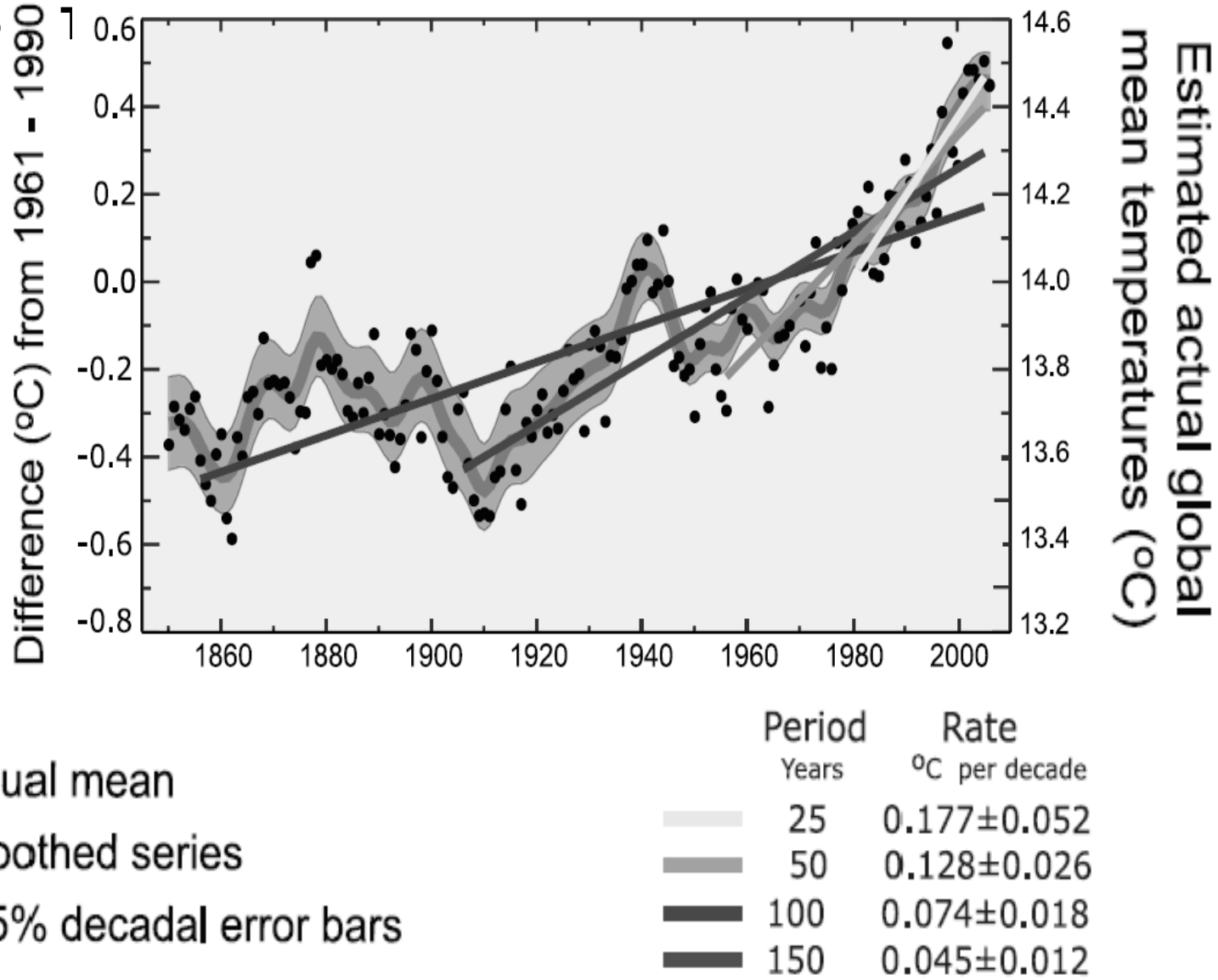


The apparent difference between the surface and (satellite derived) atmospheric temperature trends has been resolved

Trend analysis reveals <u>accelerated</u> warming

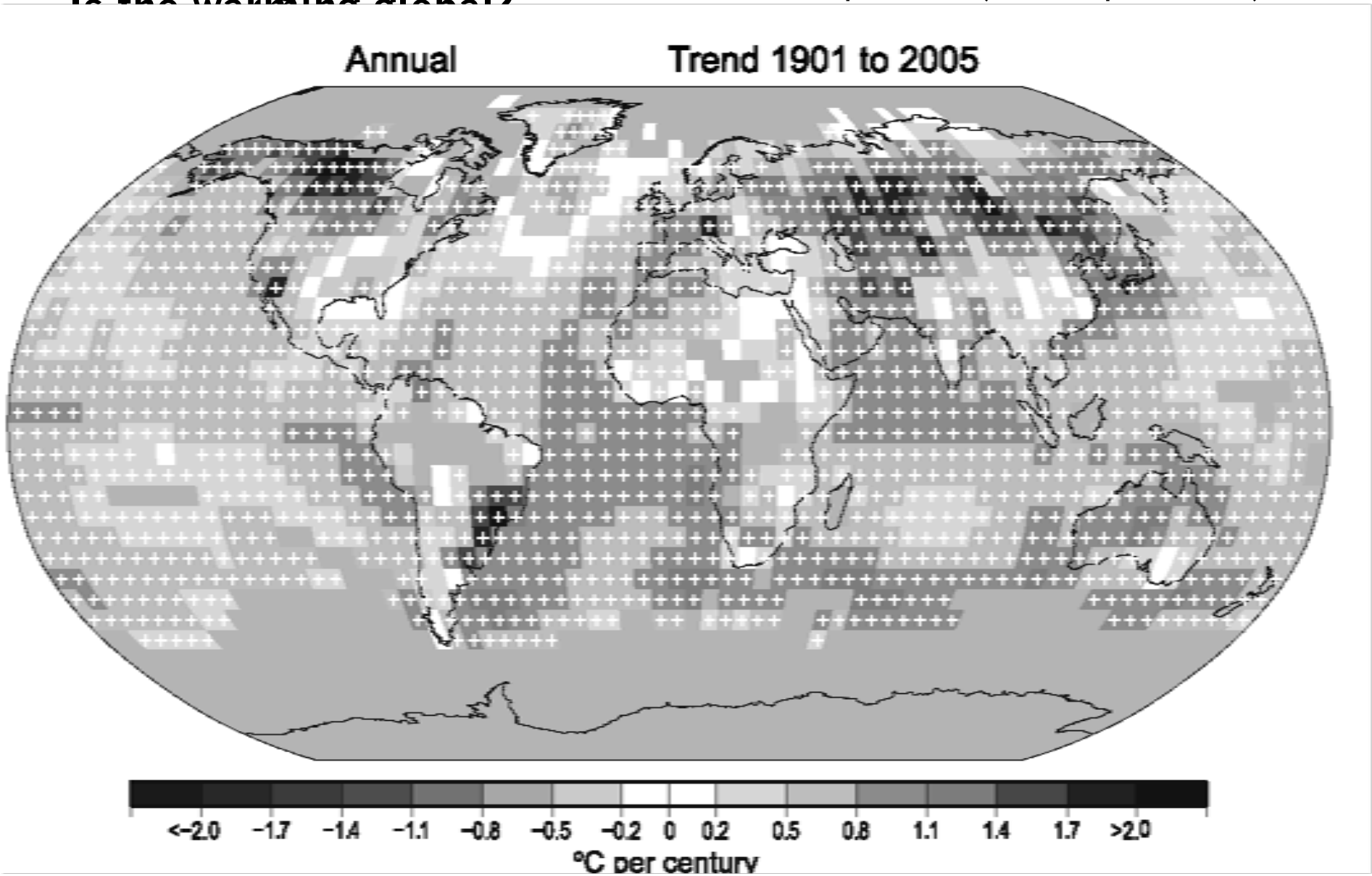
Does surfa

IPCC, 2007
WG I
Fig TS.6

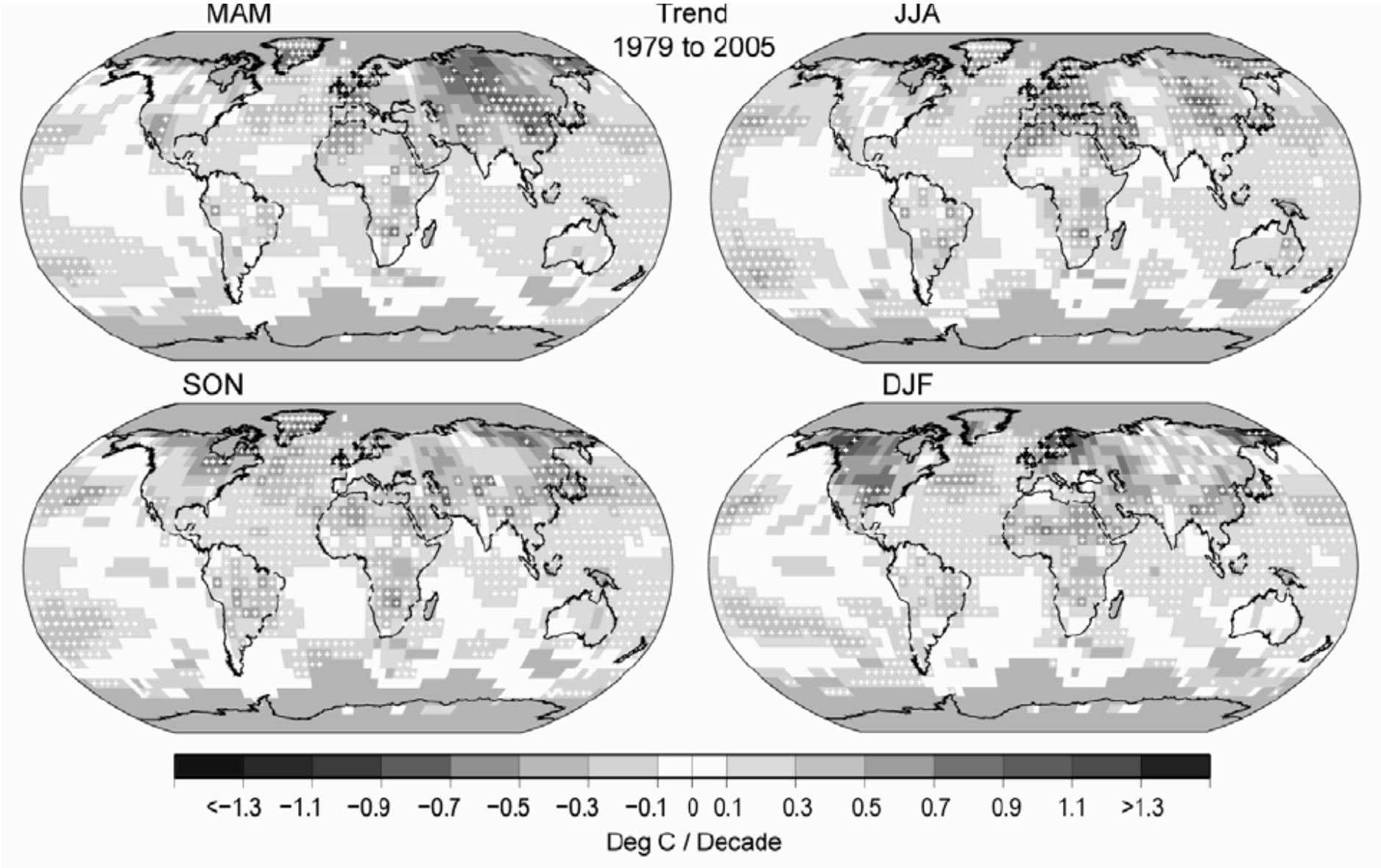


Is the warming "Global"?

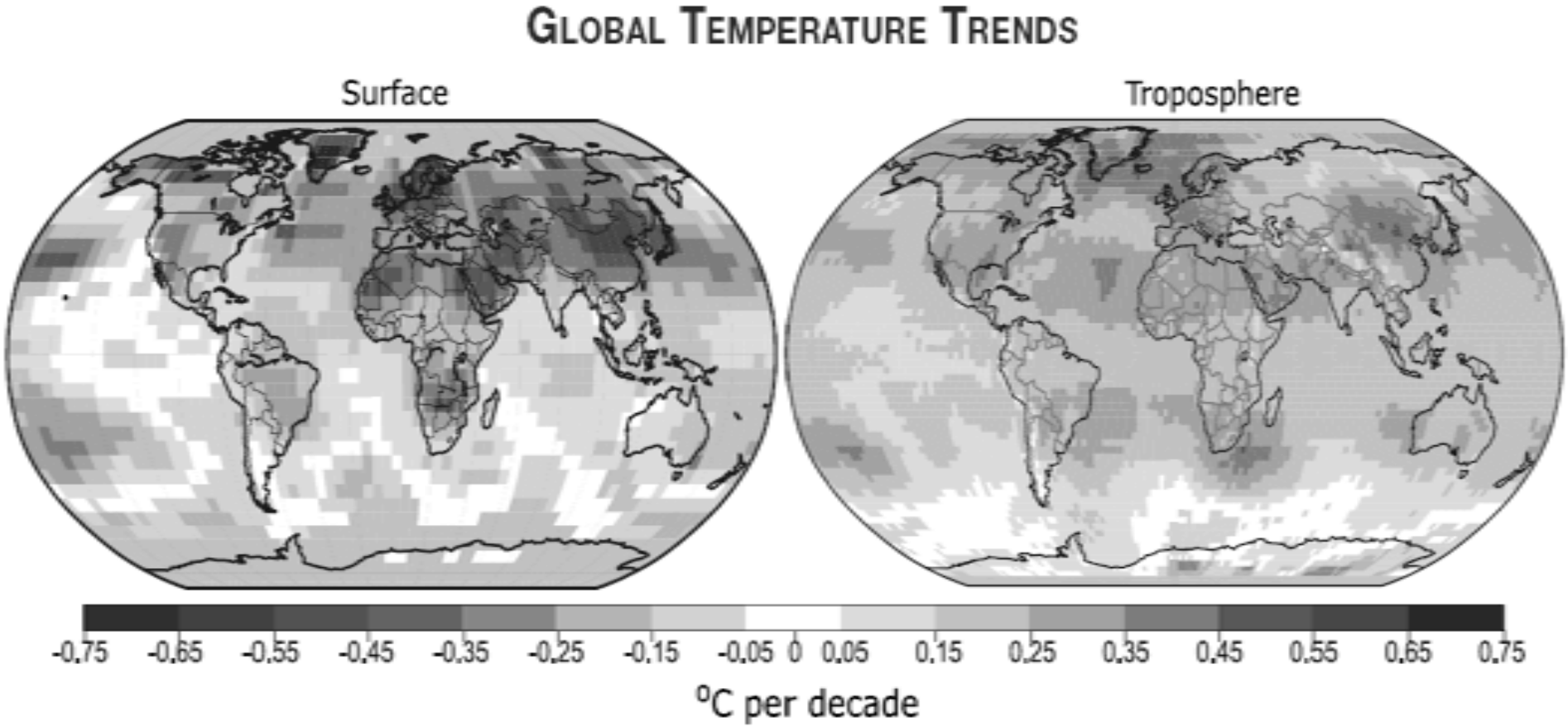
Yes, although enhanced over land at poles (as expected)



Consistency with season

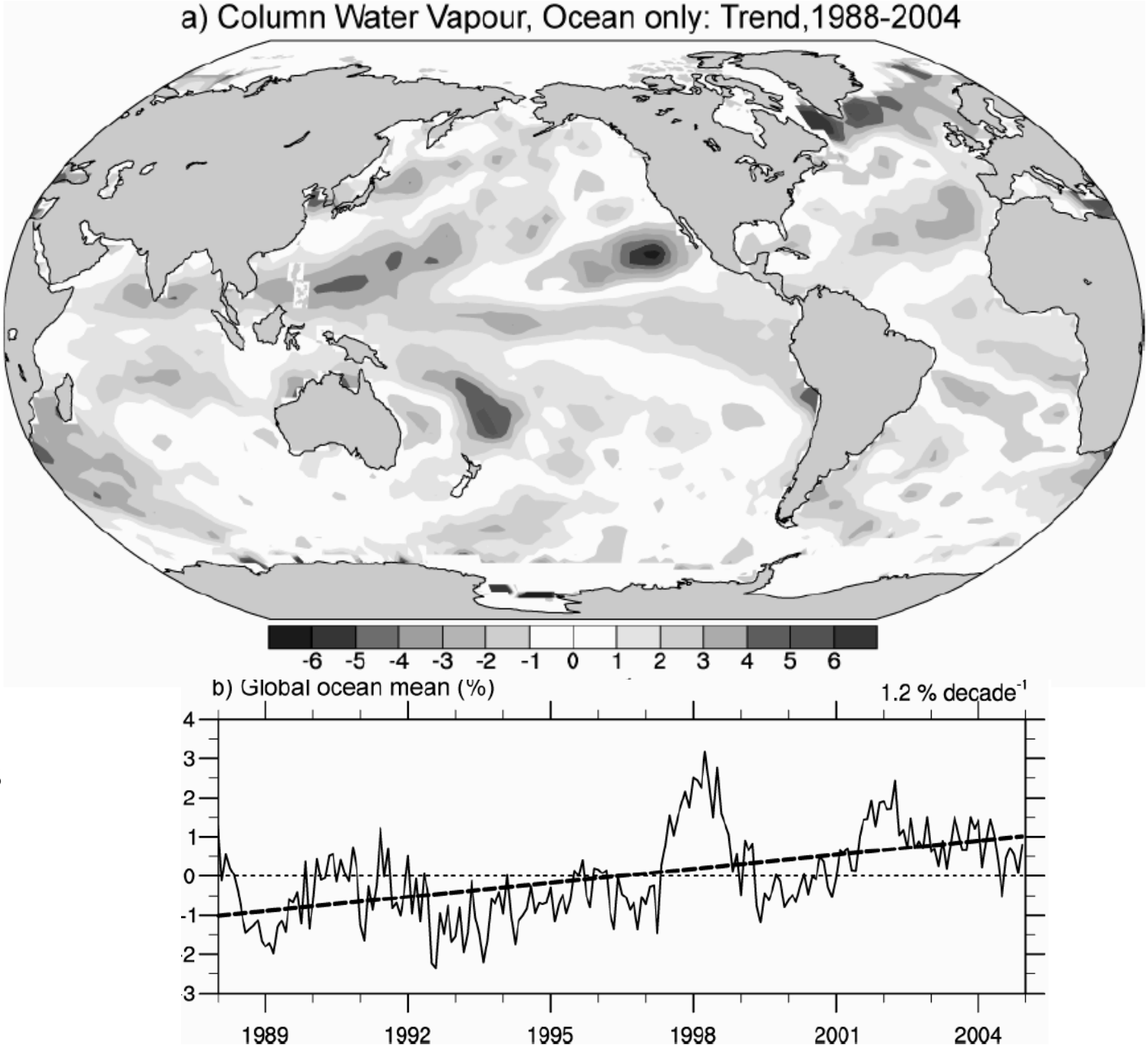


Warming extends above the surface



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

Water vapor concentration is increasing



Other signs of (global) warming

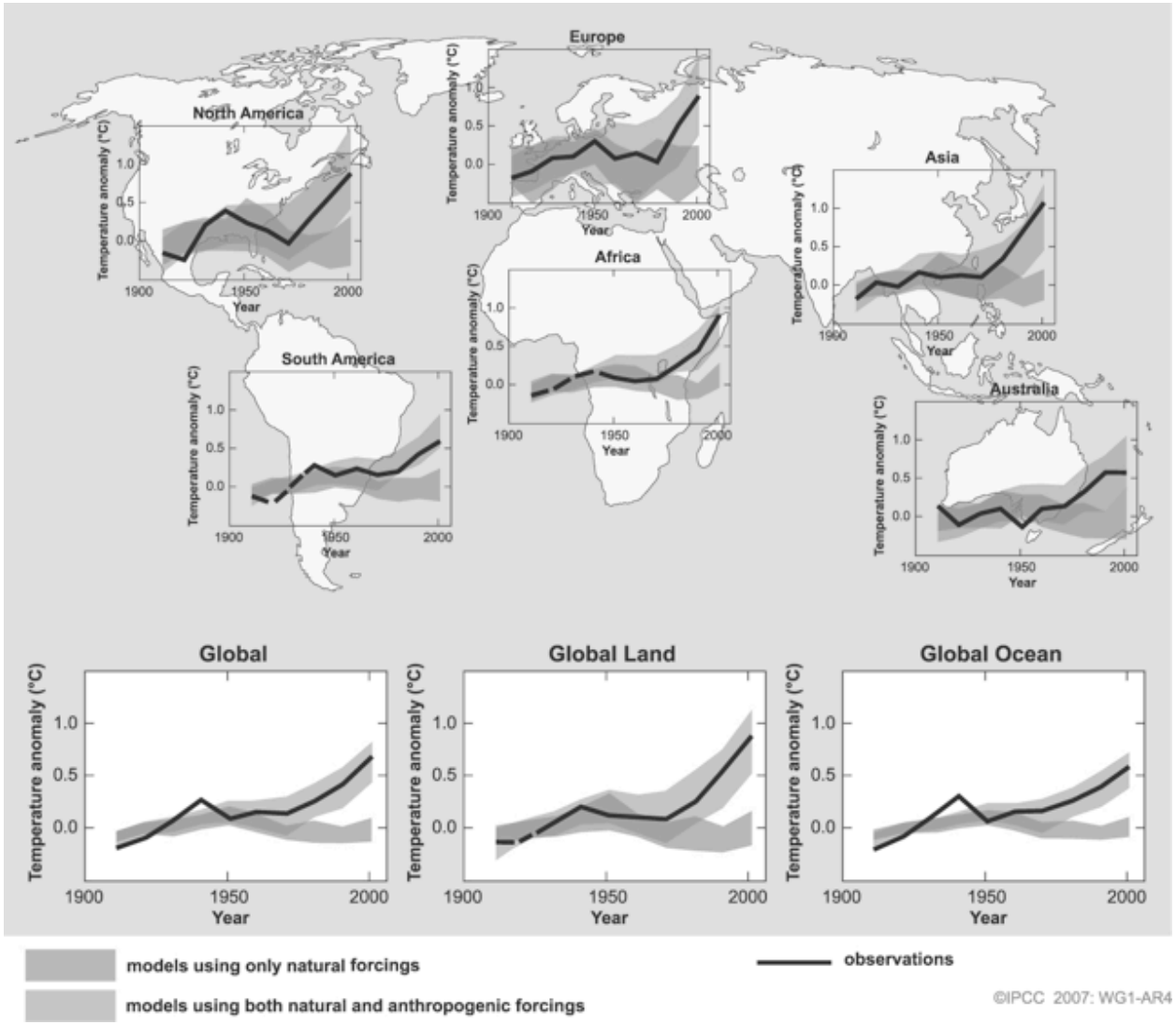
- melting mountain glaciers
- decrease in winter snow cover
- increasing atmospheric water vapor
- warming of global oceans
- rising sea level (due to warming and ice-melt)
- timing of seasonal events
  e.g. earlier thaws, later frosts
- thinning and disappearing Arctic sea ice
- species range shifts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

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

Detection and Attribution

1) Determine the change is above the natural variability
2) Determine the cause of the change

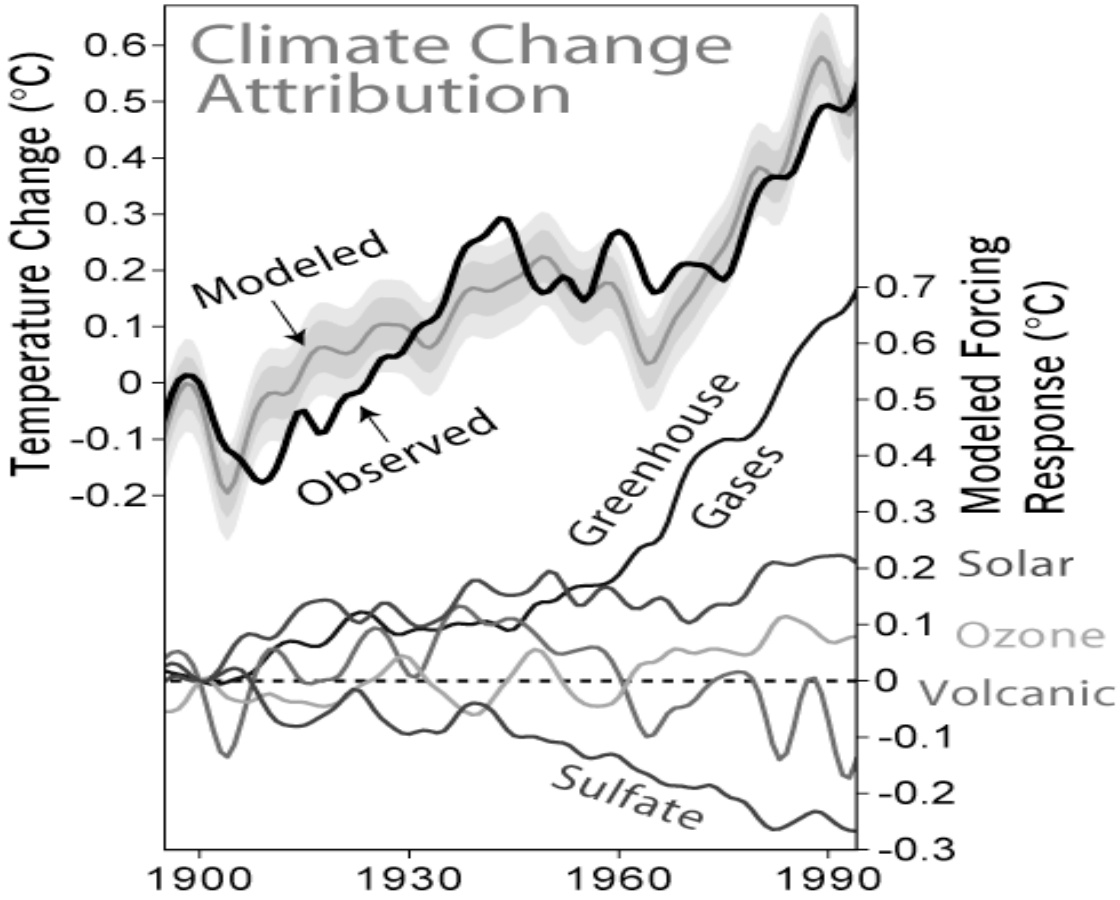
- Warming seen over all land and ocean regions
  - More in higher latitudes than in tropics; more over land than water



IPCC Fig SPM4

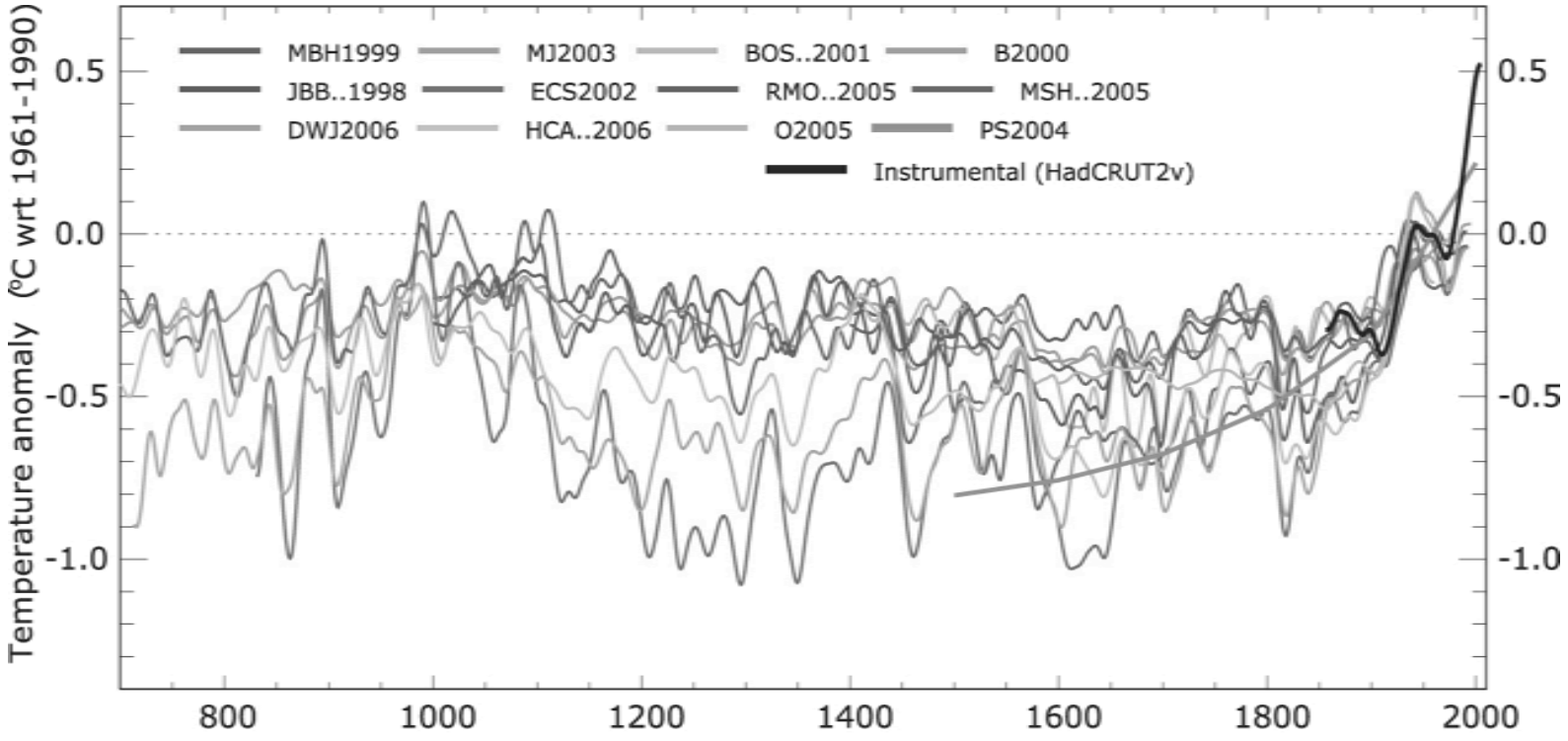
Attribution of the 20th Century Temperature Trends

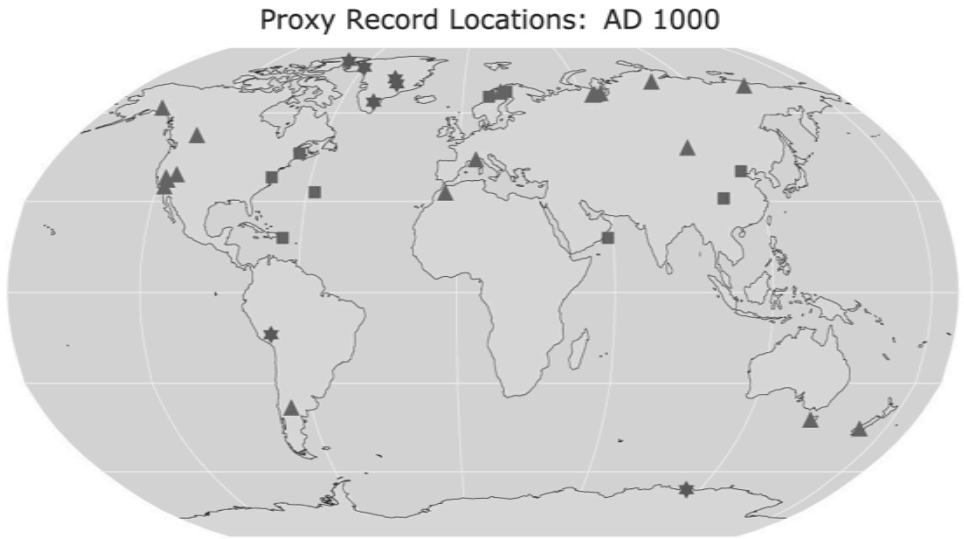
The pause in warming from ~1950-1980 is consistent with the natural (volcanoes and solar) and human (sulfate) forcing.



The warming trend can only be explained by – and is consistent with – human induced increases in greenhouse gases.

Northern Hemisphere average surface temperature from “Proxies”





△ Tree rings ○ Boreholes

☆ Ice cores □ Other

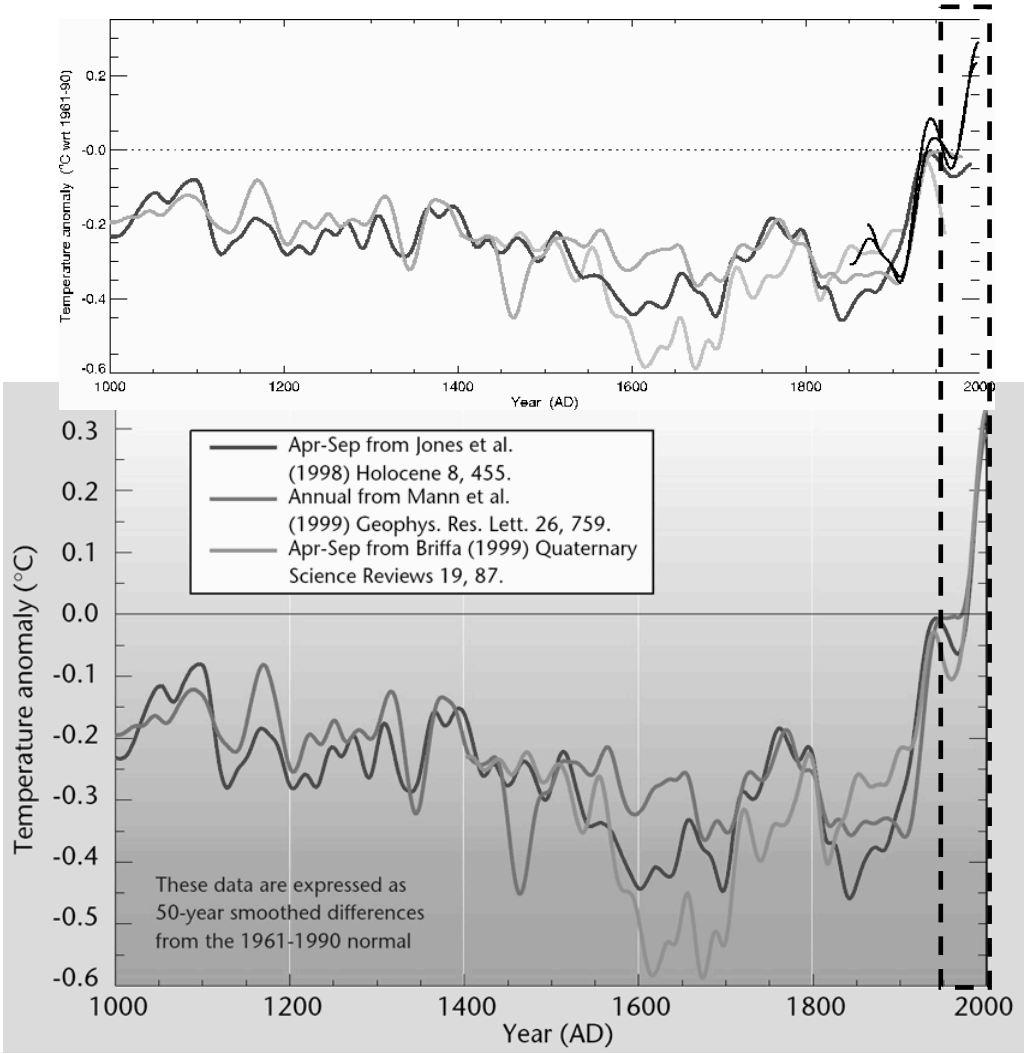
IPCC 2007 TS.20

From: Phil Jones. To: Many. Nov 16, 1999

"I've just completed Mike's Nature [the science journal] trick of adding in the real temps to each series for the last 20 years (ie, from 1981 onwards) and from 1961 for Keith's to hide the decline."

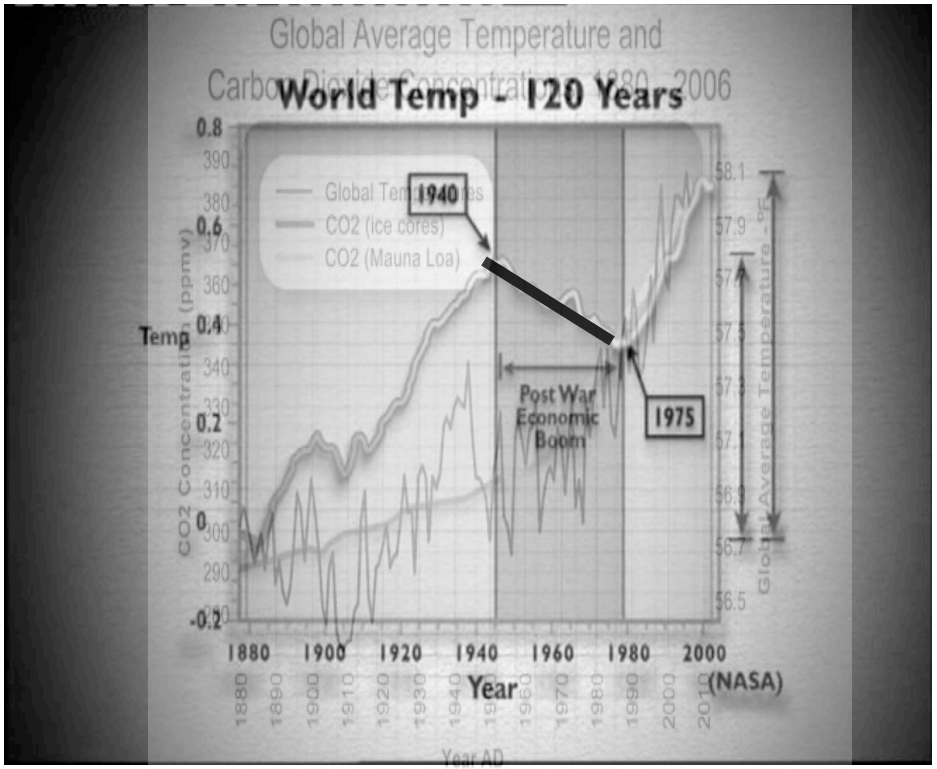
Damning Excerpt (?) from the Stolen Emails

Skeptics cite this email as evidence that data was manipulated to mask the fact that global temperatures are falling.

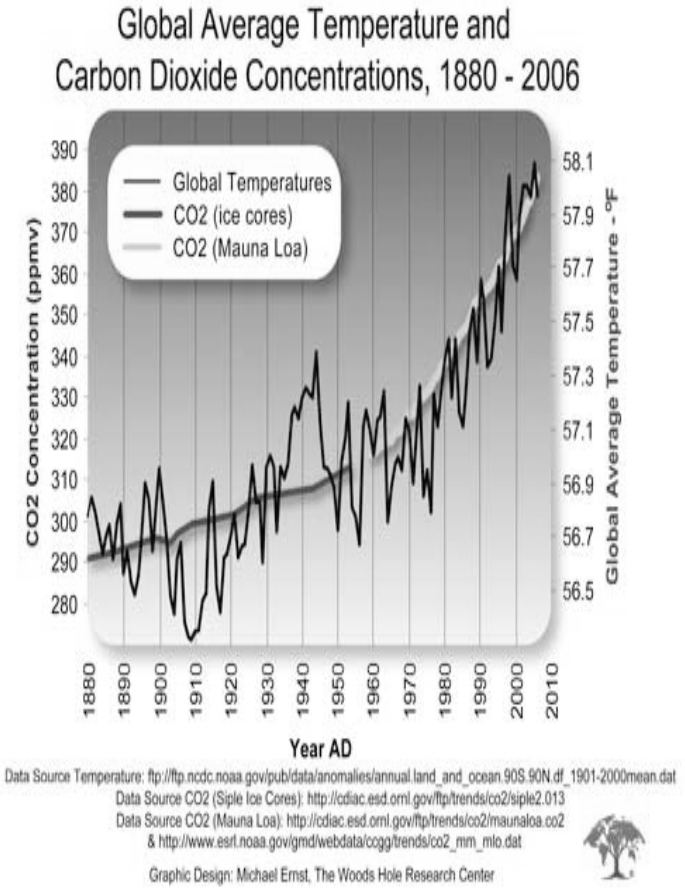


Blending the instrumental temperature data to extend the tree ring reconstruction to 1999 is “the trick” that *doesn’t* “hide the decline” in temperature from 1950-75.

A movie called “The Great Global Warming Swindle”:
Claims that global temperature dropped between 1940-75, just when CO2 was increasing fastest



Note: the temperature data (above in blue) shown in this movie are not consistent with any published data



Not to mention CO2 is increasing faster now

How do we know scientific studies are ri

- The **rules of science**:
  - In any study, you are required to
    - **Describe your methods** exactly
      - Good enough so that anyone else can **repeat your work**
    - Mention **all assumptions** you made & why
  - This assures no BSing…

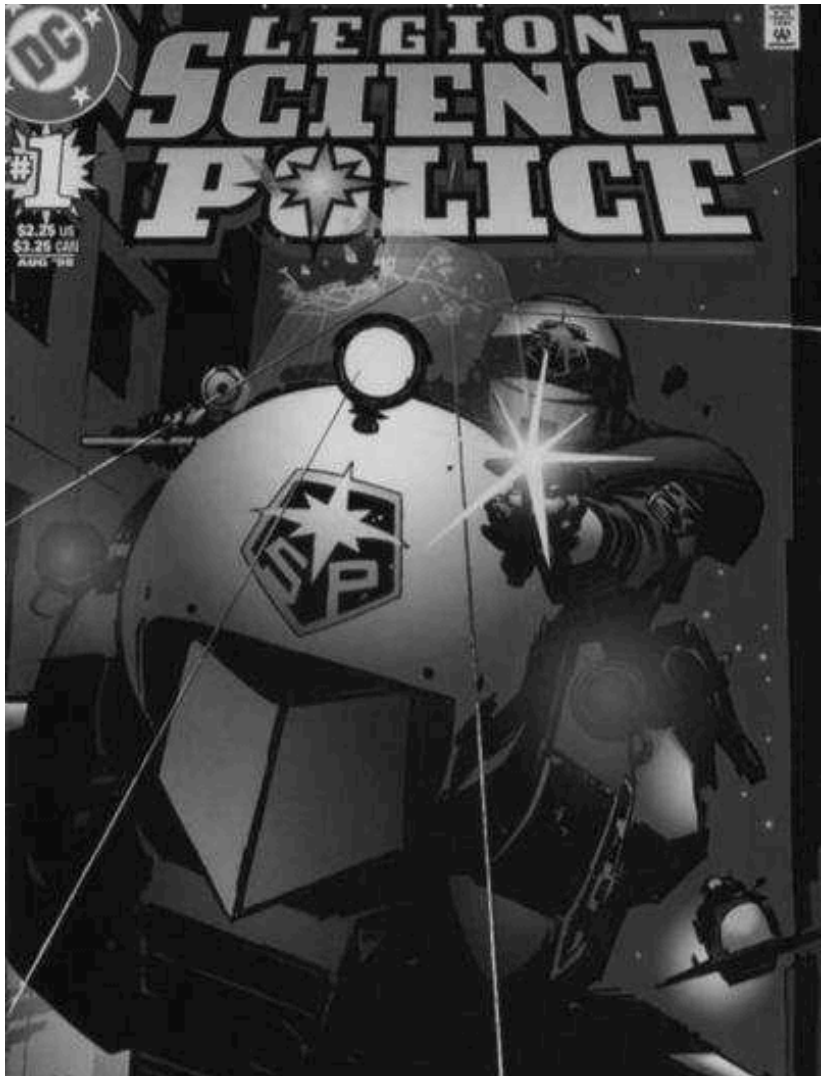
  - Further, most data/models are publicly available so it's not that hard to check methods/procedures yourself
    - Exceptions are a few proprietary datasets that are used to make money as well

Science is Wrong!

- With any study, there is some **interpretation** of results, which often reasonable people can disagree with
  - Common missteps:
    - "Correlation is not causation"
      - Just because two things are happening together doesn't mean one causes the other
    - Apparent trends can just happen randomly
    - Etc etc
- Another informal rule: don't claim your study says more than it actually does
  - Often it takes many many studies to make an important conclusion with confidence

The Science Police

- How are the rules enforced?
- Any scientific paper is **"peer reviewed"**
  - Other scientists read it to make sure it follows good scientific practices, that the arguments make sense, etc
  - Authors get a chance to respond to reviewers, add information, modify their conclusions, etc
  - If the reviewers aren't convinced, the editor can reject the paper
- Peer review is pretty tough

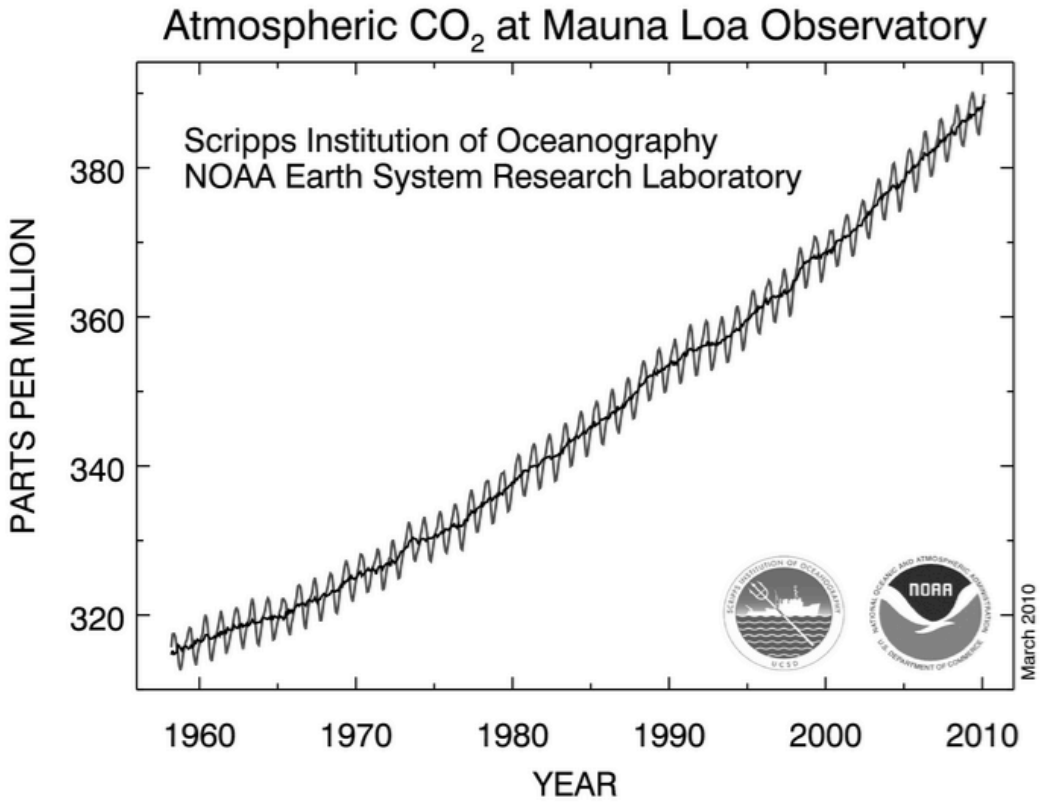


Scientific Assesments

- For important societal issues (energy, stem cells, wetlands, etc), there are often assessments of the state of the science
  - **Intergovernmental Panel on Climate Change** (IPCC) is the organization that does this for climate change
- IPCC summarizes the current climate research every 5-7 years
  - Kind of like peer review of the whole state of the science
  - Tends to be relatively conservative in terms of scientific claims
  - IPCC is currently under a lot of scrutiny for some mistakes in the report (Himalayas will melt by 2035 instead of 2350, etc).

Back to Climate Records

- A final important climate record: **carbon dioxide** levels
  - That CO2 is rising rapidly due to human activity is **equally important** as the temperature rise in the whole big picture of global warming
  - Monitored accurately at **Mauna Loa** Observatory, Hawaii since 1958

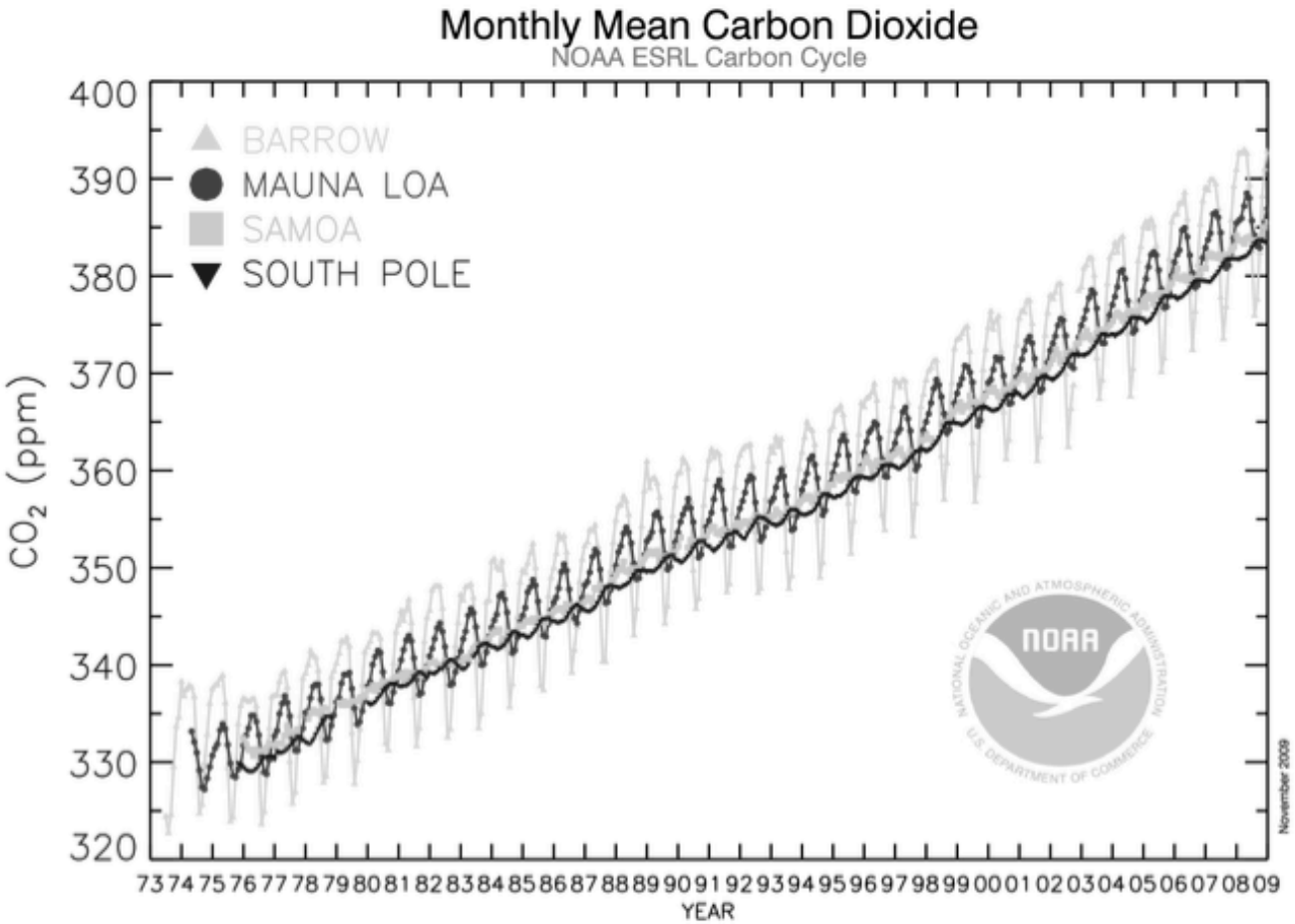


Carbon Dioxide at Other Sites

- Other sites agree with Mauna Loa, but with different seasonality

Seasonality is due to the growth of **vegetation** during summer, decay during winter

(May has the highest CO2 concentration in the NH)

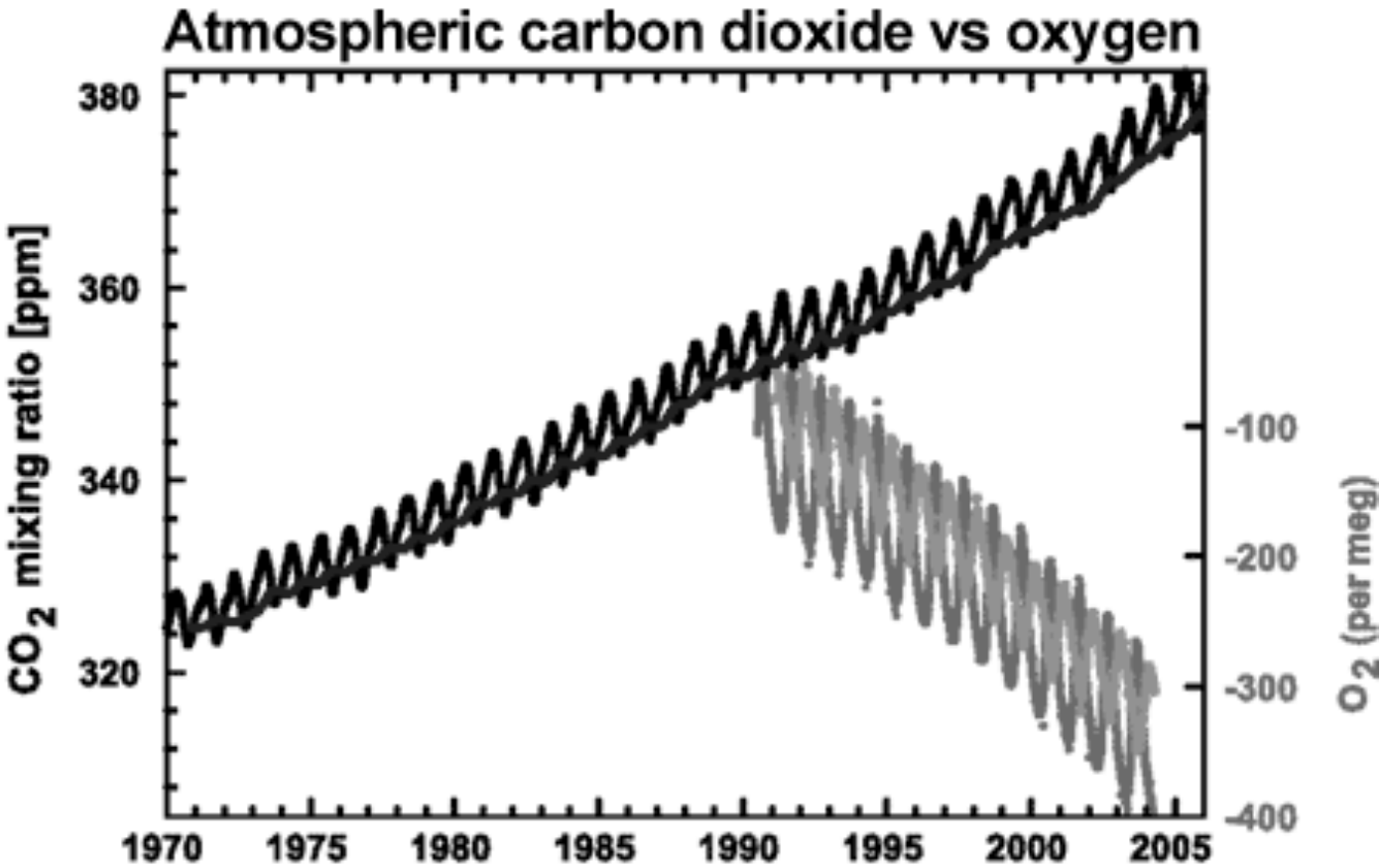


Evidence of Anthropogenic Rise

- Comparisons with industrial fossil fuel usage and deforestation rates show **emissions** are larger than atmospheric increase
  - 55% of emissions goes into the ocean or terrestrial biosphere (plants, ferns, etc), 45% stays in the atmosphere
- As with the temperature record, there is **complementary evidence** for anthropogenic causes of carbon dioxide rise as well...

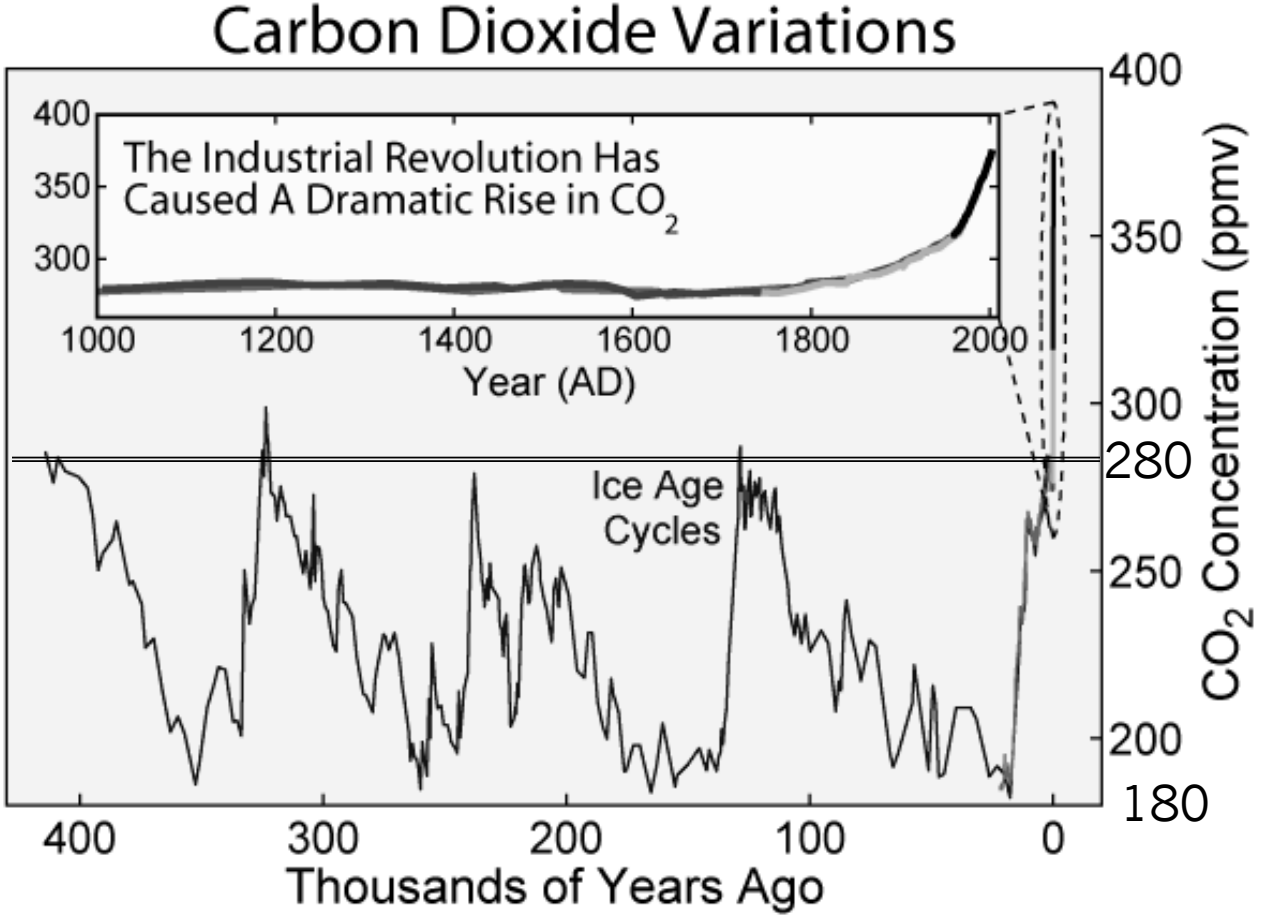
Evidence of Anthropogenic Rise

- Concentrations of **oxygen** have also been **decreasing**
  - Oxygen is used up when fossil fuels/forests are burned
  - If exchange with the ocean was the culprit, oxygen levels would stay the same



Connection to Paleoclimate

- We also know carbon dioxide levels are higher than they've been in several *hundred thousand years*



Natural variation over Ice Age Cycles:
180-280 ppm

Next time: How we know about this and other climate information from the past

Summary

- Records of global surface, ocean, and atmospheric temperature all show near-universal warming in the 20th Century. Only a few isolated parts of the world have shown cooling.
- Combined with other indicators – sea level rise, glacier melt, etc – this evidence for global warming is *unequivocal*.
- CO_2 and other greenhouse gases are the only cause that can explain the magnitude of the warming that we've seen so far.
- Anthropogenic emissions – not natural ones – are the cause of CO_2 increases in the atmosphere.