Lecture 7

Global Warming/Climate Change

(Observations and Attribution of Cause)

METR/ENVS 113
Spring Semester 2011
May 3, 2011

Reading …

- Henson “Rough Guide”
  - Chapter 1
  - Pages 75 – 127; 215; 227 - 244
  - Other pages (scan through, it’s a short book)
- Ahrens Chapter 14

Some background …

- Weather vs. Climate
- Trends vs. Fluctuations

What is weather vs. climate?

- **Weather:**
  - The state of the atmosphere at some time and place.
  - For example, the maximum temperature in San Jose on Wednesday August 25, 2010 was 100˚F.
- **Climate:**
  - The **average** state of the atmosphere over many daily or seasonal weather events over a long time period (generally many years).
  - Local & Regional Climate: Average of weather events just in a particular place or region (e.g. San Jose or SF Bay Area)
  - Global Climate: Average of weather events over entire globe.
  - For example, the average (“normal”) maximum temperature in San Jose on August 25 is 82˚F.

Question …

- Are the following statements about weather or climate?
  - It was rainy in Southern Europe last week.
  - The gulf-stream ocean current causes the U.S. east coast to be warm during the summer.
  - Tornados are frequent in the U.S. Midwest.
  - Next year is expected to be a “La Nina” year.

Question …

- Are the following statements about weather or climate?
  - It was rainy in Southern Europe last week. Weather
  - The gulf-stream ocean current causes the U.S. east coast to be warm during the summer. Climate
  - Tornados are frequent in the U.S. Midwest. Climate
  - Next year is expected to be a “La Nina” year. Weather

Climate is the average of weather …

- Given the following data, calculate the average maximum temperature on August 25 in San Jose, California…

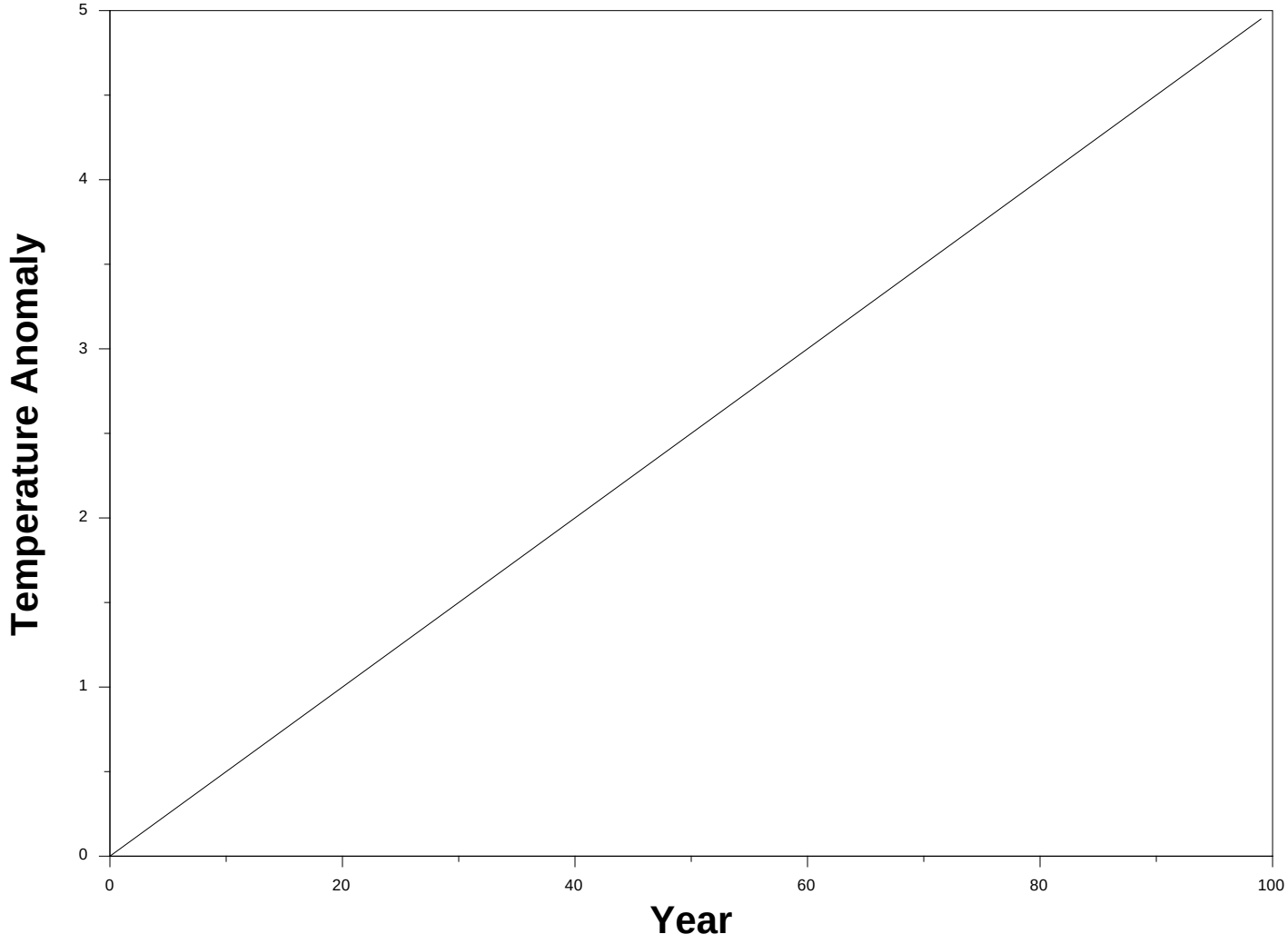
Year	Tmax	Year	Tmax	Year	Tmax
1971	83	1981	79	1991	77
1972	85	1982	73	1993	93
1973	77	1983	77	1994	82
1974	82	1984	74	1995	76
1975	84	1985	79	1996	76
1976	80	1986	83	1997	81
1977	80	1987	84	1998	88
1978	78	1988	97	1999	95
1979	80	1989	89	2000	89
1980	76	1990	74	2001	82
AVERAGE (10 YEAR)	**80.5**		**80.9**		**83.9**
AVERAGE (30 YEAR)					**81.8**

~ 82˚F

Trends vs. Fluctuations

- **Fluctuations**
  - Short-term
  - Also called “noise”
  - Sometimes explainable, sometimes not (“random”)
  - No discernable long term trend in fluctuations (they “cancel out”)
- **Trend**
  - Long-term rise or fall over period of interest
  - Also called “signal”
  - Explainable (through hypothesis or theory)
  - Climate scientists attempt to explain trends in climate, not fluctuations.

Fig. 1. A linear trend.



Weak vs. Strong Trend

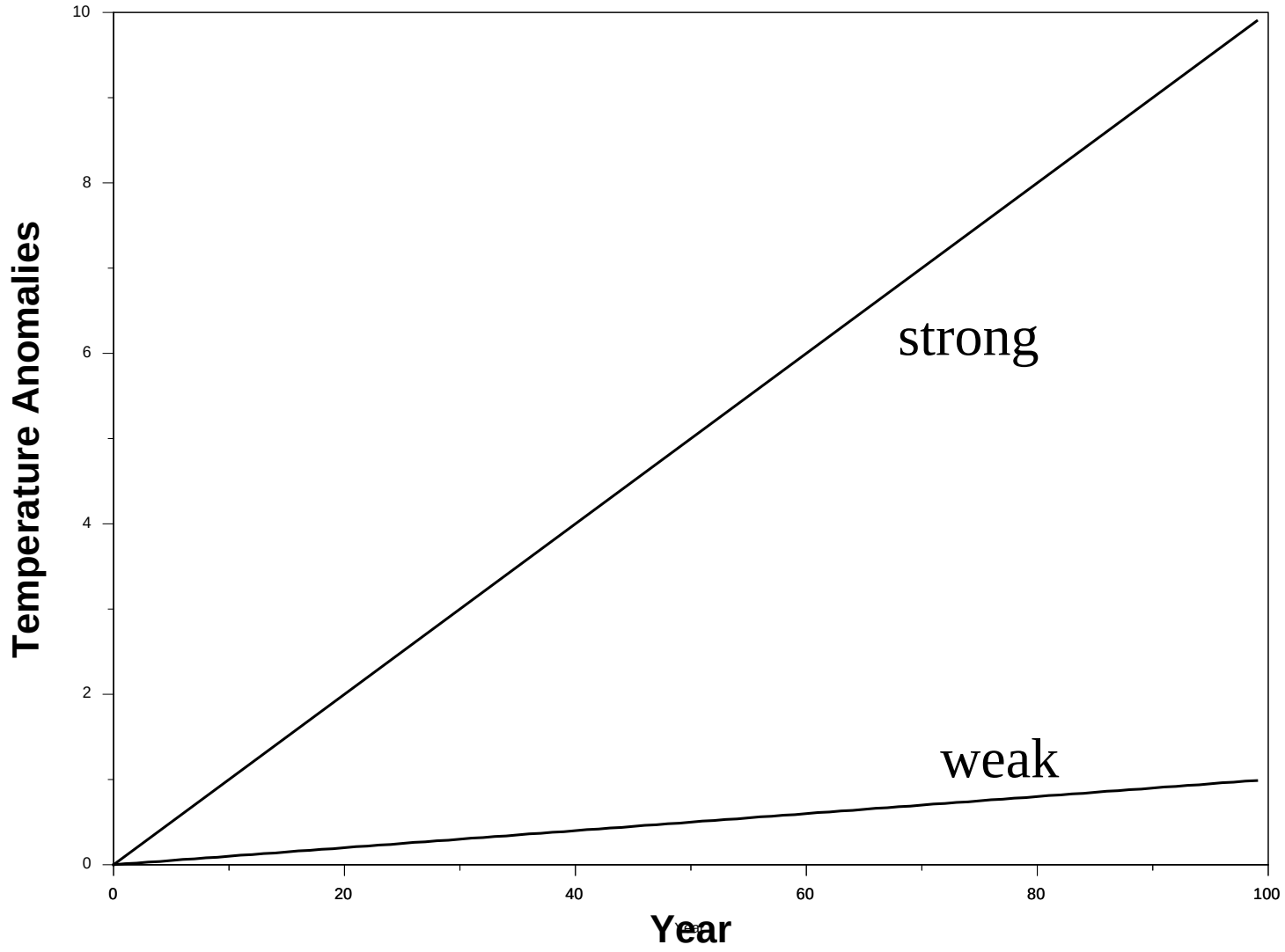


Fig. 2. Random fluctations.

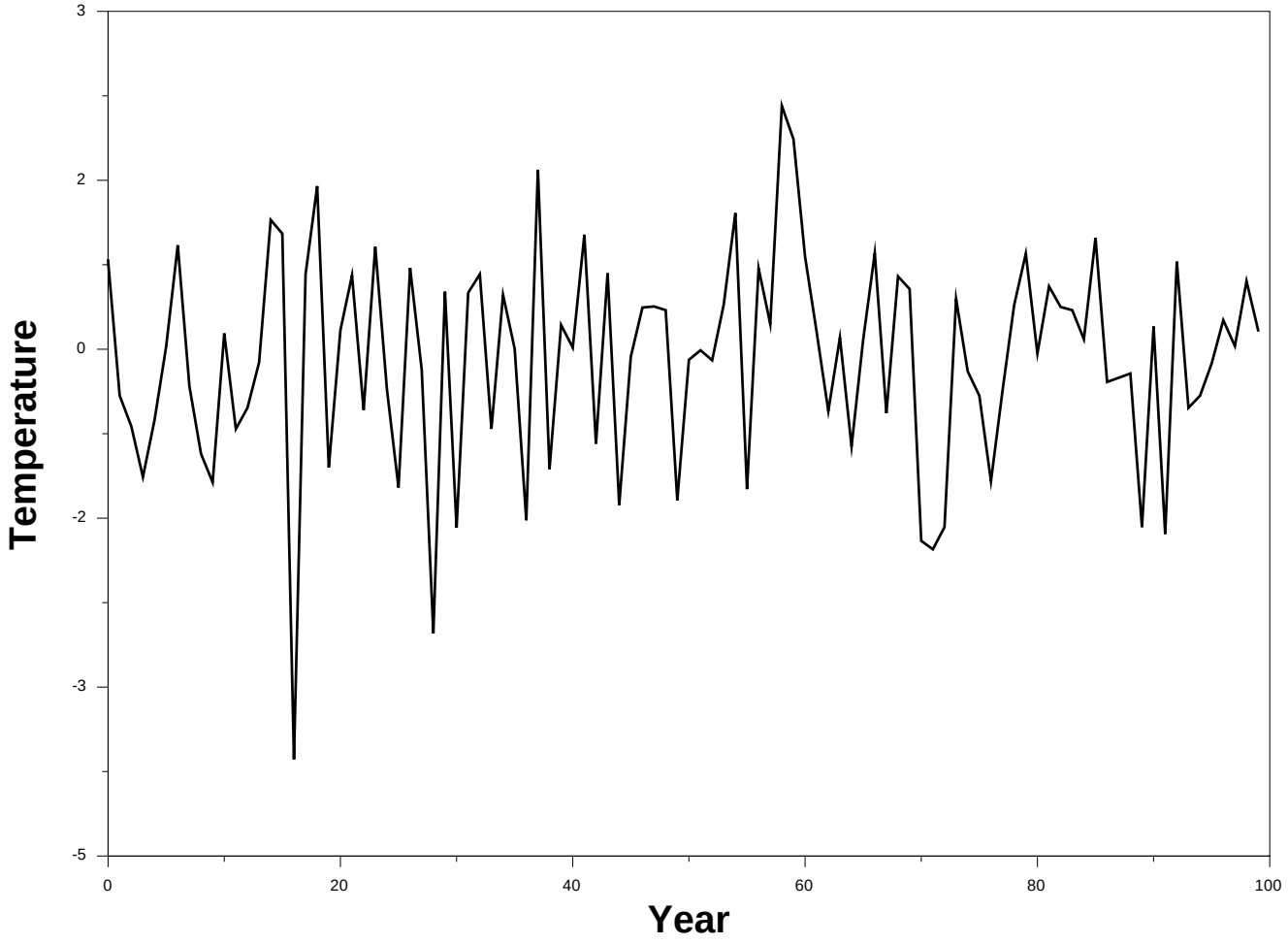
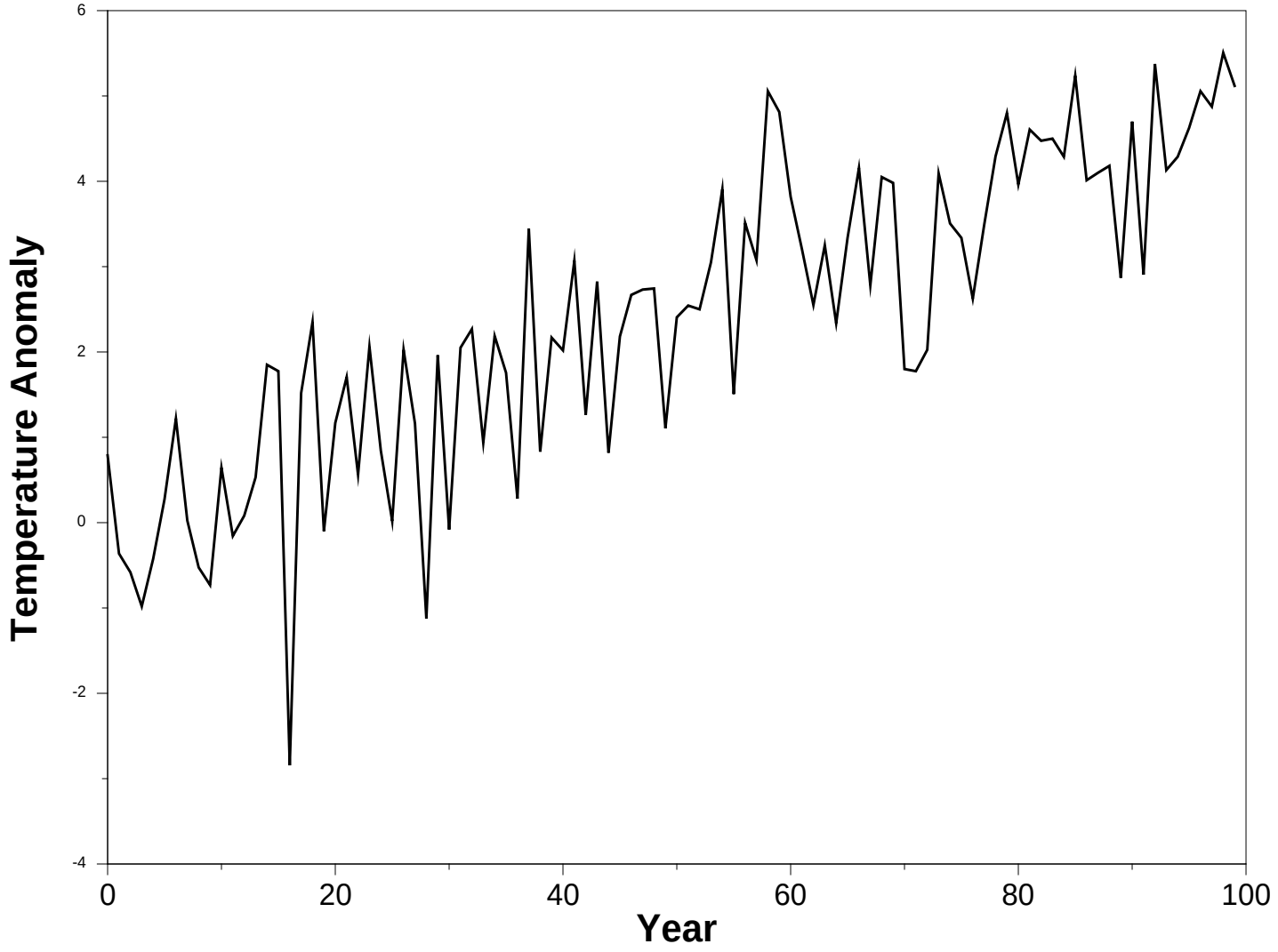
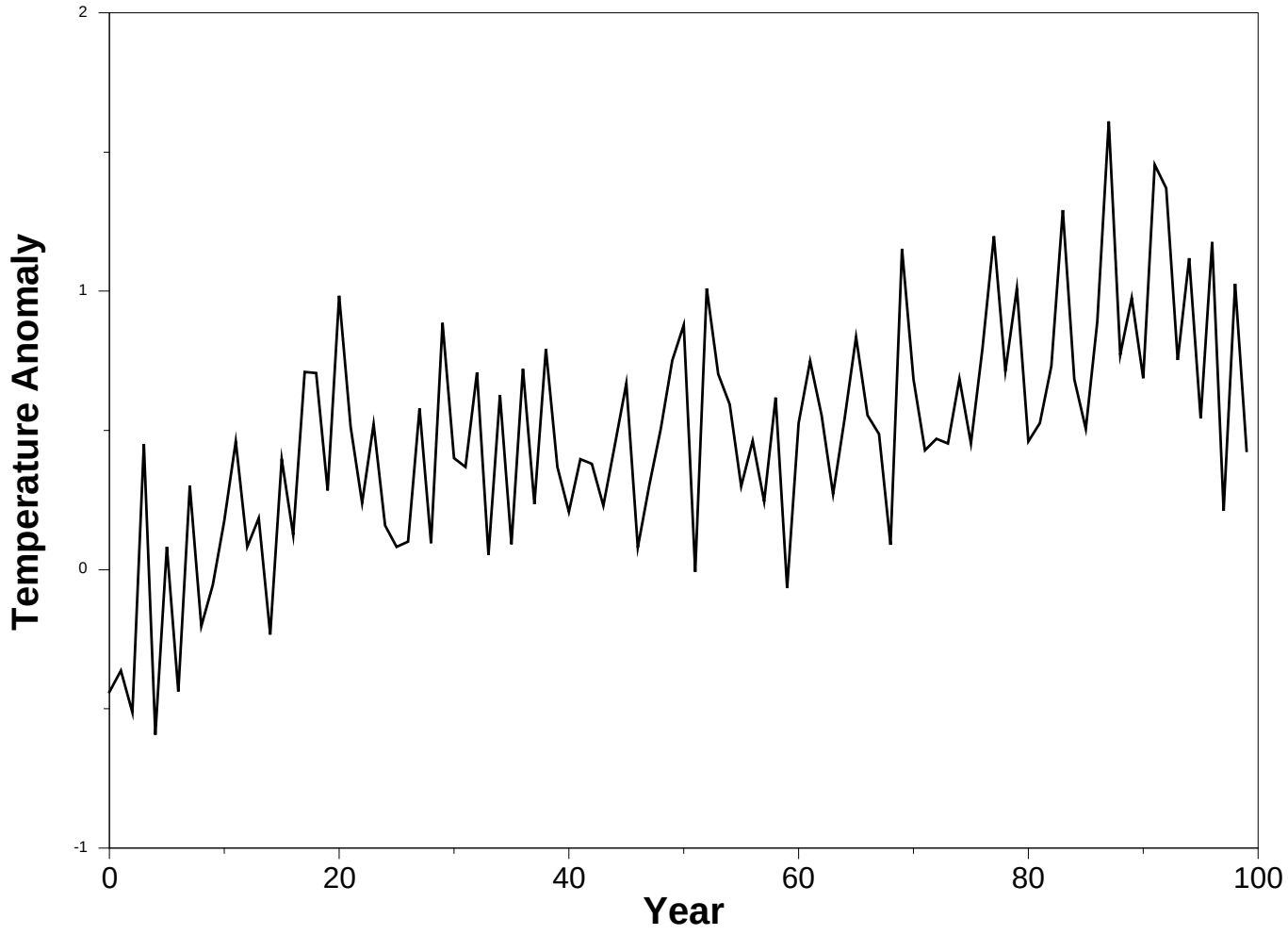


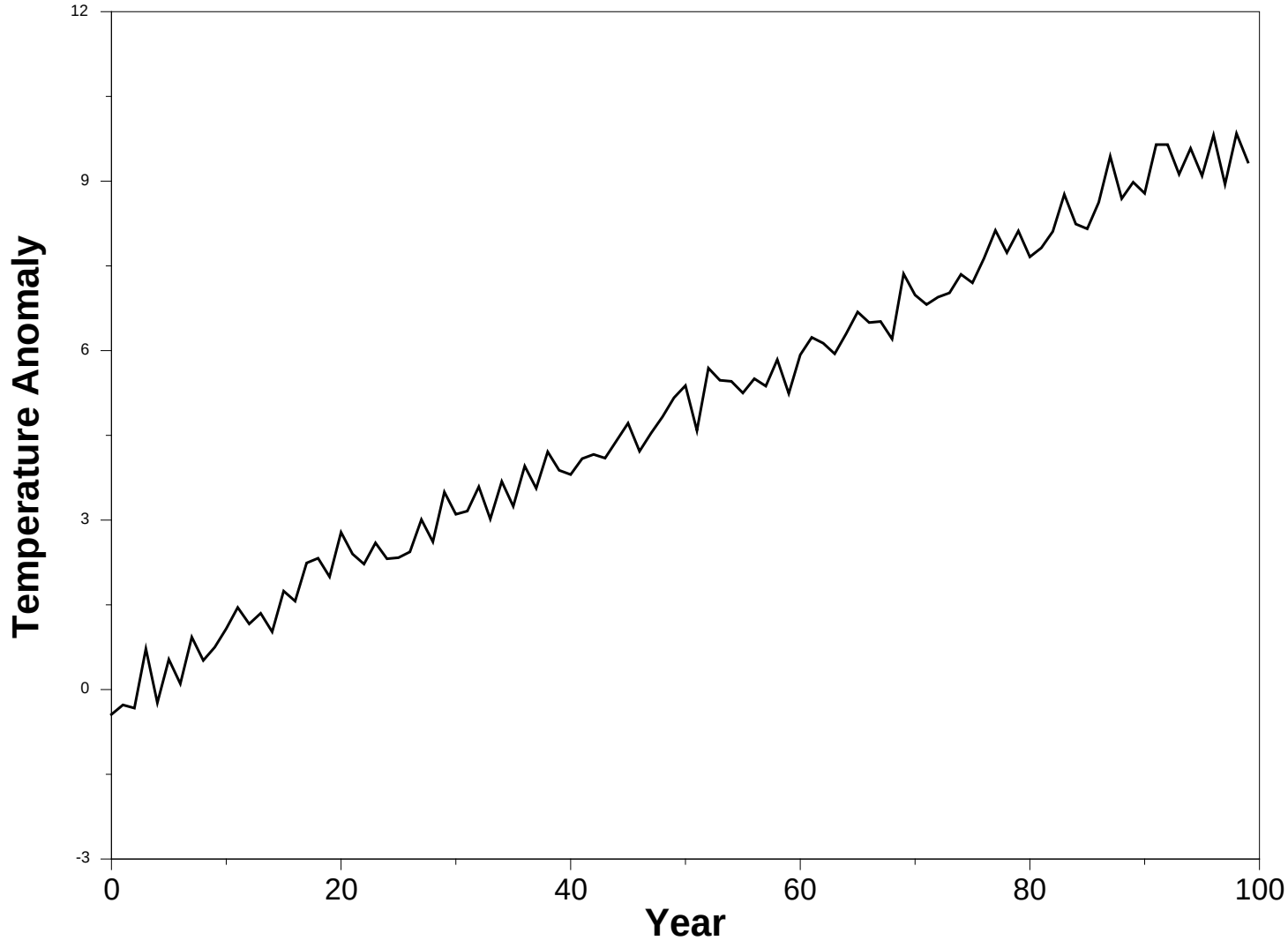
Fig. 3. Rising trend with random fluctuations.



Weak Trend w/ Strong Fluctuations



Strong Trend with Weak Fluctuations



Signal-to-Noise Ratio

- **Signal**
  - Trend over a given time
- **Noise**
  - Average size of fluctuations
- **High Signal to Noise ratio**
  - More signal than noise
  - Trend is evident
  - In this case, trend usually has high “statistical significance”
- **Low Signal to Noise ratio**
  - More noise than signal
  - Trend is not very evident
  - In this case, trend usually has low “statistical significance”

Length of Record

- If trend persists, signal-to-noise ratio increases with time

$\Rightarrow$ eventually, trend will be detected

Example follows …

Fig. 11. Signal + Noise After 20 Years.

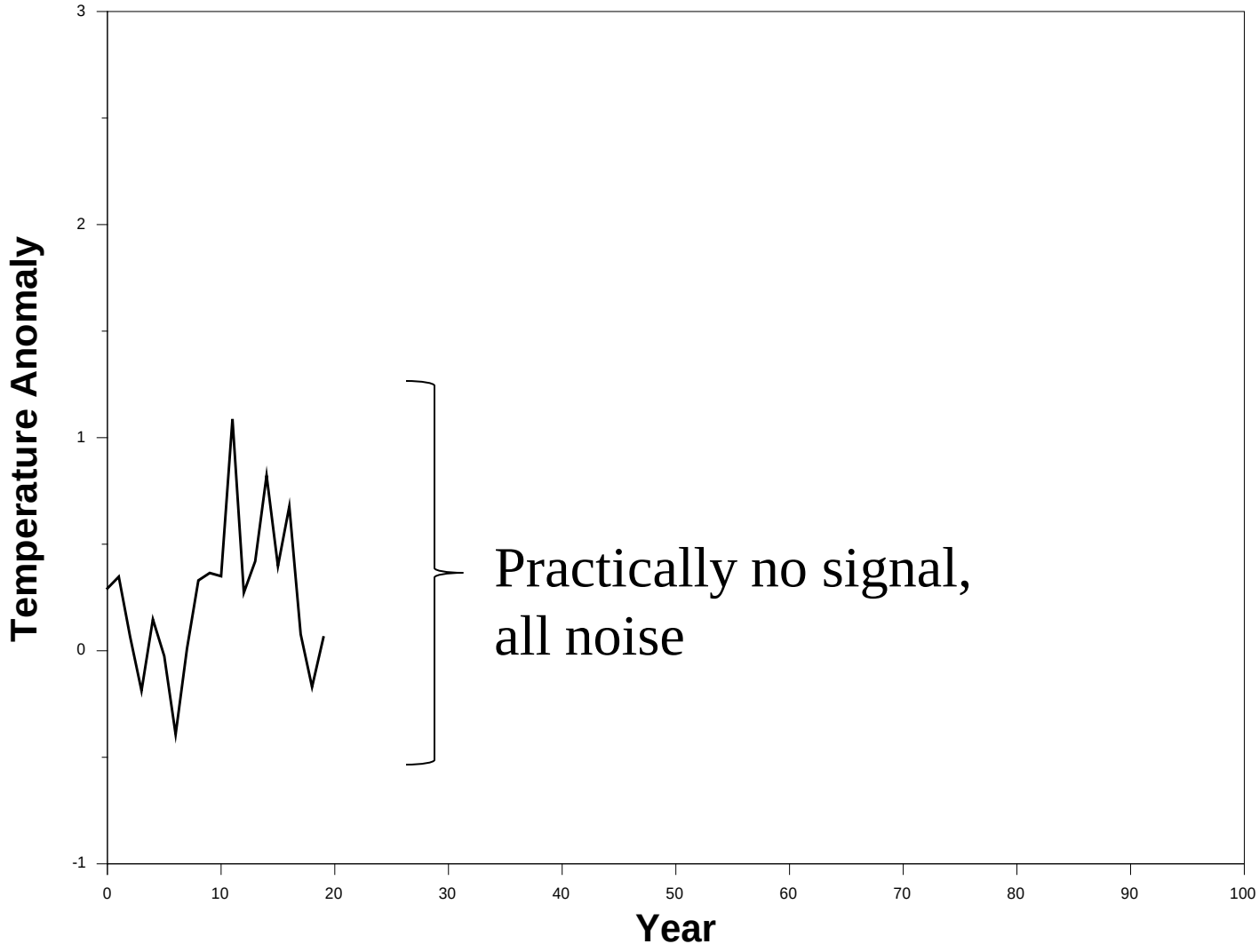


Fig. 12. Signal + Noise After 40 Years.

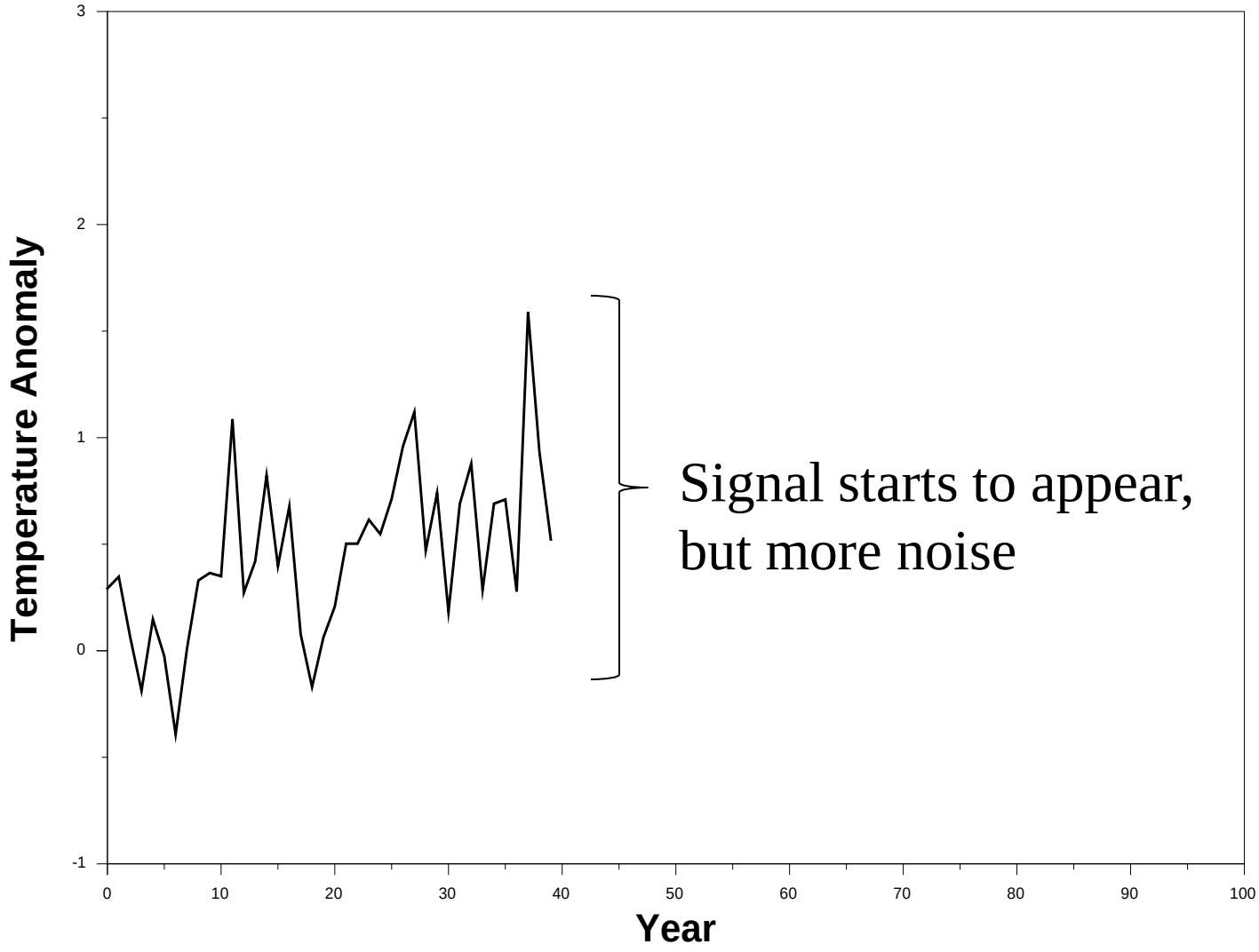


Fig. 13. Signal + Noise After 60 Years.

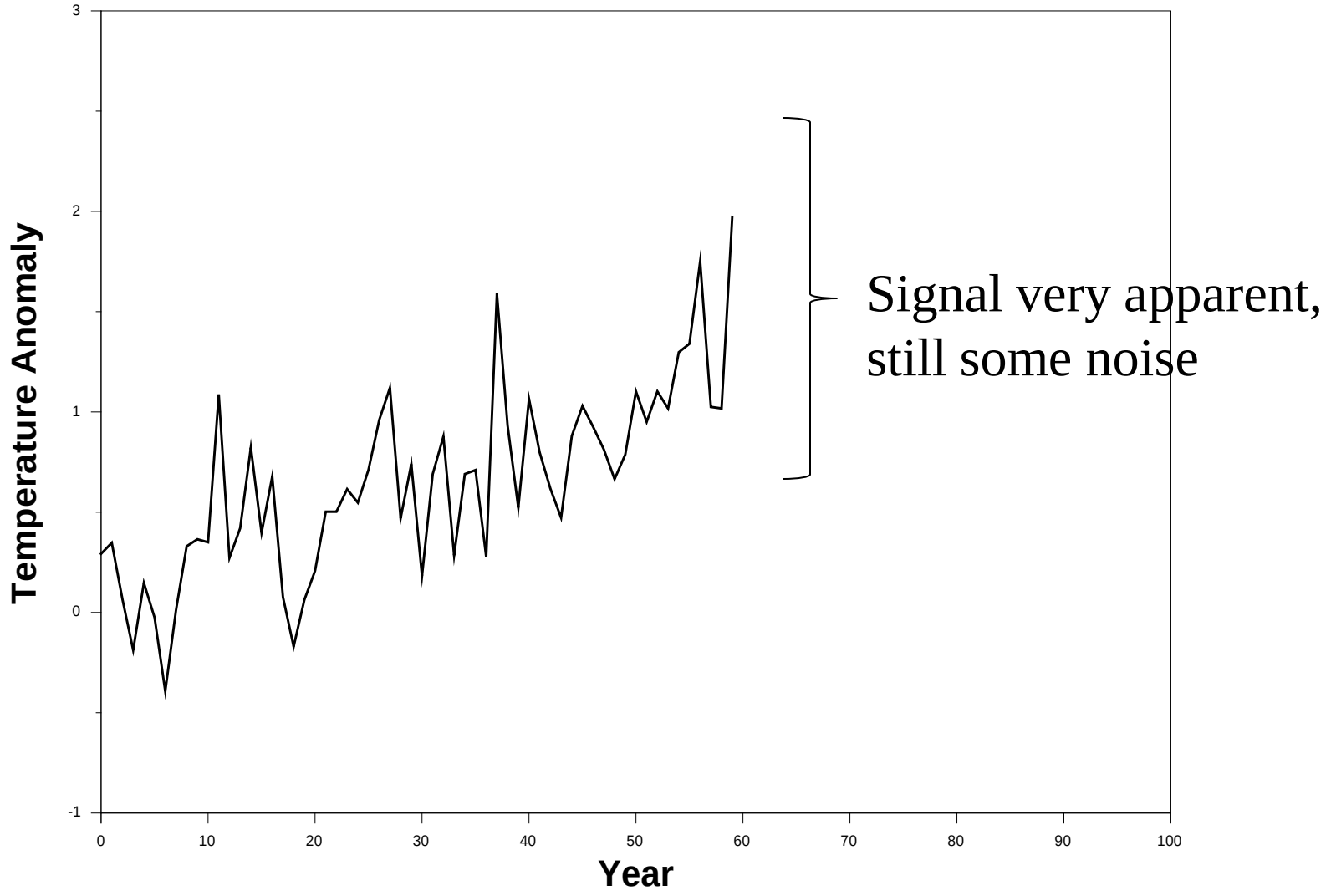


Fig. 14. Signal + Noise After 80 Years.

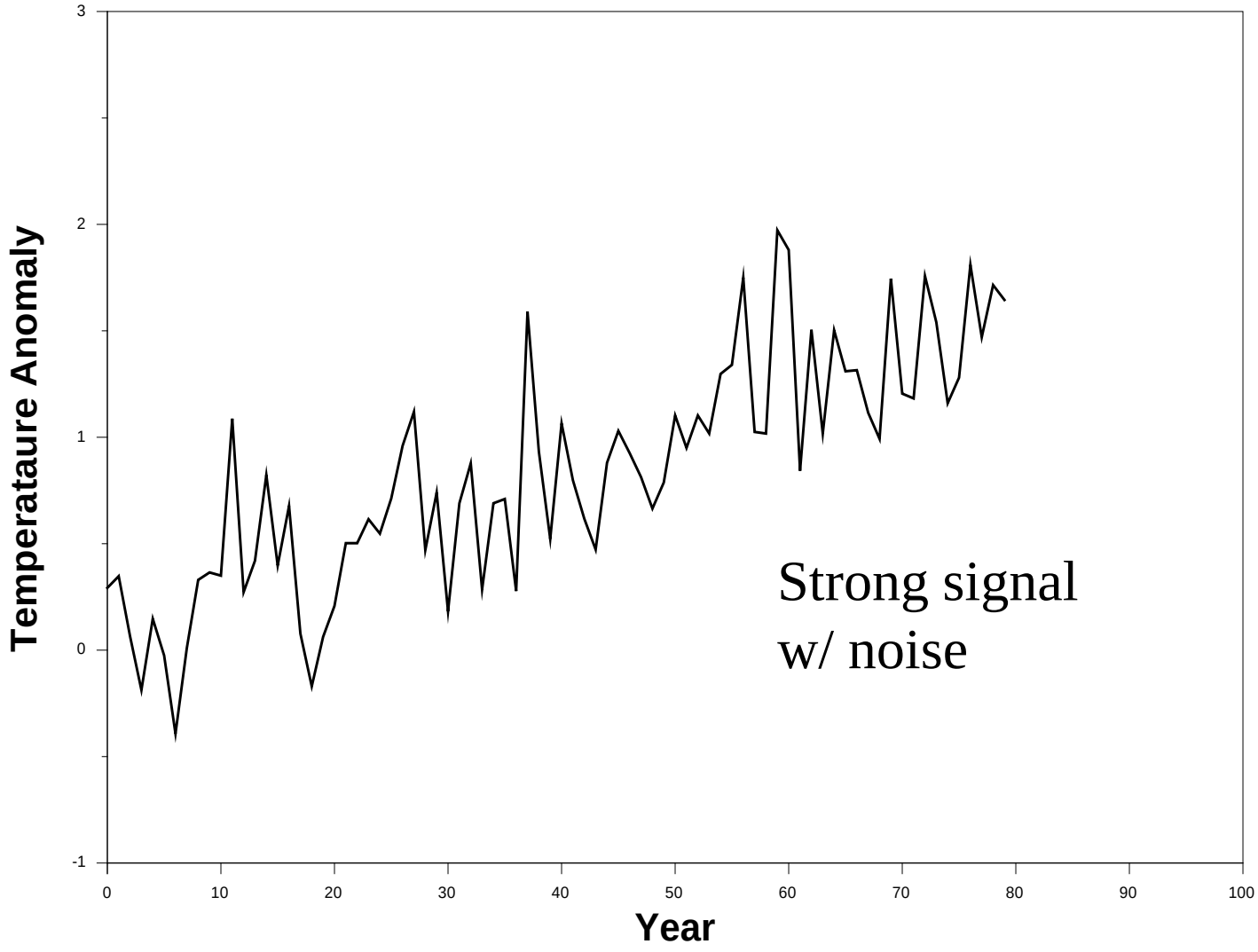
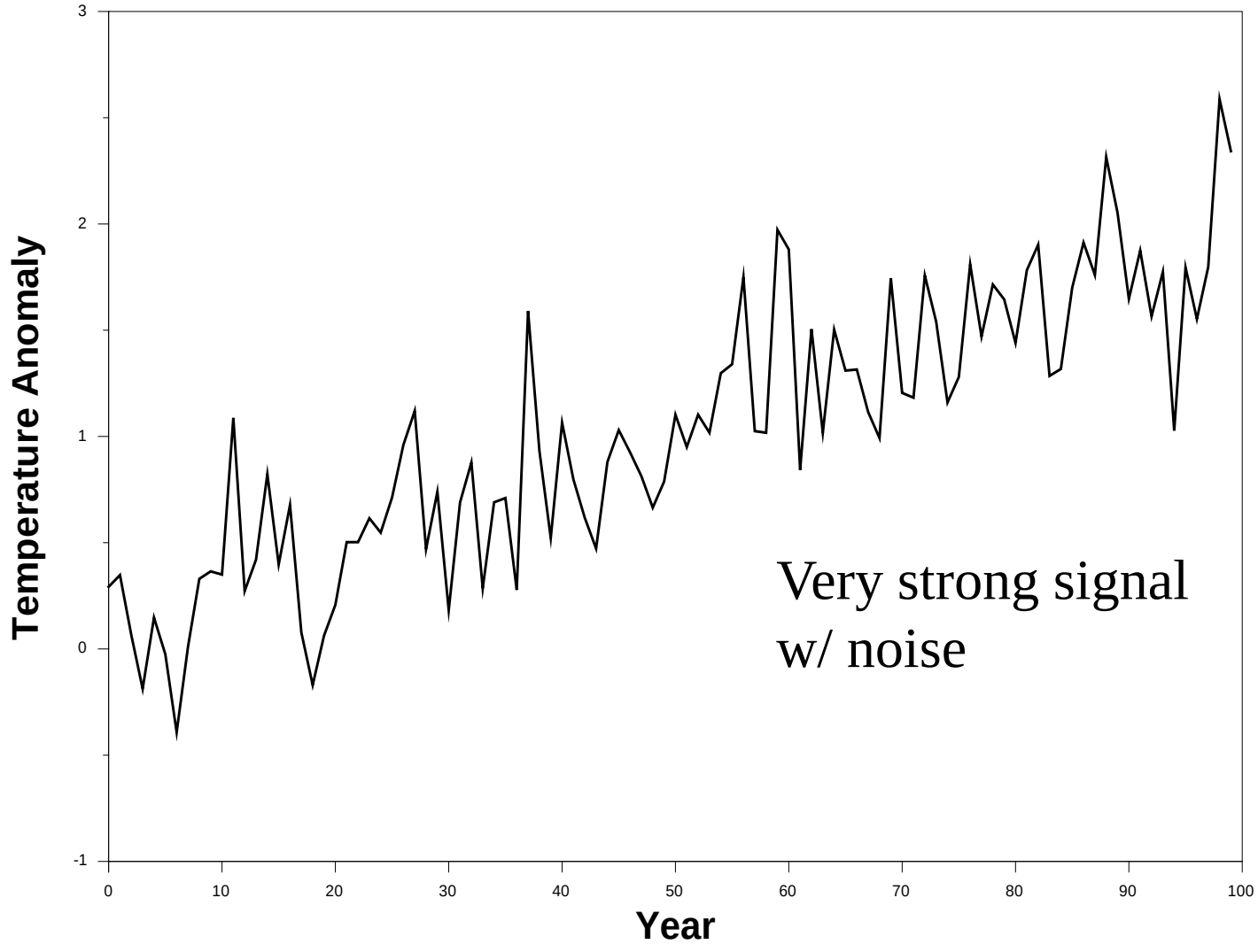


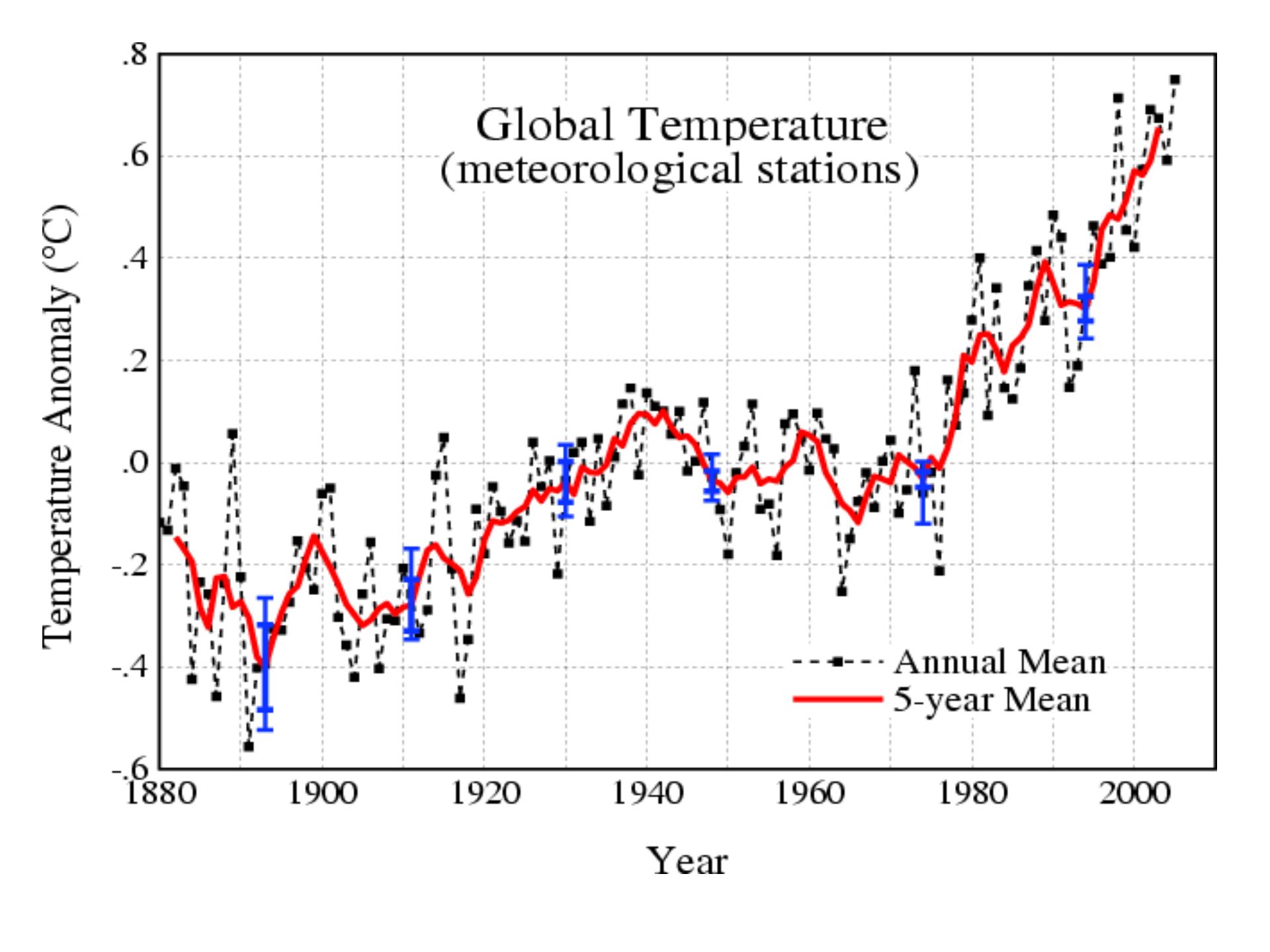
Fig. 15. Signal + Noise After 100 Years.



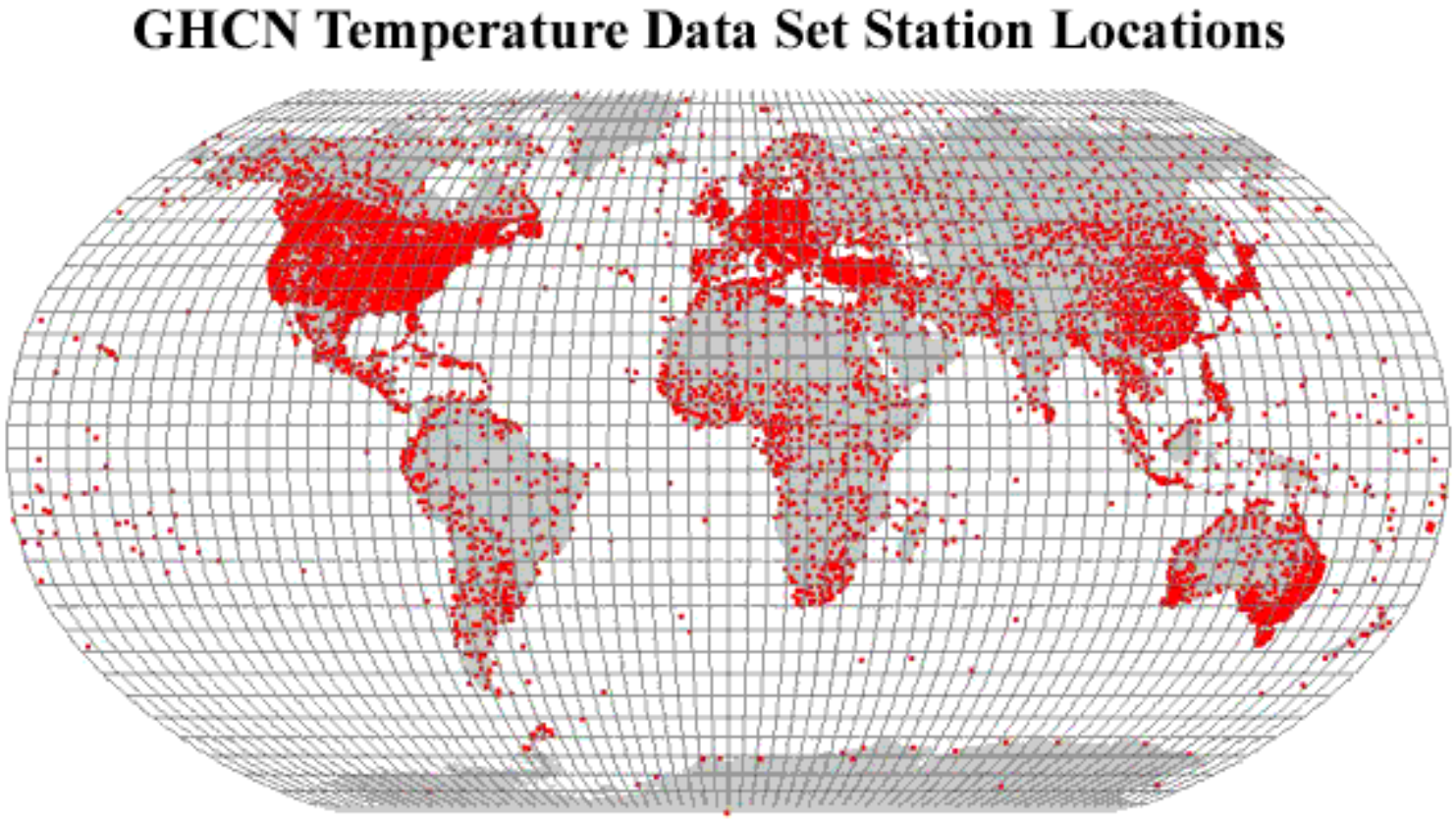
Main Point

- Earth climate record is generally noisy.
  - i.e., there are seemingly random fluctuations
  - Not all of these fluctuations can be explained
- Any trend takes time to become apparent.
- Generally need to look at evolution over several decades to see climate trends.

Observations of Warming
(Global Temperature the Last 100+ Years)


Global Temperature
(meteorological stations)
Temperature Anomaly (°C)
.8
.6
.4
.2
.0
-.2
-.4
-.6
1880
1900
1920
1940
1960
1980
2000
Year
Annual Mean
5-year Mean

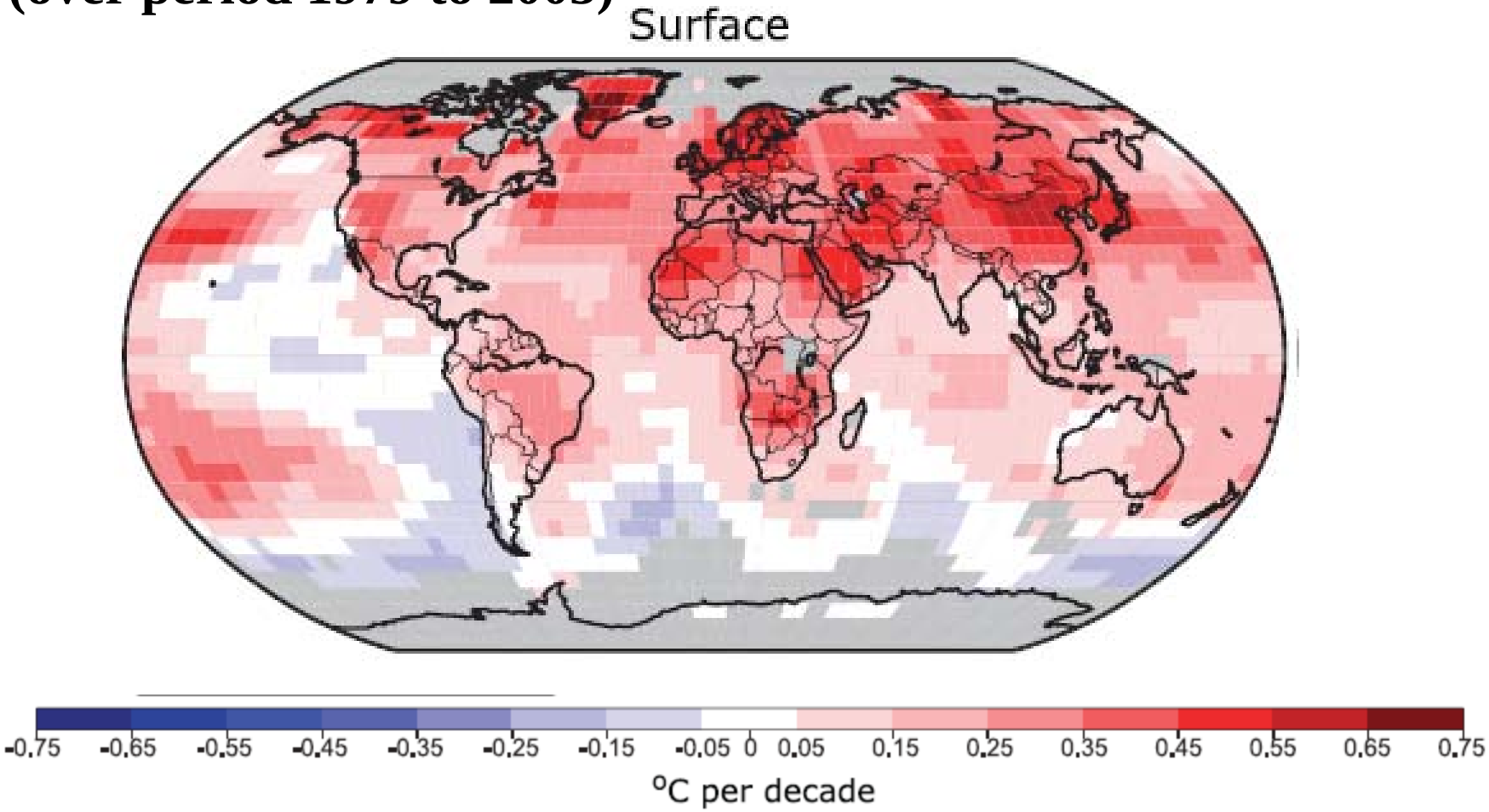
Global Historical Climate Network



Station locations are indicated by the individual red circles that are superimposed on top of the 5° latitude by 5° longitude grid boxes to which they belong.

http://www.ncdc.noaa.gov/oa/climate/ghcn monthly/index.php

Spatial Pattern: Rate of Surface Temperature Change (over period 1979 to 2005)

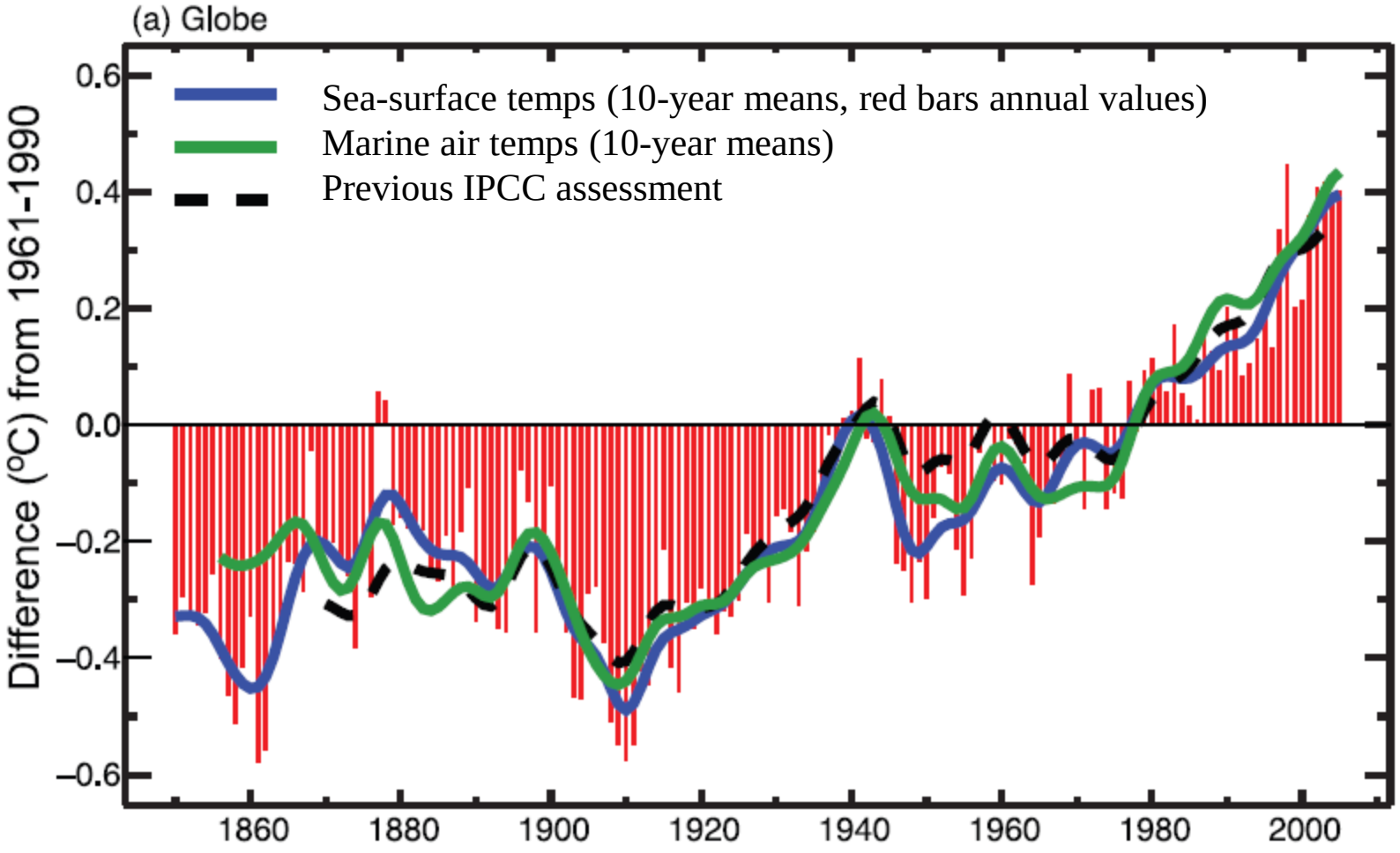


http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-3-1.html

Summary: Surface Temperature Record (Industrial Era, last 100+ years)

- Increase of around 1ºC over last century in global average temperature
- Higher increase in Northern Hemisphere
  - More land area in NH (land has lower heat capacity than water)
  - Snow melt, lower albedo, more sunlight
- Uncertainties in surface temperature network
  - Changes in location & method of measurement at a station over time
  - Sparse station data in certain locations (oceans & southern hemisphere)
  - Error bars on graphs indicate range of uncertainty, appears modest and decreases with time.

Sea Surface Temperatures …

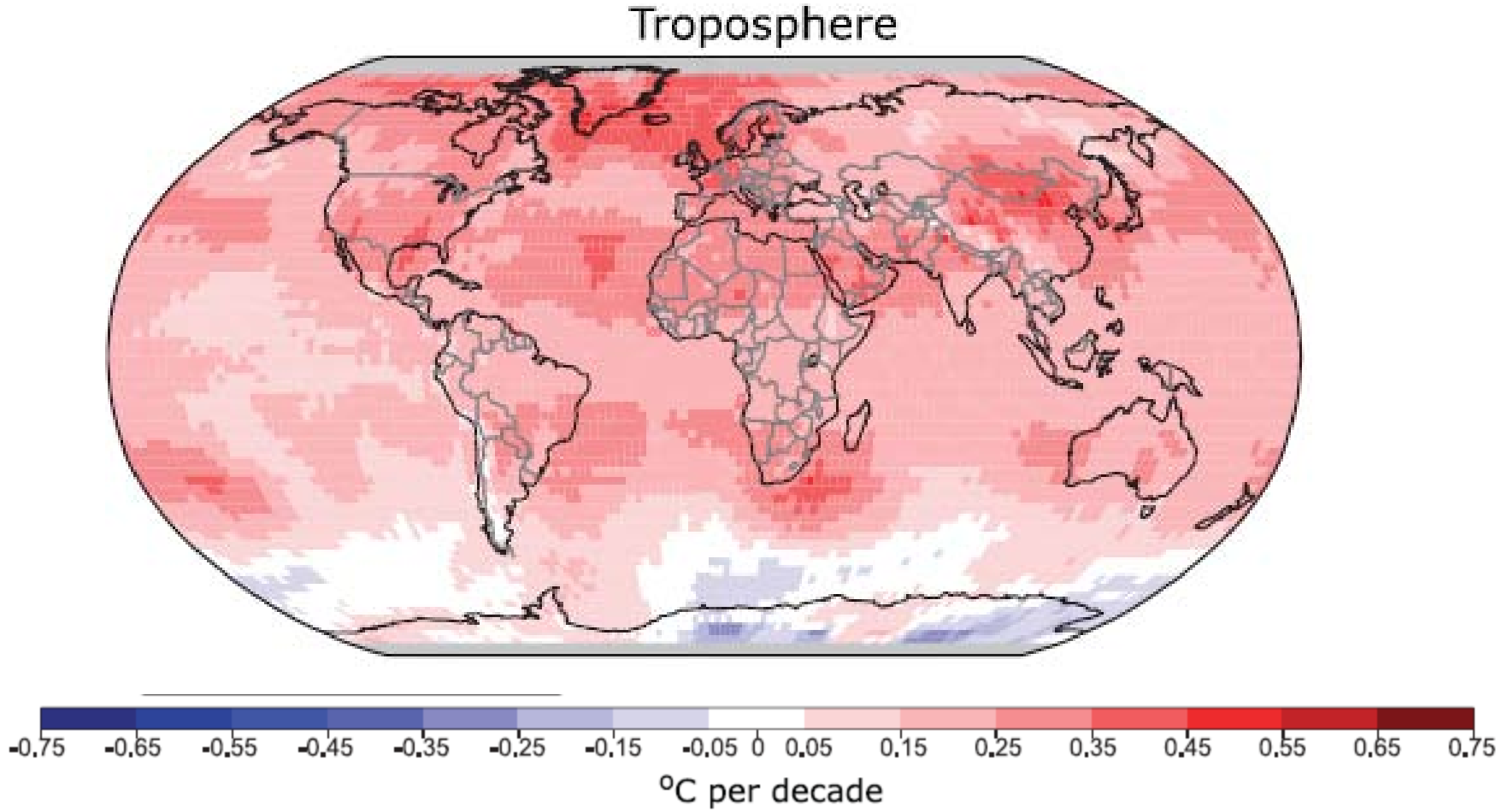


http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch3s3-2-2-3.html

Temperature Change Above Surface: (Troposphere & Stratosphere)

- Balloons
  - Also called “rawinsondes”
  - Since 1960s
- Microwave Satellites
  - Since 1980s
  - Advantage: Uniform global coverage

Spatial Pattern: Rate of Tropospheric Temp. Change (1979 to 2005, determined from balloons and satellites)



http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-3-1.html

Other Signs of Warming …

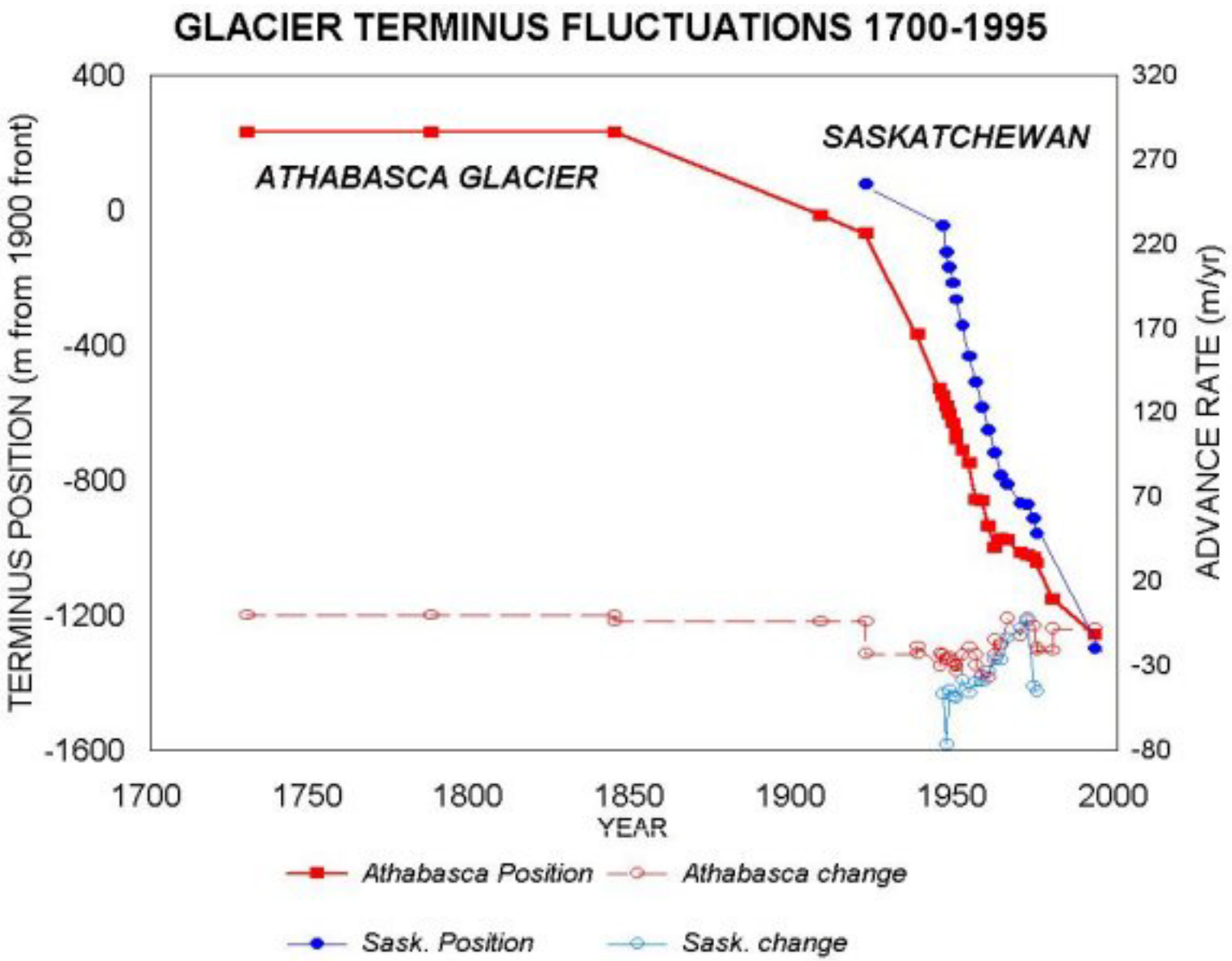
Ice and Snow

- Shrinking of mountain glaciers
- Reduced area and volume of arctic sea ice
- Increased melting of Greenland ice sheet
- Rapid melting on Antarctic Peninsula

Athabasca Glacier – Recent Photo

Previous Positions

1890 Position


GLACIER TERMINUS FLUCTUATIONS 1700-1995
ATHABASCA GLACIER
SASKATCHEWAN
TERMINUS POSITION (m from 1900 front)
ADVANCE RATE (m/yr)
400
0
-400
-800
-1200
-1600
320
270
220
170
120
70
20
-30
-80
1700
1750
1800
1850
1900
1950
2000
YEAR
Athabasca Position
Athabasca change
Sask. Position
Sask. change

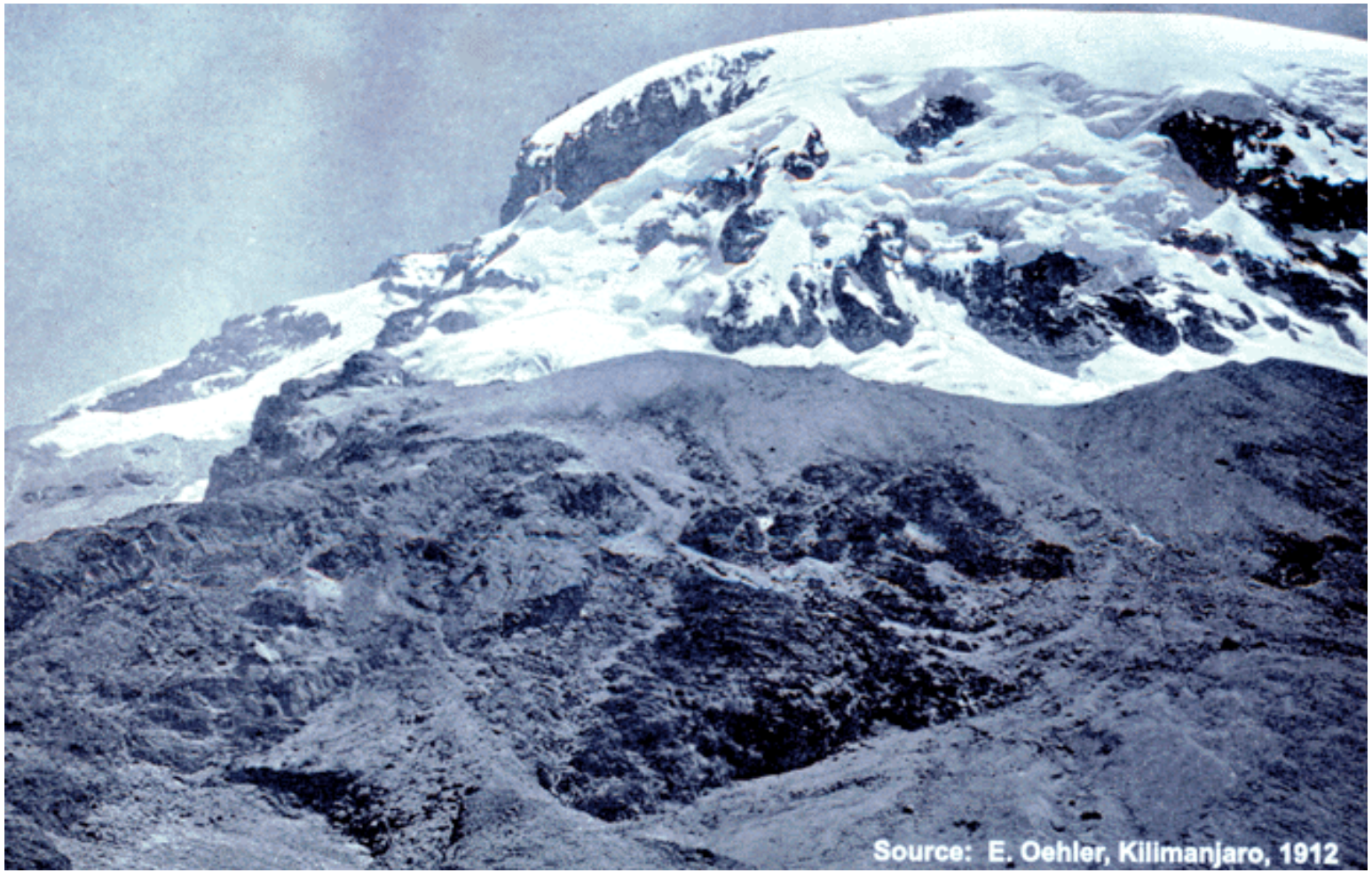
- http://www.worldviewofglobalwarming.org/pages/glaciers.html

An Alaskan Glacier

1914

2004

Mt. Kilamanjaro -- 1912

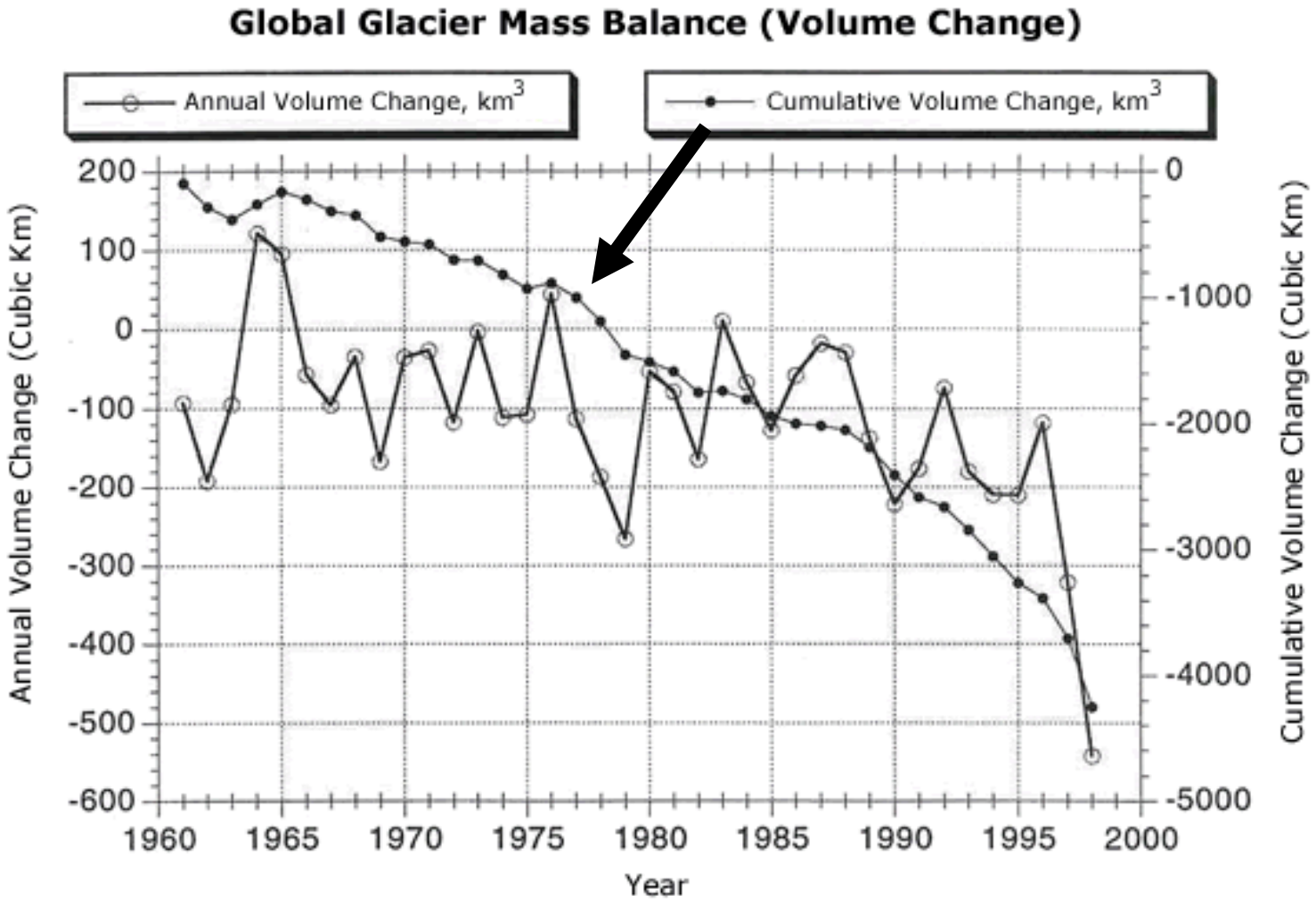


Mt. Kilamanjaro -- 2000

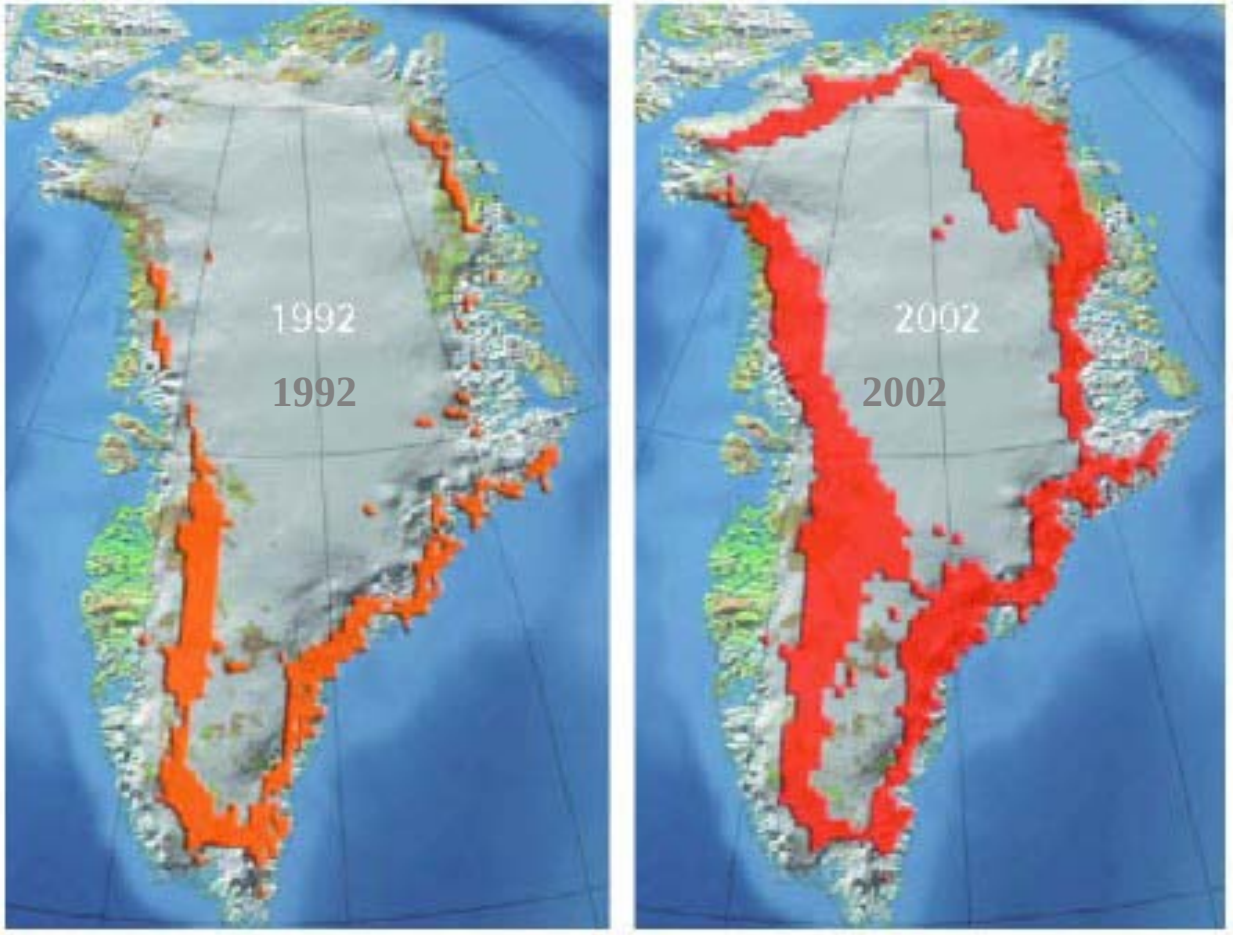
Worldwide

- http://www.climatehotmap.org/

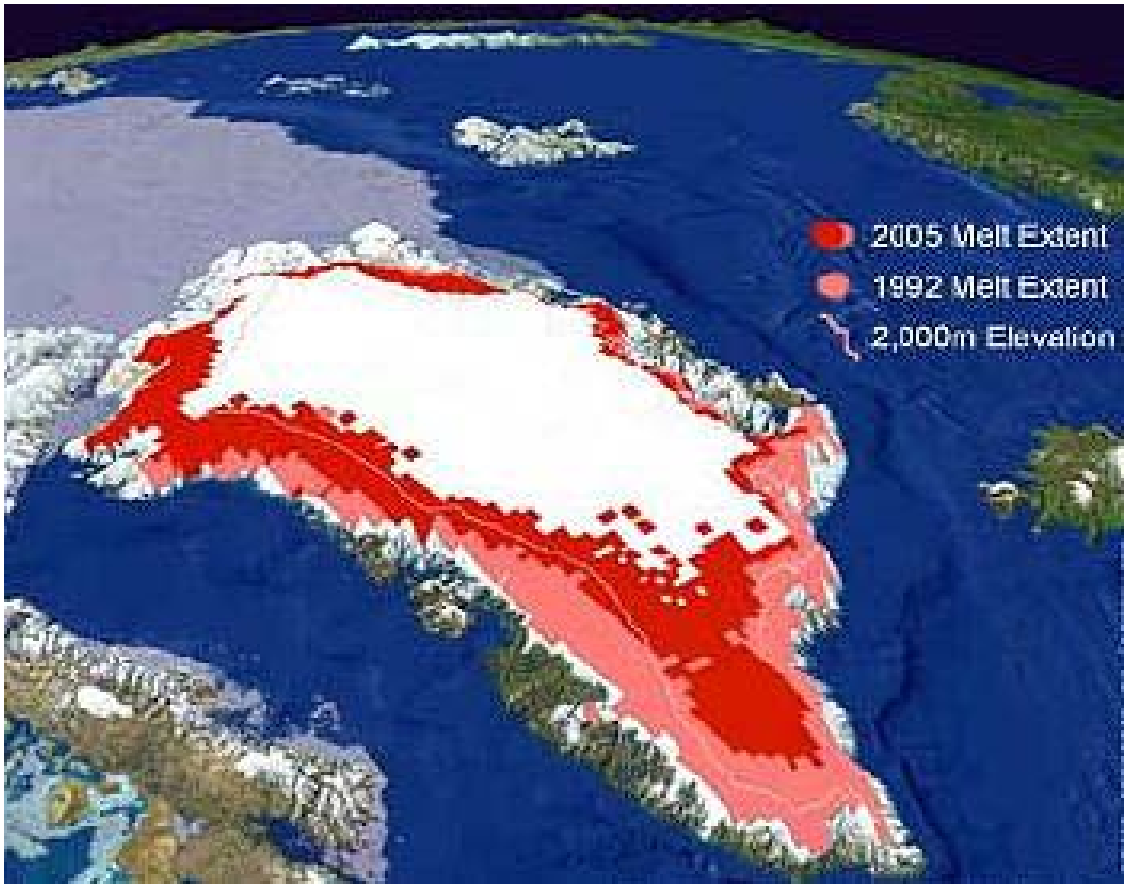
Global Loss of Ice: Mountain Glaciers



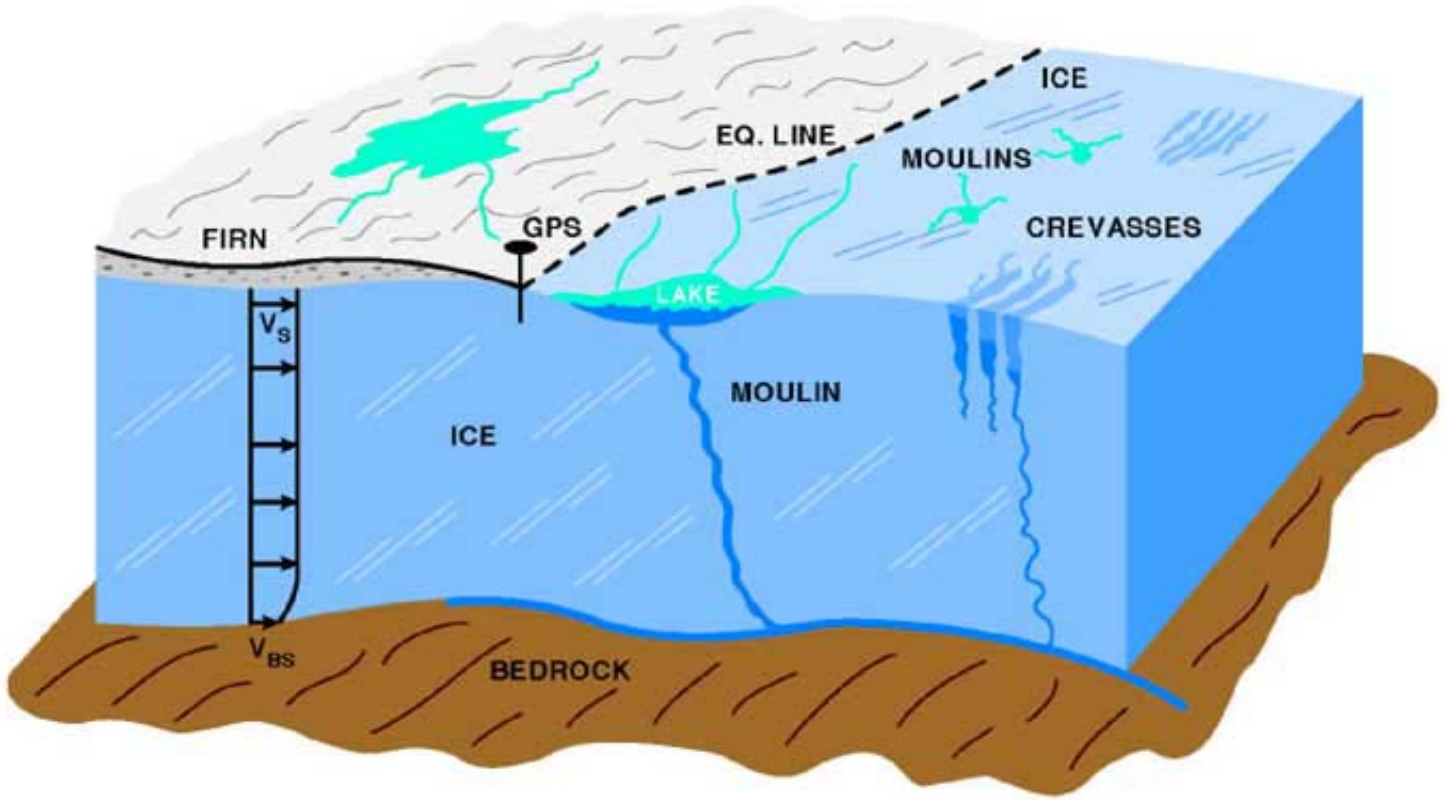
Increased Summer Melting of Greenland Ice Sheet



Update



Moulin Schematic



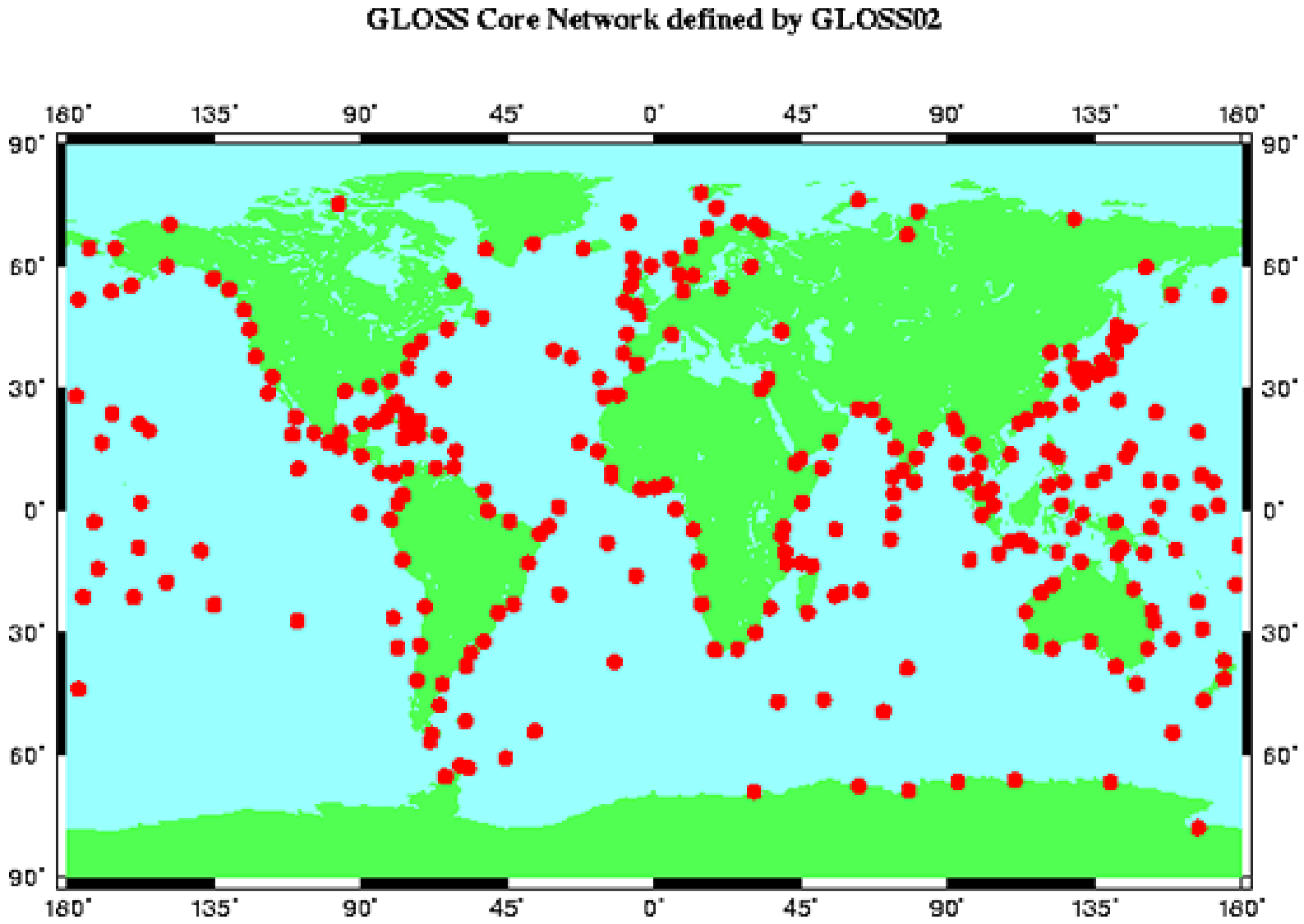
http://en.wikipedia.org/wiki/Moulin_(geology)

A “Moulin”

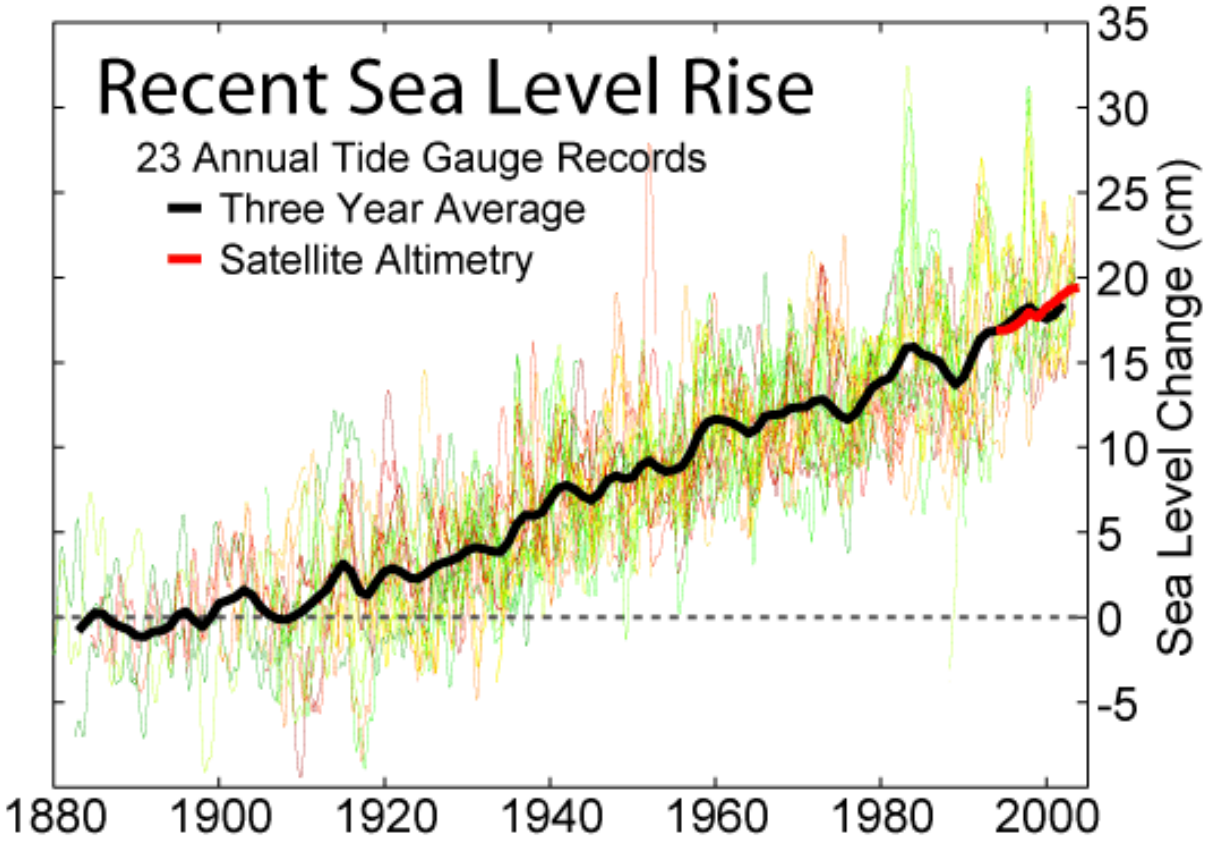
- A tunnel through which melt water flows to the bottom
- Provides lubrication between ice sheet and bedrock, facilitating movement into sea.
- More surface melting, more lubrication, easier movement offshore.

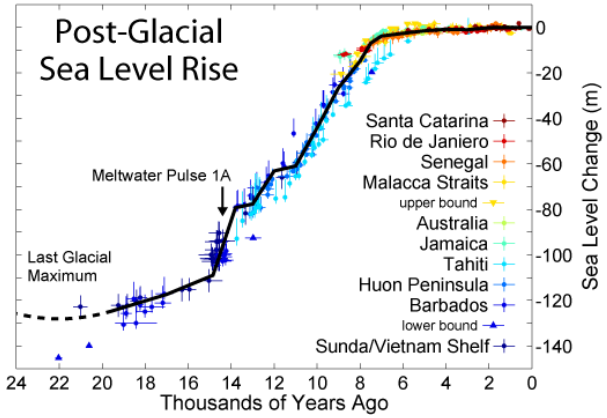
Rising Sea Level

- Two main reasons
- **Reason 1**: Thermal expansion of sea water as sea-surface temperature rises
- **Reason 2**: Melting/Break-up of land ice (snow, ice sheets & glaciers) and resulting flow to sea.
- **Note**: Melting of sea ice or ice shelves does not cause sea-level rise since these are already in the sea



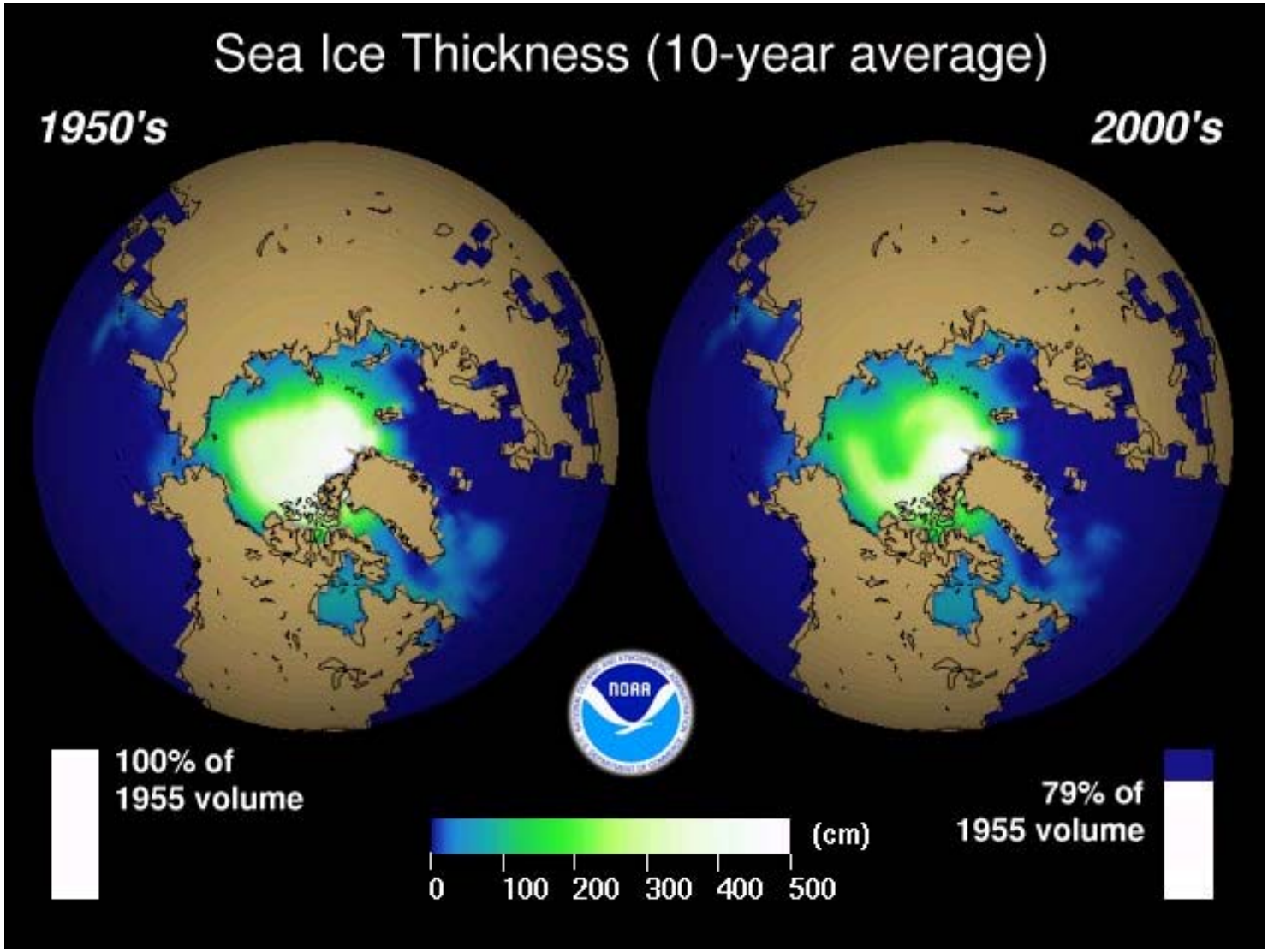
Global Sea-Level Observing System (GLOSS)
http://www.gloss-sealevel.org/

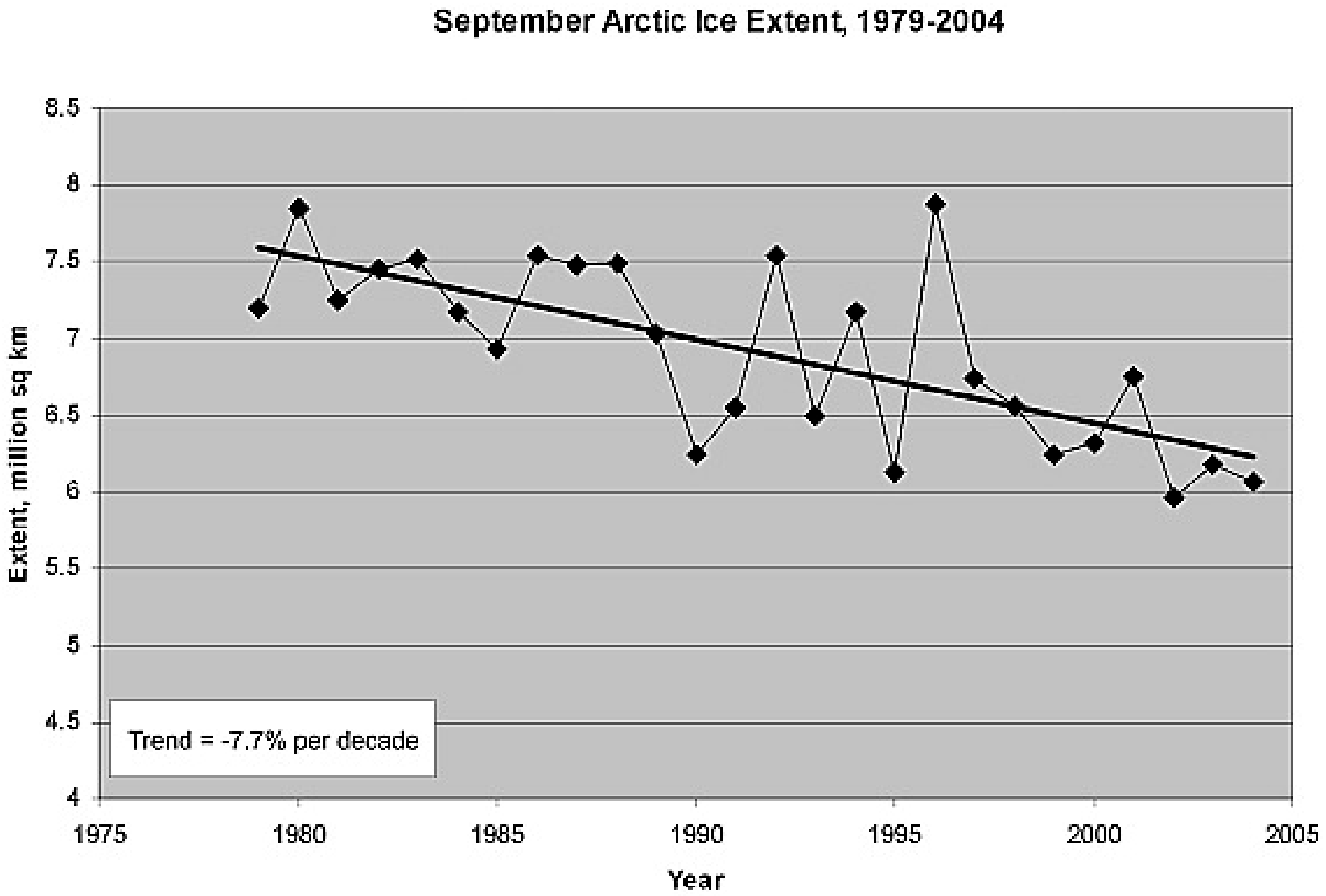




http://en.wikipedia.org/wiki/Current_sea_level_rise

Arctic Sea Ice: Last 50 years




September Arctic Ice Extent, 1979-2004
Extent, million sq km
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
1975
1980
1985
1990
1995
2000
2005
Year
Trend = -7.7% per decade

Summary

- Widespread indications of global warming last 100+ years
  - Warming Land surface temperatures
  - Warming Sea Surface Temperatures
  - Melting Land Ice (Ice Sheets, glaciers)
  - Rising Sea Level
  - Melting Sea Ice

Attributing Cause of Warming
(“Attribution”)

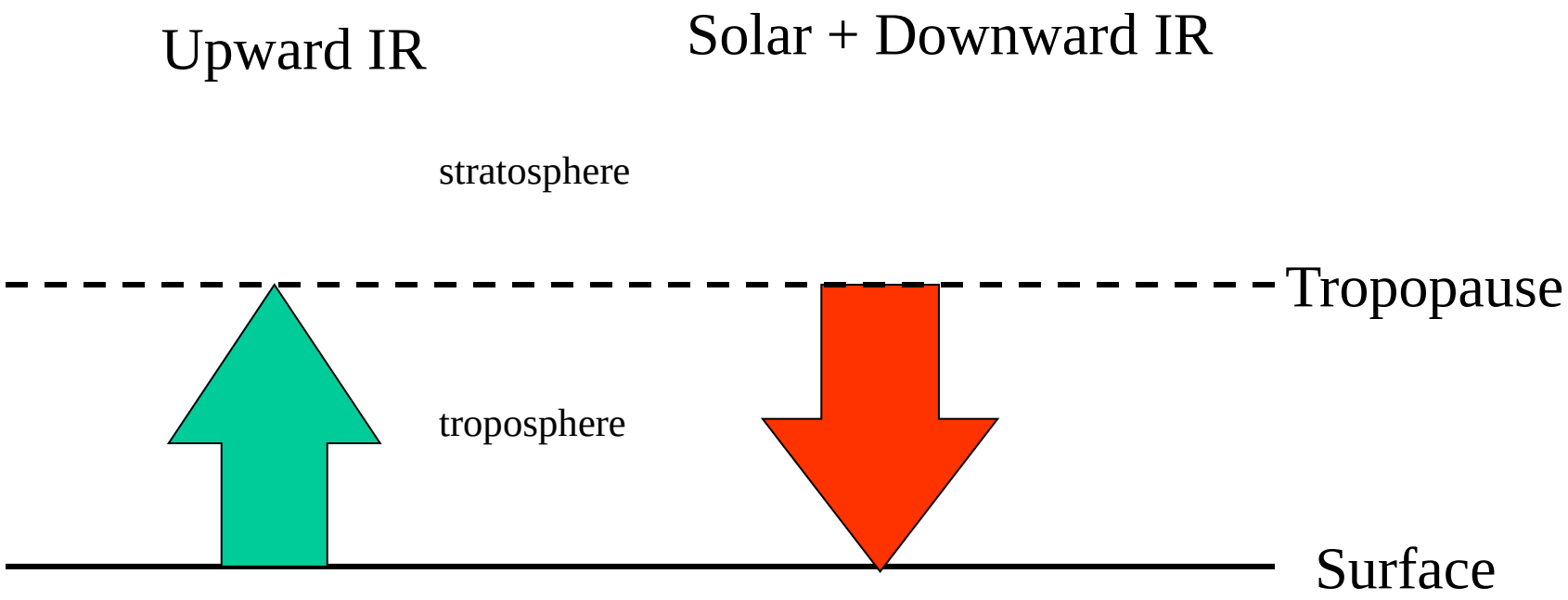
A Key Point from Previous Slides ... Global Warming is “Global”

- It is a global phenomenon, as opposed to local or regional

- Because it is global, there must be a radiative imbalance between the IR + solar radiation entering vs. IR radiation leaving the surface/troposphere system.

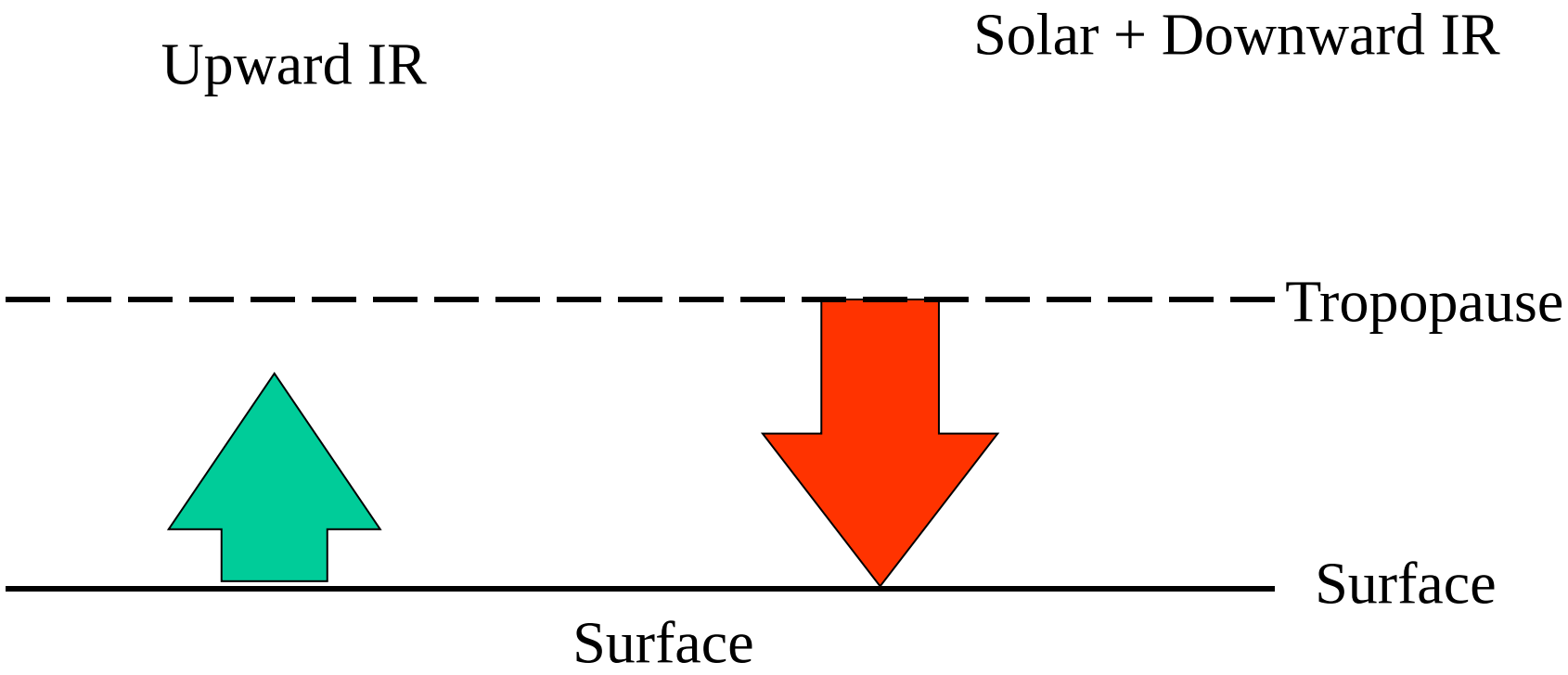
- i.e. there must be a **positive radiative forcing**

Zero Radiative Forcing



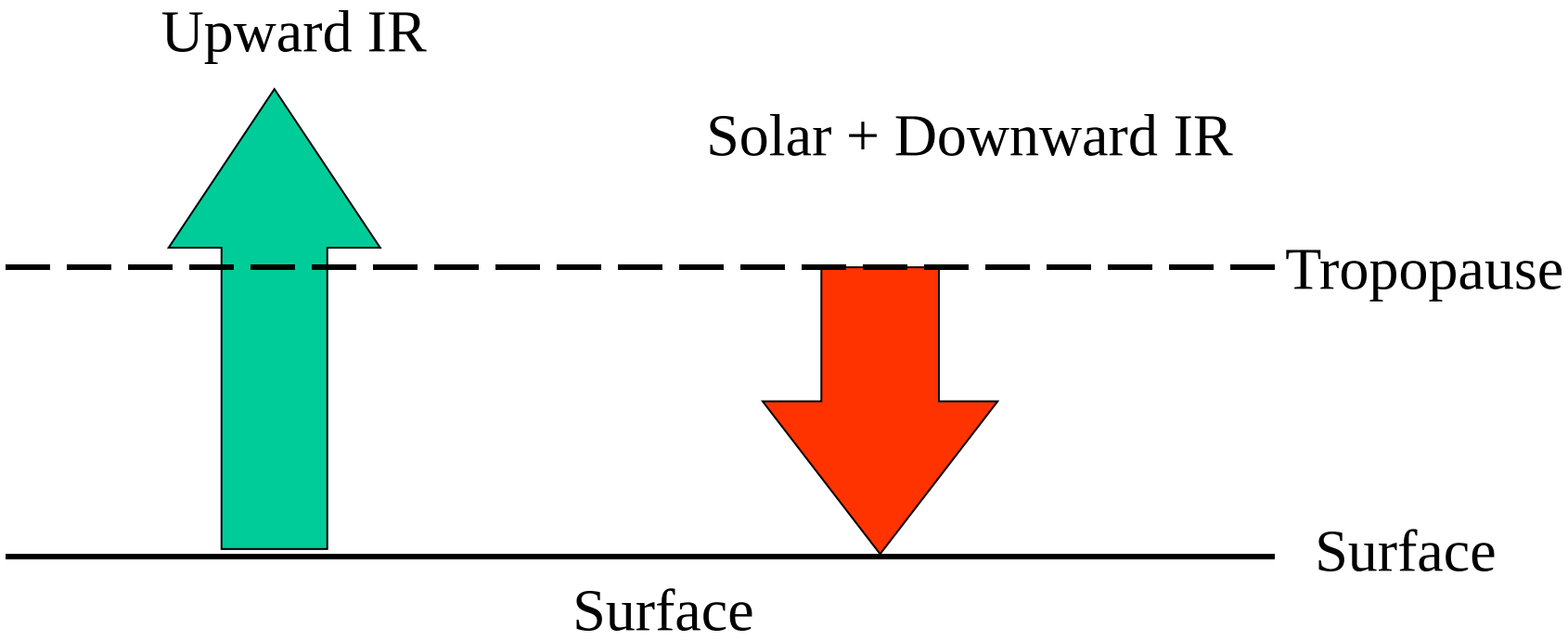
- Upward IR balances Solar + Downward IR
- No change in globally-averaged temperature
- This is the natural state of affairs, observed over “short” geologic time scales (over several decades/centuries)

Positive Radiative Forcing



- Upward IR less than Solar + Downward IR
- Increase in globally-averaged temperature in this case
- This is what has been observed last 100+ years …
- i.e. total radiative forcing last 100+ years has been positive (> 0)

Negative Radiative Forcing



- Upward IR greater than Solar + Downward IR
- Decrease in globally-averaged temperature in this case
- May result, for example, from additional aerosols in atmosphere reflecting more solar radiation back to space.

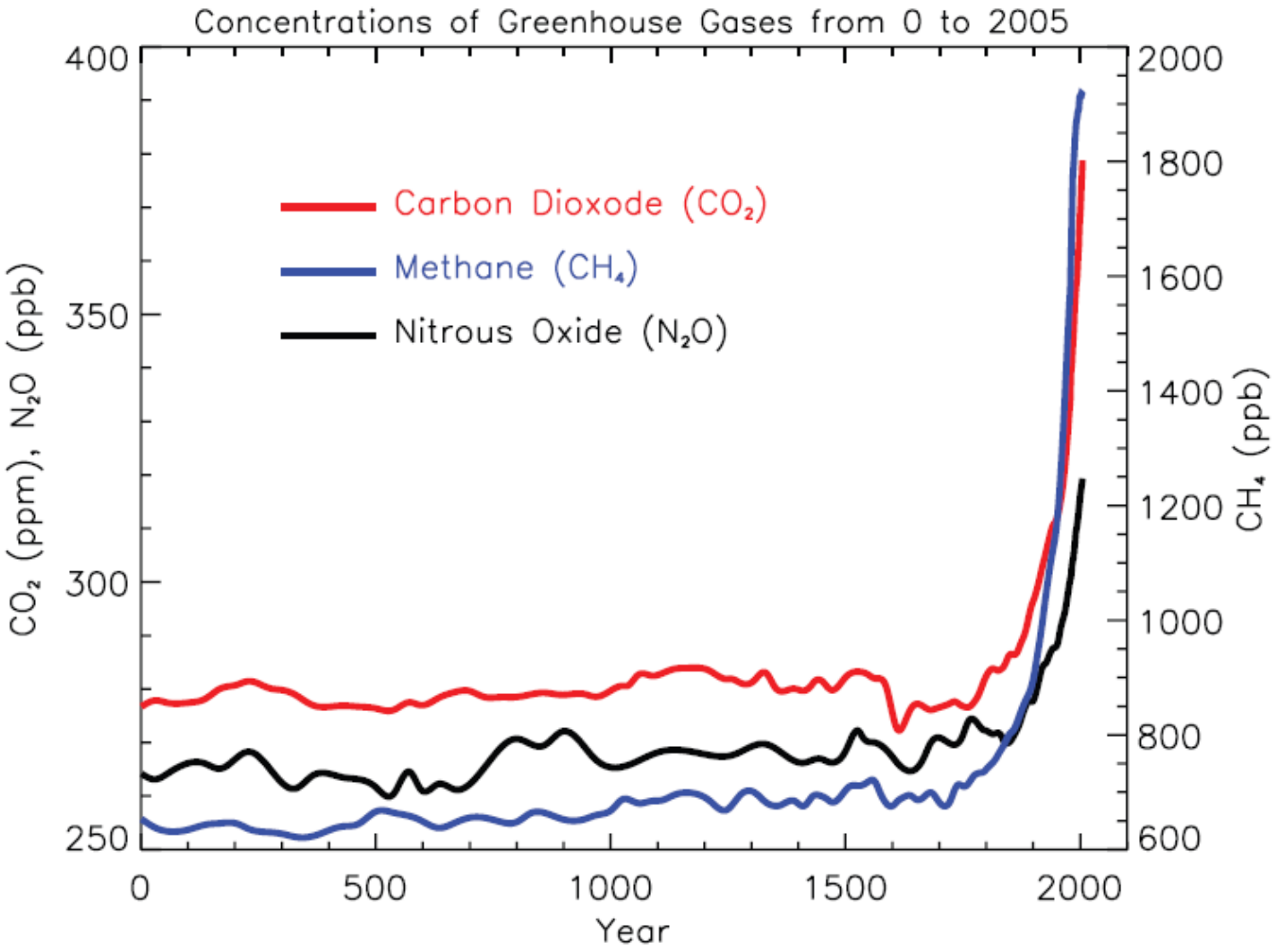
How is Concept of Radiative Forcing Used to Attribute Cause for Temperature Rise?

- Determine amount RF due to various changes that have taken place since beginning of industrial era (circa 1750)
  - Increased GHG concentrations
  - Increased particle concentrations (sulfates, black carbon, others)
  - Changes in ozone levels (tropospheric and stratospheric)
  - Land use changes
  - Solar intensity changes
  - Others ….

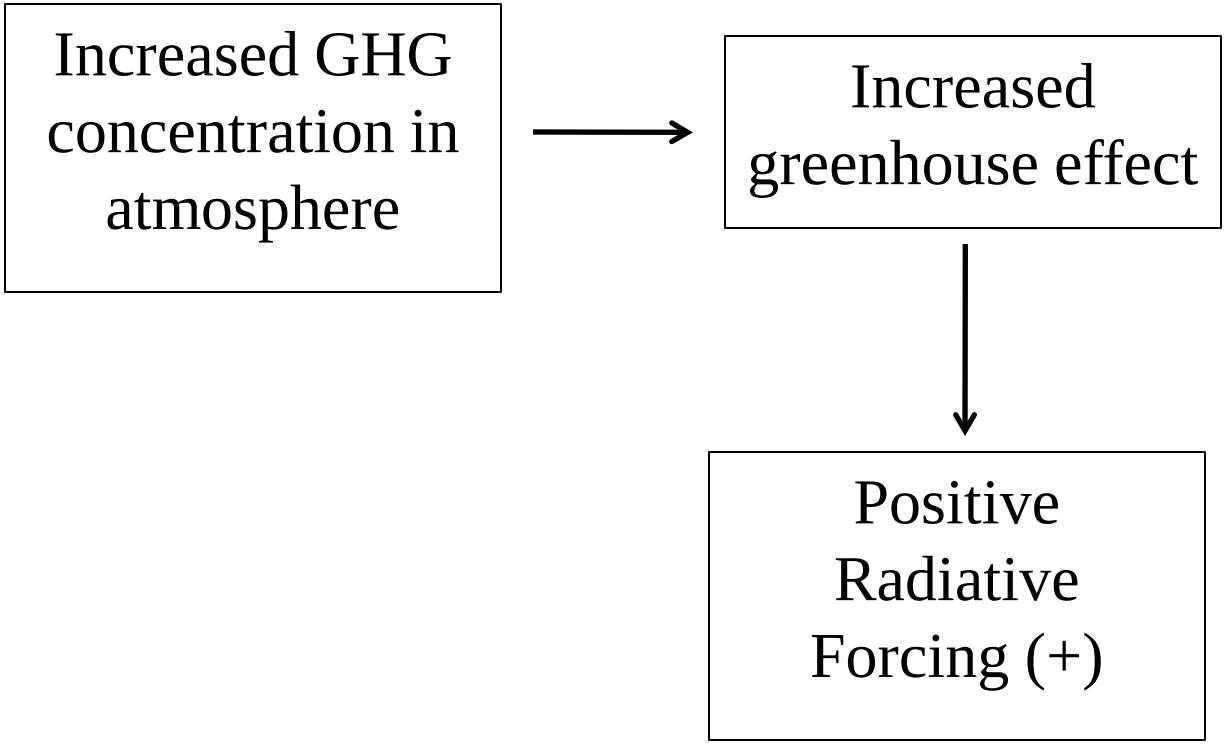
Changes since 1750:

1. Increased GHG gases

Changing GH gas concentration …



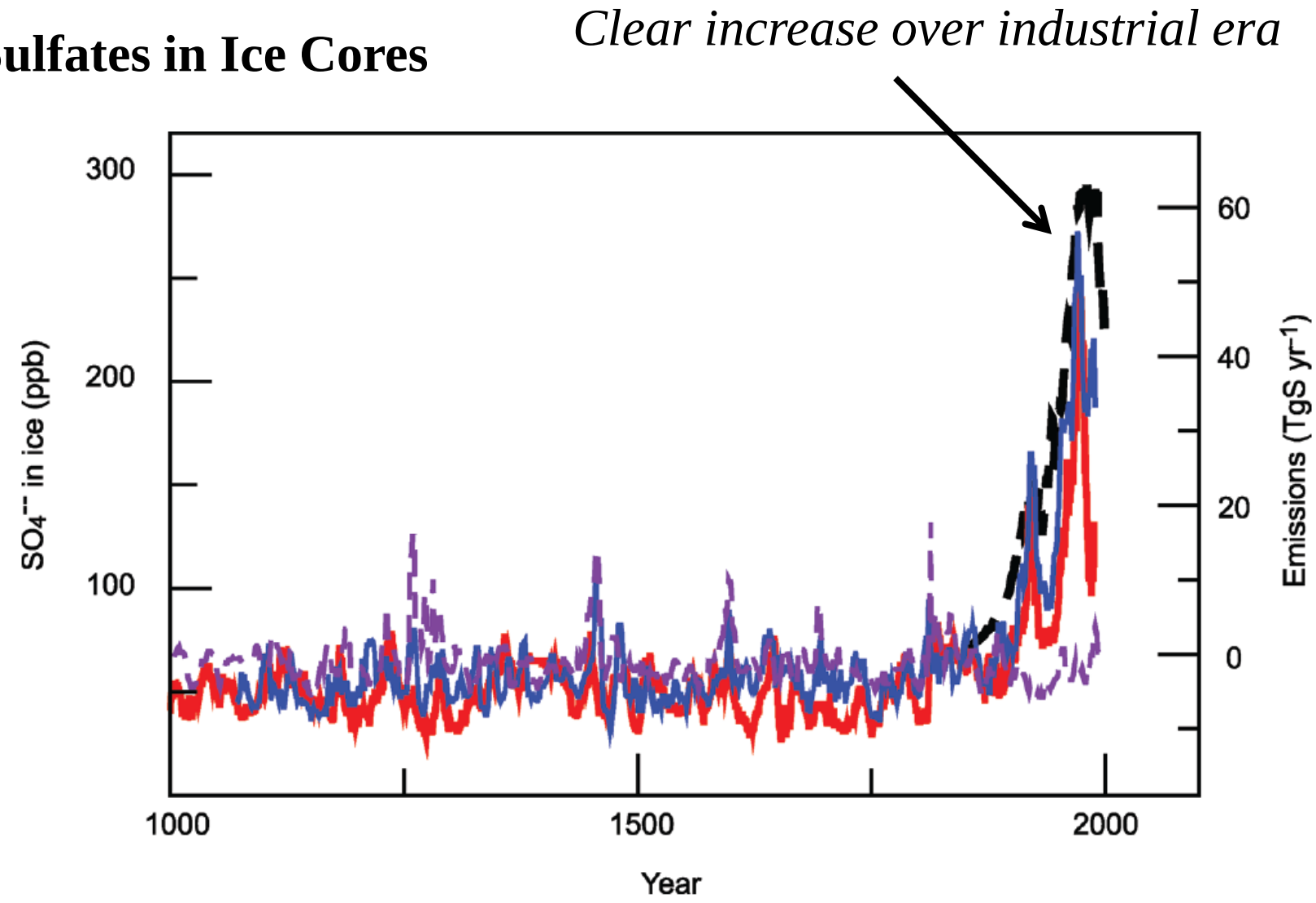
Radiative Forcing due to increase in GHG concentrations



See previous lectures for further explanation …

Changes since 1750:
2. Increased aerosol concentration

Sulfates in Ice Cores



Purple, Red: Sulfate concentration measurements in ice (ppb)
Black: Emissions (Tg Sulfur per year)

Black Carbon

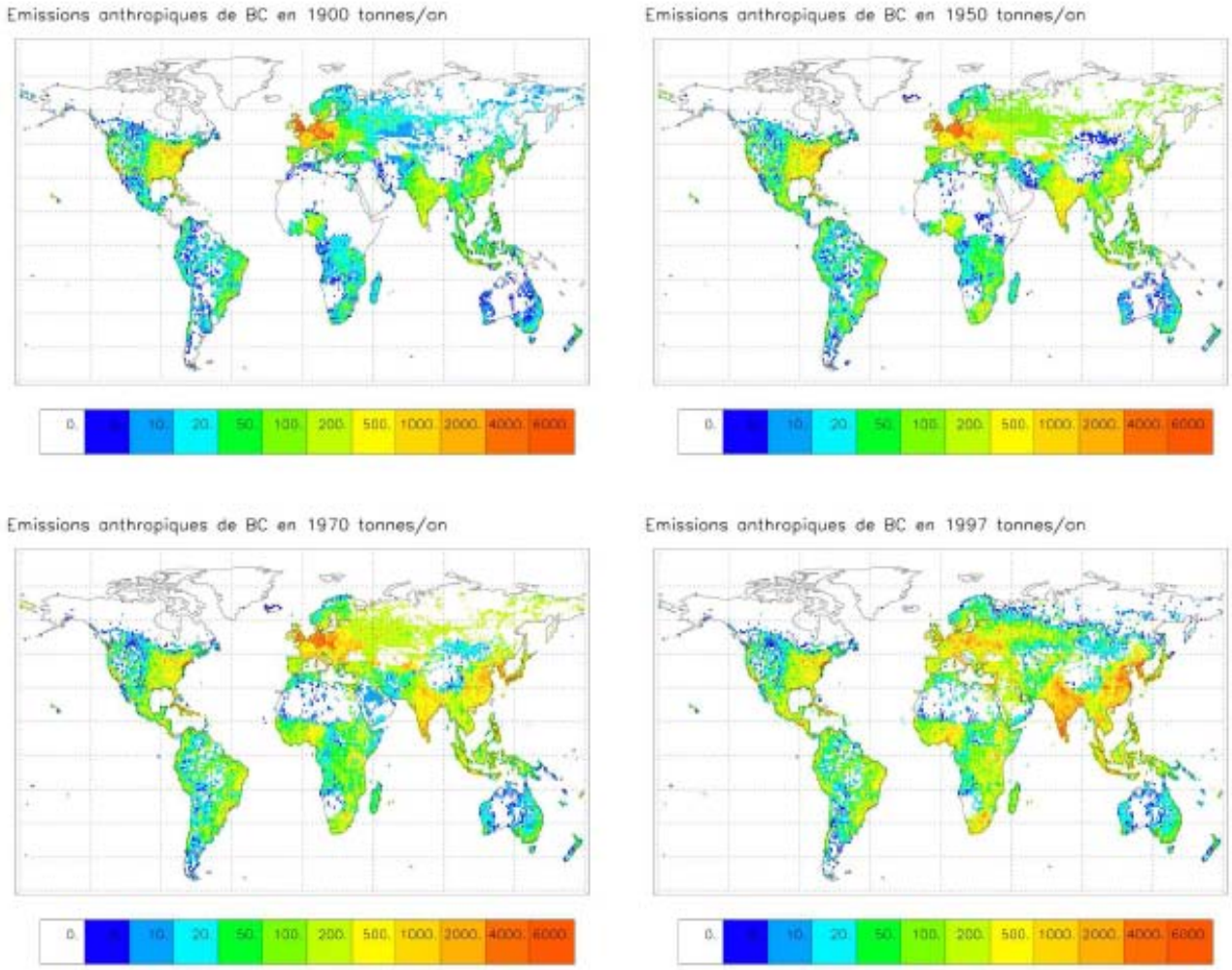
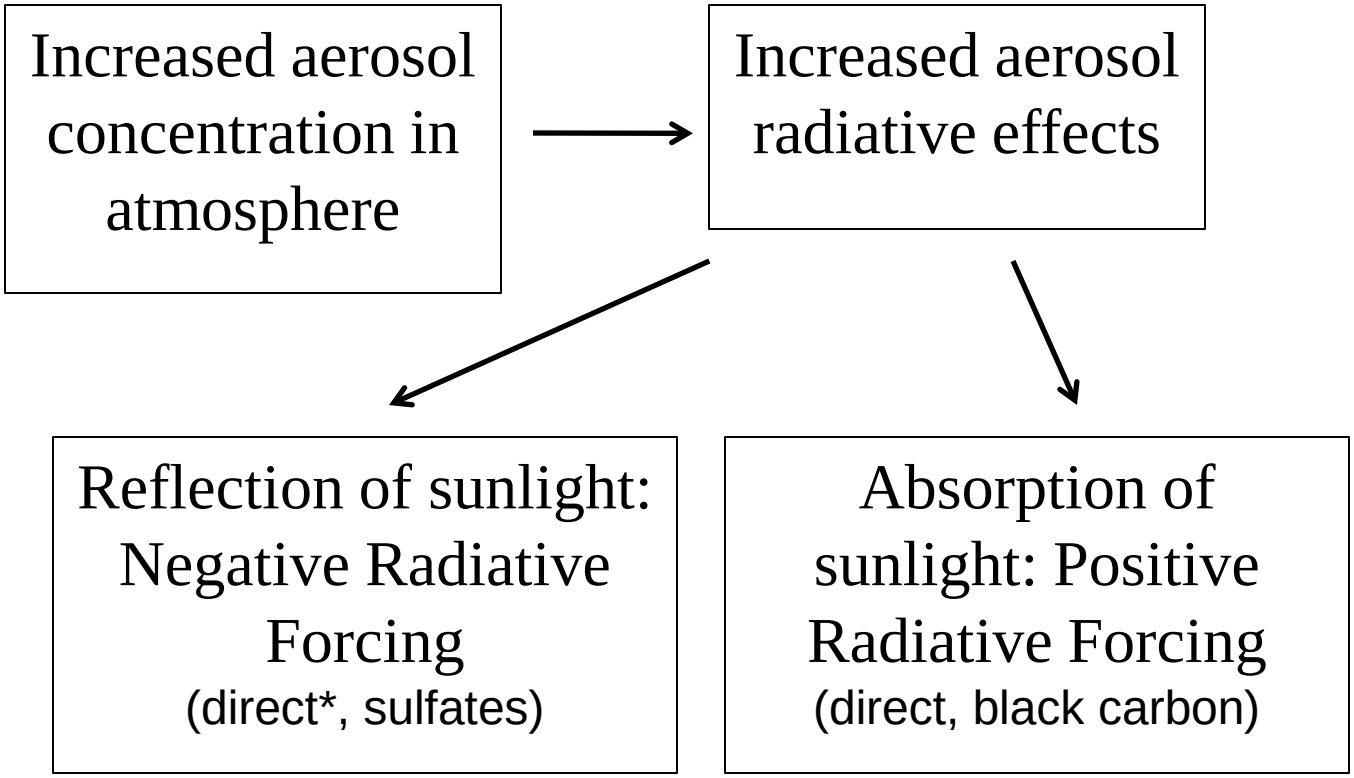


Figure 3 : BC anthropogenic emissions in 1900, 1950, 1970 et 1997 : emissions are given in Tg C/year.

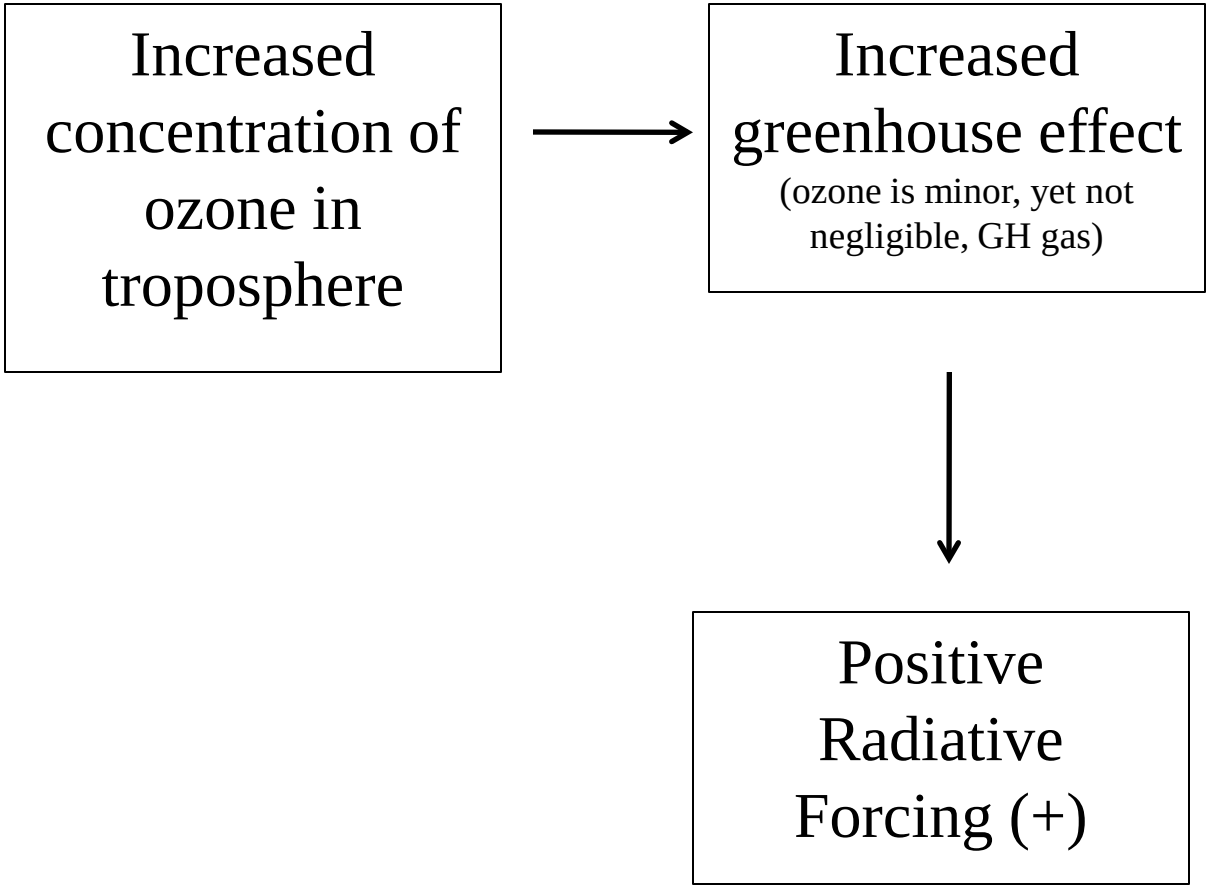
Mechanism: Aerosol Direct Forcing …



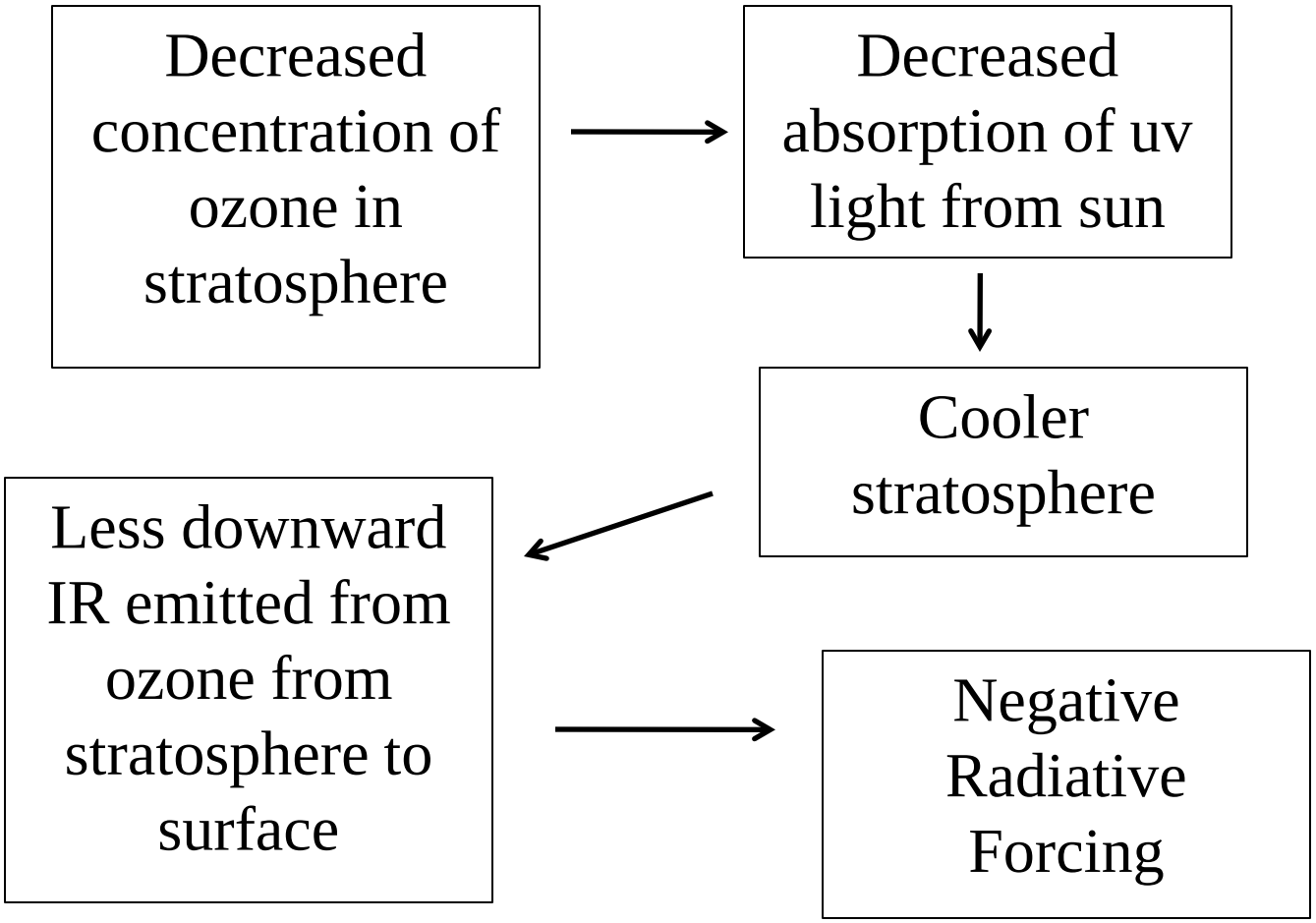
*There are also “indirect” forcings due to aerosol effects on clouds. These will not be discussed …

Changes since 1750:
3. Changes in ozone concentration

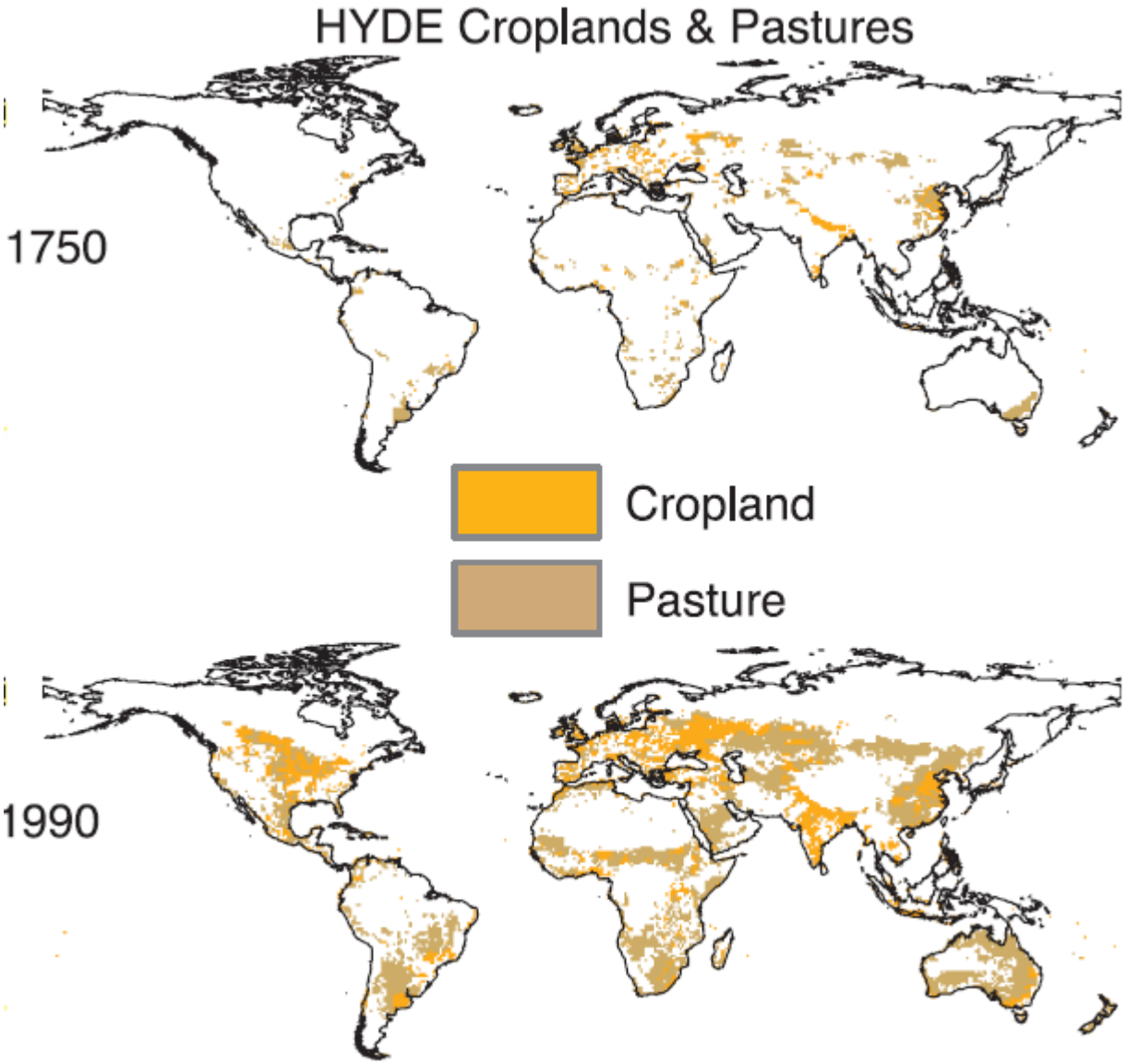
Mechanism: Ozone forcing (troposphere)

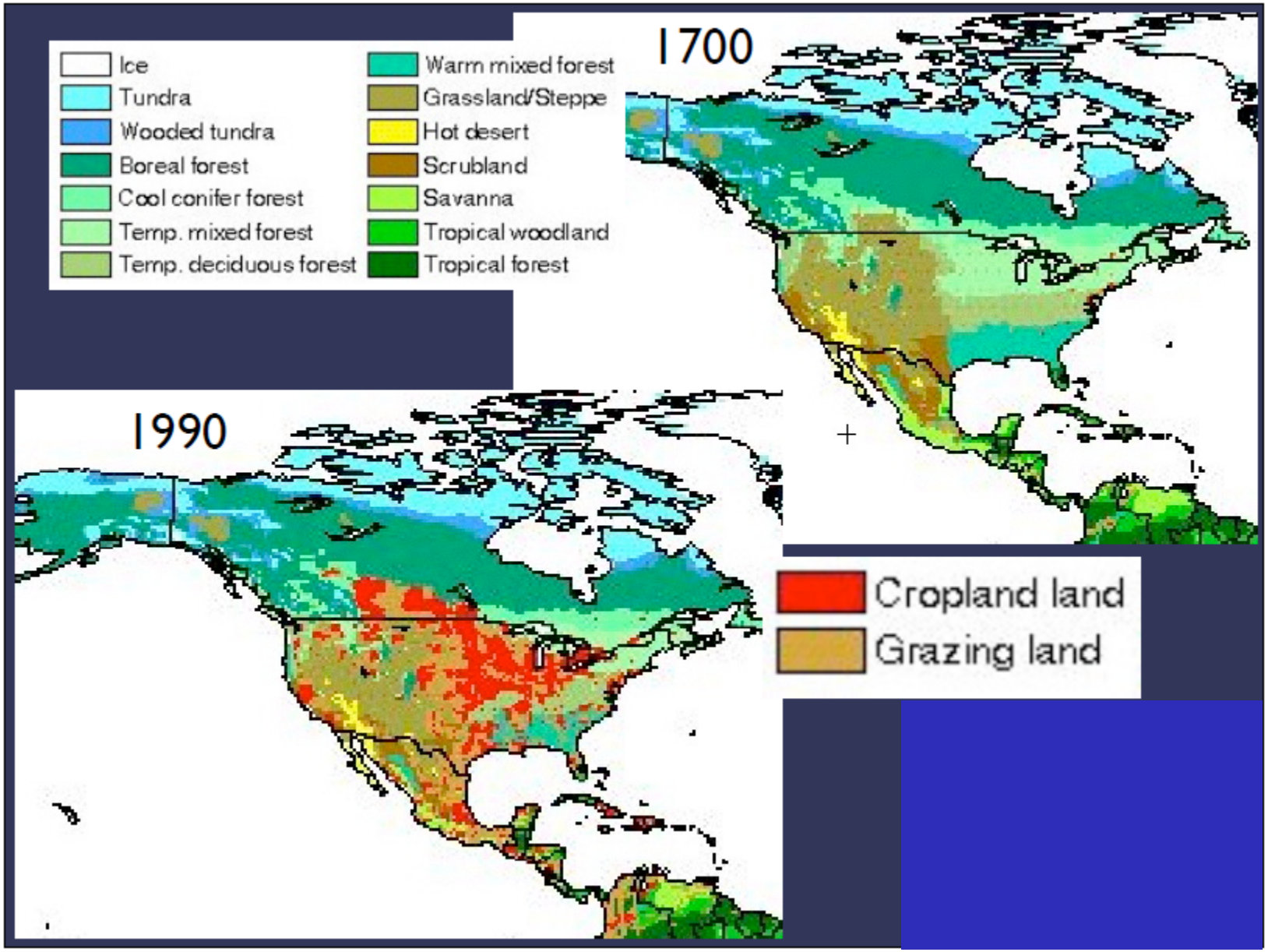


Mechanism: Ozone forcing (stratosphere)

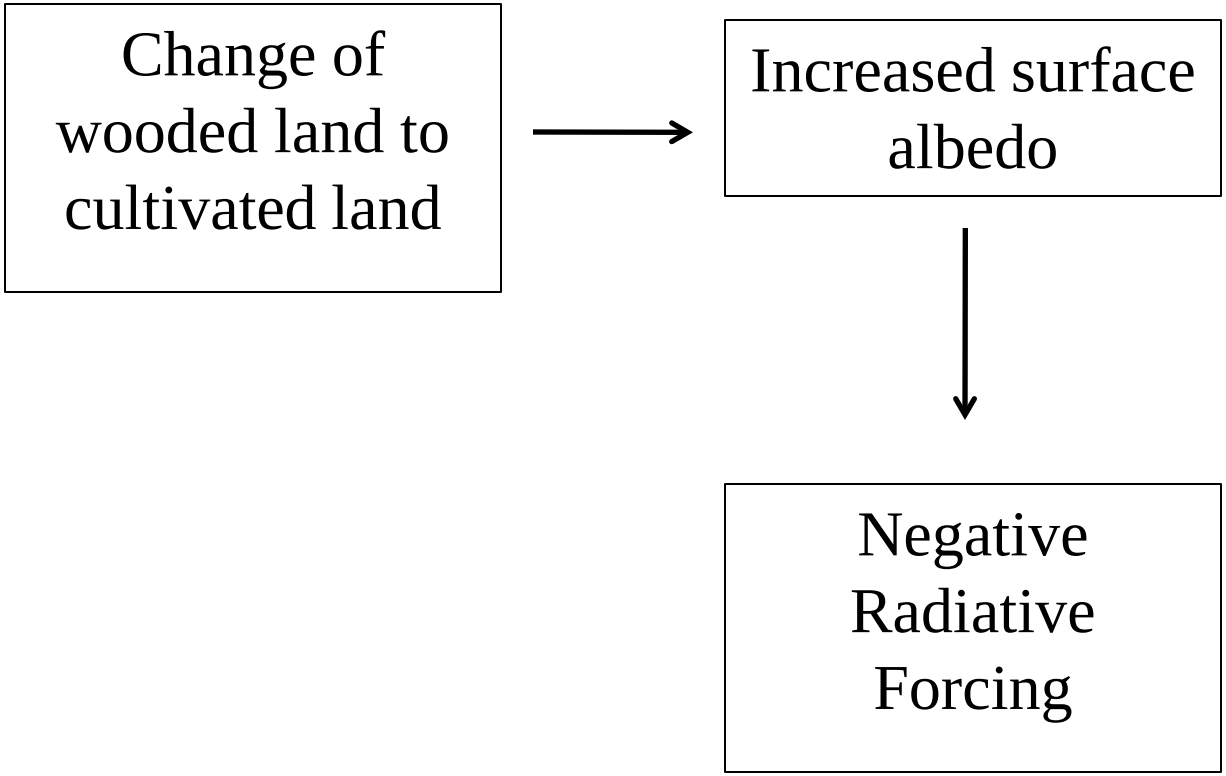


Changes since 1750:
4. Land Use Changes


HYDE Croplands & Pastures
1750
Cropland
Pasture
1990


Ice
Tundra
Wooded tundra
Boreal forest
Cool conifer forest
Temp. mixed forest
Temp. deciduous forest
Warm mixed forest
Grassland/Steppe
Hot desert
Scrubland
Savanna
Tropical woodland
Tropical forest
1700
1990
Cropland land
Grazing land

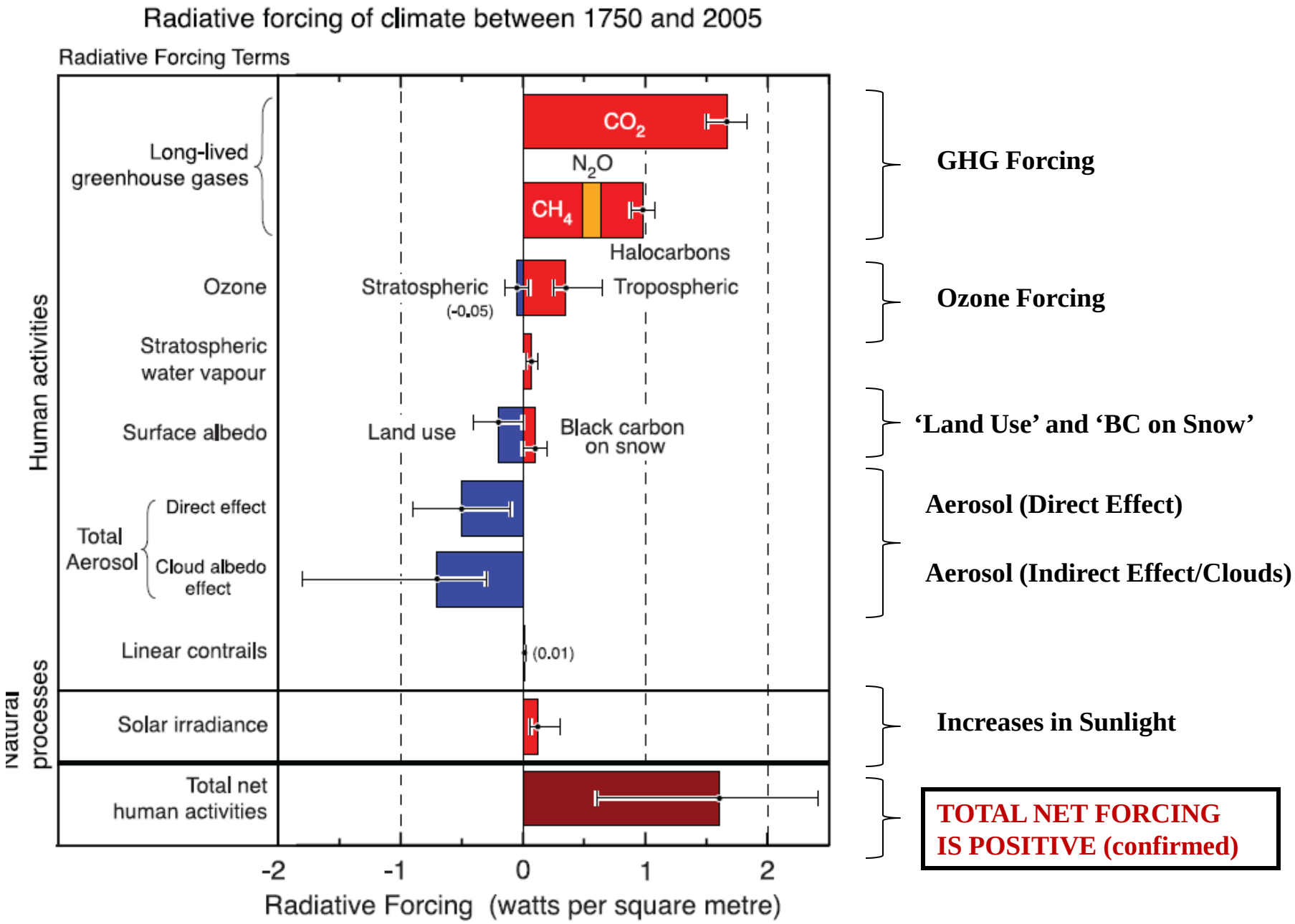
Mechanism: Land Use Change forcing …



Changes since 1750:
5. Other Things

- Changes in Solar Intensity (Sunlight)
- Water Vapor increases in stratosphere
- Black Carbon on Snow
- Contrails
- Various other things of lesser importance …

Results:
Radiative Forcing Comparison


Radiative forcing of climate between 1750 and 2005
Radiative Forcing Terms
Human activities
Natural processes
Long-lived greenhouse gases
CO_2
N_2O
CH_4
Halocarbons
Ozone
Stratospheric
(-0.05)
Tropospheric
Stratospheric water vapour
Surface albedo
Land use
Black carbon on snow
Total Aerosol
Direct effect
Cloud albedo effect
Linear contrails
(0.01)
Solar irradiance
Total net human activities
-2
-1
0
1
2
Radiative Forcing (watts per square metre)
GHG Forcing
Ozone Forcing
'Land Use' and 'BC on Snow'
Aerosol (Direct Effect)
Aerosol (Indirect Effect/Clouds)
Increases in Sunlight
TOTAL NET FORCING IS POSITIVE (confirmed)

Summary

- RF calculations confirm total radiative forcing is positive.
  - Best Estimate: +1.6 W/m2
  - This amount of radiative forcing is roughly in line with observed warming of 1 deg C over last 100+ years*.

- Greenhouse gas forcing (CO_2, methane, etc …) is by far the largest positive radiative forcing contributing to total radiative forcing.

- Therefore, GHG forcing is the only positive forcing identified to date that could explain warming over last century.

- In particular, GHG forcing much greater than solar forcing

This is based on the fairly well scientifically confirmed fact that the earth's average temperature would rise around 2 – 4.5 deg C for a radiative forcing equal to a doubling of CO2, or in other words that the earth's "climate sensitivity" is 2 – 4.5 degrees C.

An interesting video …

http://www.youtube.com/watch?v=2T4UF_Rmlio

- Watch video …
- First part gives a good history of climate change science, emphasizing how a consensus among climate scientists that global warming was mainly due to anthropogenic greenhouse gas forcing has been around for a long time.
- Second part is very interesting, discussing origin of efforts by interested parties to not acknowledge this consensus, and thereby exaggerate (invent?) scientific uncertainty about global warming.
- **Be prepared to answer a multiple choice question about history of global warming research as it pertains to attribution to increase GHG concentration. Also, be prepared to incorporate this and other general ideas of video as part of a broader short-answer question on 'attribution' on final exam. First part of video emphasized.**

Final Exam:
Some Multiple Choice Questions

Which of the following best describes the global spatial pattern of global warming seen the last 100+ years?

a) Increase in temperature over most of the globe, largest around the equator.
b) Increase in temperature over the entire globe, with small variation from place to place.
c) Increase in temperature over most of the globe, largest over the oceans
d) Increase in temperature over most of the globe, largest in high latitudes of northern hemisphere.

Some anthropogenic activity occurs and as a result there is an increase in black carbon in the atmosphere as well as deposited on the surface. What would you expect to occur?

a) Negative radiative forcing, thereby cooling the surface.
b) Positive radiative forcing , thereby cooling the surface.
c) Negative radiative forcing, thereby warming the surface.
d) Positive radiative forcing , thereby warming the surface.

According to IPCC estimates, how do the sign and values for radiative forcing due to changes in solar radiation and land use compare to the radiative forcing due to increases in greenhouse gas (GHG) concentrations the last 100+ years?

a) Signs of all three are positive;
Value of GHG forcing is much greater than both solar and land use forcing

b) Signs of all three are positive;
Value of GHG forcing about the same as land use forcing and much greater than solar forcing.

c) Signs of GHG and solar forcing are positive, sign of land use forcing is negative;
Value of GHG forcing much greater than solar forcing.

d) Signs of GHG and land use are positive, sign of solar forcing is negative;
Value of GHG forcing much greater than land use forcing.