Climate is changing: are we contributing to it and what can we do?

NASA Langely Center

Hampton,VA

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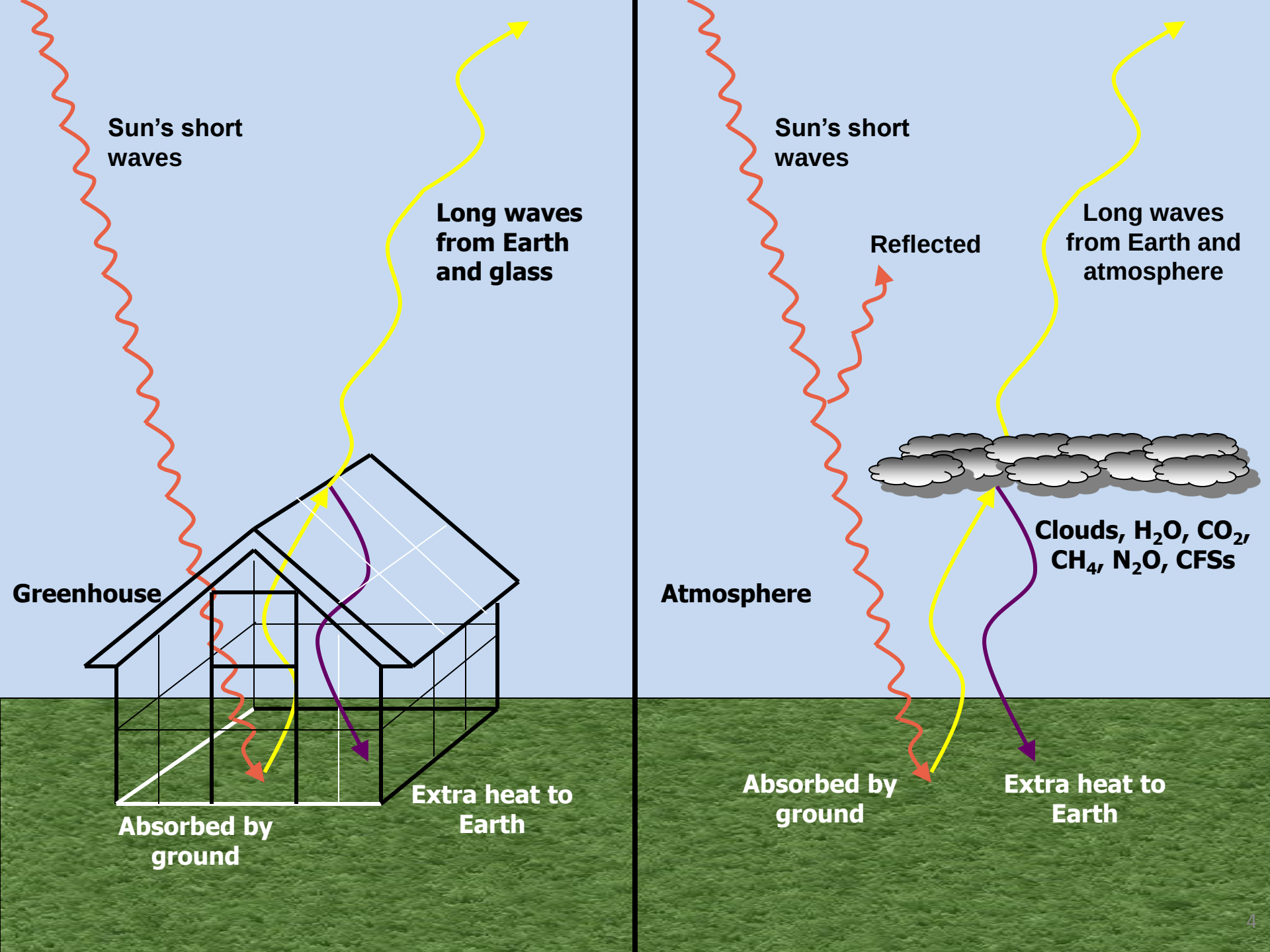
About 75% of the mass of the Atmosphere is in the troposphere (diagram not in scale)

Radius of Earth: ~6,378.1 km

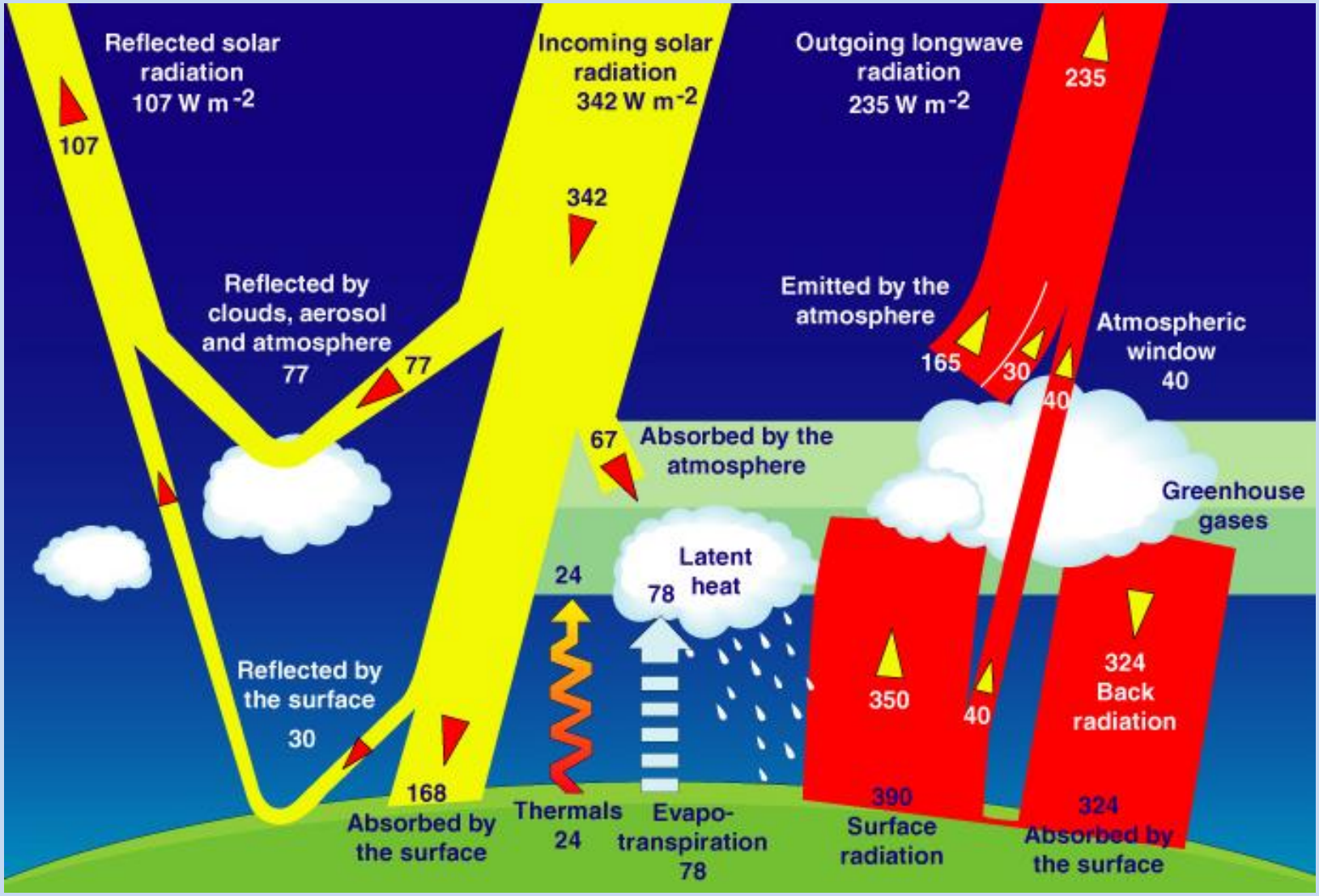
Troposphere: about 8 km at the poles and 16 at the equator

Weather, climate, climate change and natural variability

- Weather is the state of the atmosphere at some place and time.
- Climate is a statistical concept involving averages and frequency of occurrence and intensity of severe weather events and hurricanes
- Climate change refers to long-term shifts that can be characterized by a uniform trend or by stronger or even sudden fluctuations
- Natural variability refers to fluctuations about a mean that does not change. The time series is stationary.


Sun's short waves
Long waves from Earth and glass
Greenhouse
Absorbed by ground
Extra heat to Earth
Sun's short waves
Reflected
Long waves from Earth and atmosphere
Clouds, H_2O, CO_2, CH_4, N_2O, CFSs
Atmosphere
Absorbed by ground
Extra heat to Earth

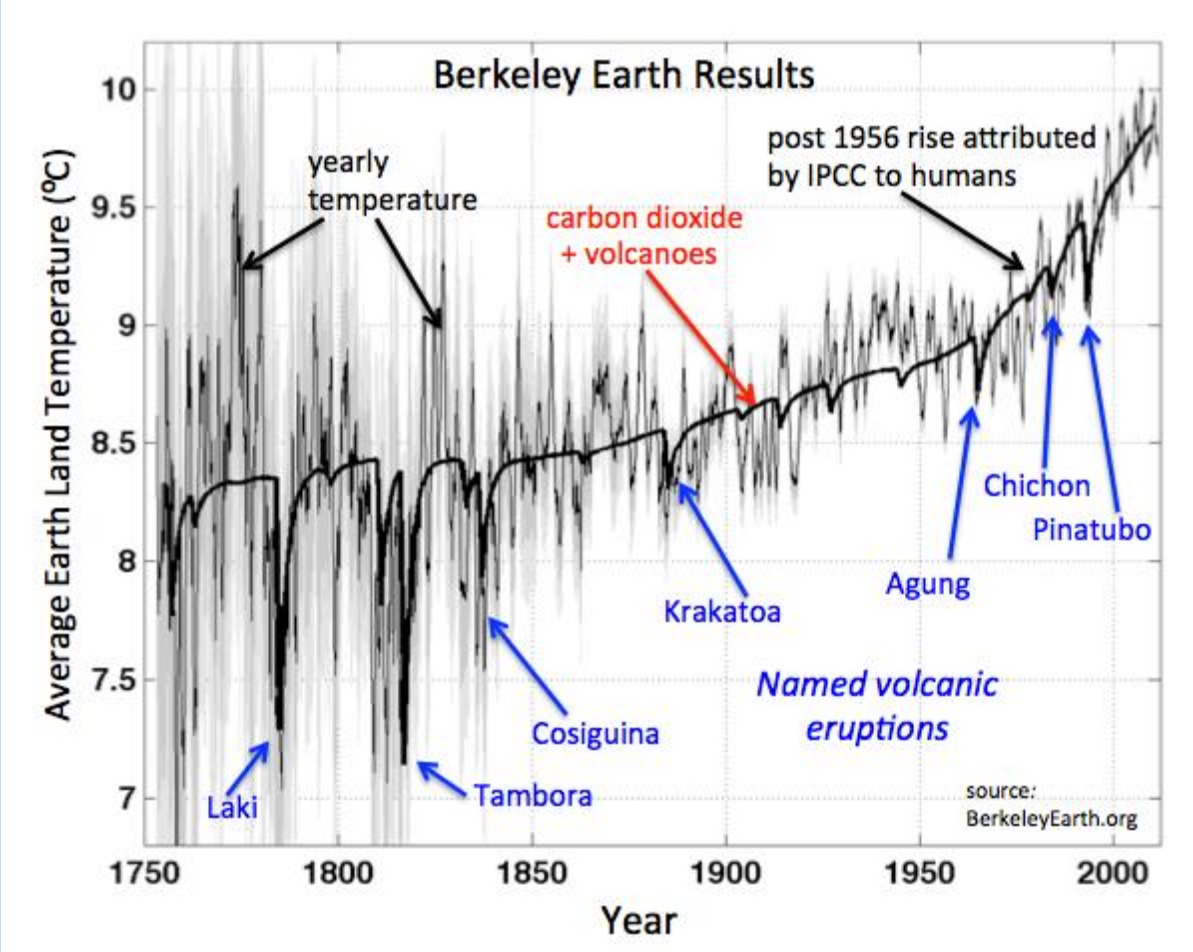
Earth's Energy Balance



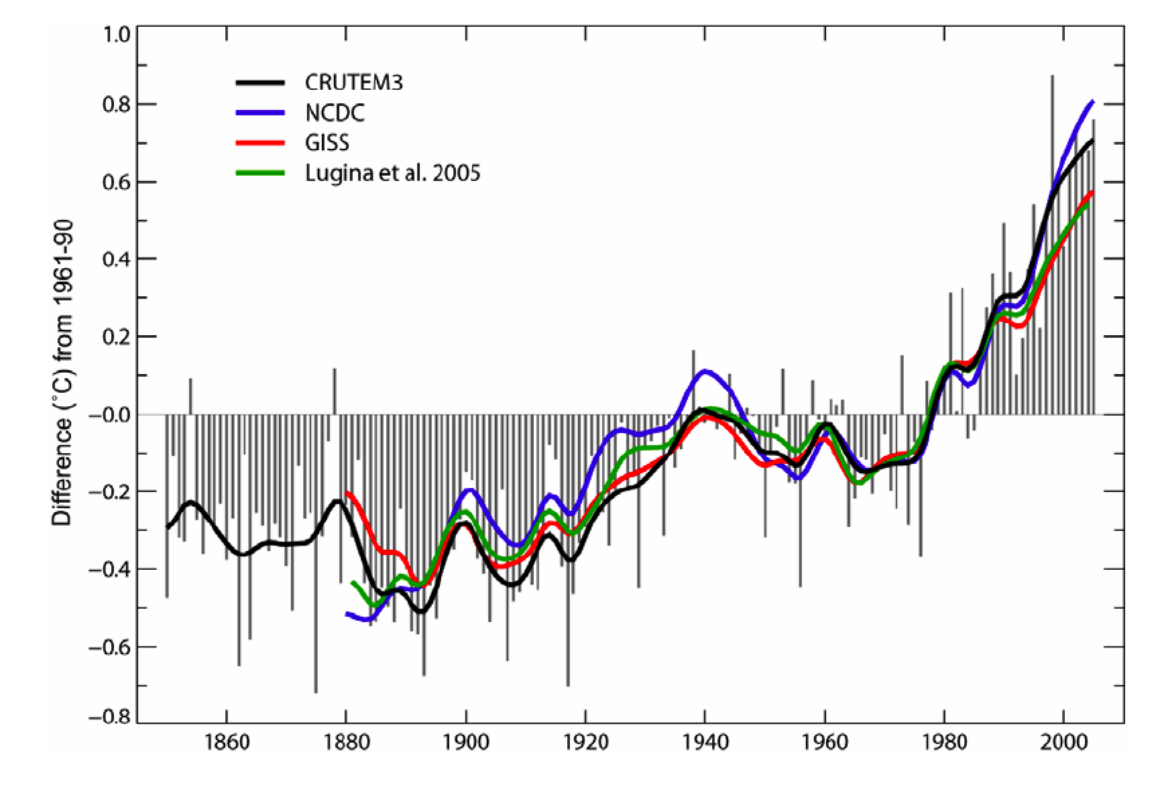
The thermal energy emitted from the surface of the Earth is reflected in part by clouds, aerosols and trace gases such as CO_2, CH_4, etc.

Is the temperature increasing?

Average Earth-Land Temperature since 1750



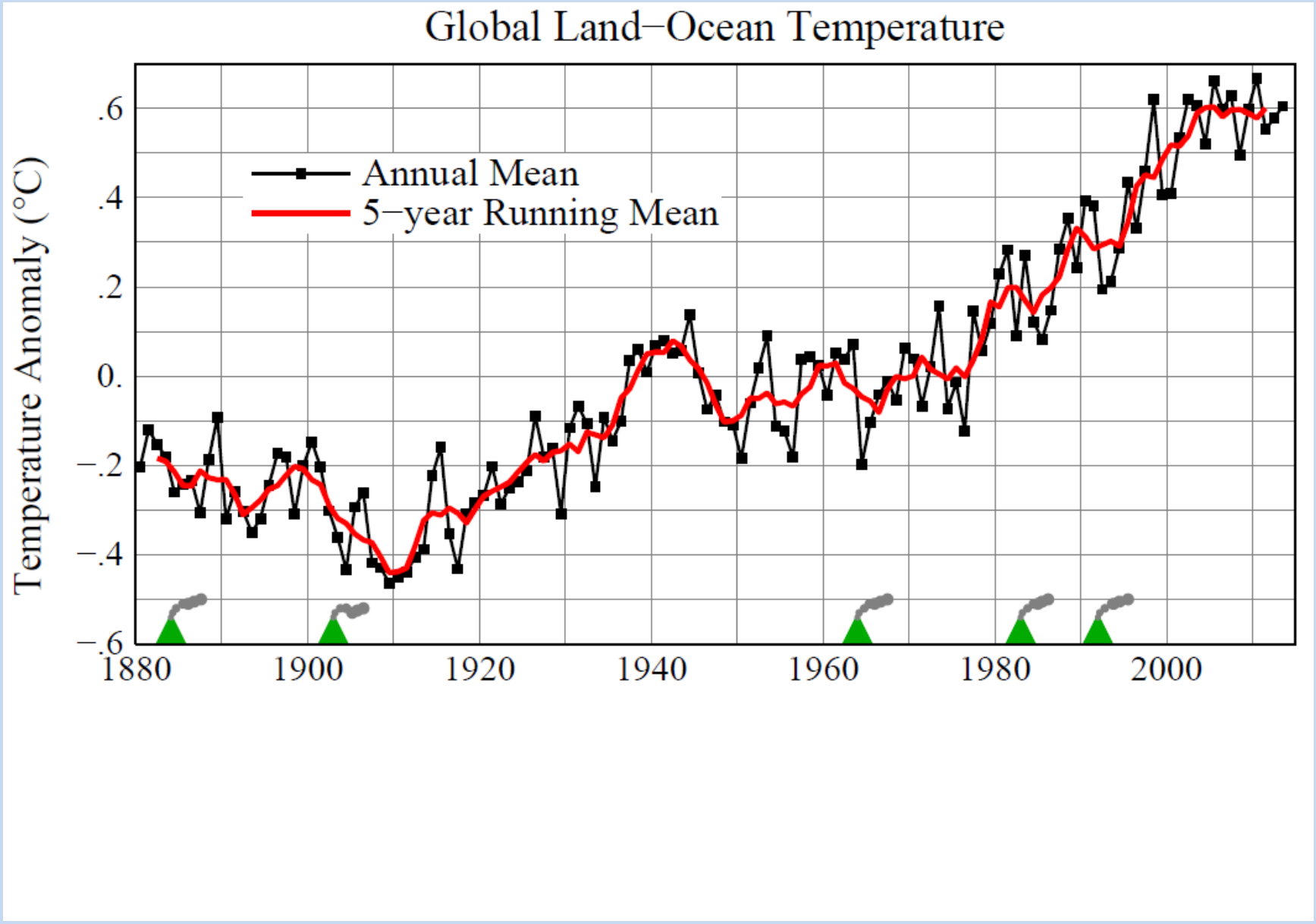
The World Has Warmed

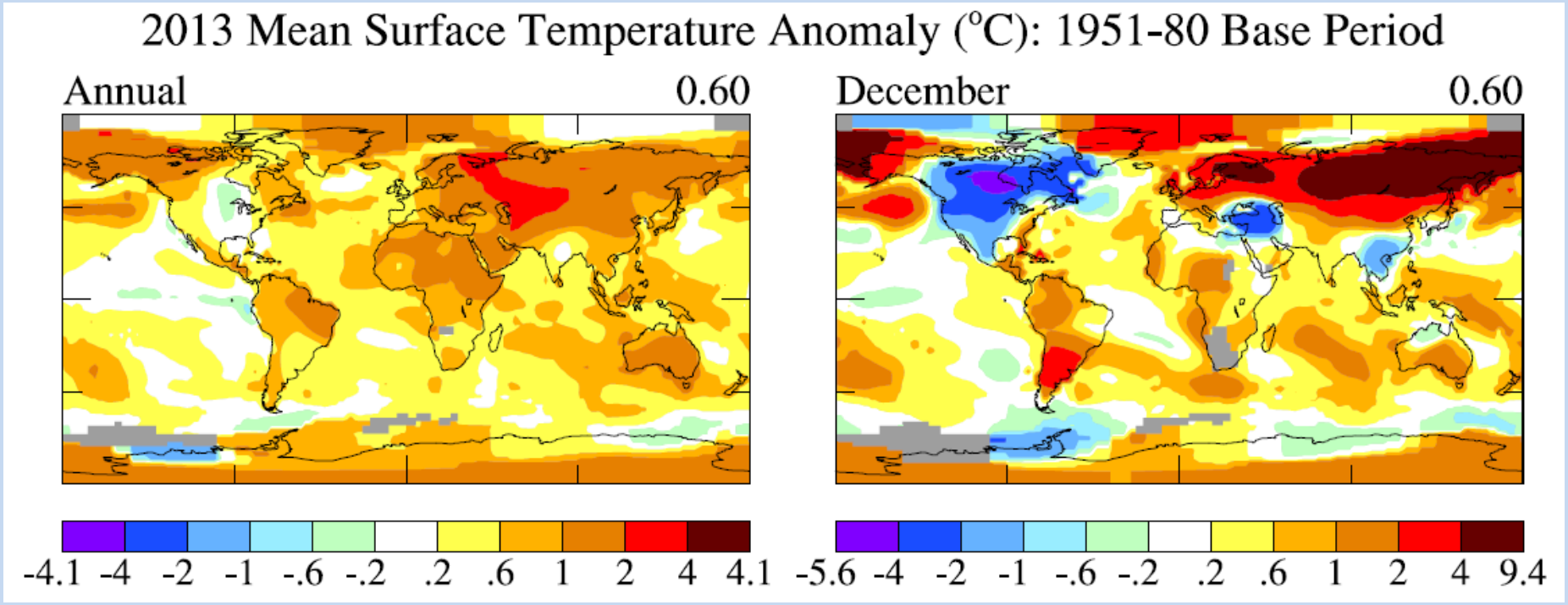


Rank	Year
1	2005[1]
1	1998[1]
3	2002
4	2003
5	2004
6	2001
7	1997
8	1990
9	1995
10	1999
11	2000
12	1991
13	1987
14	1988
15	1994
16	1983
17	1996
18	1944
19	1989
20	1993

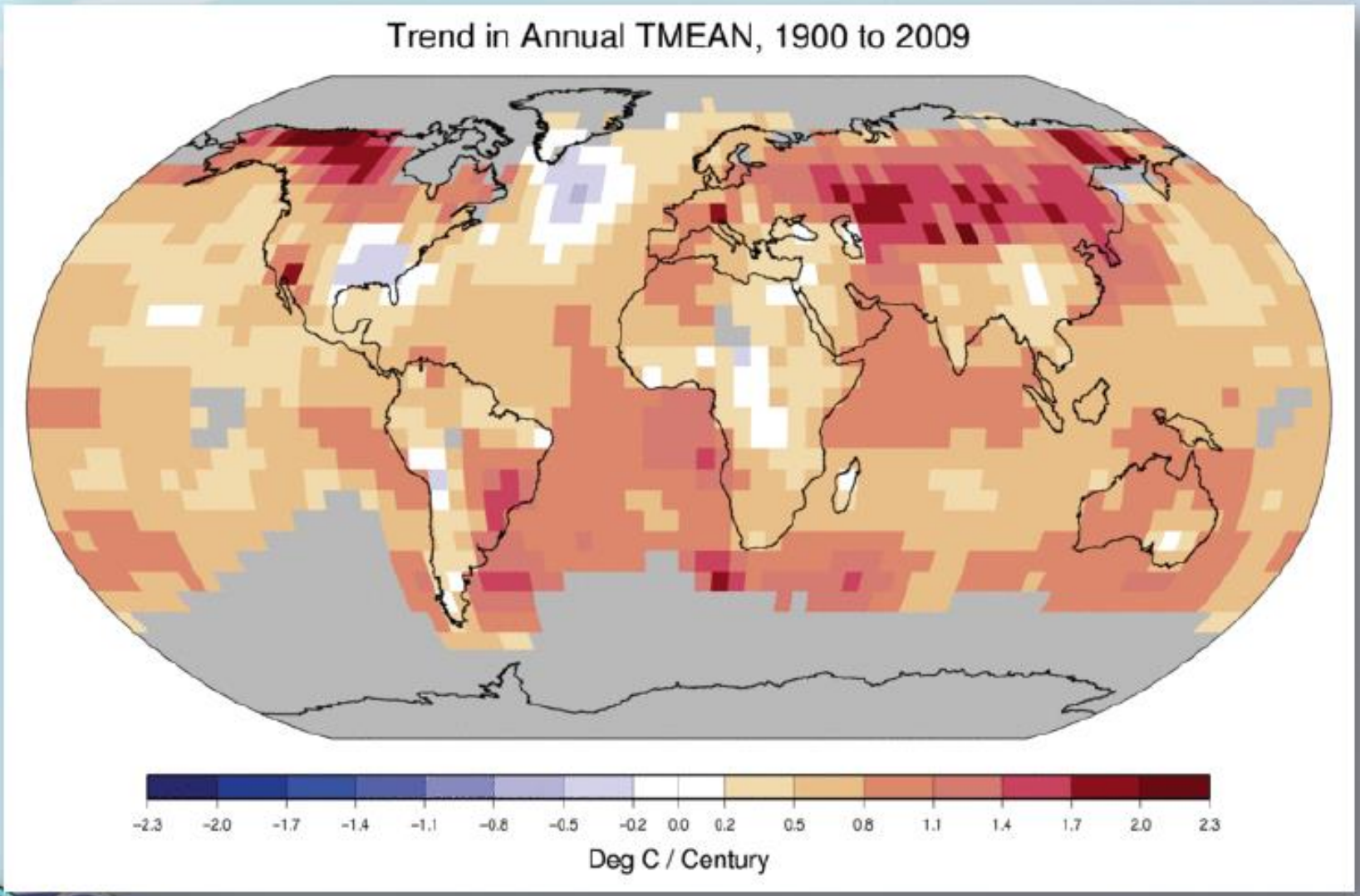
Widespread warming has occurred. Globally averaged, the planet is about 0.75˚ C warmer than it was in 1860, based upon dozens of high-quality long records using thermometers worldwide, including land and ocean.

IPCC (2007) ch 3

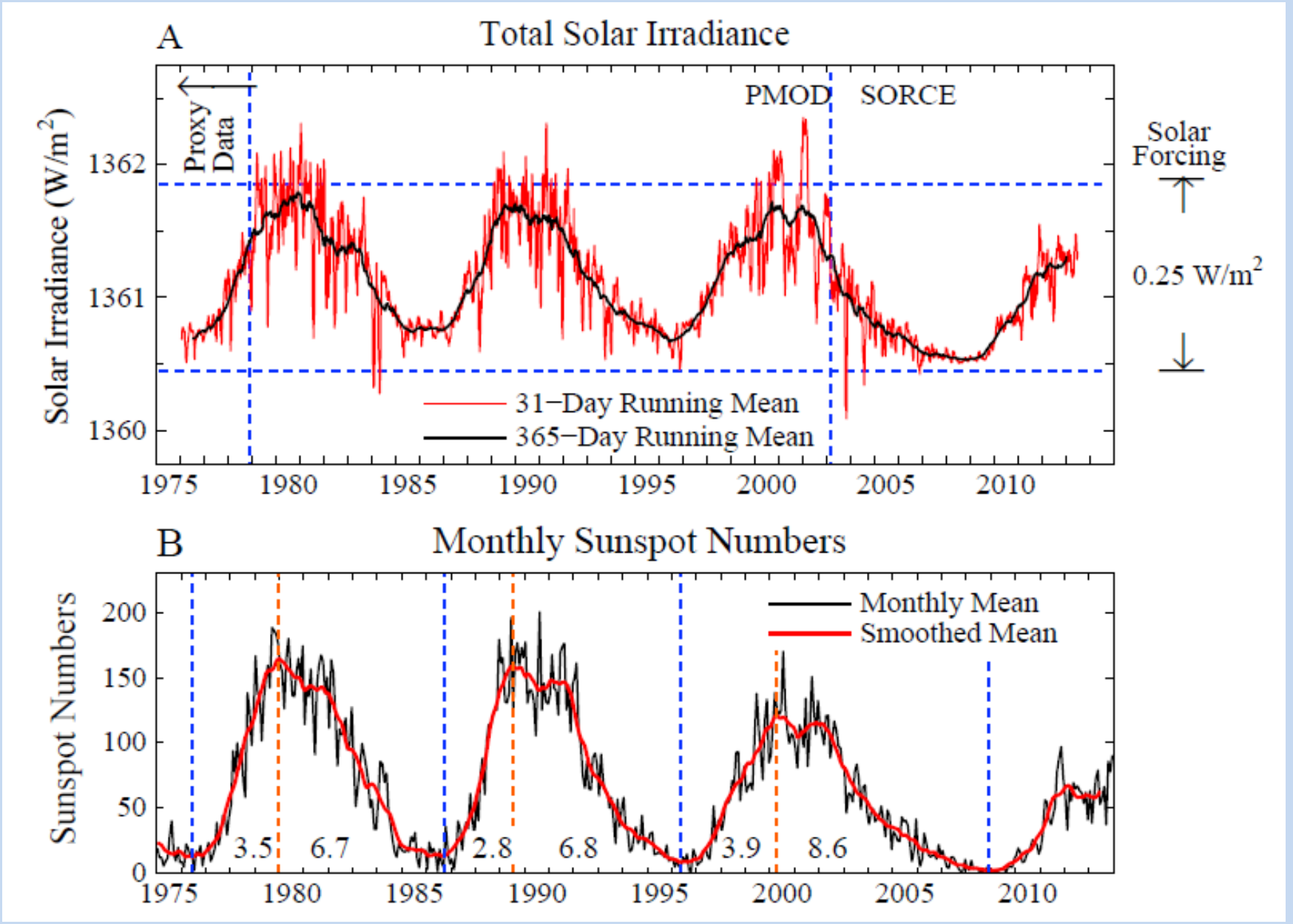

Global Land–Ocean Temperature
Temperature Anomaly (°C)
.6
.4
.2
0.
−.2
−.4
−.6
Annual Mean
5–year Running Mean
1880
1900
1920
1940
1960
1980
2000


2013 Mean Surface Temperature Anomaly (°C): 1951-80 Base Period
Annual
0.60
-4.1 -4 -2 -1 -.6 -.2 .2 .6 1 2 4 4.1
December
0.60
-5.6 -4 -2 -1 -.6 -.2 .2 .6 1 2 4 9.4

Global Warming is not Uniform Around the Globe

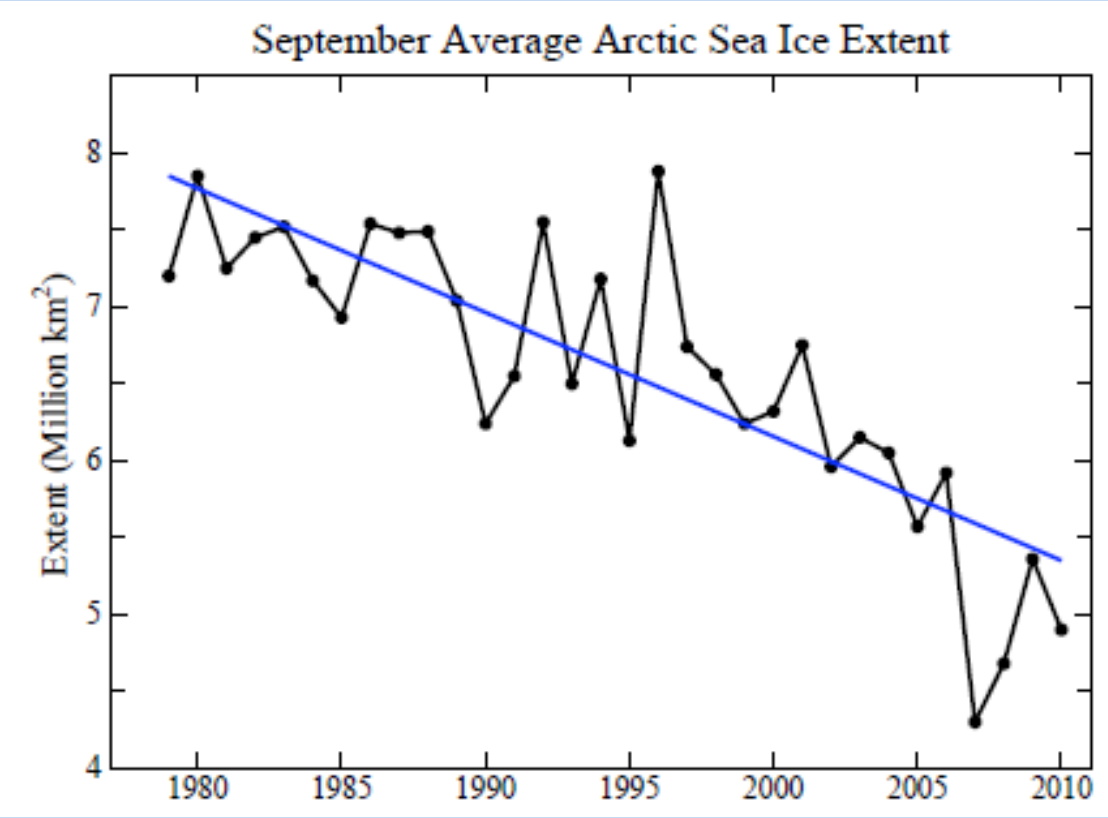


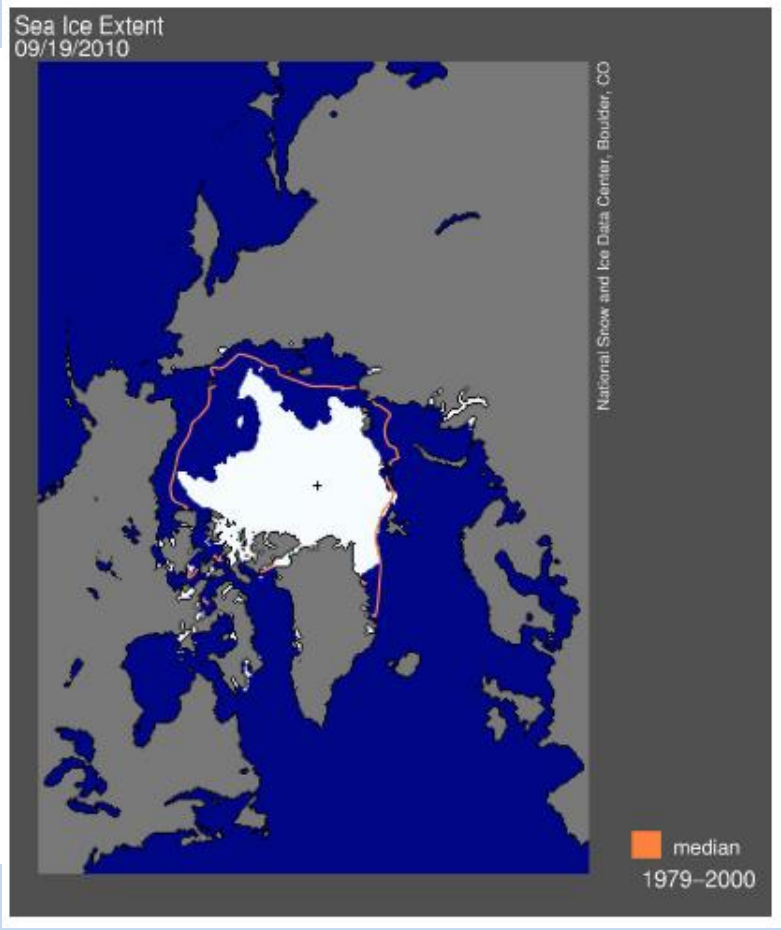
Is it possible that global warming be due to an increase of solar radiation?


A
Total Solar Irradiance
Solar Irradiance (W/m^2)
Proxy Data
PMOD
SORCE
Solar Forcing
0.25 W/m^2
1362
1361
1360
31−Day Running Mean
365−Day Running Mean
1975
1980
1985
1990
1995
2000
2005
2010
B
Monthly Sunspot Numbers
Sunspot Numbers
Monthly Mean
Smoothed Mean
200
150
100
50
0
3.5
6.7
2.8
6.8
3.9
8.6

Other examples of impact of warming

Arctic sea ice area at summer minimum.

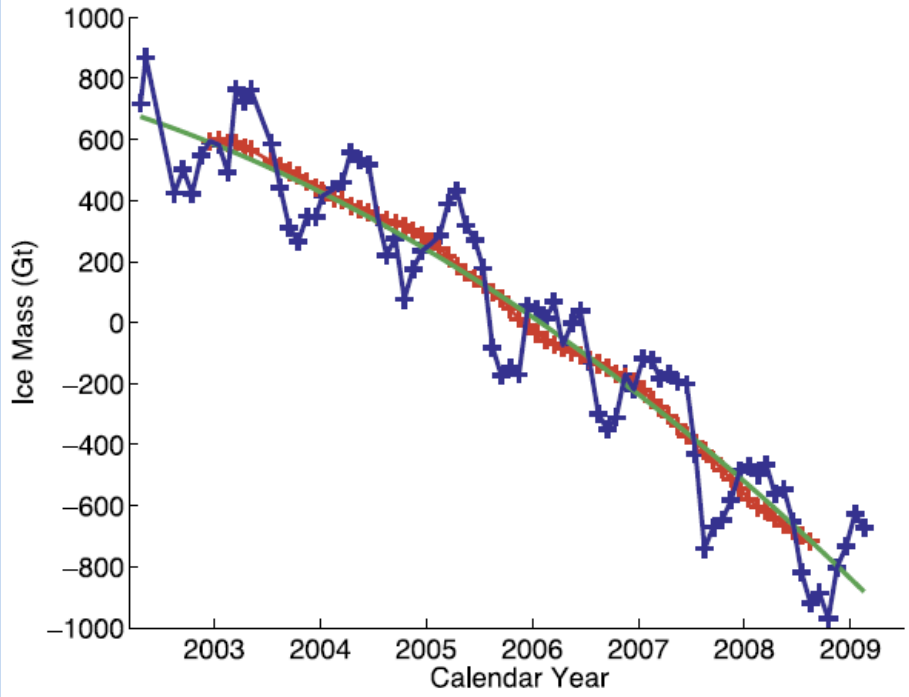




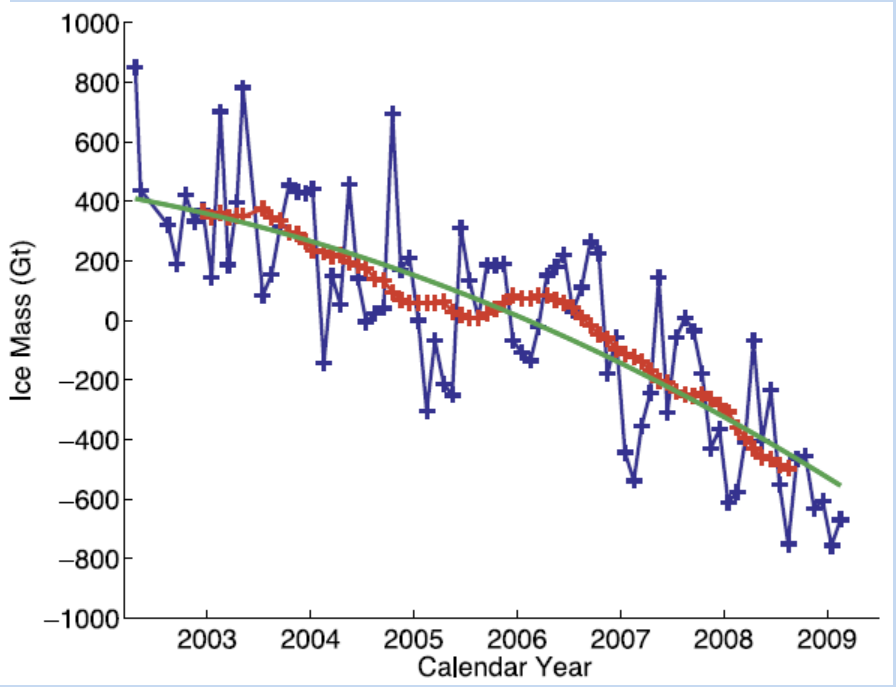
Warm season sea ice minimum has declined more than one-third.

Data source: National Snow and Ice Data Center, Boulder, CO

Gravity Satellite Ice Sheet Mass Measurements



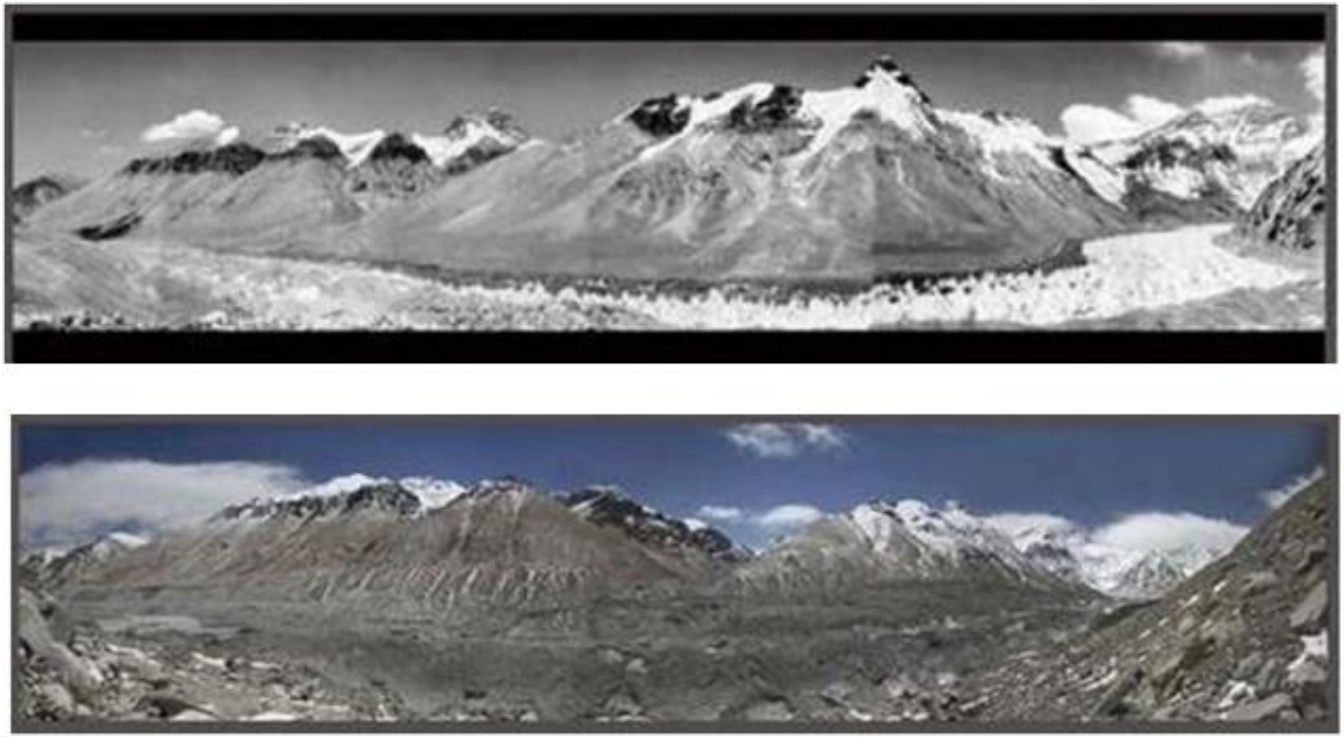
Greenland Ice Sheet



Antarctic Ice Sheet

Source: Velicogna, I. *Geophys. Res. Lett.*, **36**, L19503, doi:10.1029/2009GL040222, 2009.

Himalayan (Rongbuk) Glacier



Rongbuk, the largest glacier on Mount Everest's northern slopes, in 1968 (top) and 2007.

Glaciers are receding rapidly world-wide, including the Rockies, Andes, Alps, Himalayas.

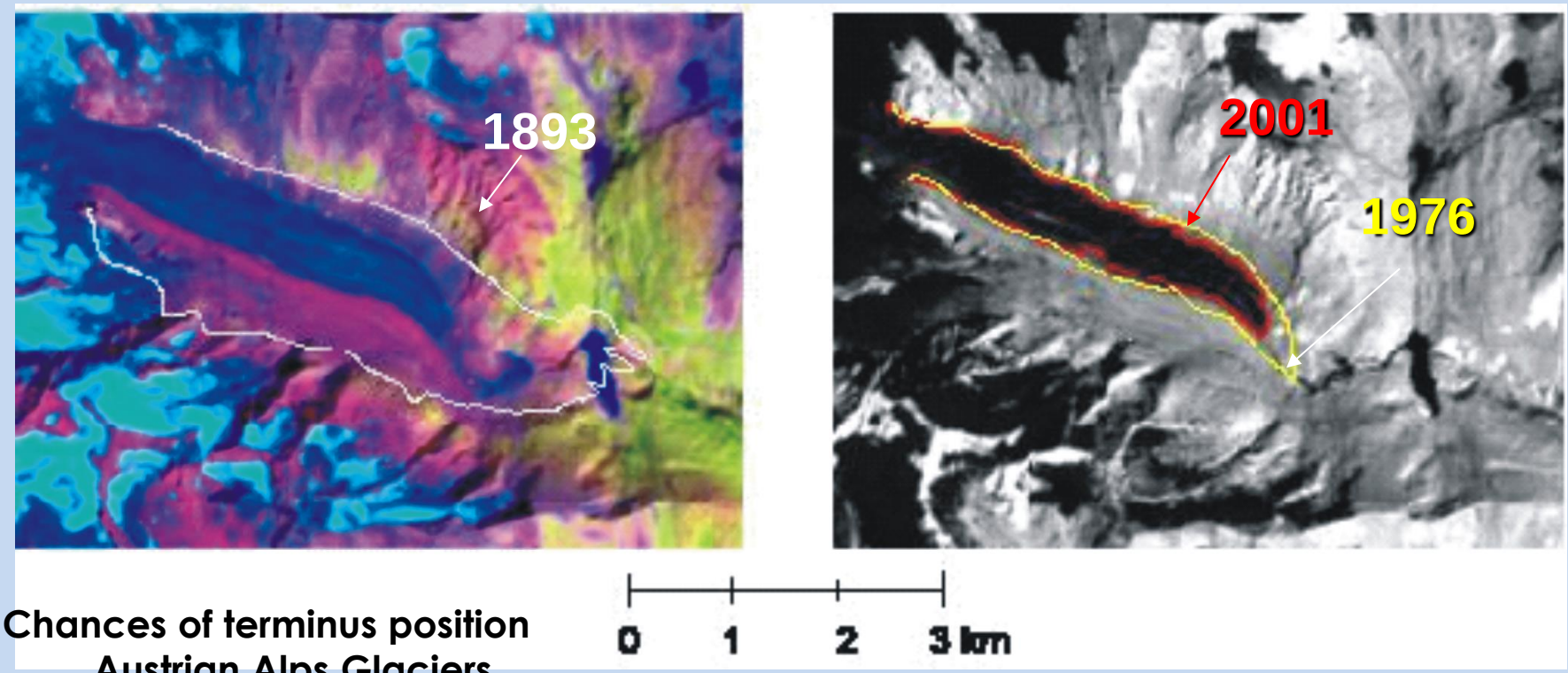
Glaciers provide freshwater to rivers throughout the dry season and reduce spring flooding.

The Qori Kalis glacier descends from the Quelccaya ice cap in Peru, the world ‘s largest tropical ice sheet. Quelccaya is a huge ice cap sitting on a volcanic plain 18000 feet above sea level

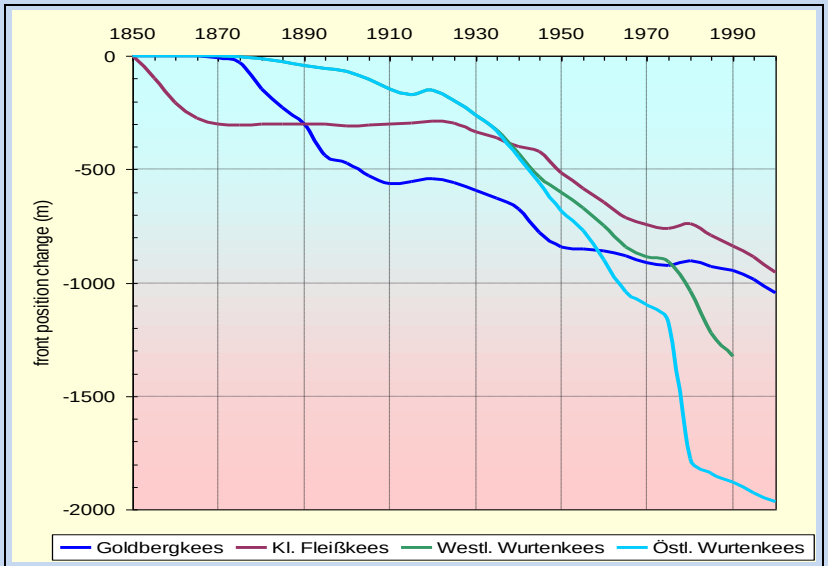
Qori Kalis in 1978

Qori Kalis 30 years later

Pasterze Glacier tongue: 1893-2001

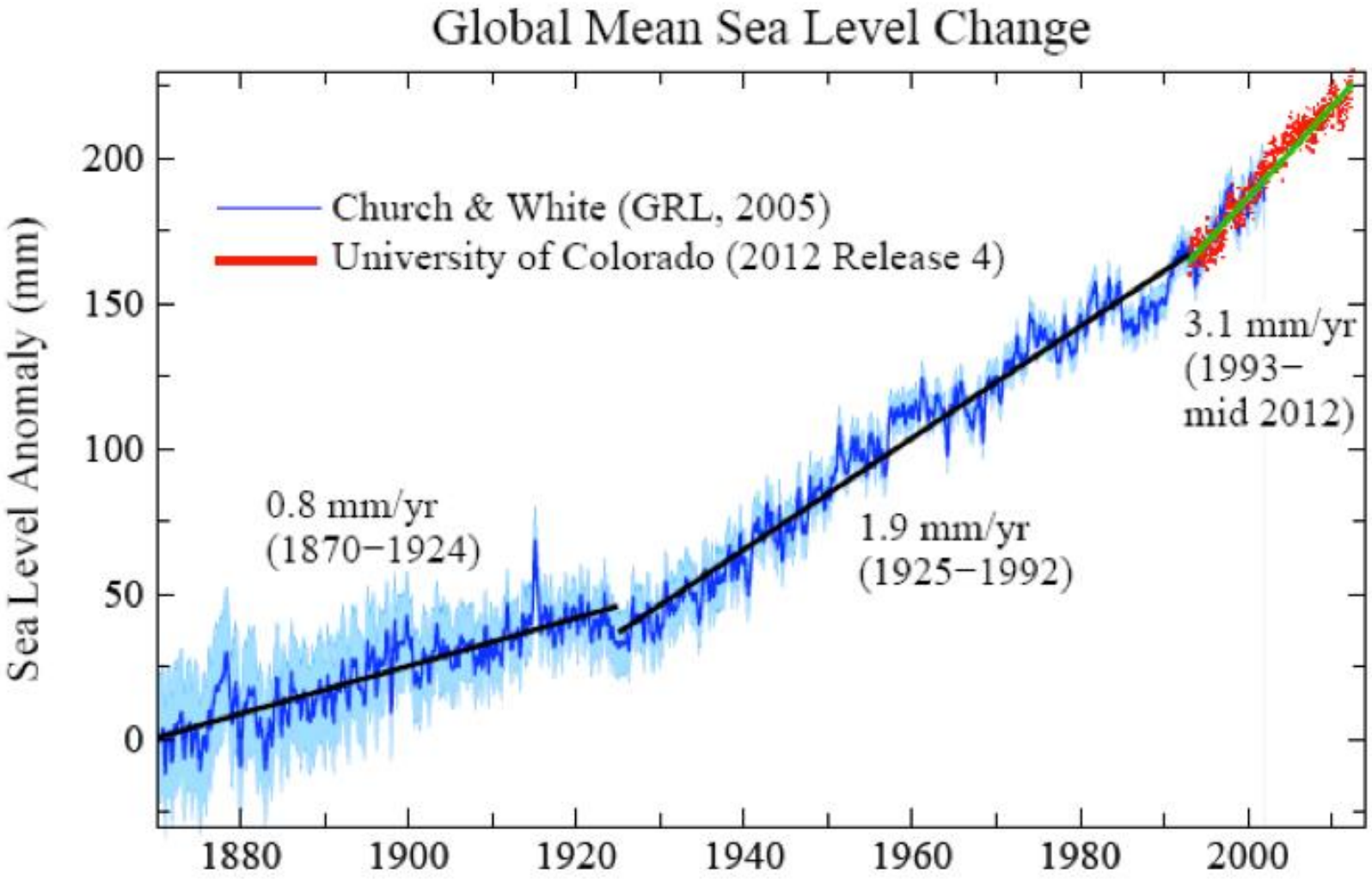


Chances of terminus position Austrian Alps Glaciers



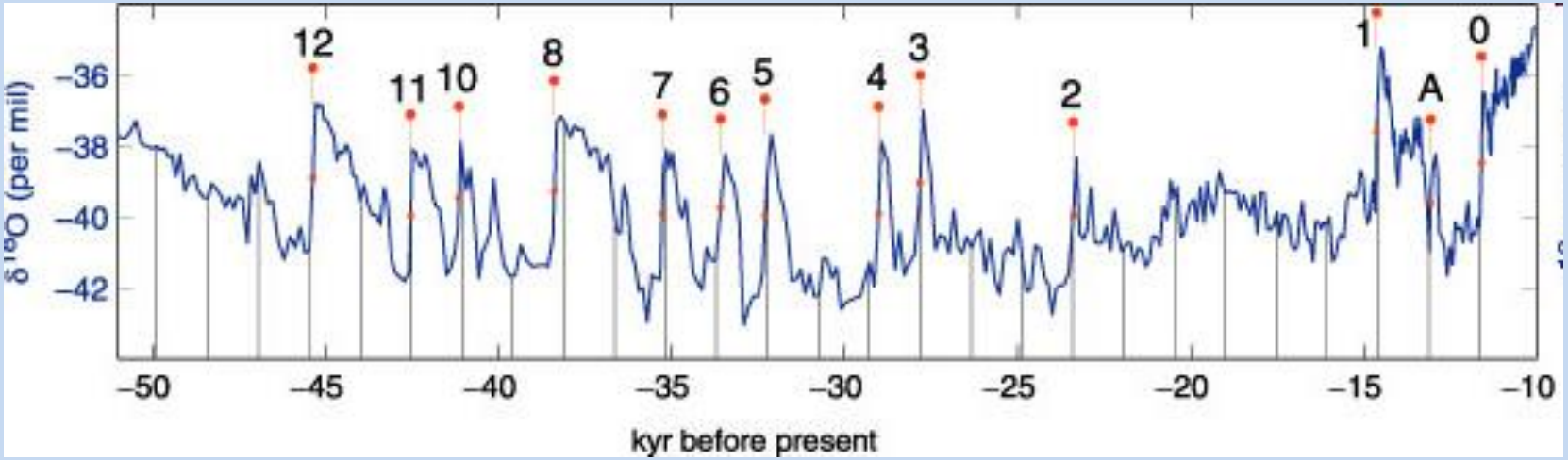
The Pasterze Glacier tongue receded ~1.2 km from 1893 to 2001

Glaciers in the European Alps have lost 50% of their volume in the last 150 years

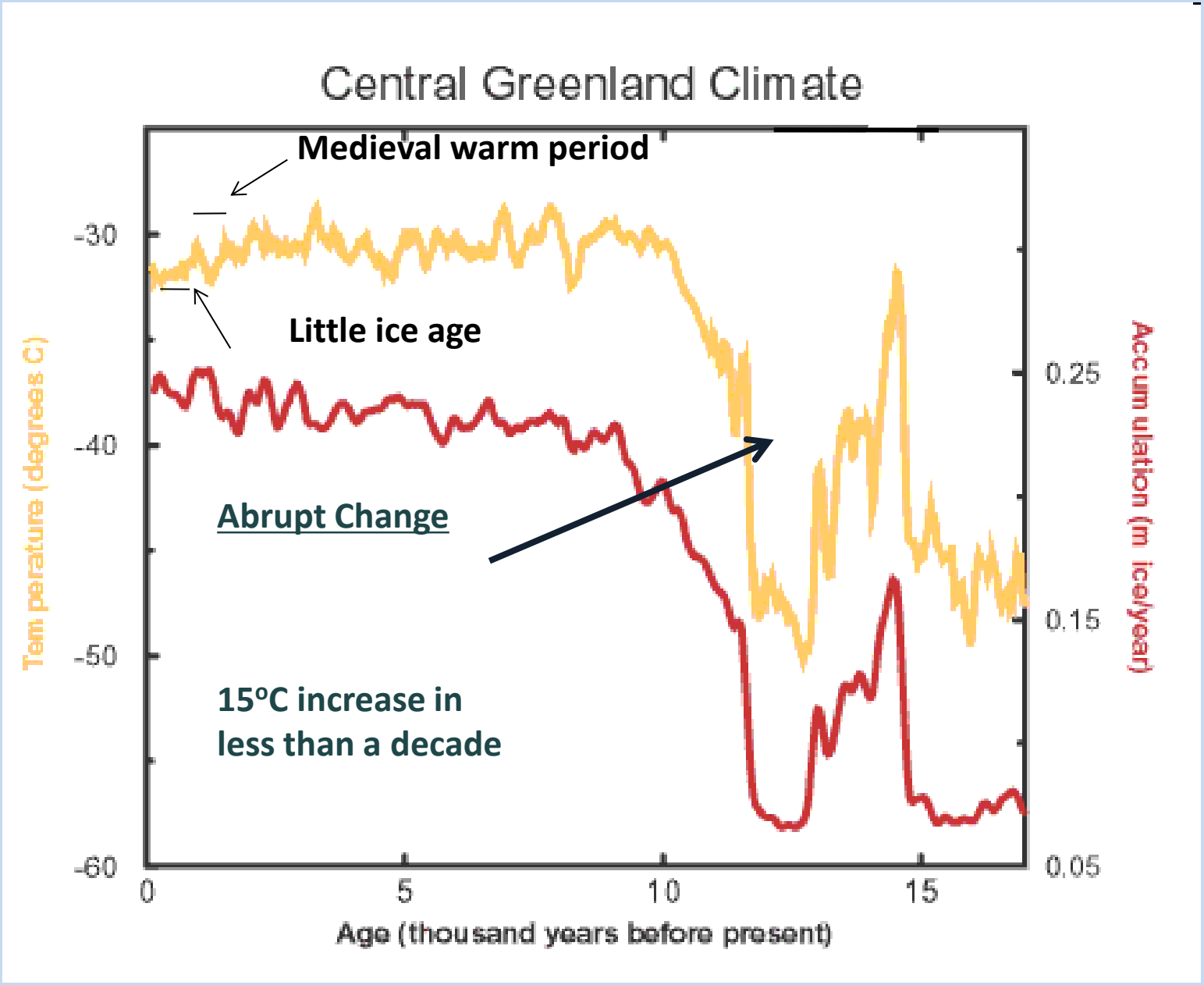

Global Mean Sea Level Change
Sea Level Anomaly (mm)
200
150
100
50
0
1880
1900
1920
1940
1960
1980
2000
Church & White (GRL, 2005)
University of Colorado (2012 Release 4)
0.8 mm/yr
(1870−1924)
1.9 mm/yr
(1925−1992)
3.1 mm/yr
(1993−
mid 2012)

Abrupt Changes in the Earth's Climate

The Dansgaard-Oeschger Events



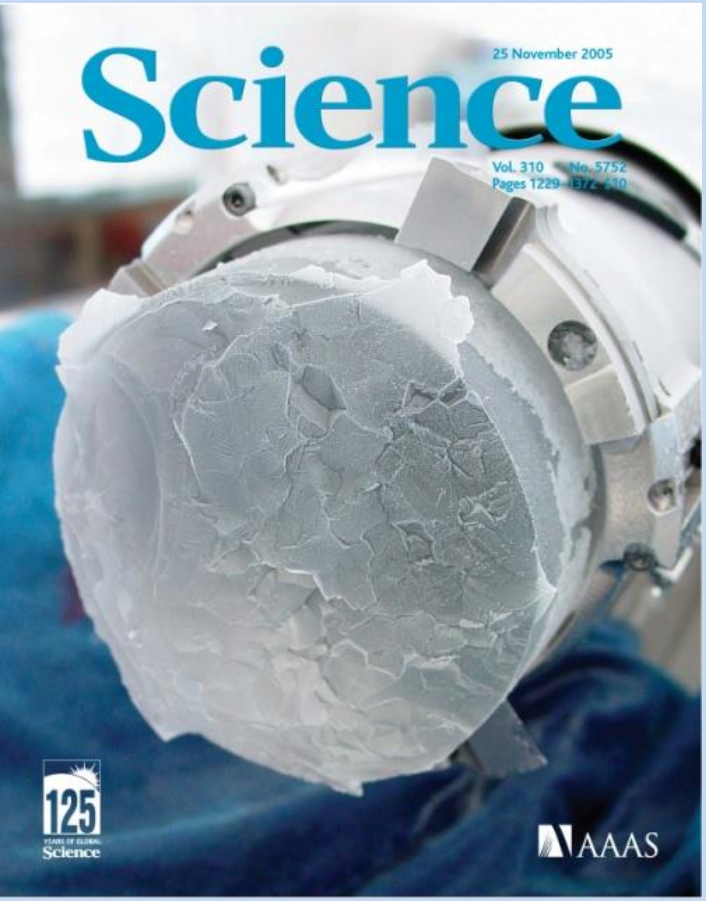
^{18}O levels extending back to ~50,000 years before present (b.p.) recovered from the Greenland Ice Sheet

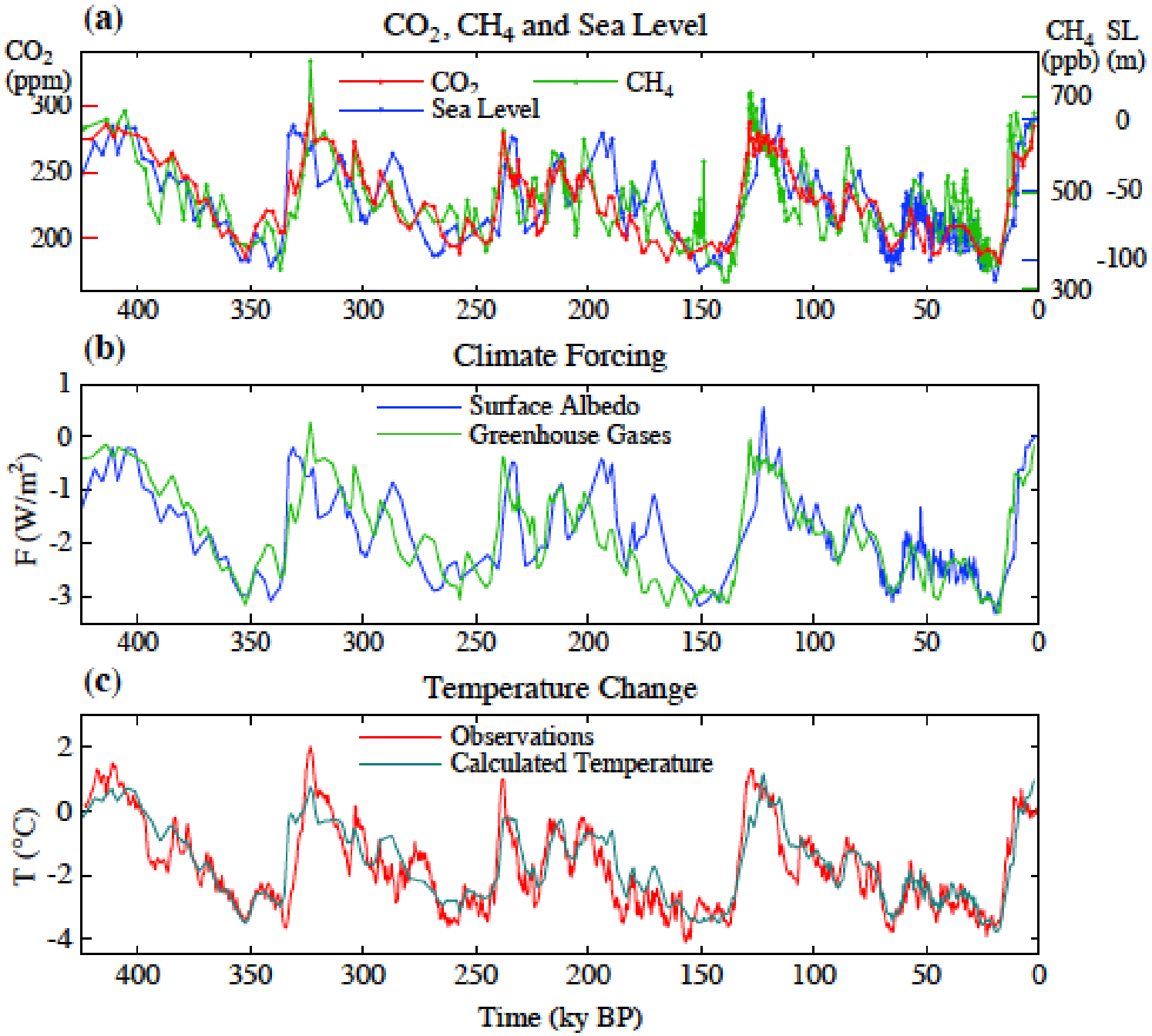

Central Greenland Climate
Medieval warm period
Little ice age
Abrupt Change
15°C increase in
less than a decade
Tem perature (degreas C)
-30
-40
-50
-60
Accumulation (m ice/year)
0.25
0.15
0.05
0
5
10
15
Age (thousand years before present)

Variability at the thousands of millennia time scale

Glacial and interglacial periods

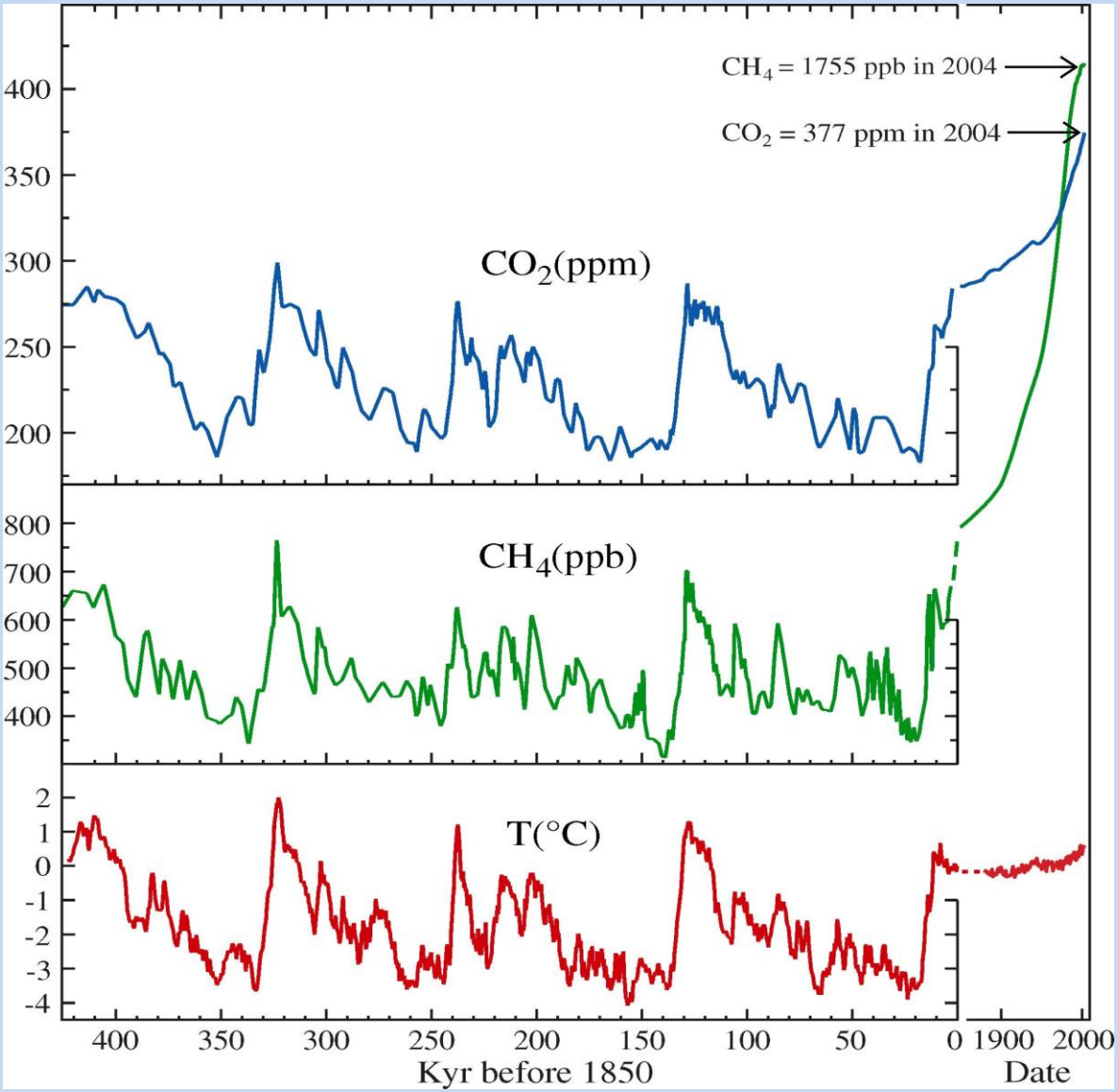
What does an ice core look like?



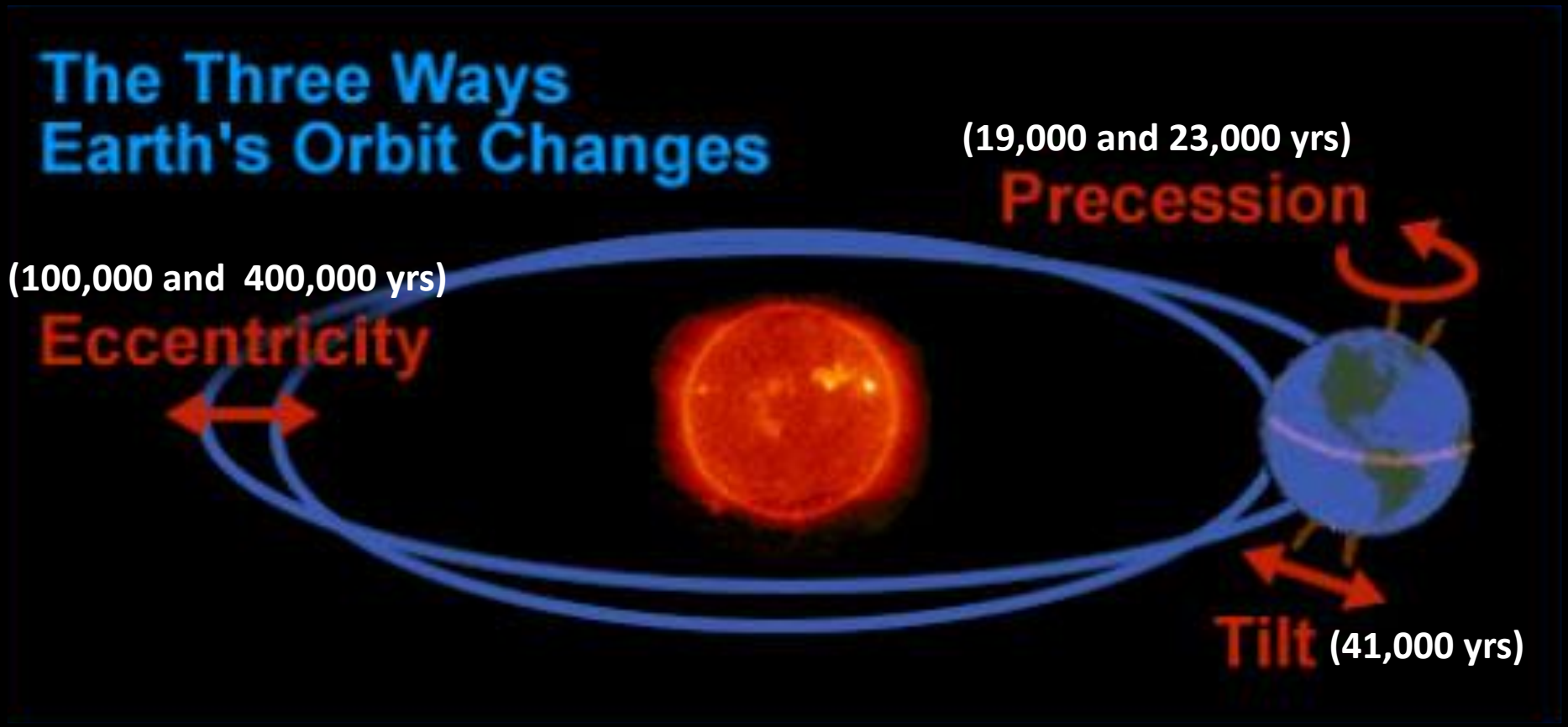

(a)
CO2, CH4 and Sea Level
CO2 (ppm)
CH4 (ppb)
SL (m)
CO2
CH4
Sea Level
300
250
200
700
500
300
0
-50
-100
400
350
300
250
200
150
100
50
0
(b)
Climate Forcing
Surface Albedo
Greenhouse Gases
F (W/m2)
1
0
-1
-2
-3
(c)
Temperature Change
Observations
Calculated Temperature
T (°C)
2
0
-2
-4
Time (ky BP)

CO_2,CH_4 and estimated global temperature (Antarctic $\Delta T/2$ in ice core era) 0 = 1880-1899 mean.

Source: Hansen, *Clim. Change*, **68**, 269, 2005.

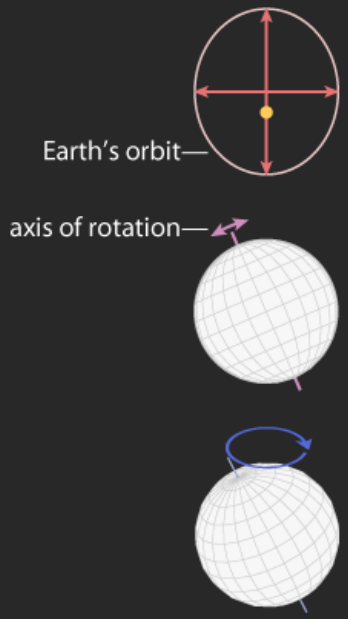


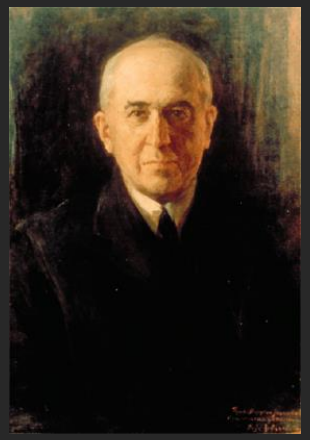
Natural Variability and the Variation of the Orbital Parameters

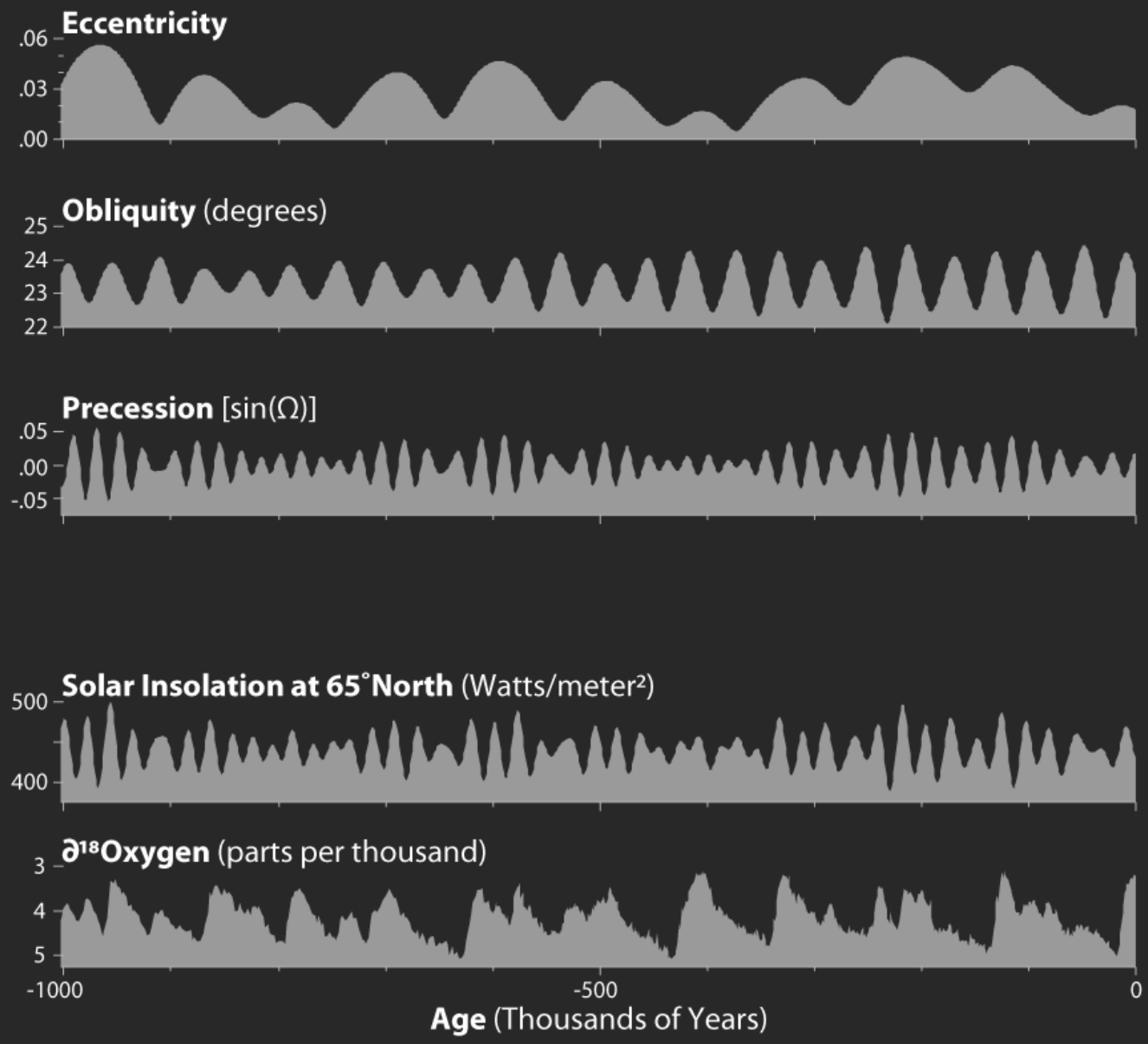


Orbital variations are producing changes in the seasonal and latitudinal distribution of incoming solar radiation at the top of the atmosphere.

Orbital Variations, insolation at 65º N and Milankovitch theory







What causes the glacial and interglacial periods?

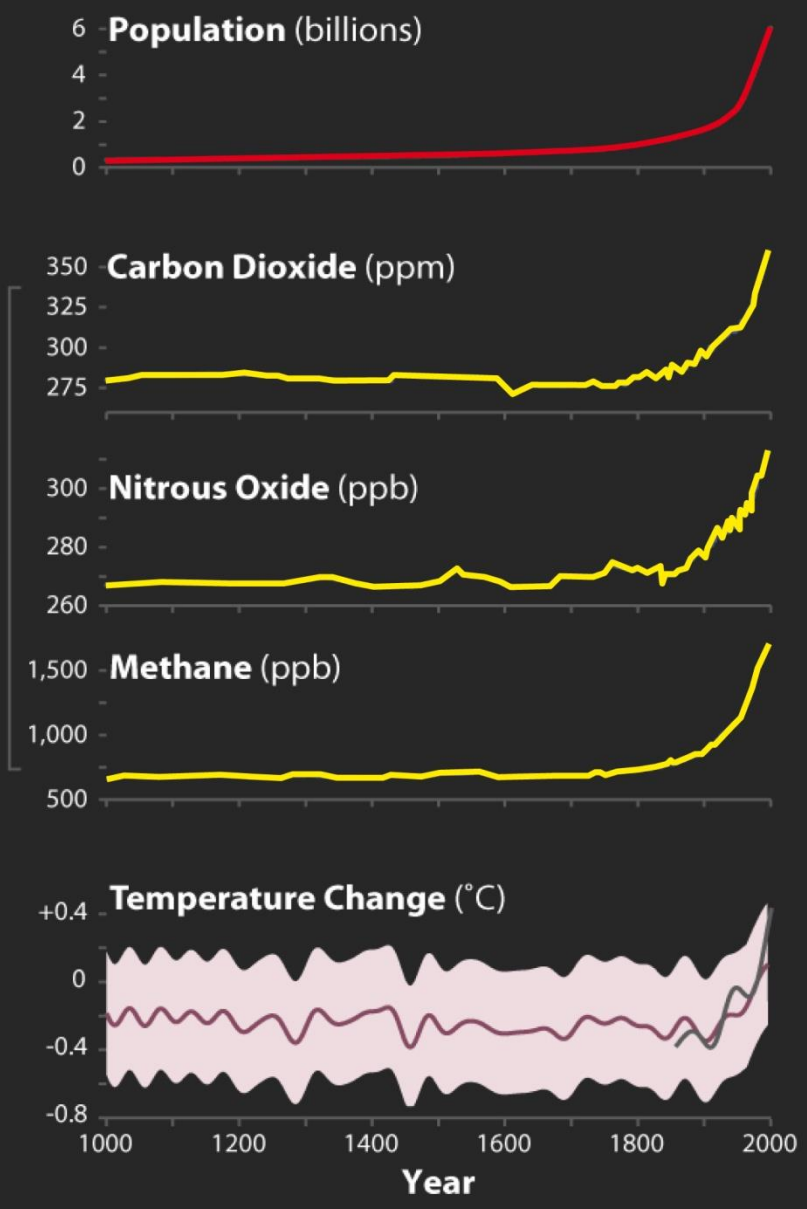
- Milankovitch was the first to recognize the perfect agreement between the ice-age cycles and the variations in the Earth orbit

- Further, he recognized that the solar insolation at 65º North displays a complex structure that includes the periodicities due to orbital variations

- Milankovitch theory: ice ages are triggered by minima in summer insolation near 65^0 N, enabling winter snowfall to persist

To which extent are humans responsible for changes in climate?

Human Fingerprints on the Climate

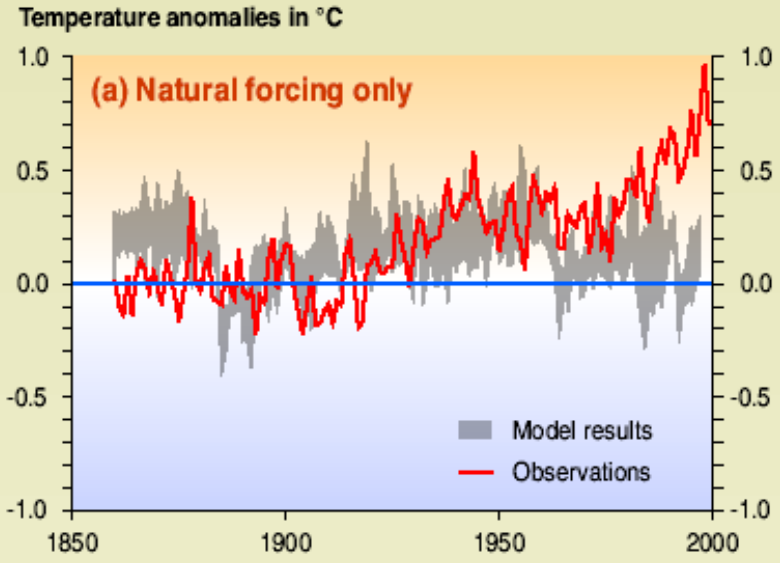


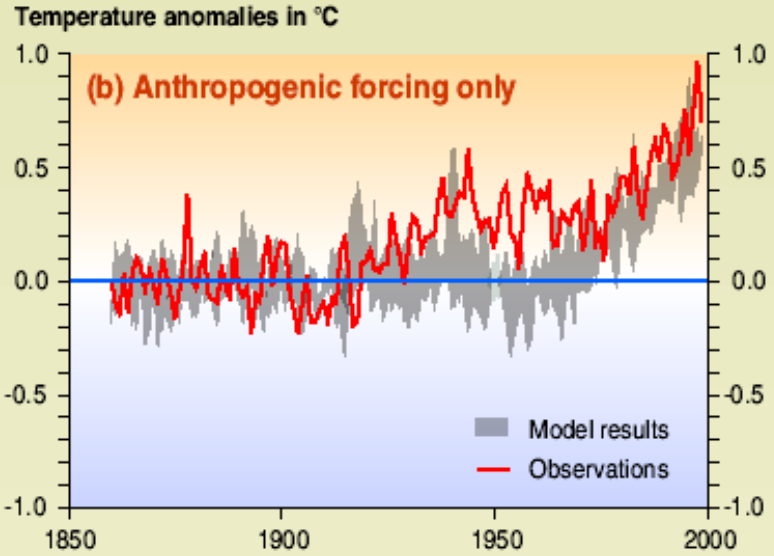
Population doubled & then doubled again over the last century, from 1.65 billion to almost 7 billion inhabitants.

- The rise in the three most abundant persistent greenhouse gases mirrors the growth in human population.
- Isotopic analysis and carbon cycle models established that the increase in carbon dioxide was due to fossil fuel consumption.

With the rise in those greenhouse gases, Earth experienced an unusually rapid rise in its average temperature—increasing ~0.75˚ C since 1880.

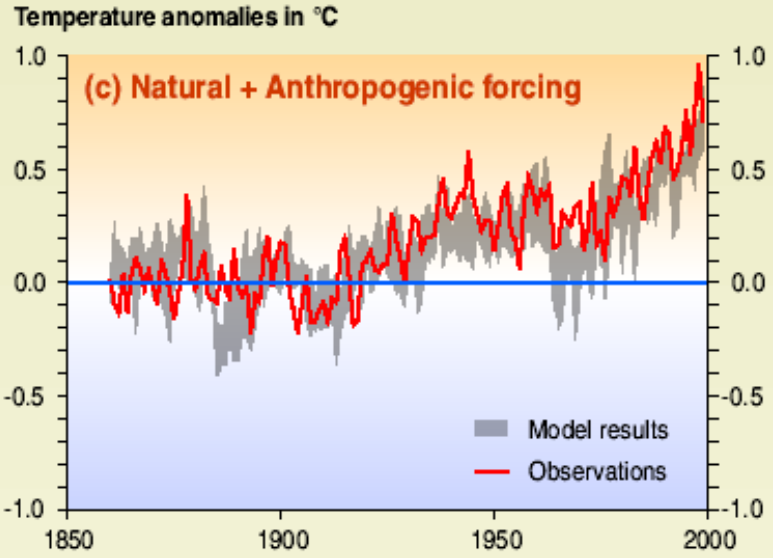
Comparison between modeled and observations of temperature rise since the year 1860





Solar variation and volcanic activity

GHGs and aerosols



Such results suggest that anthro forcings provide plausible explanation for a substantial part of the obs temp change over the past century.

Radiative forcings are imposed perturbations of the Planet's energy balance, which tends to alter its temperature

- Climate forcings internal to the Earth's System:
  - Tectonic movements
  - Volcanic emissions
  - Changes in albedo
  - Changes in chemical composition of the atmosphere
  - Changes in the ocean circulation
  - Changes in the Earth's orbital parameters

- Climate forcings external to the Earth's System:
  - Changes in solar radiation

- Climatic forcings related to human presence:
  - Increase in population
  - Increase in standard of living
  - Use of fossil fuels and other energy sources

The Planet is a complex system:

Feedbacks

and

Tipping points

FE

Climate feedbacks and tipping points

- Positive feedbacks: mechanisms that reinforce and accelerate initial changes in climate
- Negative feedbacks: mechanisms that offset initial changes in climate
- Tipping points: climate configurations that when reached are irreversible, i.e., unstoppable

An example of a positive feedback: Amplification of change in the Arctic

- There are four main reasons for positive feedbacks in the Arctic:
  - ➢ Due to sea ice melting:
    - ✓ Temperature increases ➔ White sea ice melts ➔ ocean water exposed ➔ more heat absorbed ➔ temperature increases
  - ➢ Due to Greenland ice sheet melting on land:
    - ✓ Temperature increases ➔ Greenland ice melting ➔ wet surface exposed ➔ more heat absorbed ➔ temperature increases
  - ➢ Due to snow melt on land:
    - ✓ Temperature increases ➔ dry snow melts on land ➔ wet surface exposed ➔ more heat absorbed ➔ temperature increases

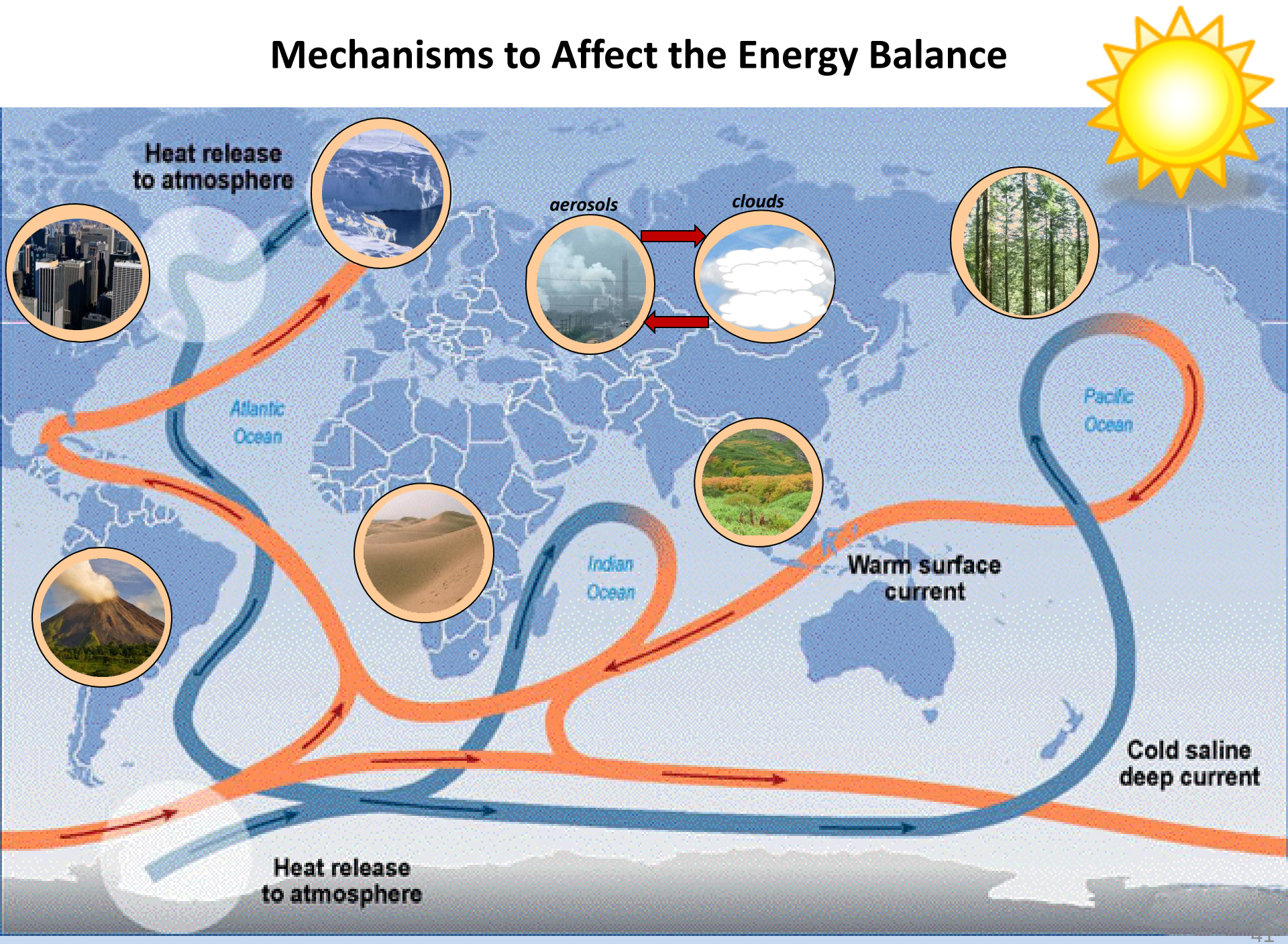
An example of a positive feedback: Amplification of change in the Arctic

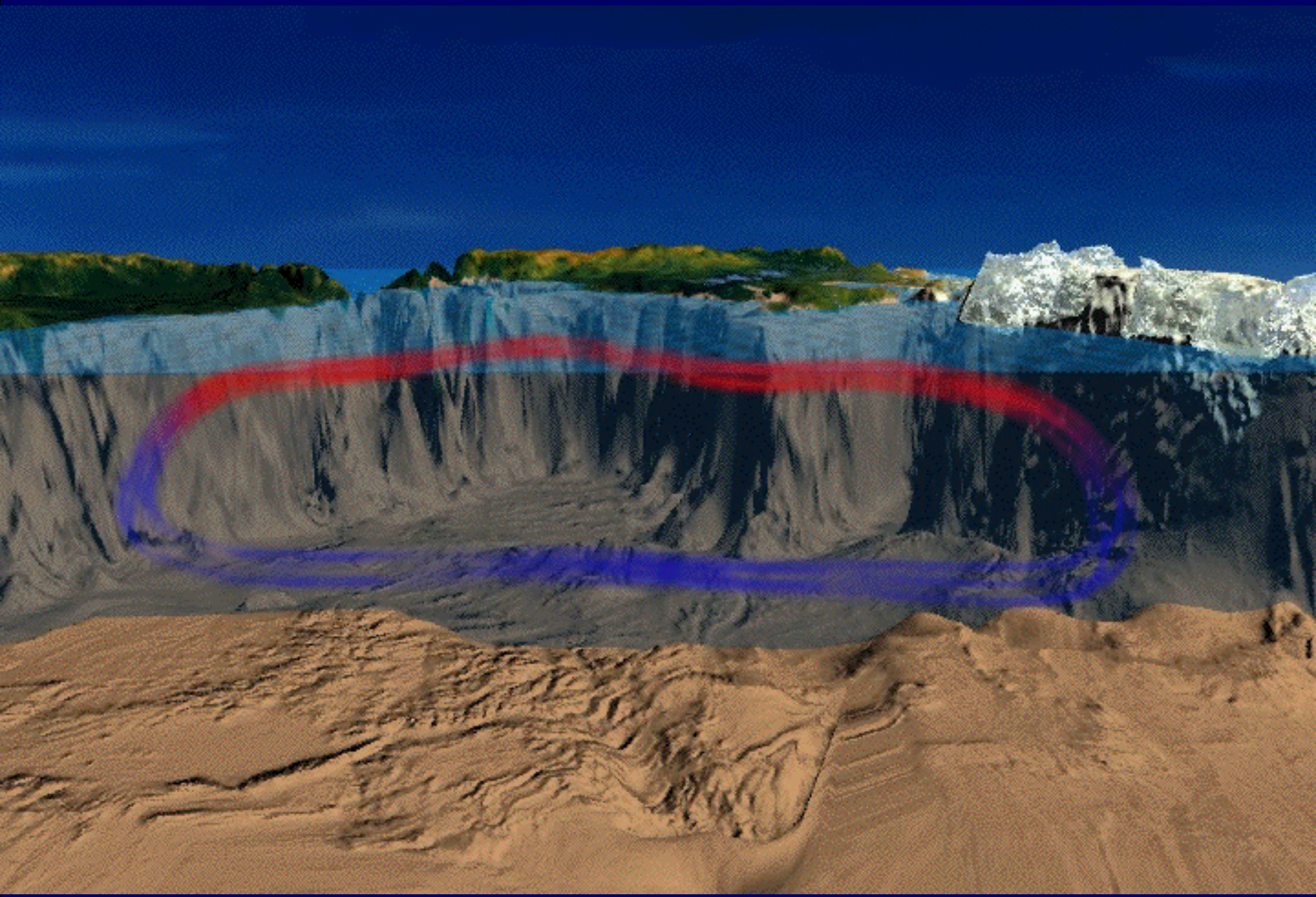
- Due to warmer snow having smaller albedo:
  - ✓Temperature increases ➔ warmer snow ➔snow grains larger ➔ larger absorption cross section ➔ lower albedo

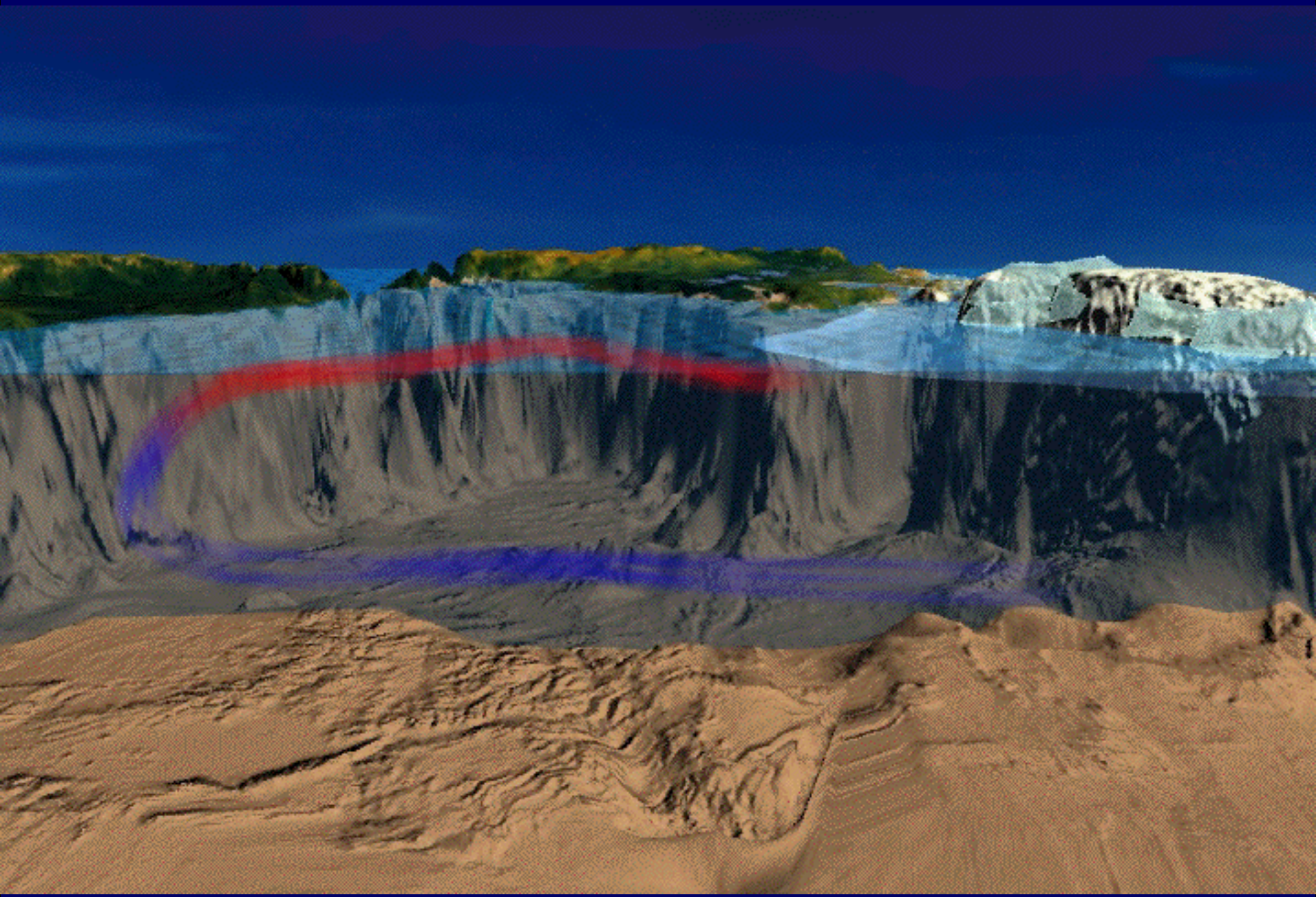
Tipping points are climate configurations that when reached are irreversible, i.e., unstoppable

- The great ice sheets on Greenland and Antarctica accelerate the melting
- The West Antarctic ice sheet begins to collapse
- Thawing of the permafrost accelerates

Mechanisms to Affect the Energy Balance







How will Climate Change evolve?

A difficult question because the Earth System is complex and we do not know how humans will continue to contribute:

- ✧ The source of the Greenhouse gases
- ✧ The nature of the feedbacks
- ✧ The critical points of the Earth System
- ✧ The cost associated with reducing the warming are difficult to evaluate

Sources of Greenhouse gases

Gas	Natural source	Anthropogenic source
Carbon dioxide (CO_2)	Terrestrial biosphere Oceans	Fossil fuel combustion (coal, petroleum); Cement production Effect of land-use modification
Methane (CH_4)	Natural wetlands Termites Oceans and freshwater lakes	Fossil fuels (natural gas production, coal mines, petroleum industry, coal combustion) Enteric fermentation Rice paddies Biomass burning Landfills Animal waste Domestic sewage
Nitrous oxide (N_2O)	Oceans Tropical soils (wet forests, dry savannas) Temperate soils (forests, grasslands)	Nitrogeneous fertilizers Industrial sources (adipic acid/nylon, nitric acid) Effect of land-use modification (biomass burning, forest clearing) Cattle and feed lots
Chlorofluorocarbons (CFCs)		Rigid and flexible foam Aerosol propellants Teflon polymers Industrial solvents

Eight Major Climate Risks mentioned in the 2013 IPCC Report

- Death or harm from coastal flooding
- Harm or economic losses from inland flooding
- Extreme weather disrupting electrical, emergency, or other systems
- Extreme heat, especially for the urban and rural poor

Eight Major Climate Risks mentioned in the 2013 IPCC Report

- Food insecurity linked to warming, drought, or flooding
- Water shortages causing agricultural or economic losses
- Loss of marine ecosystems essential to fishing and other communities
- Loss of terrestrial and inland water ecosytems

Some additional findings mentioned in the last HPCC report

- Current concentrations of CO_2 far exceed the levels observed for at least 650,000 years
- The best estimate of the global temperature increase from 1900 to 2100 is between 1.8 and 4.0 ^{0}C depending on assumed scenario
- The range of estimates of sea-level rise over the twenty-first century is between 18 and 60 centimeters depending on assumed scenarios but excluding the effects of large ice sheets disintegration

Some findings findings mentioned in the last HPCC report

- Temperatures are expected to rise more rapidly over land and much more rapidly in the Arctic
- The Arctic ocean is expected to be largely ice free during the summer by the end of the twenty-first century and it might occur much sooner
- The intensity of hurricanes is expected to increase
- Increasing atmospheric CO_2 concentrations will lead directly to acidification of the oceans

Some important findings from the last HPCC report and recent scientific results

- Many regions will see more hot days and fewer cold days, but the evidence on other extreme events is still unclear

- Major uncertainties exist on the role of aerosols. They can cool/warm the climate by reflecting/absorbing solar radiation. They can also affect the climate by influences cloud formation and evolution, a role not yet fully understood

Some important findings from the last HPCC report and recent scientific results

- The intensification and frequency of occurrence of severe storms and hurricanes may occur
- Down spouts may increase
- The frequency of occurrence and length of droughts may increase
- The frequency of occurrence of floods may increase

The future will depend on the answers to the following questions:

- How rapidly will the world population grow?
- How much energy will we use?
- How will energy be produced in fifty years?
- Will electricity be produced using nuclear power plants?
- Will be economically convenient to use renewable energies sources such as solar, wind and geothermal?

The future will depend on the answers to the following questions

- What will the role be of the developing countries?
- Don’t developing countries have the same rights to improve their standards of living the way we did?
- How will we modify the surface of our planet?
  - ✓Deforestation
  - ✓Increase of urban centers
  - ✓Agricultural developments

The future will depend on the answers to the following questions

Other questions exist regarding processes in nature that may or may not depend on human activities:

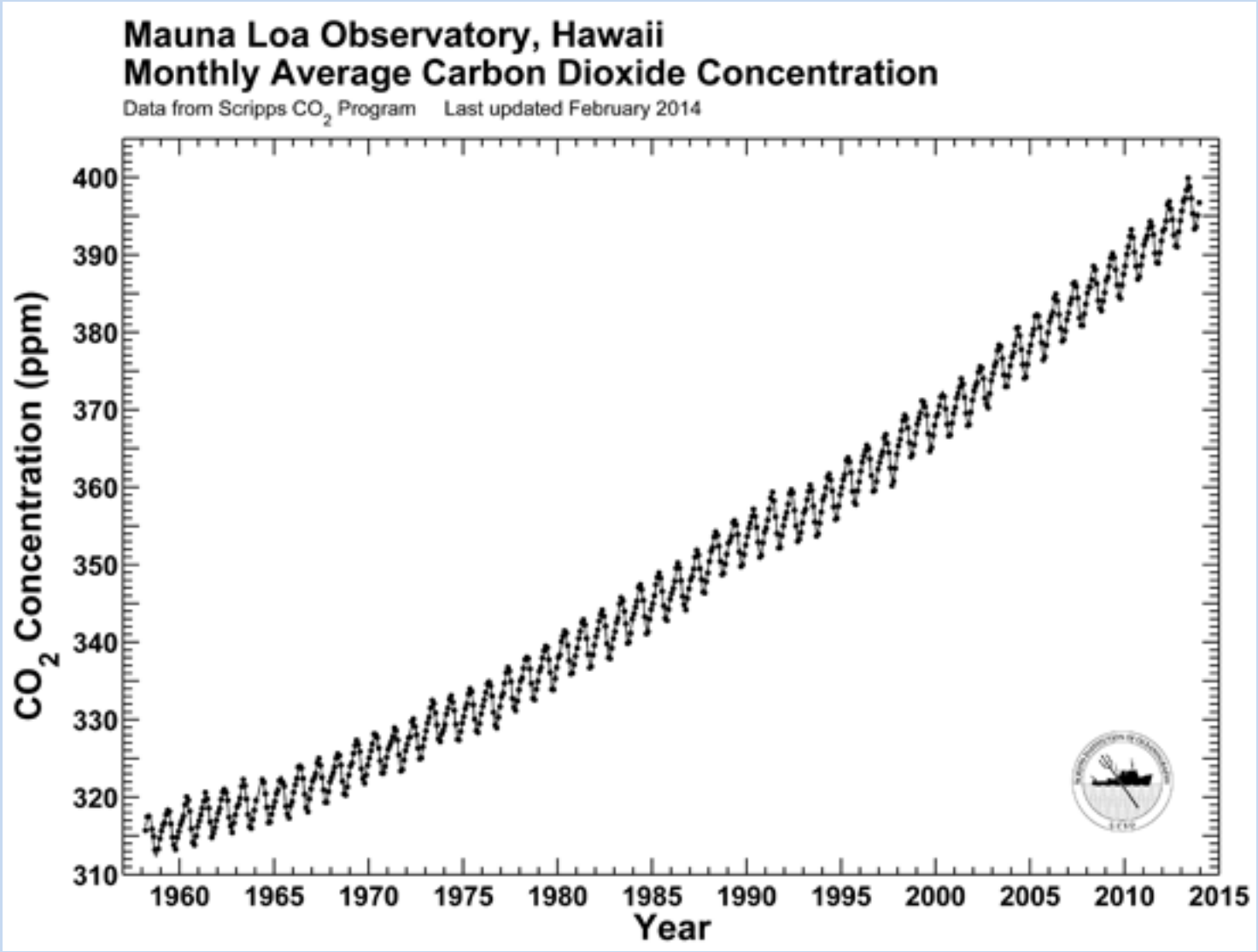
- How rapidly will sea ice in the Arctic Ocean continue to melt?
- How will proceed the melting of ice in Western Antarctica?
- How rapidly will ice sheets continue to melt?
- How rapidly will see level continue to increase?
- How strong will the feedbacks be?

What can we do?

- Continue to study the processes of climate change and to monitor its evolution
- Continue the identification and economic production of new energy sources
- Improve the efficiency of existing technologies and activities
- Develop new technologies

Costs to reduce climate change are

difficult to evaluate


Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration
Data from Scripps CO2 Program Last updated February 2014
CO2 Concentration (ppm)
400
390
380
370
360
350
340
330
320
310
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year

Is human kind carrying out an experiment?

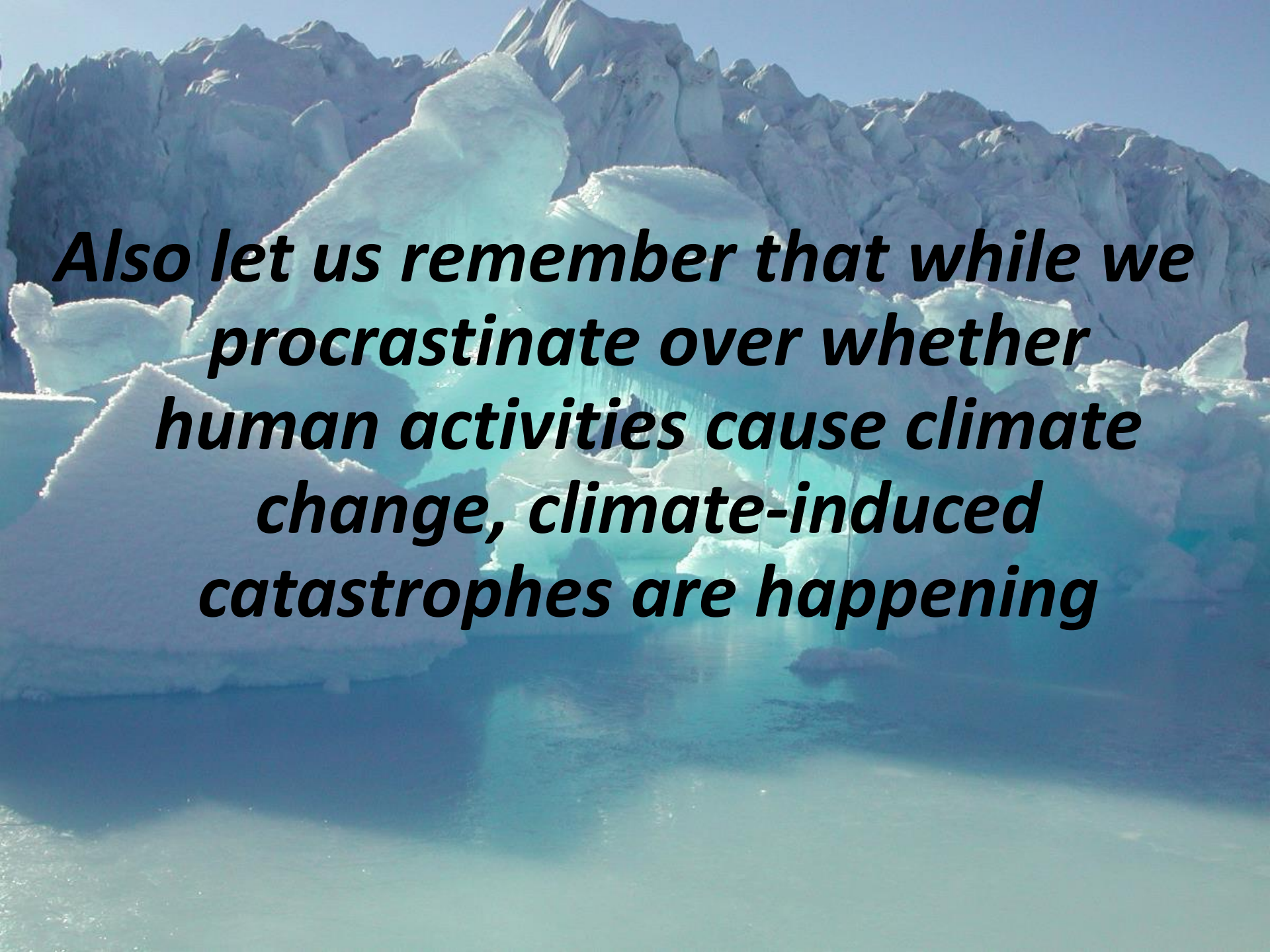
"Is the mean temperature of the ground in any way influenced by the presence of the heat-absorbing gases in the atmosphere?"

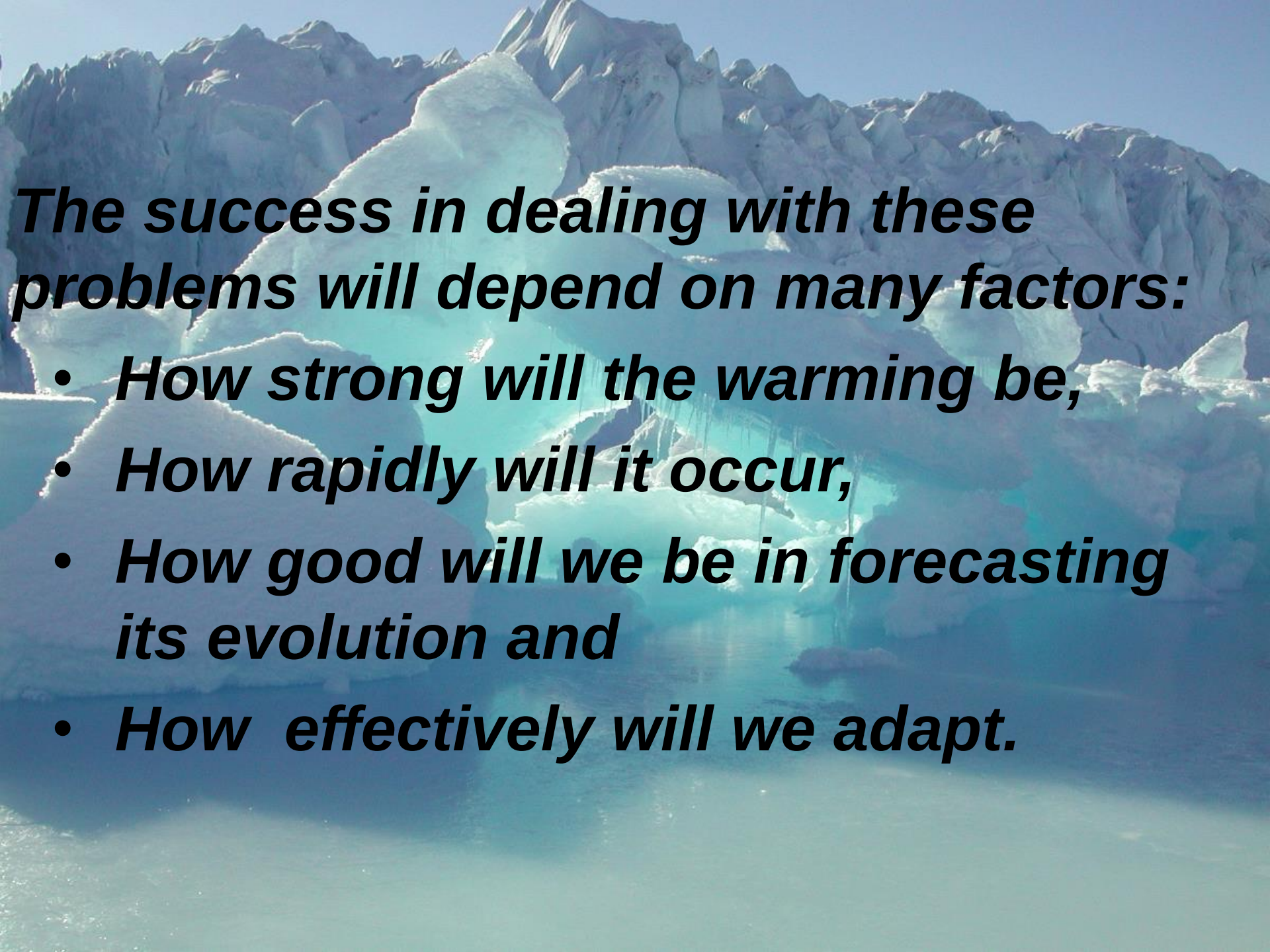
Svante Arrhenius, Journal of Science, 1896

" By increasing "carbon acid" we may hope to enjoy ages with more equitable and better climates."

Svante Arrhenius, Journal of Science 1908


The Earth's environment is changing and we are entering unfamiliar territory.


Also let us remember that while we procrastinate over whether human activities cause climate change, climate-induced catastrophes are happening



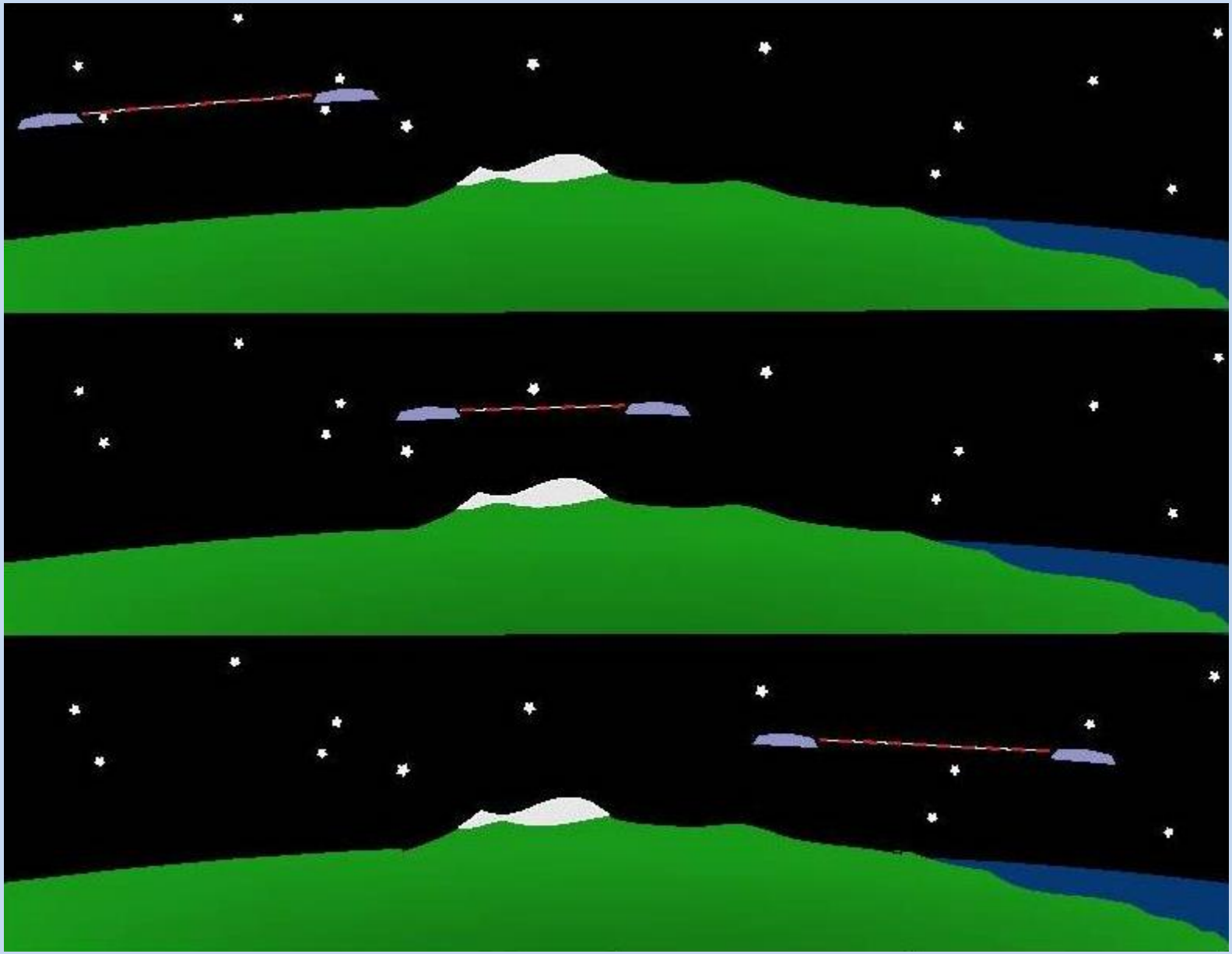
The success in dealing with these problems will depend on many factors:

- ***How strong will the warming be,***
- ***How rapidly will it occur,***
- ***How good will we be in forecasting its evolution and***
- ***How effectively will we adapt.***

Gravity Recovery and Climate Experiment (GRACE)

- Two identical spacecrafts fly in a polar orbit about 220 kilometers apart and 500 kilometers above Earth.
- The ranging system is sensitive enough to detect separation changes as small as 10 micrometers
- As the twin GRACE satellites circle the globe 15 times a day, they sense minute variations in Earth's gravitational pull
- When the first satellite passes over a region of slightly stronger gravity, a gravity anomaly, it is pulled slightly ahead of the trailing satellite
- The distance between the satellites increases
- When the first spacecraft passes the anomaly, it slows down
  The second spacecraft accelerates and then decelerates over the same point

GRACE Intersatellite Ranging



Thank you