Climatic Variability

July 14th, 2021

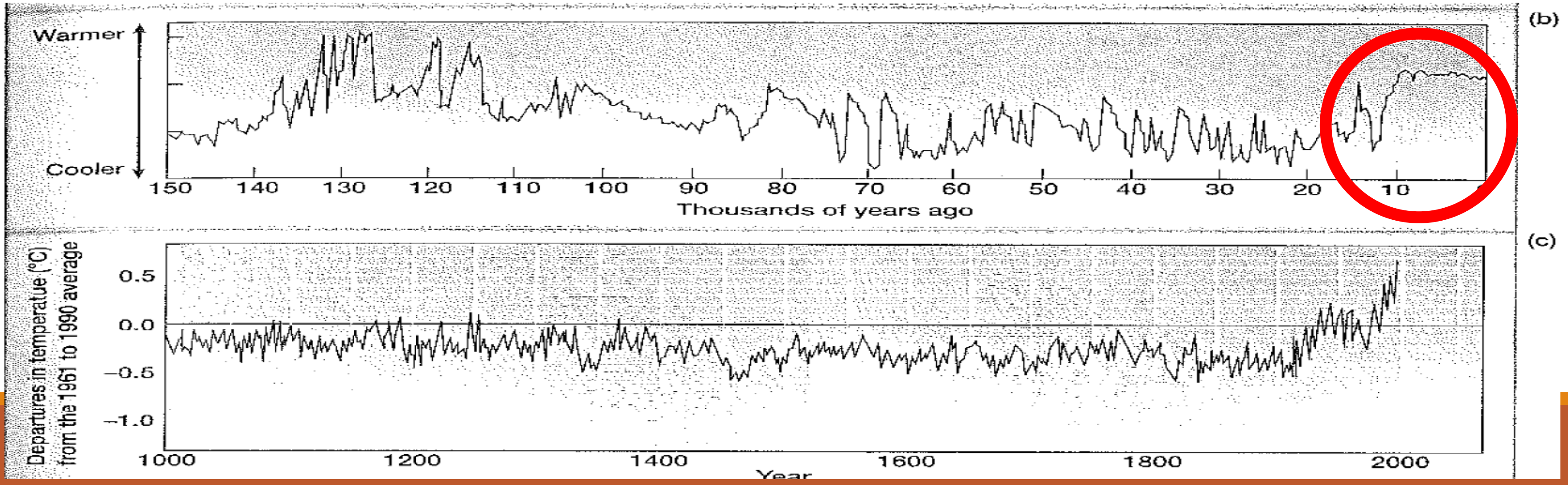
Global Climate Change

There are always fluctuations in weather from year to year.

Time scale of observations influence what kind of patterns stand out in the climate record.

Patterns that have been observed:

- Over the last 150,000 years, temperatures fluctuated significantly until about 100,000 years ago when temperatures increased sharply.
- 10,000 years, sharp warm up
- Over the last 150 years a warming trend appears underway.



The Nature of Global Change

A. Systemic Global Change

Change operating a global scale, e.g. global changes in climate brought about by atmospheric pollution, i.e. the enhanced greenhouse effect.

B. Cumulative Global Change

Snowball effect of local changes – add up to produce change on a worldwide scale.

Change that has significant effect on a global resource.

Turner *et al*. 1990

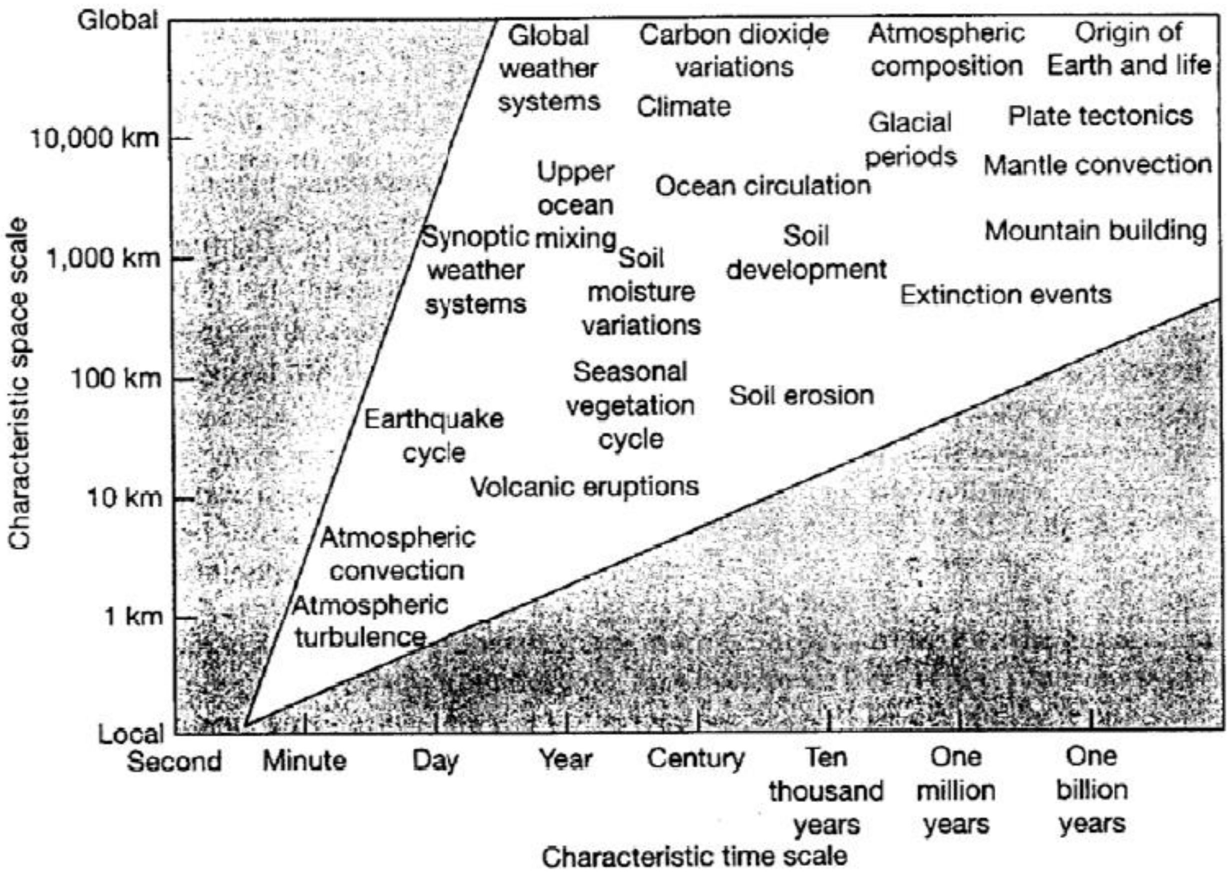
Table 1. Types of global environmental change.

Type	Characteristic	Examples
Systemic	Direct impact on globally functioning system	(a) Industrial and land use emissions of 'greenhouse' gases (b) Industrial and consumer emissions of ozone-depleting gases (c) Land cover changes in albdeo
Cumulative	Impact through worldwide distribution of change	(a) Groundwater pollution and depletion (b) Species depletion/genetic alteration (biodiversity)
	Impact through magnitude of change (share of global resource)	(a) Deforestation (b) Industrial toxic pollutants (c) Soil depletion on prime agricultural lands

Turner et al. 1990

Space and Time Scales

- Local vs regional or global
- Slow vs fast
- Changes vs variability
  - *Change implies unidirectional*
  - Variability implies shifts about some mean position
- Systems can exhibit both change and variability



Earth system processes grouped according to their space and time scales. The space scale is logarithmic, and the time scale is relative. (After Graedel and Crutzen, 1993.)

Mackenzie, 2003

Global Climate Change

Paleoclimatology

- the study of past climates.
- Proxy measures of climate (e.g., ice cores, tree rings)
- Proxy measures are used because detailed climate measurements only go back a few hundred years.

Proxy Records of Climate

1. **Ice Cores**

2. **Geological evidence**
   - Deep sea sediments
     - Fossils
     - Oxygen and carbon isotopes
     - Faunal and floral assemblages/abundance
   - Inorganic sediments

4. **Terrestrial sediments**

5. **Biological evidence**

6. **Historic evidence**

Proxy Record of Climate

Ice cores

National Ice Core Laboratory in Denver, CO

http://www.denverpost.com/news/ci_14451598

Greenland Ice Core

http://oceanworld.tamu.edu/resources/oceanography-book/evidenceforwarming.htm

Ice cores

- Russian and French Scientists collected the deepest cores from the Vostok base in Antarctica
- Provide 800,000 years of atmospheric data and eight glacial cycles
- U.S. and European teams drilled two cores in the Iceland ice cap

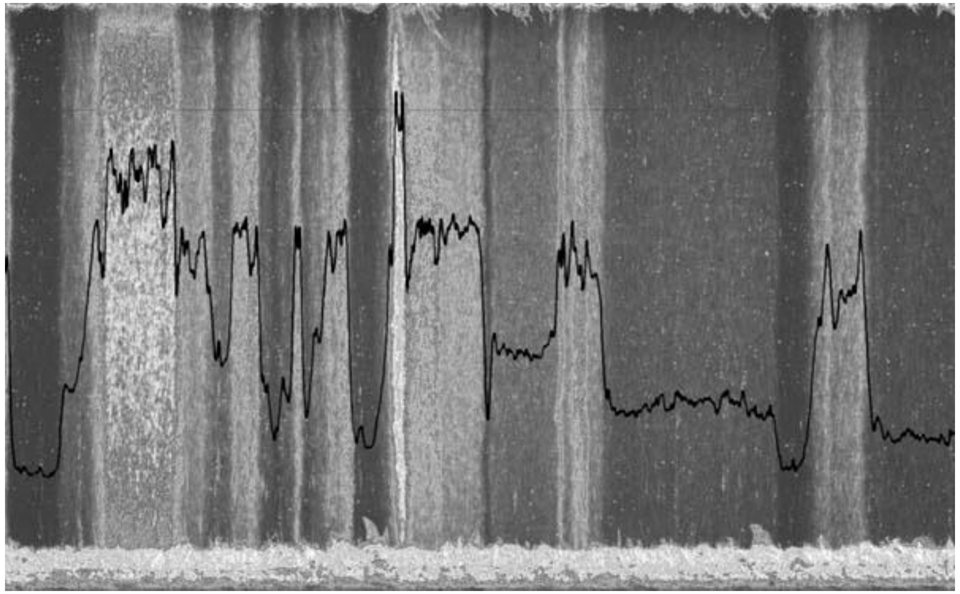
Ice cores

Analyze: **Ice, Meltwater, Air bubbles**

Oxygen isotopes:

- Stable isotopic composition, especially the ratio ($^{18}O/^{16}O$) where ^{18}O is the concentration of the oxygen 18 isotope, and ^{16}O is the concentration of oxygen 16 isotope, (and the concentration of deuterium).
- ^{16}O “light” and ^{18}O “heavy”
- The oxygen isotope ratio gives the temperature at which H_2O condensed as water or snow on the surface of the ice sheet.
- The warmer the air is when water vapor formed, the more ^{18}O there is.
- The ratio of the two isotopes in the ice depends on the temperature when the snow formed and fell on the ice
- Ratio can help us determine temperature patterns over time

Ice cores



Ice in a core collected from the North Greenland Ice Core Project showing annual layers of the ice from about 1800 m depth, which means the ice is about 20 000 years old. The curve shows the variations in light intensity measured by a line scanner showing the light intensity scattered from the ice. (2001)

http://www.ncdc.noaa.gov/paleo/slides.html

Ice cores

- Air bubbles, especially carbon dioxide, can give us an idea of what climate might have been at the time of ice formation

Physical properties of ice

- Sulfuric acid content tells us about ***volcanic*** activity
- Ice also contains pollen

Geological evidence

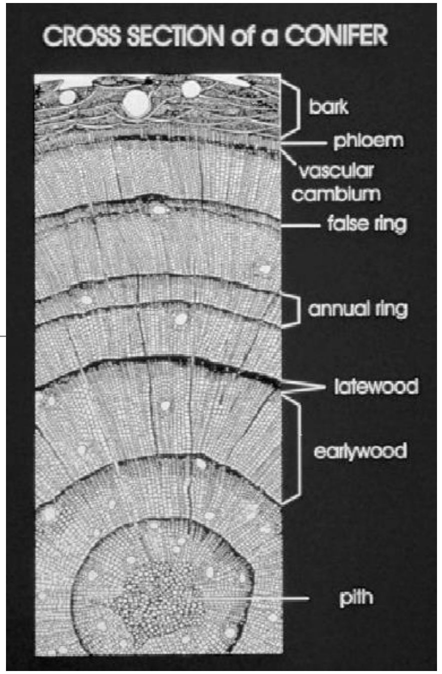
Deep sea sediments (cores of sea floor)

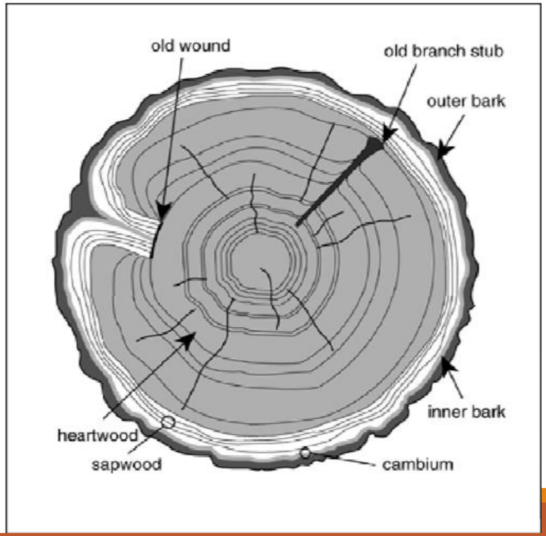
- Sediments and sedimentary rocks contain fossils of microscopic plants, animals and pollen which provide clues to climate and environmental conditions
- Oxygen and carbon isotopes
- Faunal and floral assemblages/abundance
    - Provide information on seawater temperature and composition and atmospheric composition
- Inorganic sediments
- Oxygen isotope can be used to infer surface temperature

Biological evidence

Tree Rings: the analysis of tree rings to provide information on past climates

Dendrochronology uses measurements of the width of tree rings to determine relative changes in environmental conditions influencing the growth of trees. Changes in width provide information on droughts and temperature changes



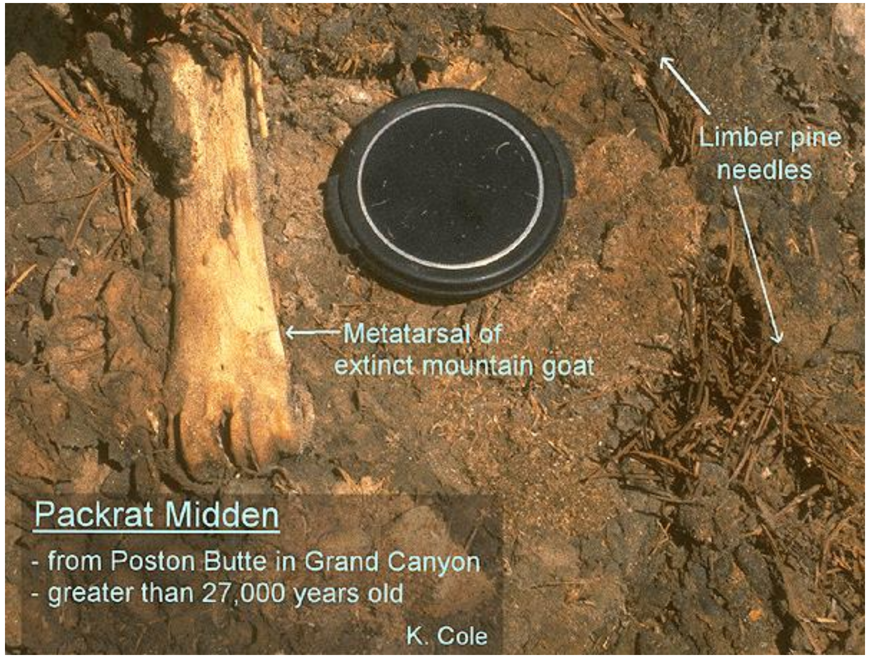


http://boojum.as.arizona.edu/~jill/EPO/Sun/Connections.html

Biological evidence

Pack-rat middens

Fossilized beetle species



http://sbsc.wr.usgs.gov/cprs/research/projects/global_change/images/hall.gif

http://sbsc.wr.usgs.gov/cprs/research/projects/global_change/middens.asp

Terrestrial sediments

Lake Varves: (like dendochronology, but with lake sediments - a varve is an annual layer of mud in the sediment)

Sediments that accumulated above sea-level

Lakes and Bays, for example, Chesapeake Bay area, Virginia, USA, and Lake Victoria, Africa

Fossils of *Bacteria*, *Archaea*, and *Eukarya* to understand carbon content

Biological evidence

Analysis of pollen

- Ancient lakes or peat bogs allow seasonal layering of pollen deposits
- Cores provide a layered representation of sediments in lakes to give the type of plants growing in the vicinity of the lake at different times.
- Types of plants depends on climate, and their types and abundance give information about past climates
- E.g. a high proportion of spruce pollen in the lower core may change to oak pollen at higher levels
  - This shows vegetation change over time
  - Spruce grows in cooler environments than oak, so the change from spruce to oak shows a change from cool to warm climates

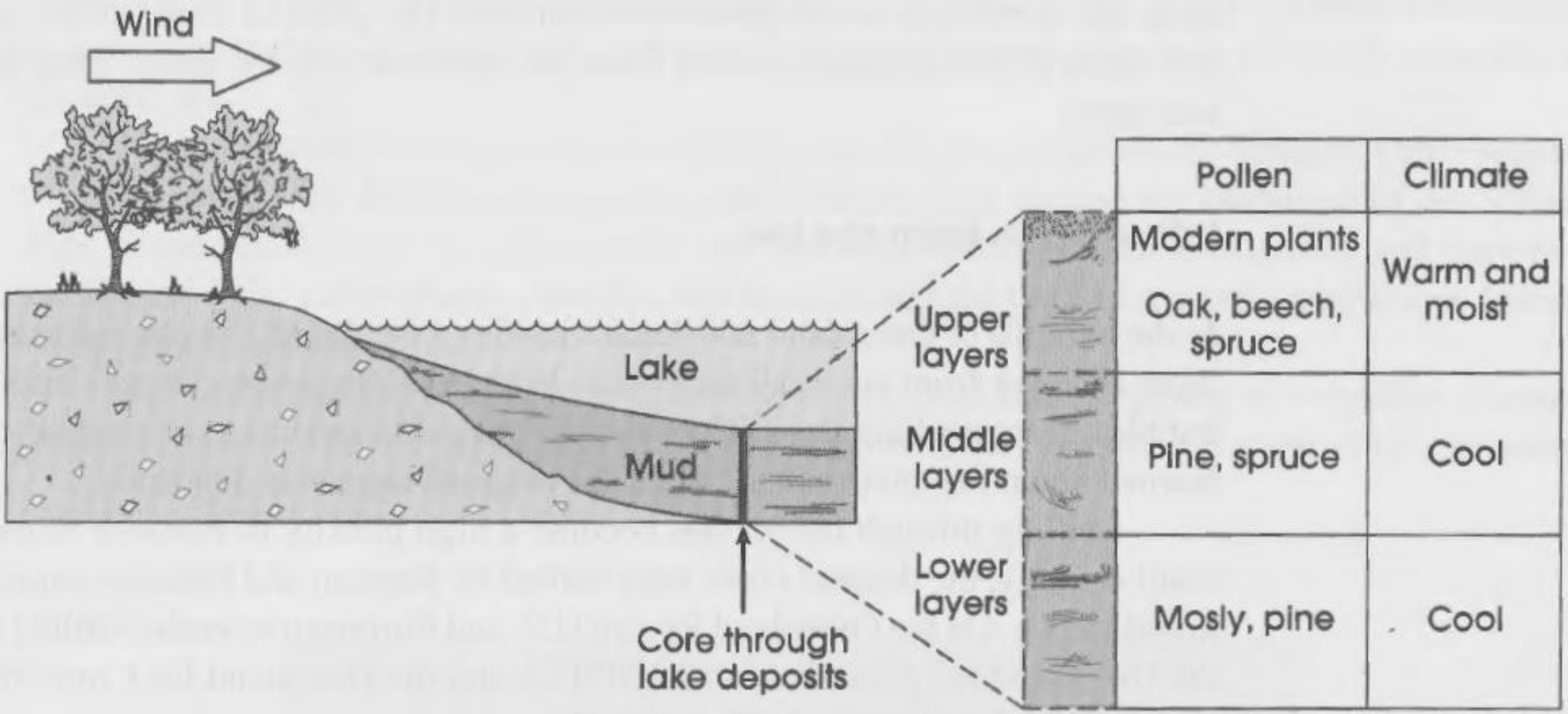


Figure 4.5 Simplified diagram showing the method of reconstructing past climates using pollen analysis. (From J. E. Oliver, *Climatology: Selected Applications*, Silver Spring, Md. V. H. Winston and Sons. p. 223.)

Pollen diagram

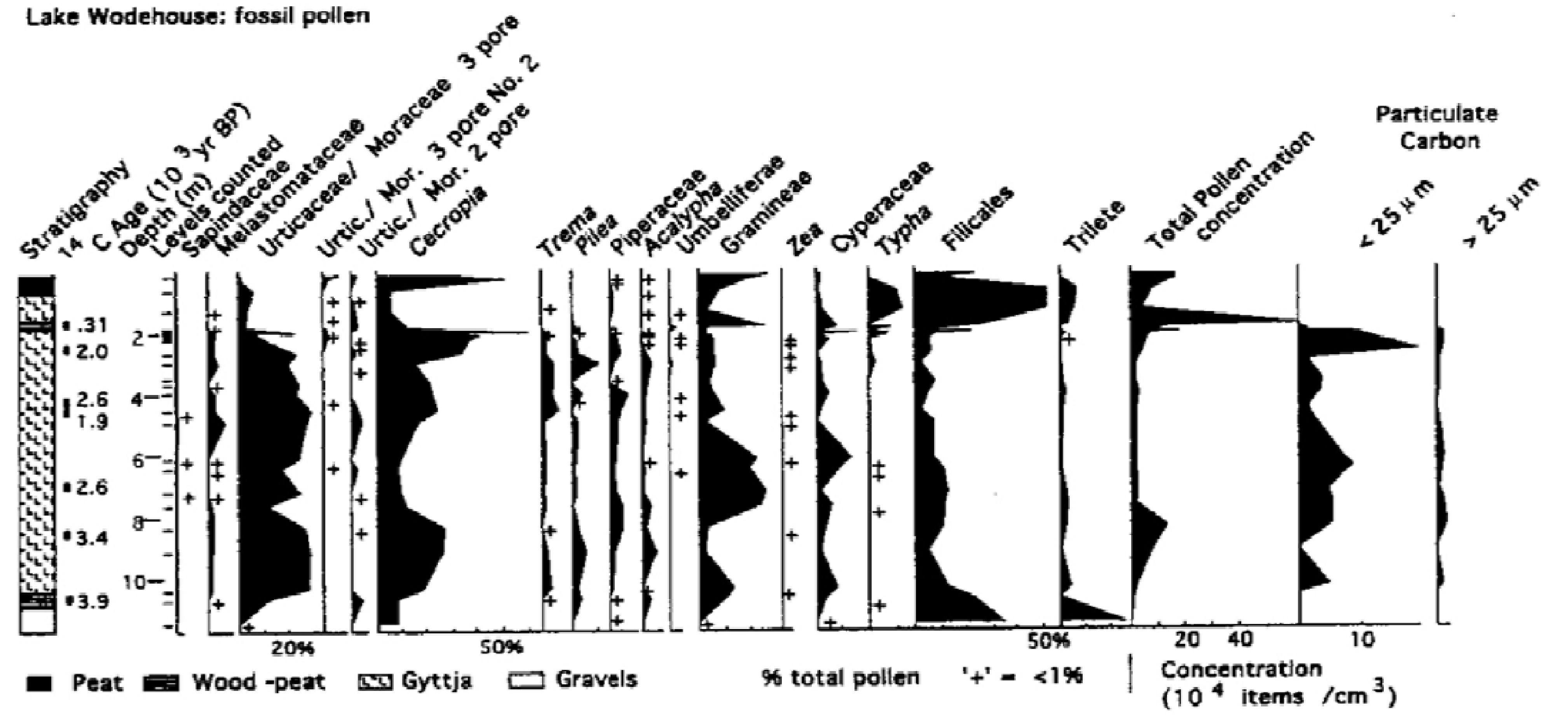


FIG. 3. Percentage data for selected pollen taxa and concentrations of total pollen and charcoal in sedimentary profiles from Lake Wodehouse, Panama.

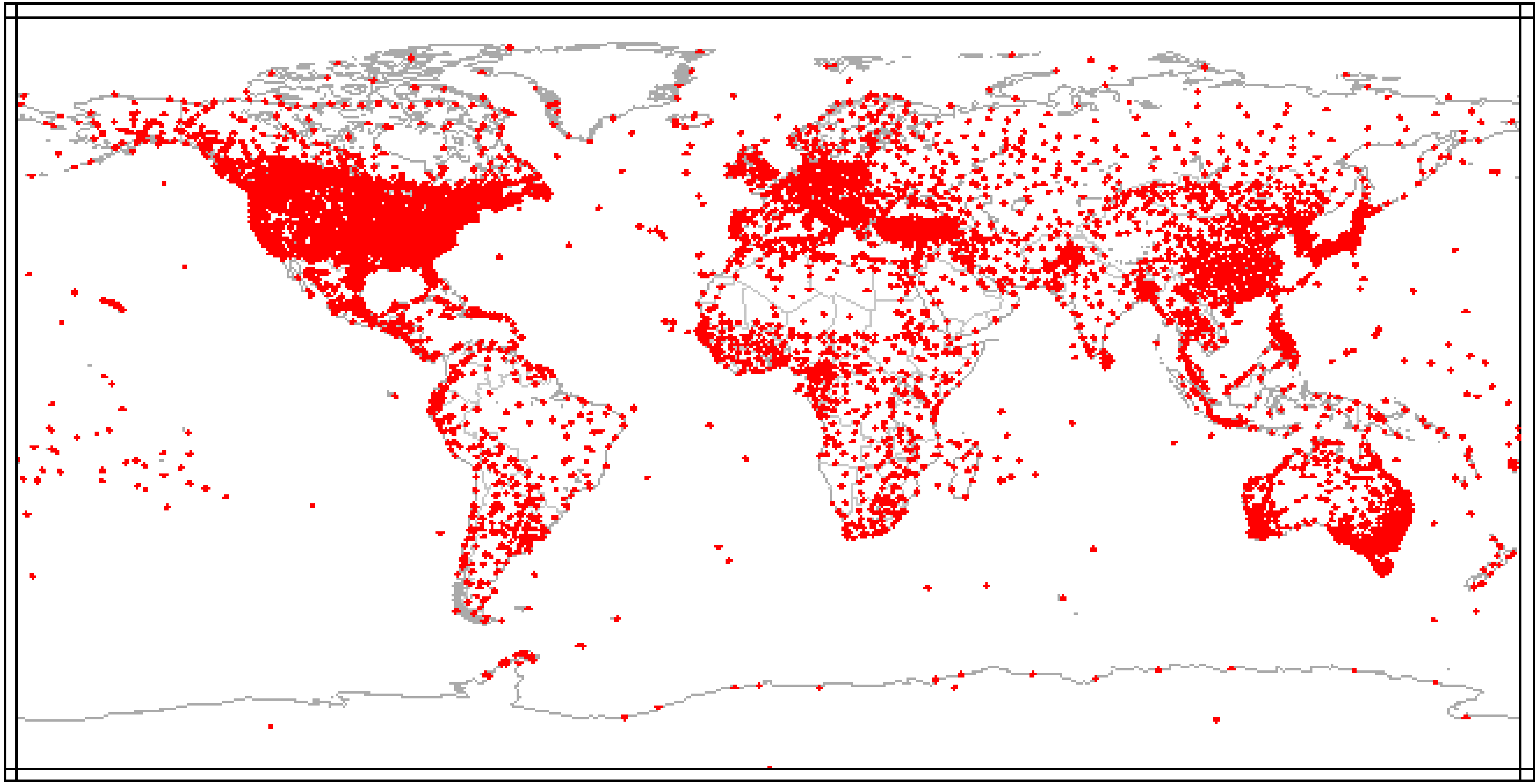
See similar paper here: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2311425/

Bush & Colinvaux 1994

Historic evidence

Ship’s logs: climatic records from China dating back 36 centuries, have provided a great deal of data on more modern climates.

Satellites, weather balloons, ships at sea, and land-based stations are employed to record temperature and other climatic variables to enable day – to-day weather forecasting and long-term climatic predictions.



Map of land stations in the Global Historical Climatology Network where air temperature was measured on land and islands. NOAA National Climate Data Center.

Factors influencing climate

Fluctuations in solar energy

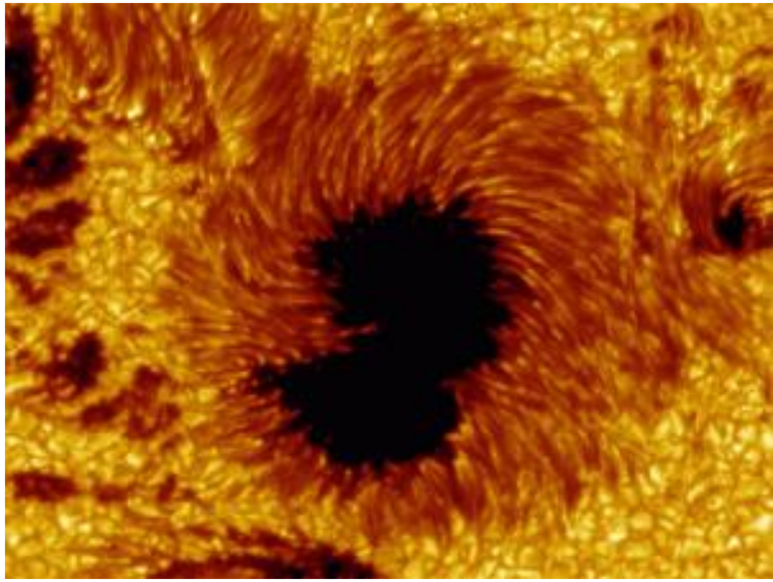
Earth's orbital parameters
- Obliquity/tilt of earth's axis
- Eccentricity of the orbit
- Precession of earth's axis

Albedo
- Aerosols
- Surfaces

Latitude*
Ocean currents*
Position of continents*
Stratospheric ozone*
(Enhanced) greenhouse effect*
***discussed already**

1. Fluctuations in solar energy

- Sun spot cycles
  - Basically dark spots on the sun that prevent solar energy from getting to the earth, but you get more solar energy coming to earth as the edges of the spots tend to be brighter emitting more energy.
  - Cooler (3000-4500 K(2727-4227 °C) than surrounding areas on the sun 5780 K (5500 °C)
  - Occur every 11 years or so
  - Earth's temperature changes (increases) by about 0.1°C with sunspots
  - Low sunspot periods linked to cooling
  - More sunspots = more energy and heat = warming



2. Earth's orbital parameters

Milankovitch 1920s suggested that these are important in understanding glacial cycles.

- Earth's Orbital Eccentricity
- Obliquity of the Plane of the Ecliptic
- Precession of Equinoxes

A. Eccentricity

- James Croll, 1860, suggested that the path Earth takes about the sun is not circular, but elliptical with the sun at one focus
- Eccentricity is the difference in the orbit from a true circle – varies in 100,000 years cycles
- Eccentricity influences the amount of solar radiation intercepted by Earth and changes the dates of the solstices and equinoxes
- These dates are the beginning of the four seasons

Part I / Geological Record of Global Change

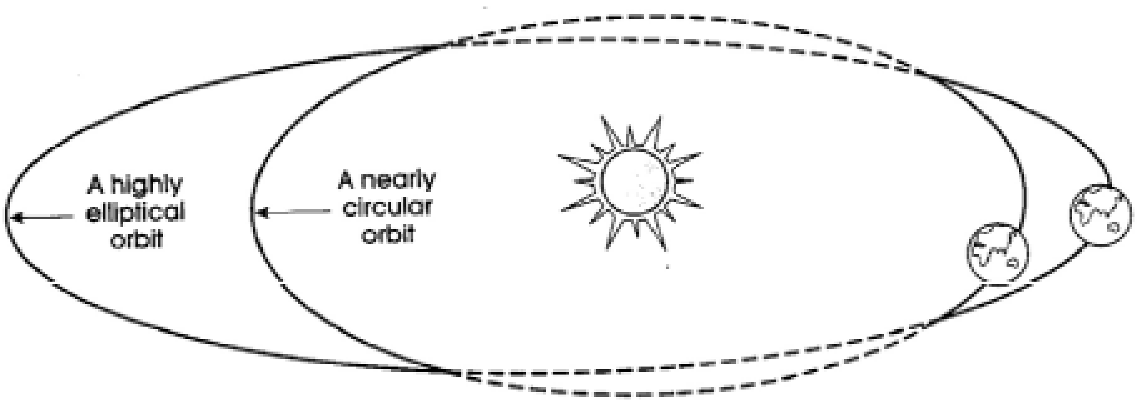


Figure 4.8 Changes in eccentricity of Earth's orbit. The period is about 100,00 years.

Hidore, 1996

B. Earth's tilt or obliquity

- The angle of the plane formed by the geographic equator and the plane in which the Earth revolves around the sun changes through time
- The angle varies around a mean value of 23.1º
- The variation is from 21º59' to 24º 36' over a period of 41,000 years.
- The present angle is about 23º27'.
- In 1904 astronomers hypothesized that changes in obliquity has far-reaching effects on climate

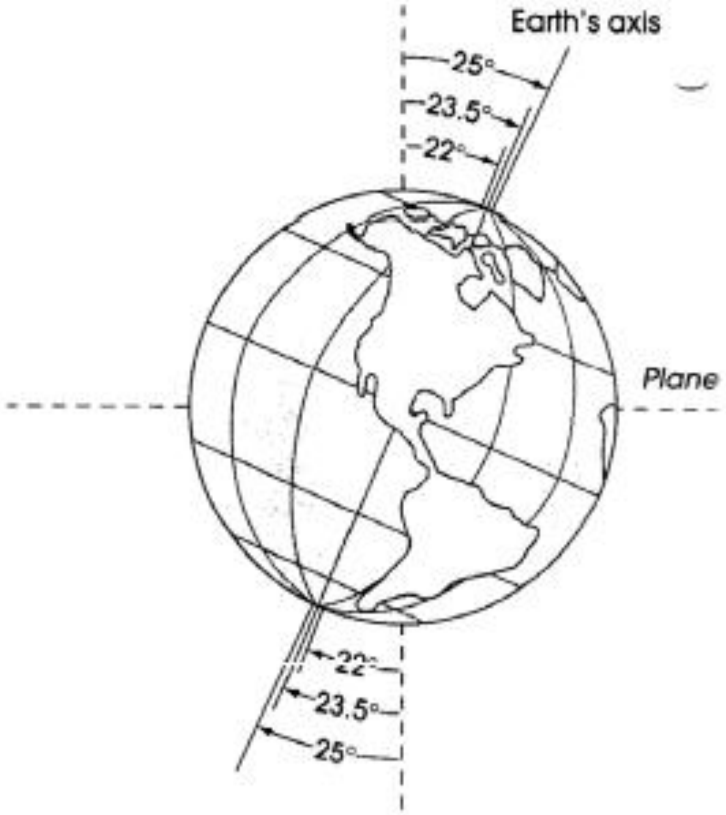


Figure 4.9 Changes in the angle of Earth's axis with the p... period is 41,000 years.

Hidore, 1996

C. Precession of the Equinoxes

- Earth wobbles a bit as it spins on its axis due to the gravity of the sun and moon pulling on the Earth's equatorial bulges.
- Earth's orientation changes over about 23,000 years, moving around in a complete circle.
- For the past several thousands of years, Earth's axis has been pointed north more or less toward ***Polaris***, also known as the North Star. But Earth's gradual precessional wobble means that Polaris is not always the North Star. About 5,000 years ago the Earth was pointed more toward another star, called ***Thubin, and*** in approximately 12,000 years will point toward Vega, which will become the next North Star.

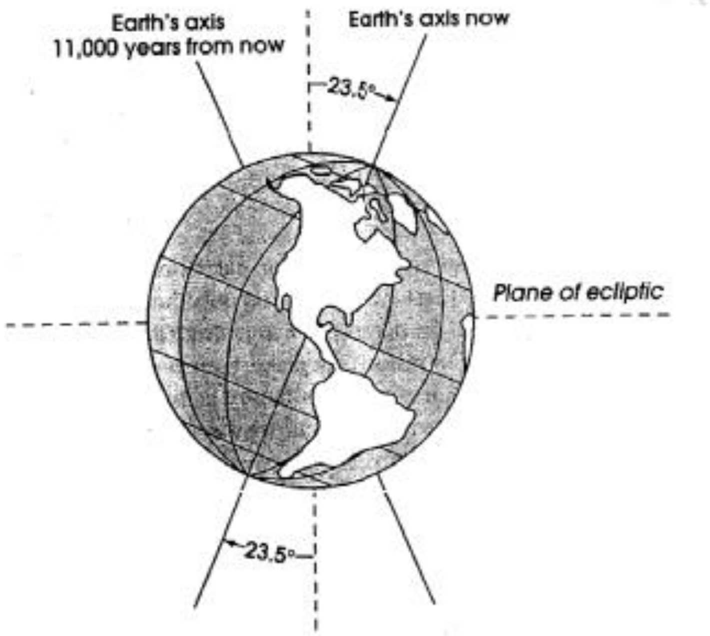


Figure 4.10 Changes in axial precession. The period is about 23,000 years.

C. Precession of the Equinoxes

- The time of year that Earth reaches its closest and farthest distance to the sun varies and the shift is important in the radiation balance of the Earth. Most of the land is in the northern hemisphere, and land and water respond differently to incoming radiation
- J.F. Adhimar, 1842, suggested that changes in precession occurs in about 23,000 years, a major factor for the ice ages occurring when earth is closes to the sun in the northern hemisphere summer, it increases the difference between the seasons.

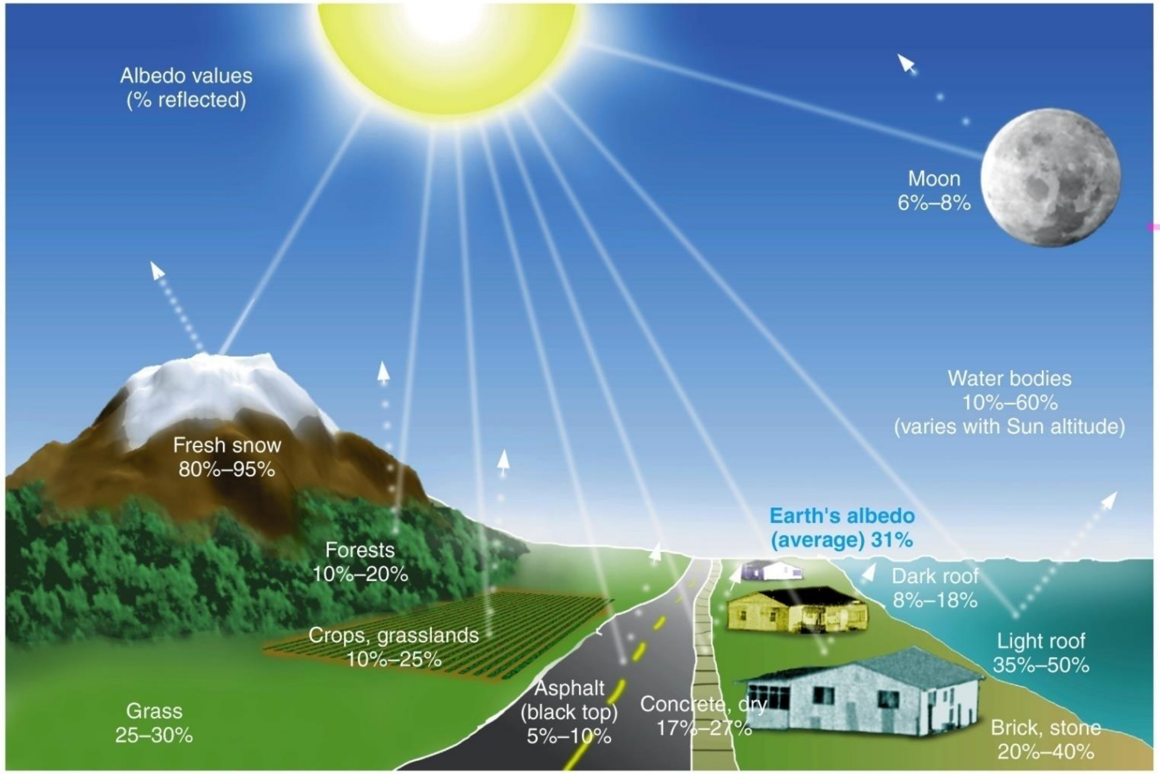
3. Ice-albedo feedback loop

Albedo is the ability of a surface to reflect insolation - the reflective quality or intrinsic brightness of a surface.

It is an important control over the amount of insolation that is available for absorption.

Stated in terms of the percentage of insolation that is reflected **(0% is total absorption; 100% is total reflectance).**

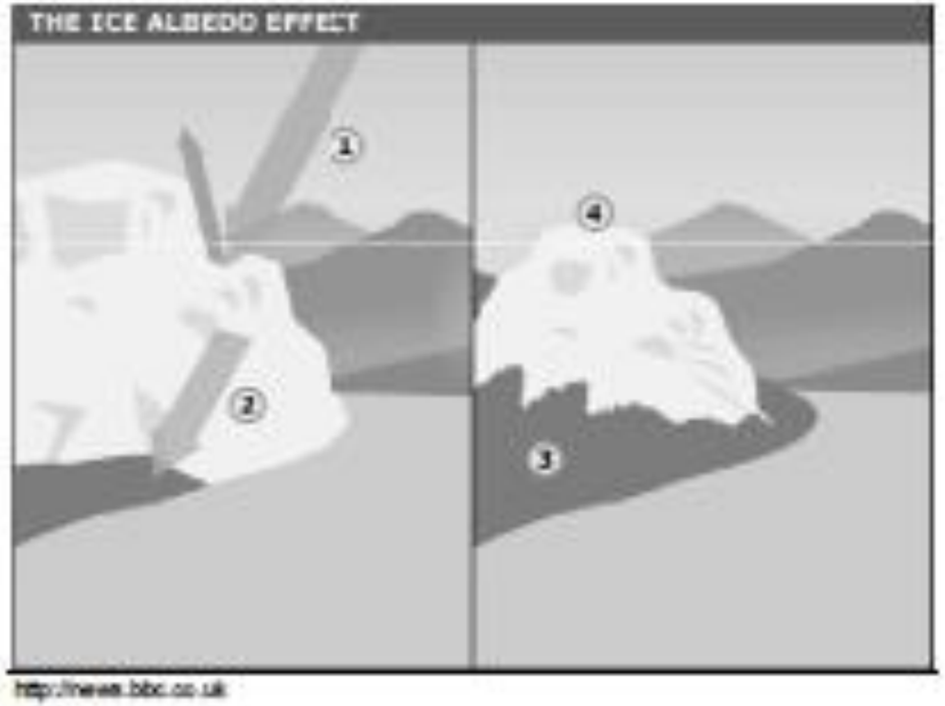
Primarily controlled by an object's colour



Ice-albedo feedback loop

Surfaces:

Warming leads to melting of ice, lowering of albedo, leading to further warming (positive feedback)



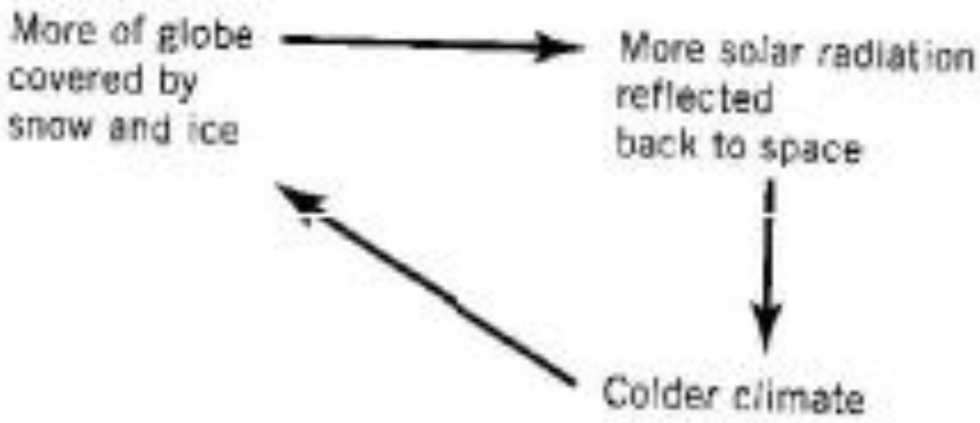
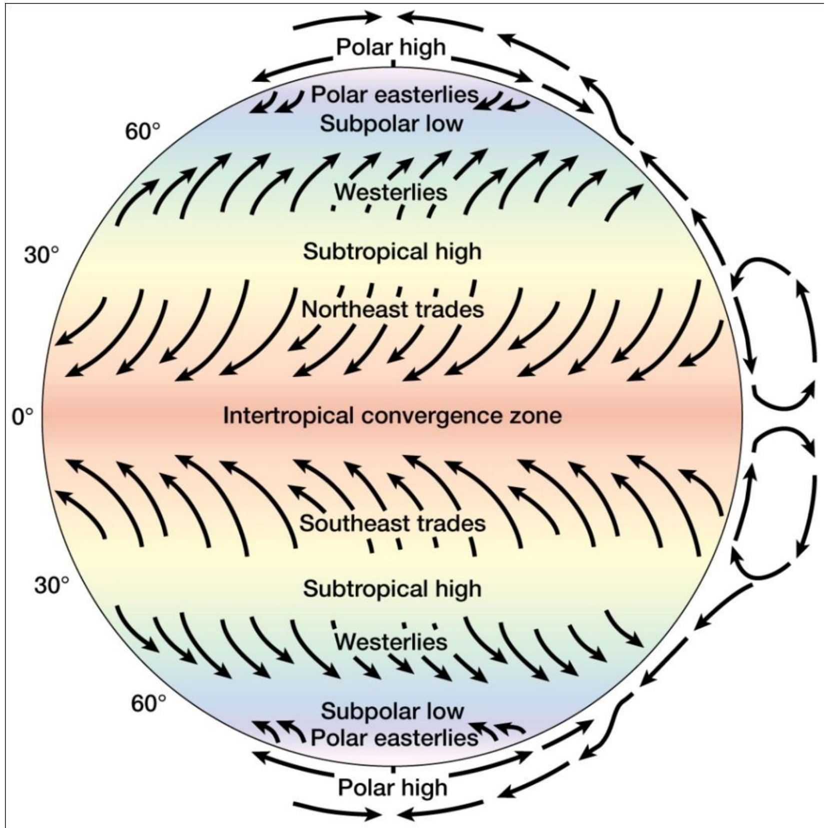


Figure 5.5 The ice-albedo feedback loop.

Latitude

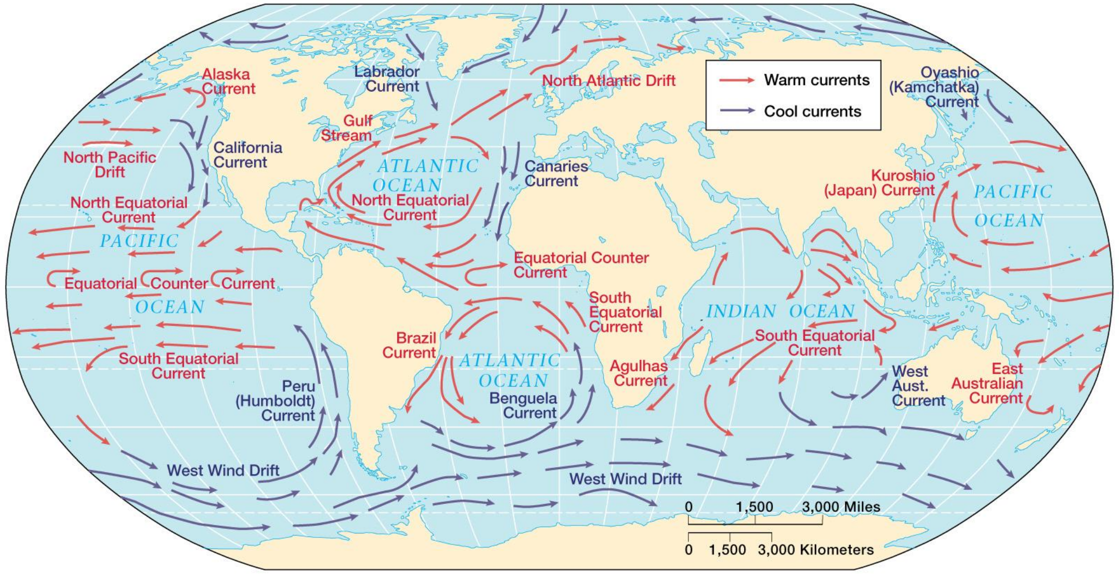
- ITCZ: Occurs at the location on earth receiving the most direct radiation
- ITCZ "shifts" to N. Hemisphere in our summer, and the S. Hemisphere in our winter (Syracuse, North America).



Ocean Gyres and Global Wind Patterns

East coasts have different climates from west coasts

Recall: the **west** coasts of continents tend to have cold currents offshore; whereas **eas**t coasts have warm currents (hence people swim at the Jersey shore, but not on the beaches of the Pacific Northwest).



Continentality:

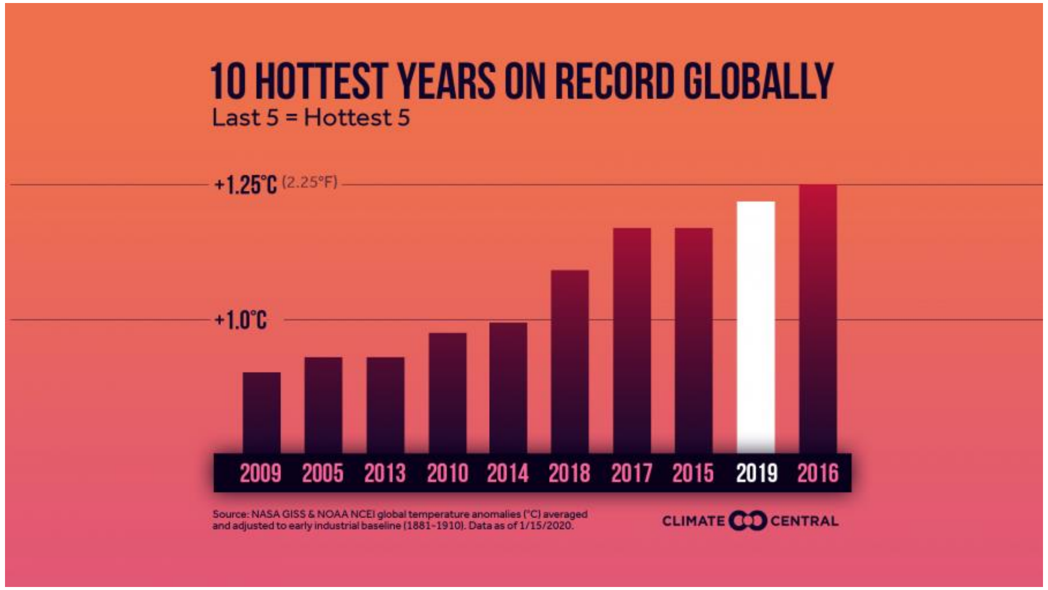
Proximity to the ocean moderates the seasonal variation in temperature

Consequences of change

Anthropogenic Climate Change

Evidence of current global warming

- The five warmest years in the global record have all come in the past five years
- The 10 warmest years on record have all come in the past 10 years!
- The 20 warmest years on record have all come since 1995
- Global temperature increasing at 0.13°C per decade
- Ocean temperatures increasing to depths of 9800 feet
- Sea level rise
- Temperatures in Arctic increasing at twice global rate

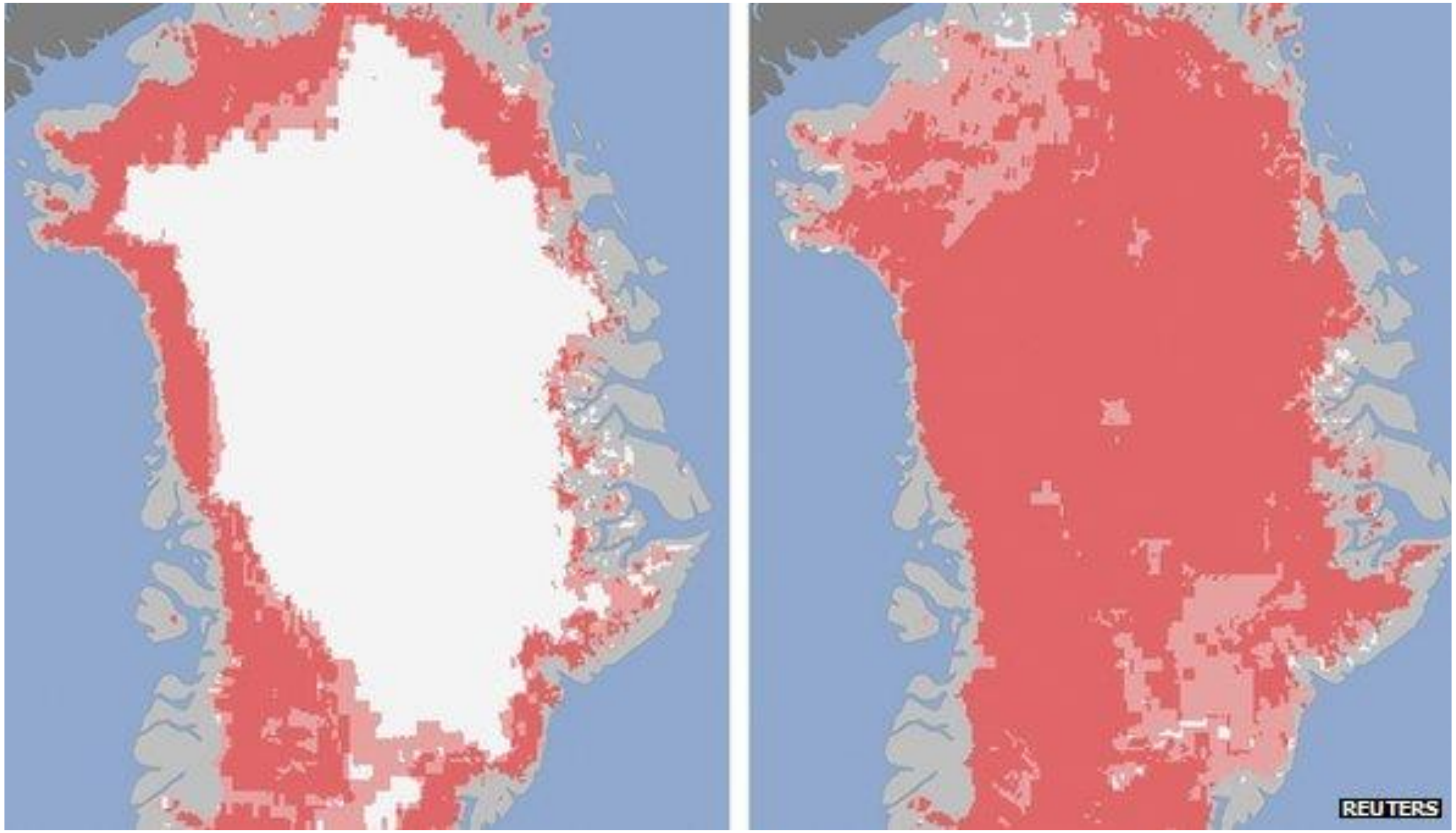


https://www.climatecentral.org/gallery/graphics/top-10-warmest-years-on-record

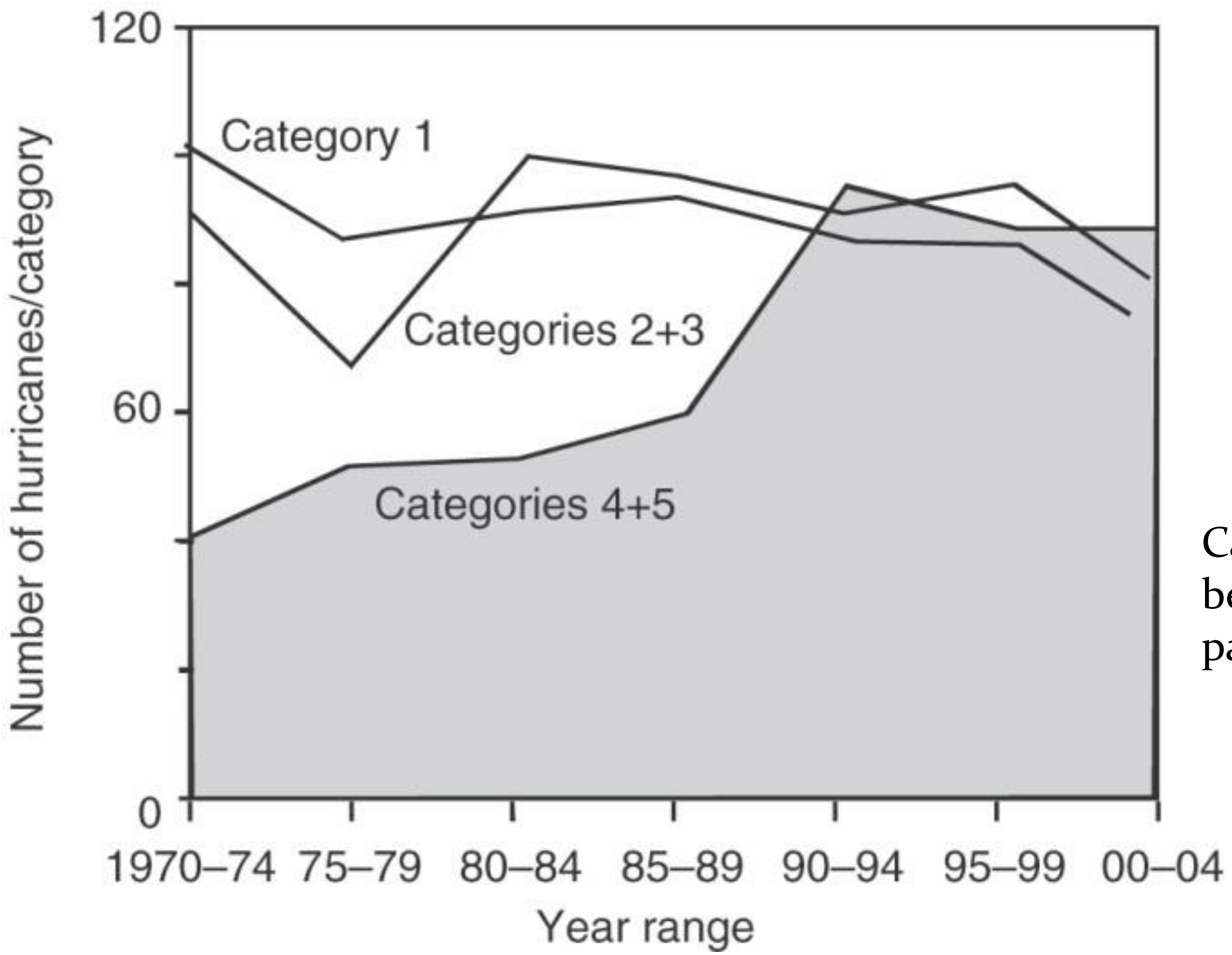
Anthropogenic Climate Change

Evidence of current global warming (cont.)

- Sea ice in Arctic decreasing by 7.4 percent per decade
- Ice caps and glacier melt leading to sea level rise
- Temperatures on top of a permafrost layer have increased by 5.4°F
- Number of intense tropical cyclones have increased since 1970
- Amount of water vapor in atmosphere has increased
- Changes in precipitation amounts
- Concentrations of carbon dioxide correlate with temperature
- Carbon dioxide concentrations correlate with increased anthropogenic greenhouse gases
- Carbon dioxide increasing at a rate faster than observed in last 800,000 years



The first image shows Greenland's ice sheet on 8 July, the second reveals the thawed area just four days later
The thawed ice area jumped from 40% of the ice sheet to 97% in just four days from 8 July.
http://www.bbc.co.uk/news/world-europe-18978483



Category 5 storms have been increasing in the past 30 years

Fig. 12.8 The frequency of different intensities of hurricanes, from Webster et al. (2005).

Anthropogenic Climate Change

Biological impacts

- Shifting biomes
- Ecological succession
- Species extinctions

Anthropogenic Climate Change

Human impacts

- Water availability – could lead to droughts
- Agriculture – loss of agricultural productivity and the inability to produce food is likely to be greater in tropical countries.
- Disease – rising temperature could widen the range of diseases such as malaria and dengue. Increasing the tropical zone could therefore lead to another kind of warm (malaria).

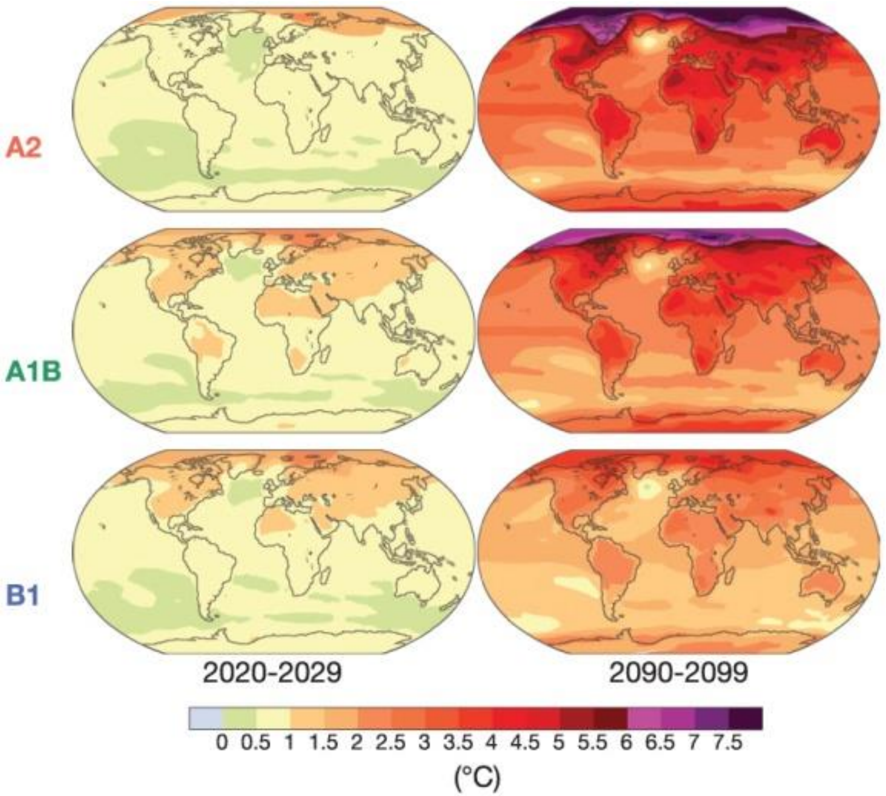
Action – is it possible?

Addressing global warming

- Kyoto protocol
- Standards for newly industrialized countries
- Mitigating and adapting
- US-China Climate Deal – Nov. 2014
  - Cut pollution 26-28% by 2025 relative to 2005 levels
- Paris Climate Agreement

Climate models

- General circulation models (GCMs)
- Numerous assumptions
- Accuracy of the models



(b) Projected global surface temperature changes for the years 2020 to 2029 and 2090 to 2099 under different IPCC emission scenarios.

A2 and A1FI: greenhouse gas emissions continue to rise through the end of the century.
B1: greenhouse gas emissions begin to decline after reaching midcentury peak.
Pink line shows the projected temperature increase if greenhouse gas concentration did not rise above its level in the year 2000 (an impossibility).