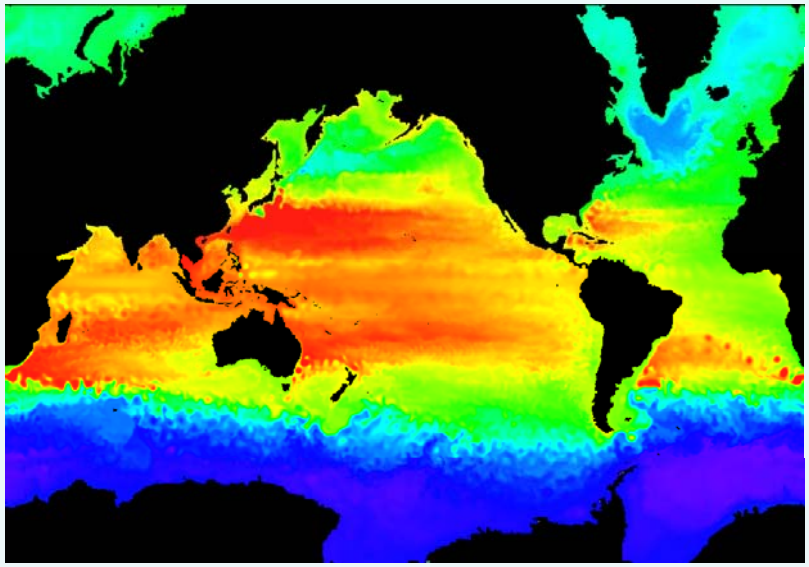
CLIMATE and CLIMATE VARIABILITY



Key terms

Weather
Climate
Climate system
Climatic response
Troposphere
Greenhouse effect
Greenhouse gases
Albedo
Aerosols
Orographic effect
Paleoclimatology
Isotope fractionation
Proxy data

Positive feedback
Negative feedback
Milankovitch cycles
Sunspots
Solar wind
heliosphere
Cosmic rays

Pre-lecture questions

What are some of the relationships between climate and the various components of the Earth's system?

What are the causes of climate change and how is climate change detected?

What are greenhouse gases and how do they affect climate? Is CO_2 the main greenhouse gas?

What is meant by positive-feedback mechanism? Can you give an example?

Do you think the Earth is presently experiencing global warming? Is it something that concerns you?

Outline

Next two lectures:

1. Components of the climate system
2. important concepts -
   Time scales of change, greenhouse effect, albedo, feedback mechanisms
3. Detecting climate variation
4. Inducing climate variation
5. Geologic vs. historical perspectives on climate change

GOAL of next two lectures - provide a very basic and superficial overview of selected topics of climate science (very complex) to allow you to become more critical of climate-related news transmitted through the media.

A few definitions

Weather: state of atmosphere at given time and place – instantaneous

Weather = f (temperature, air pressure, humidity, cloud cover, wind speed and direction)

Climate: 'average' weather – long term, i.e. ≥ 30 yrs

Climate system: all interactions between the atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere needed to describe how *climate* behaves in space and time.

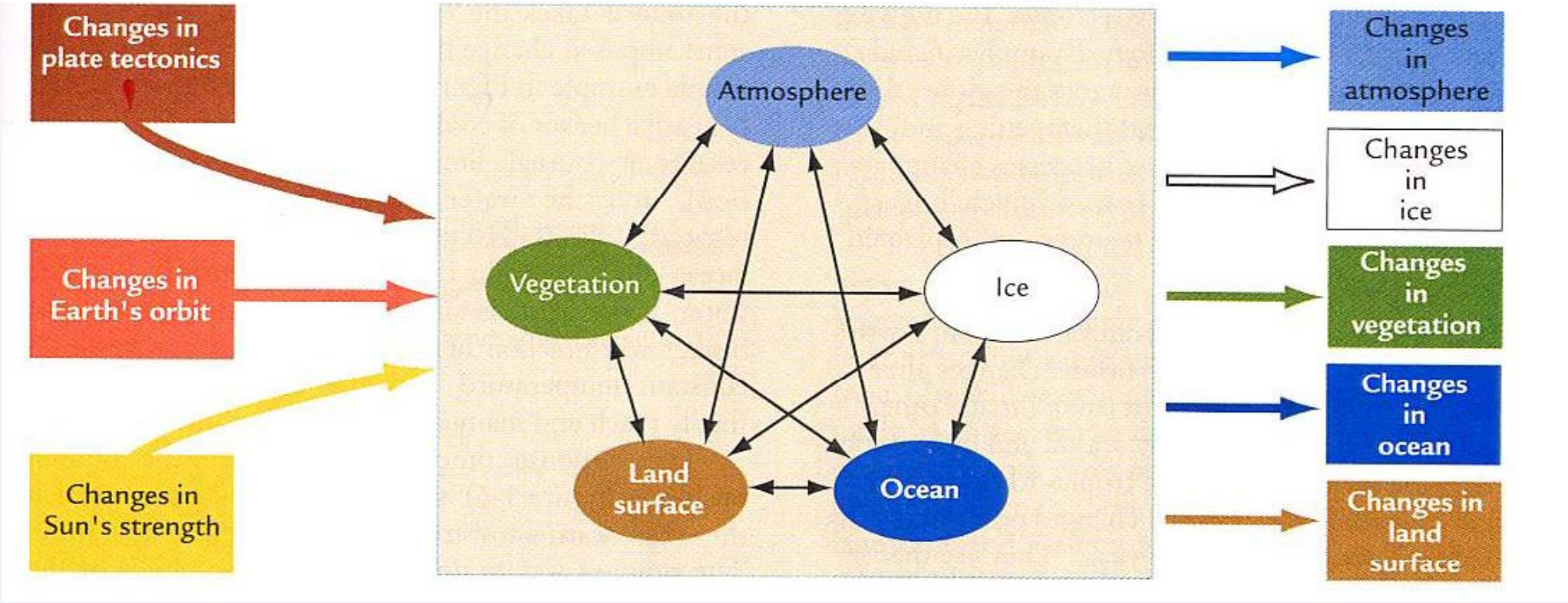
(System: group of interacting parts that form a complex whole.)

Components of the climate system

Climate change → external forcing
→ internal response and feedback

of/within CLIMATE SYSTEM

***EXTERNAL /INTERNAL** FORCING* + *INTERNAL FEEDBACK* → *CLIMATE CHANGE*



Time scales of the climate system

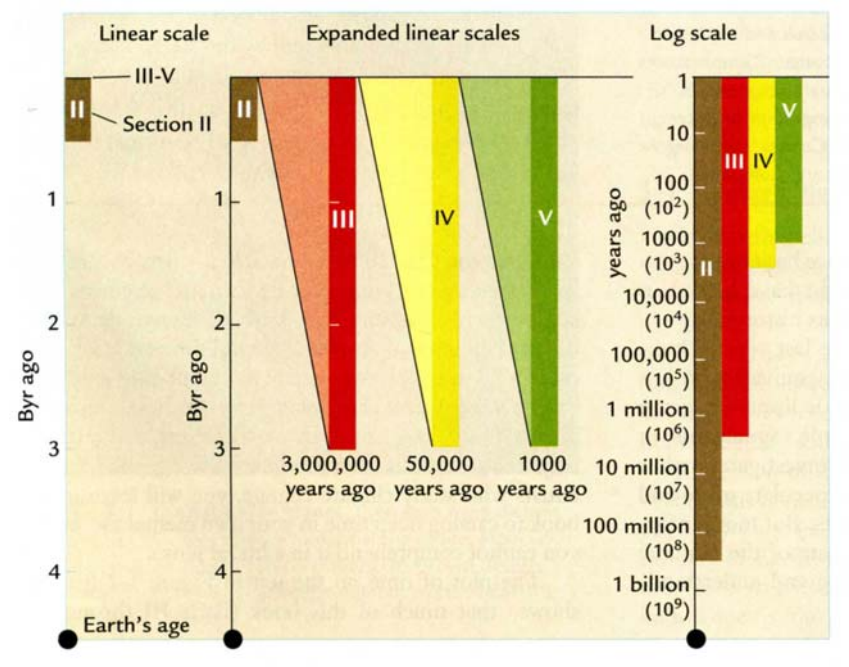
Climate change is a natural phenomenon to be expected …

Time scale**s** → CRUCIAL perspective to keep in mind

Climate varies on many time scales

from the billion year geologic-scale …

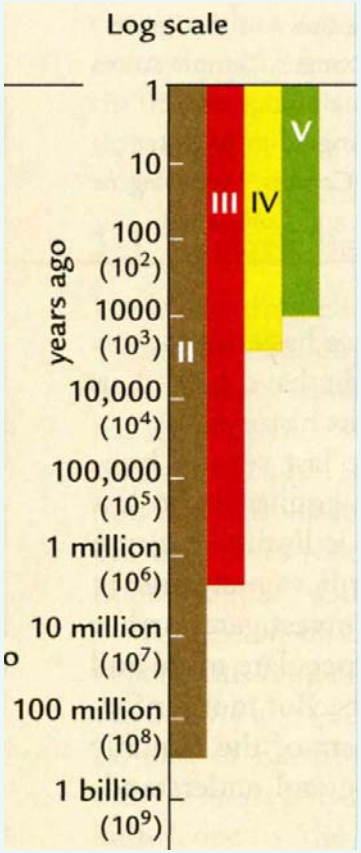
to the 100 year human lifetime-scale

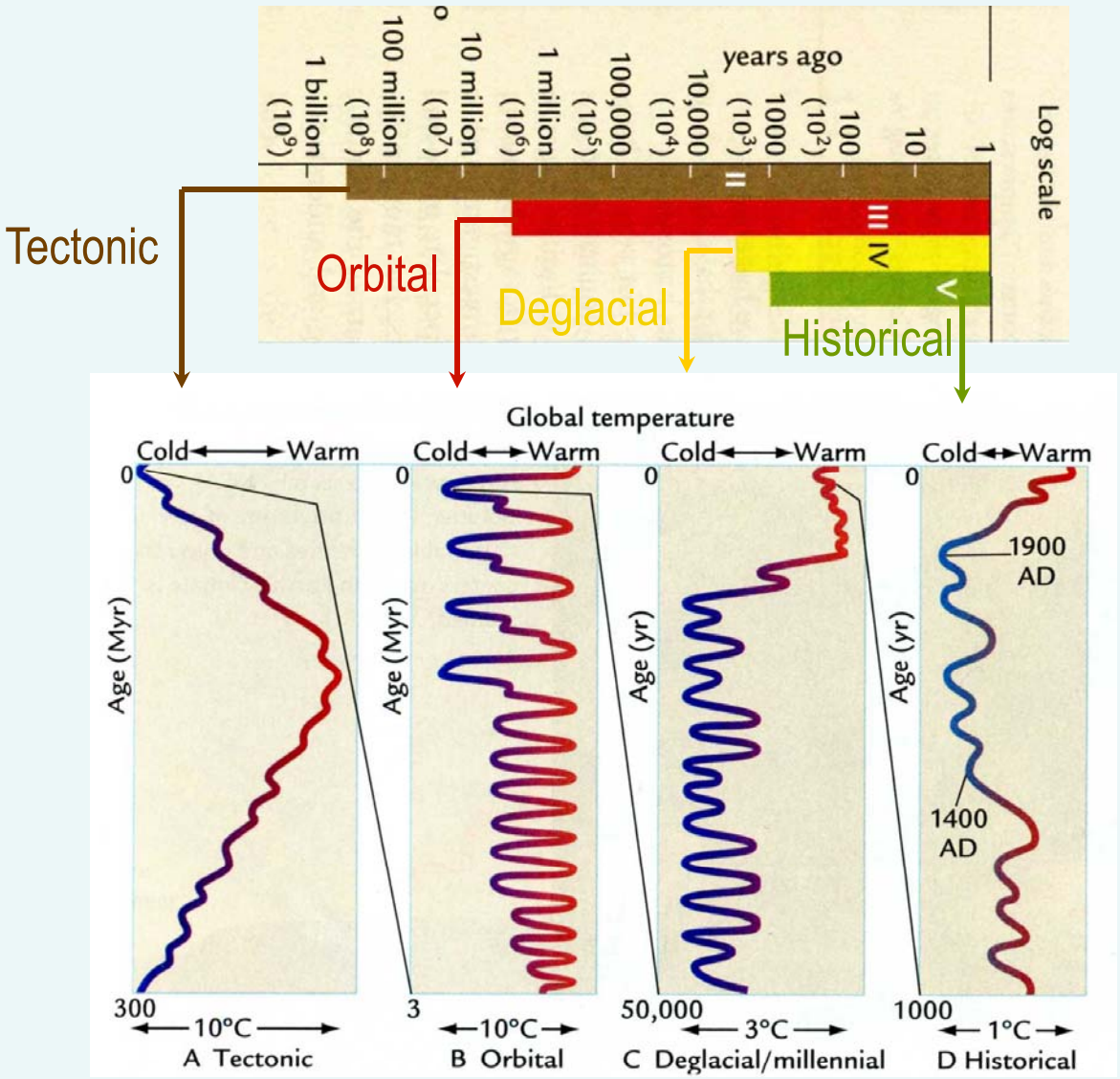


(Figure 1-2, Ruddiman 2008)

Time scales of the climate system

Time scales of climate variations





(Figure 1-2,1-3 Ruddiman 2008)

Response of the climate system

Climatic response depends on rate of change of climate forcing vs. the response time of the climate system.

Forcing commonly cyclic → climate system trying to reach equilibrium with a moving target.

Amplitude and timing of signals?

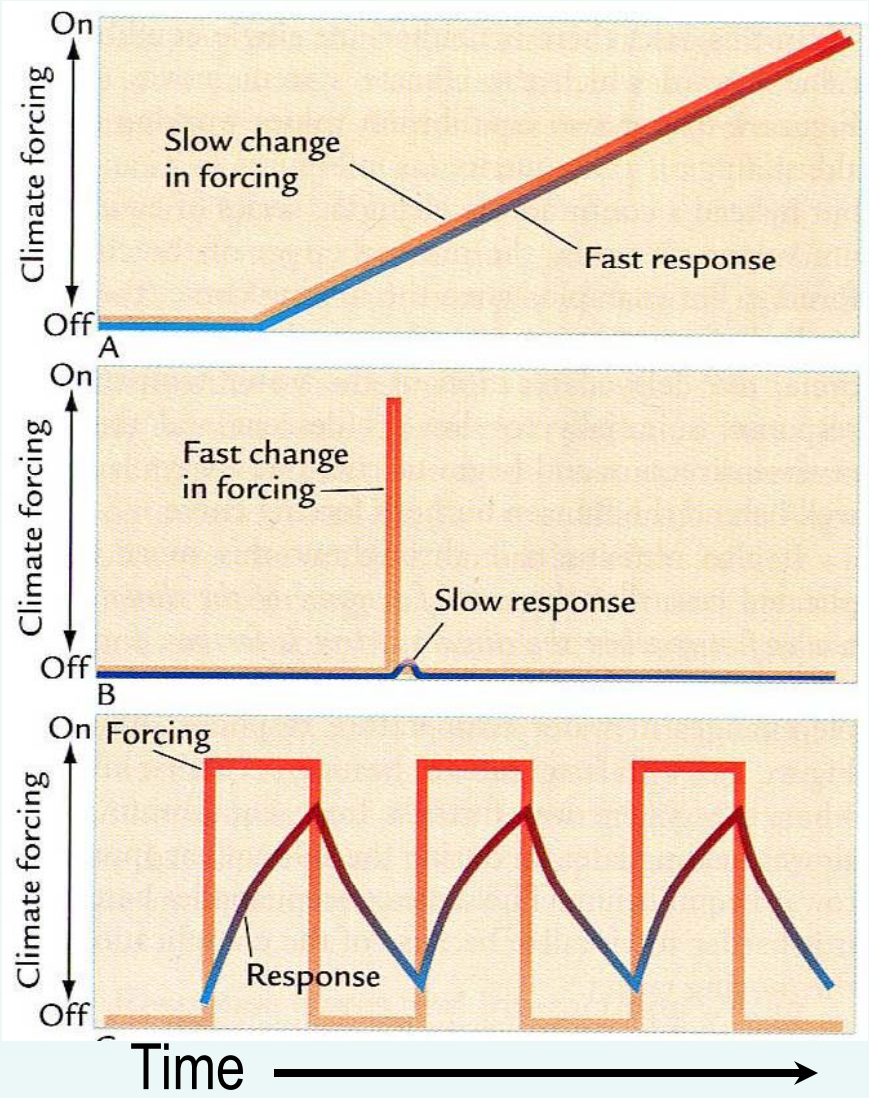


Fig. 1-7, Ruddiman 2008

Components of the climate system –

1. Atmosphere
2. Hydrosphere and cryosphere
3. Lithosphere
4. Biosphere

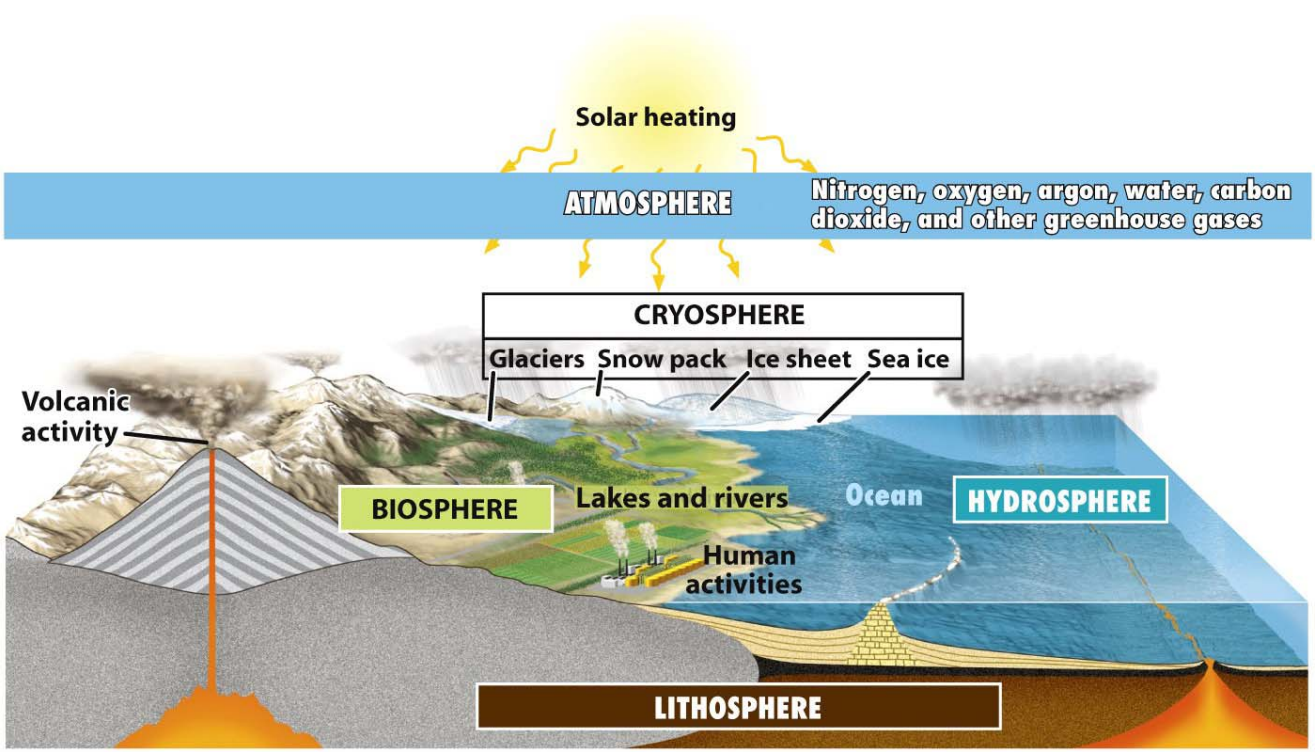


Figure 15-1
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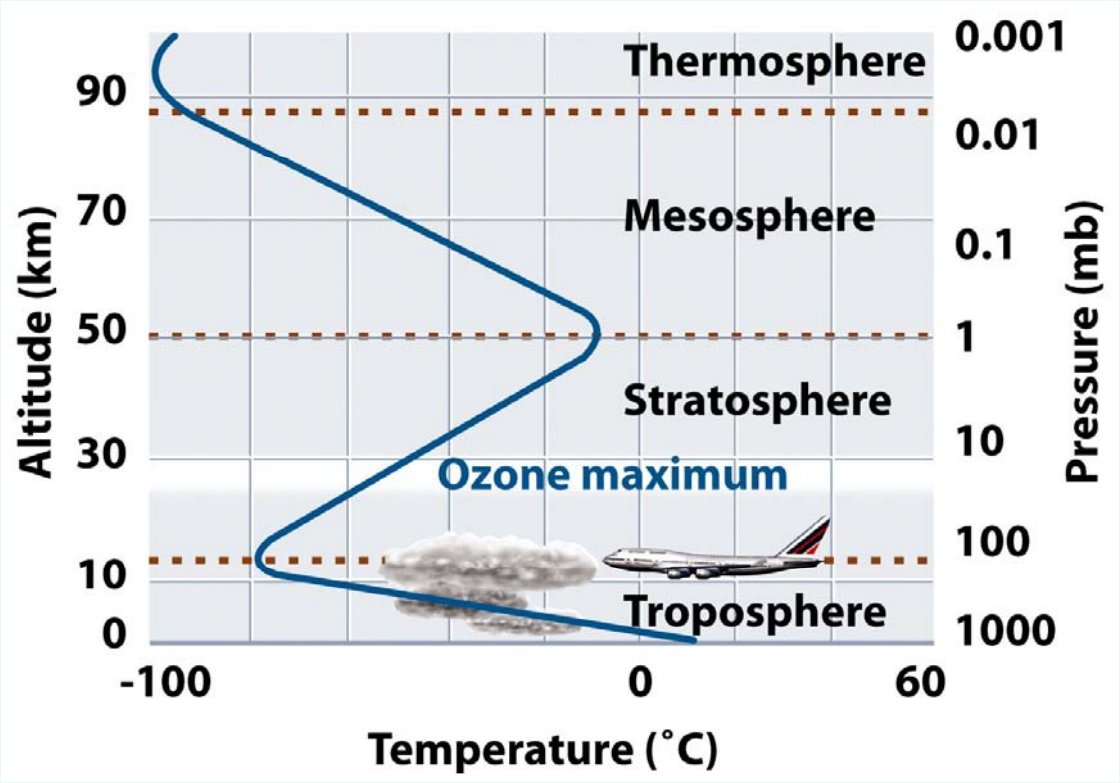
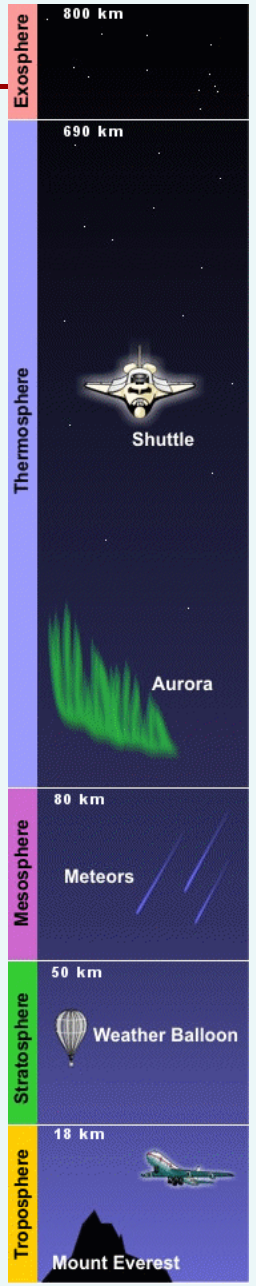
Components of the climate system – the atmosphere

Atmospheric structure – divided into 4 layers = f(T)





Troposphere: (tropos Greek 'to turn'), turbulent layer also termed the 'weathersphere'. T decreases upward. Ave. thick. 11km. Densest layer. The troposphere is where water vapour is concentrated.

Convection in troposphere → Wind, storms

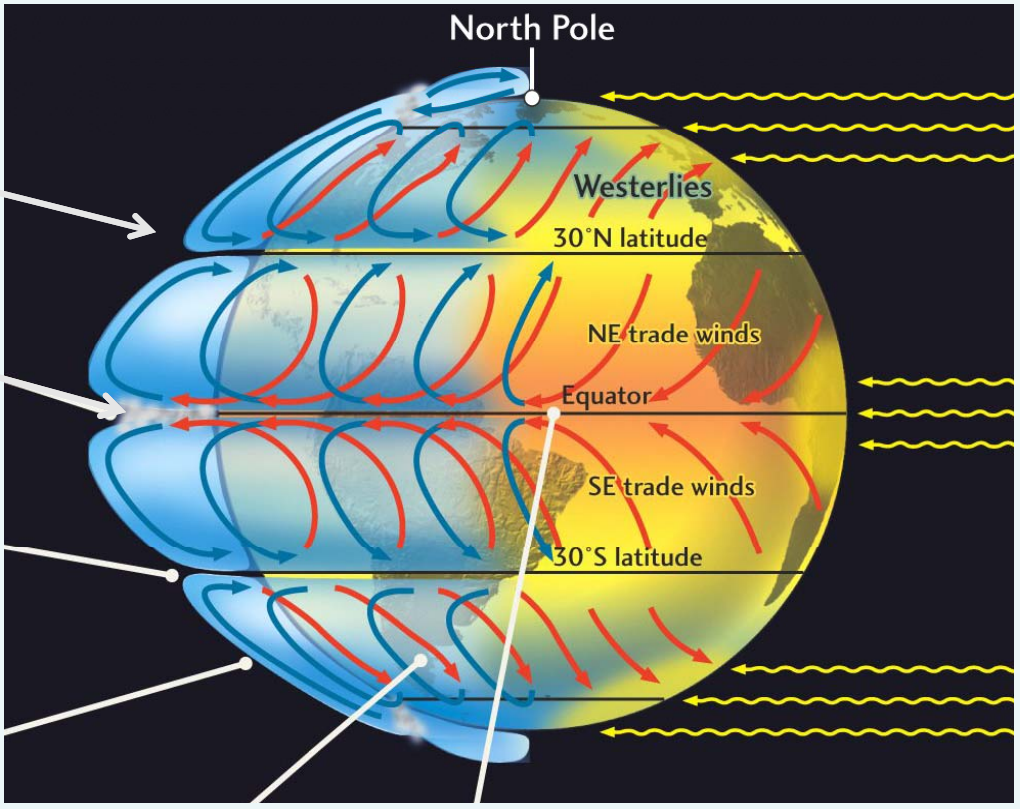
Redistribution of E from equator → poles (via circulation cells) - *recall?*

Atmospheric circulation intimately linked → climatic zones

30° latitude: cold dry air descends; desert belt

Equator: hot air rises, water vapor condenses, clouds form

Coriolis effect: deflection to right in N.Hem. …



Atmospheric composition

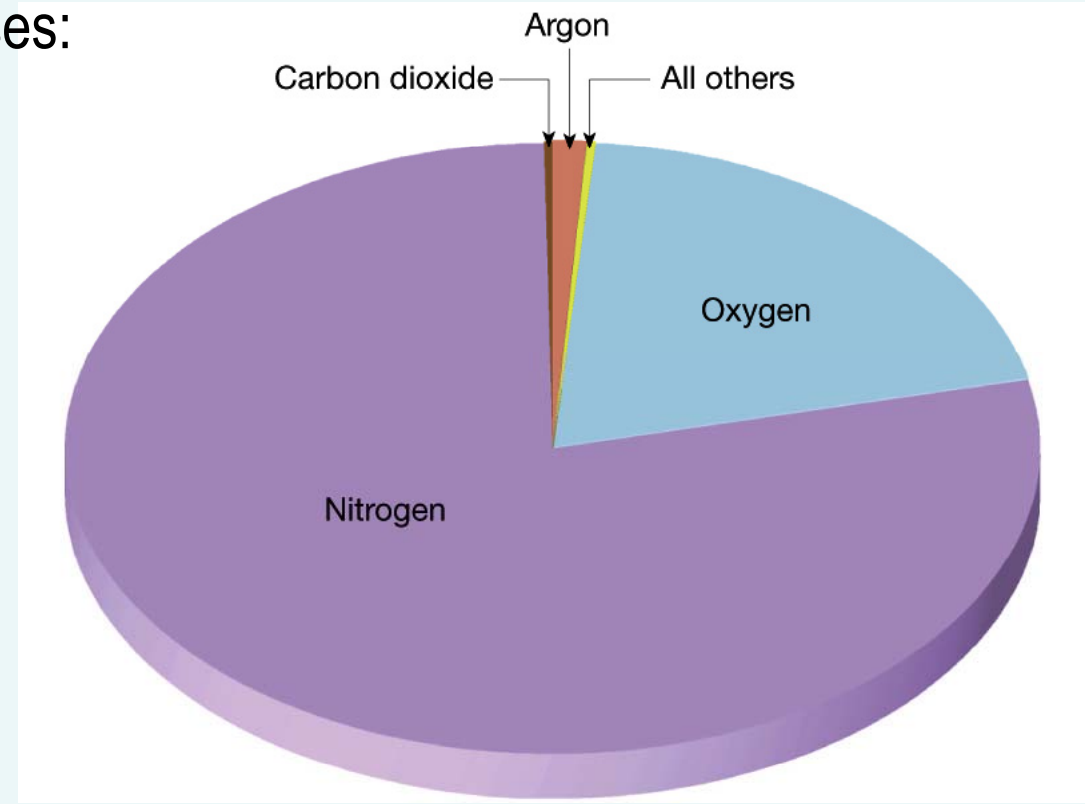
Atmosphere is a mixture of gases:

Nitrogen (N_2): 78%

Oxygen (O_2): 21%

Argon (Ar): 0.93%

99.93%



Two principal greenhouse gases →

Others: 0.07%

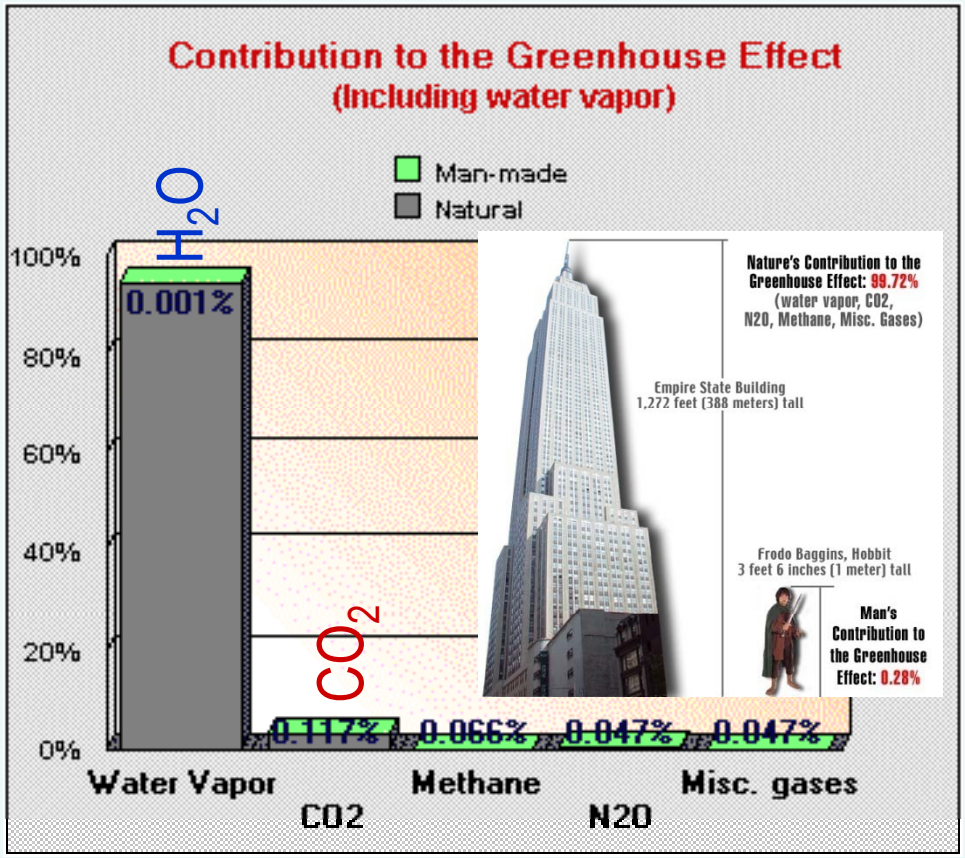
CO_2 : 0.035%

+ **water$_{vapour}$**, methane, helium, neon, hydrogen, krypton (0.035%)

Water vapour concentrated near Earth's surface [1-3%]

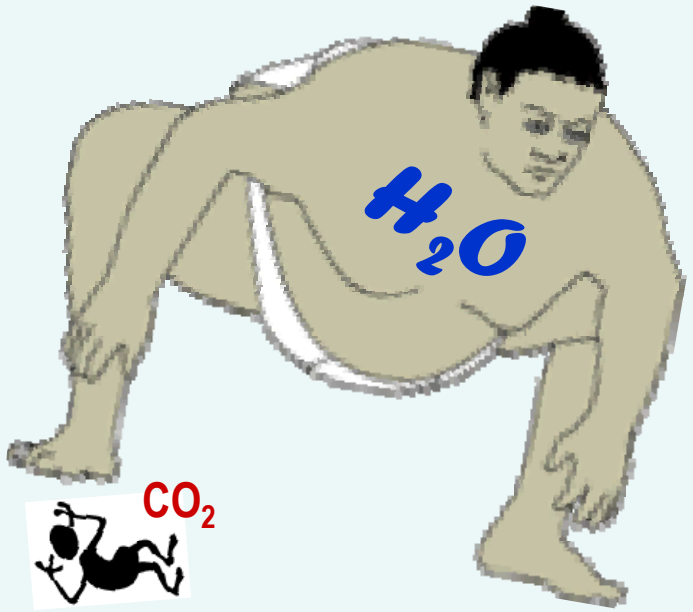
Greenhouse gases: gases in an atmosphere that absorb and emit radiation within the thermal infrared range .

Main contributors to greenhouse effect:



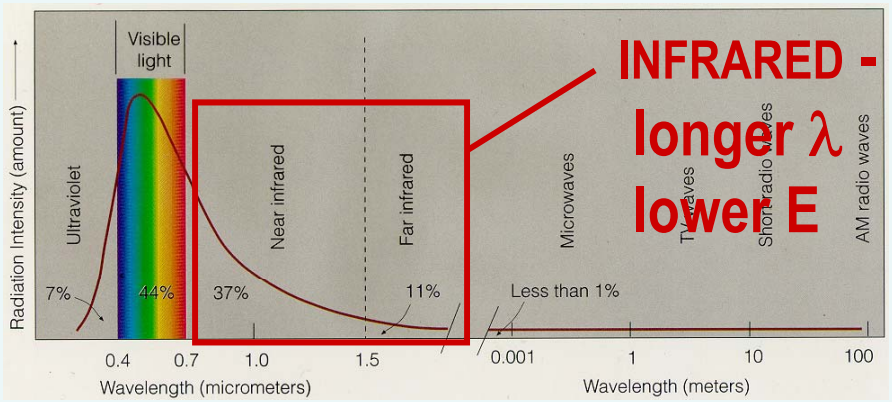
Source: www.geocraft.com

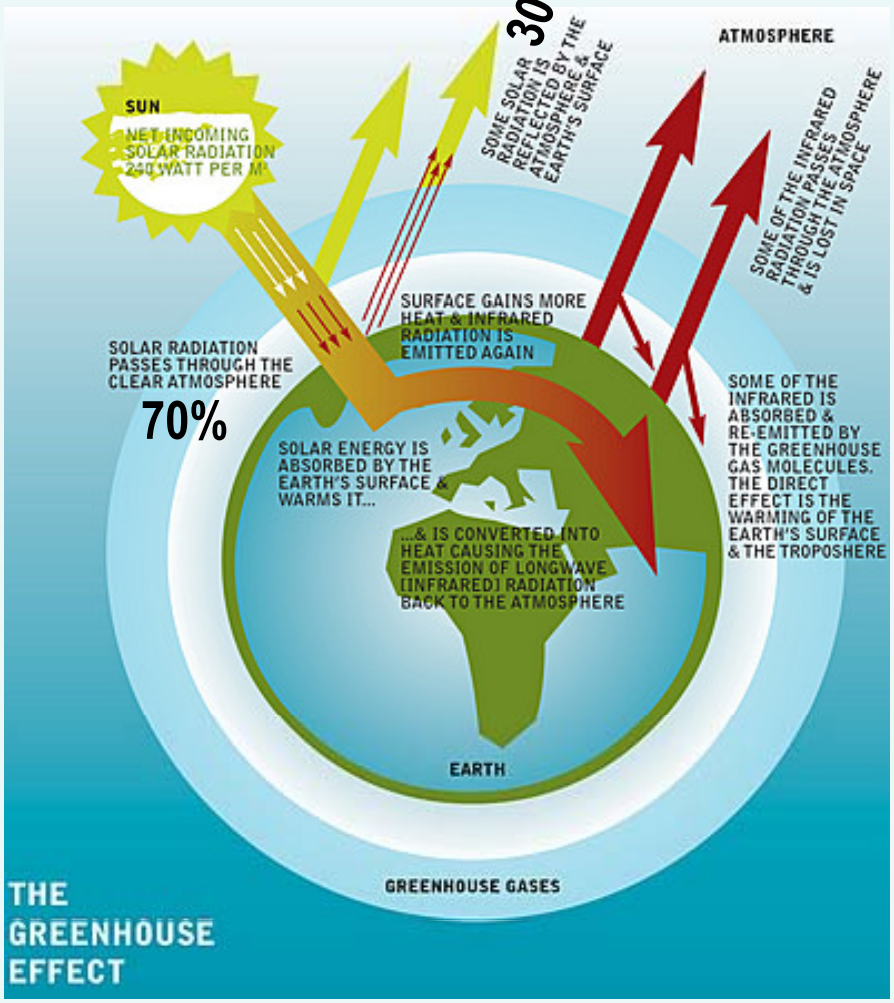
1. Water vapor → 95.000%
2. CO_2 → 3.618%
3. Methane → 0.360%
4. Nitrous oxide (N_2O) → 0.950%



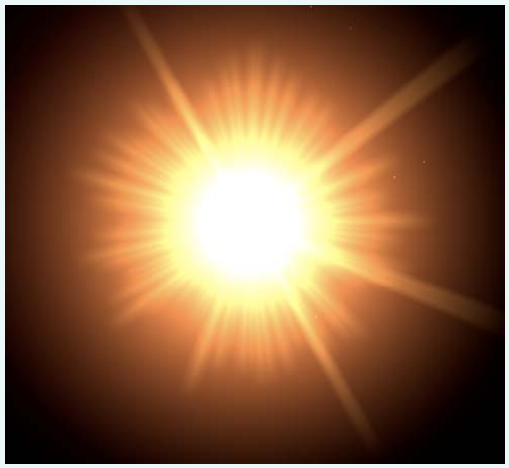
Greenhouse effect: warming effect of planet with atmosphere containing greenhouse gases that re-emit heat towards the planet's surface.

Sun's E spectrum (red curve)



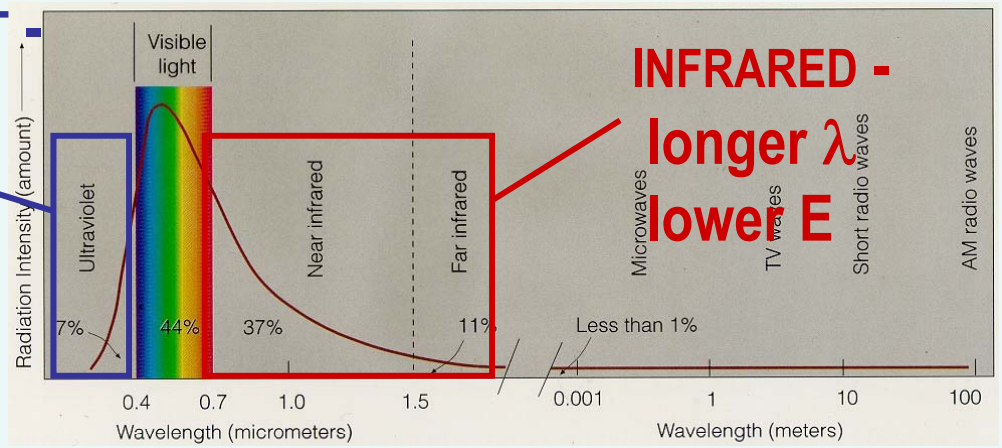


Sun emits energy (radiation) covering a broad spectrum of wavelength (λ) – most E emitted as visible light



Sun's E spectrum (red curve)

ULTRAVIOLET - shorter λ higher E



INFRARED - longer λ lower E

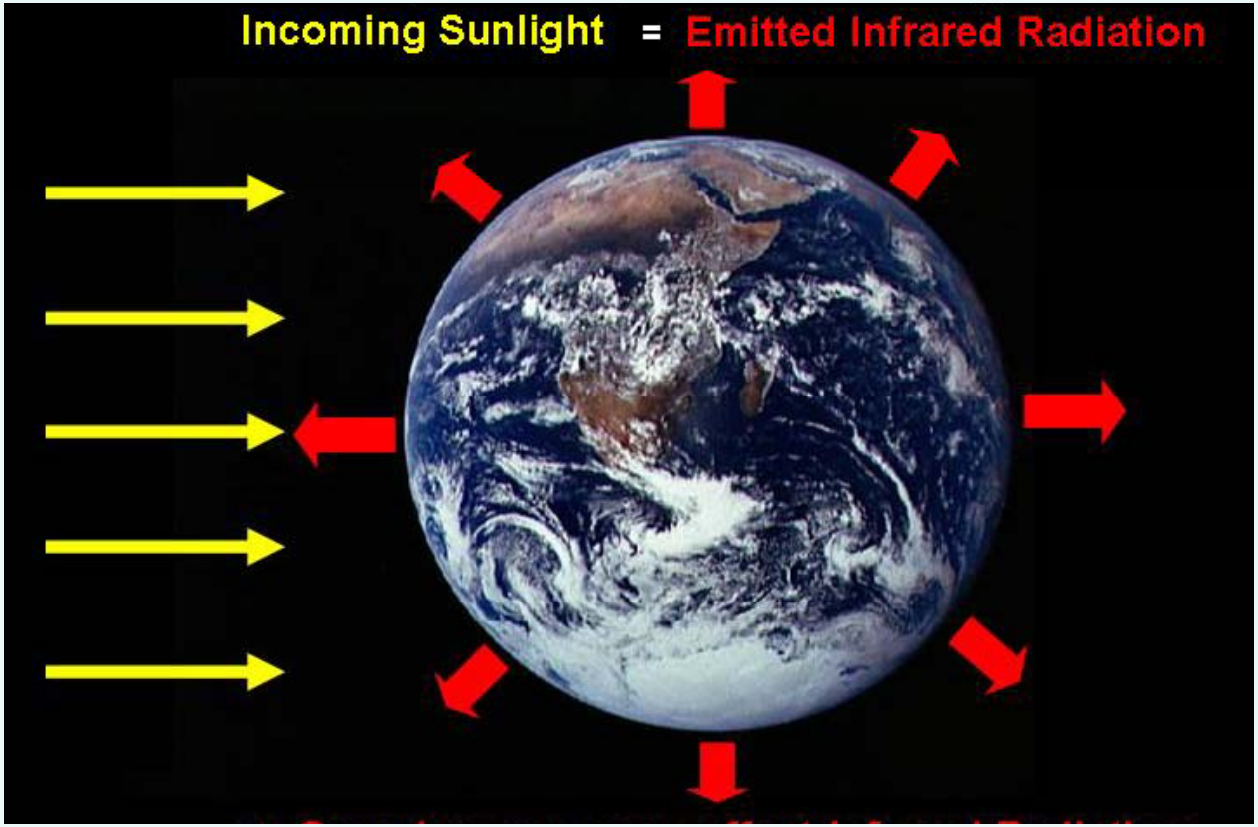
Earth re-emits … ?

4 basic laws governing radiation:

1. All objects emit radiant energy
2. Hotter objects radiate > total E than colder objects
3. The hotter the radiating body, the shorter the λ of max. radiation
4. Objects that are good radiation absorbers are also good emitters

BASIC PRINCIPLE -

Constant Earth T requires 'Radiative E balance' → ***INPUTS = OUTPUTS***



INPUTS = OUTPUTS

Incoming energy (Sun) = outgoing energy (reflected back into space)

342 W/m^2 = 107 W/m^2 (albedo) + 235 W/m^2 (surface, atmos.)

With greenhouse gases in atmosphere, more E is absorbed and less reflected (energy deficit)

To balance incoming and outgoing E, Earth must raise its surface T by 33°C

Greenhouse gases act as a blanket that ↑ surface T

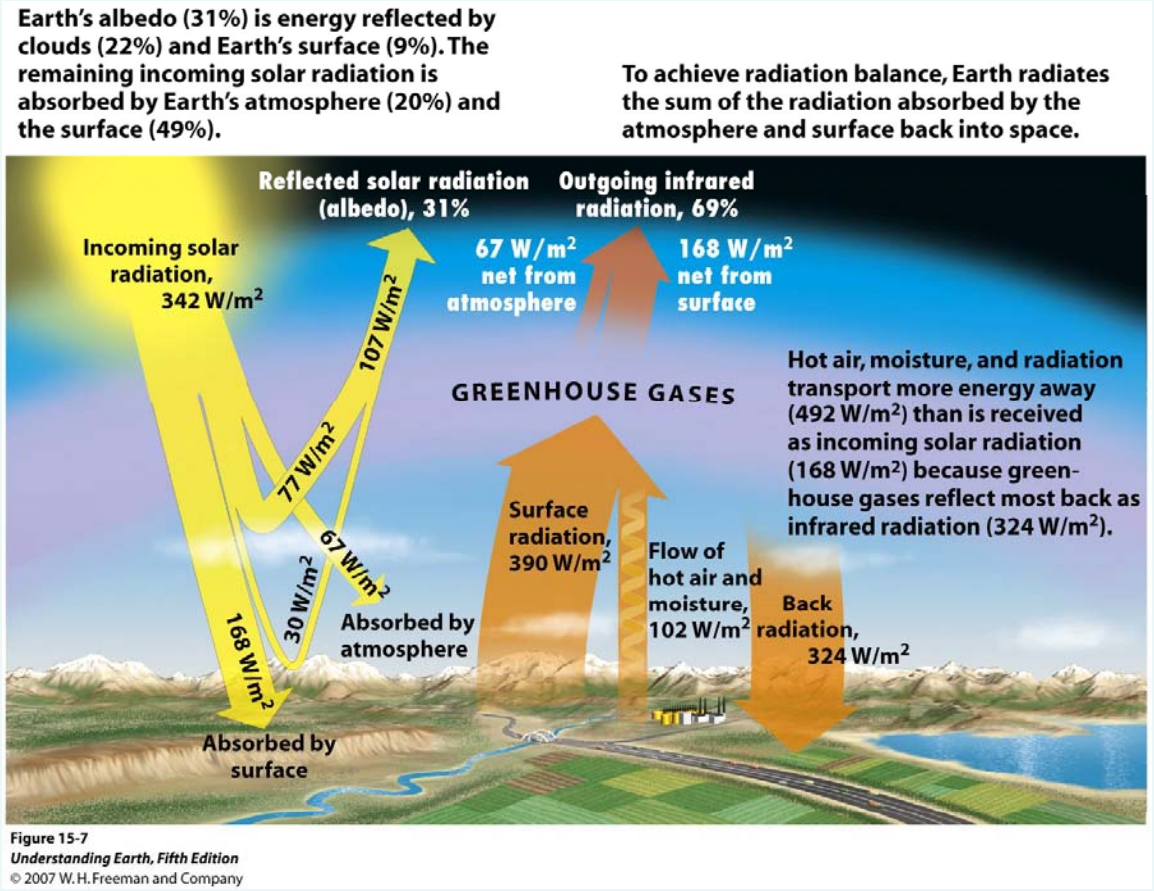


Figure 15-7
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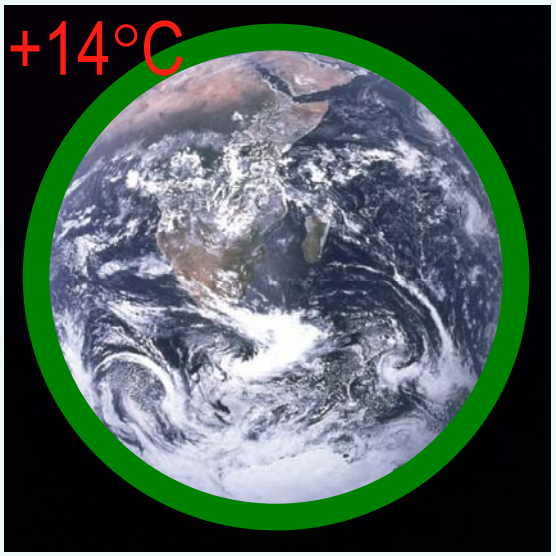
Earth's energy balance - effect of greenhouse gases

What if …?

Earth's T_{ave} <u>without</u> greenhouse gases

∇ 33°C



Earth's T_{ave} <u>with</u> greenhouse gases

Components of the climate system – the concept of albedo

Albedo: percentage of solar radiation reflected from a surface back into space.

Snow → … albedo

Oceans → … albedo

Earth's albedo?

vs.

Moon's albedo?

High albedo (45-85%): snow, clouds

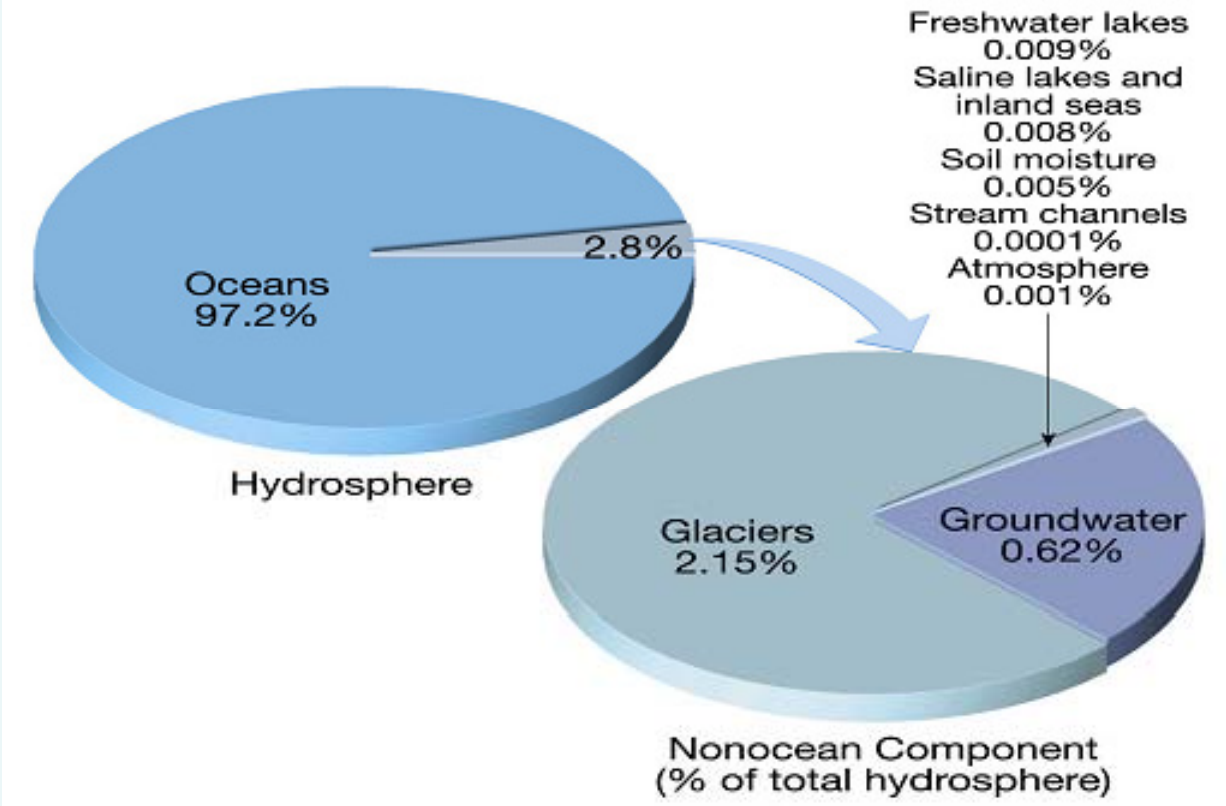
Moderate albedo (20-45%): ice, deserts, sand beaches, dry soil

Low albedo (5-20%): forests, crops, water, moist soil

Components of the climate system – the hydrosphere and cryosphere

Hydrosphere: comprises all the liquid + solid water on Earth

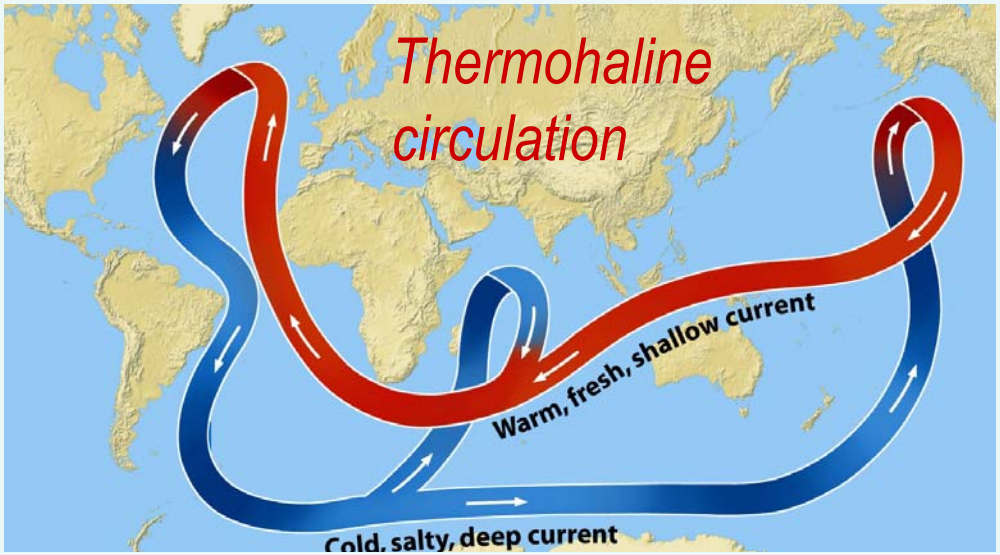
↳ Cryosphere: all solid water (ice) – 2.15% of hydrosphere

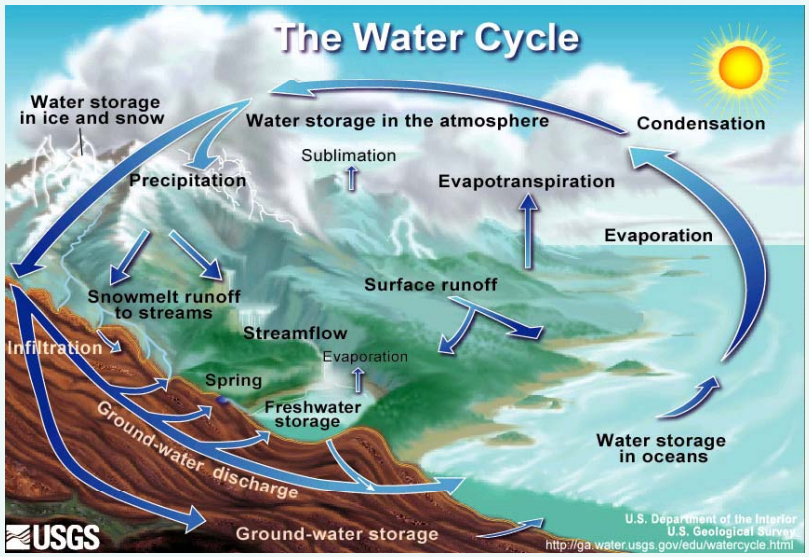


Components of the climate system – the hydrosphere

Liquid water's main contribution to the climate system -

- transfer heat (high heat capacity and low albedo); Equator → poles
- transport - sediments, nutrients, dissolved gases
- facilitate weathering (interface between atmosphere and lithosphere)
- supply water vapour to atmosphere (evaporation)





Importance –

Glacier and ice sheets (today) → 75% of Earth's fresh water

→ 10% land surface

Role –

Constant exchange between the cryosphere and hydrosphere -

e.g. 18 000 yrs ago (LGM), vol. cryosphere 3x ↑, & sea level 130 m ↓

Climatic effects –

Δ Earth albedo, atm. circulation, weathering, …

Hydrosphere vs. cryosphere

	mobility	*albedo*
water	moderate	low
ice	very low	high

Components of the climate system – the lithosphere

Lithosphere → *affects climate mostly from position and topography of landmasses*

- Land surface (30% of Earth's total area) absorbs and returns solar energy.
- Volcanism affects atmospheric dust level (blocks solar rad. and reduces T)
- Topography affects wind and rain patterns
- Supercontinent assembly and orogeny kick start weathering …

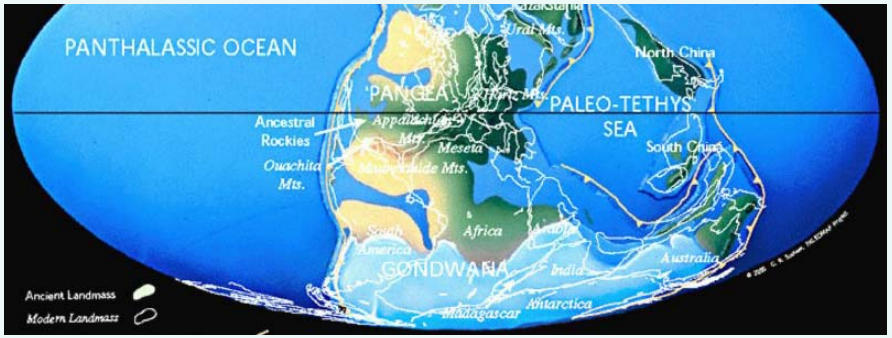
Lithosphere → *affects climate mostly from <u>position</u> and <u>topography</u> of landmasses*

- Land surface

  e.g. migration of landmasses over poles allows formation of continental ice-sheets

e.g. Antarctica ice-sheet

e.g. Permian glaciation



Components of the climate system – the lithosphere

- Land surface position partly controls ocean currents, and … climate!
  e.g. emergence of Panama

5 Ma - closure of connection between Pacific & Atlantic Oceans

Possible consequence: initiation of Pleistocene glaciations(?)

Components of the climate system – the lithosphere

- Volcanism → emit aerosols & greenhouse gases (CO_2, SO_2)

Aerosols: tiny solid and liquid particles that suspend in atmos.; block solar radiation, and ↓ T
(fraction of a degree for months to yrs)

Mt Pinatubo pre-eruption

Mt Pinatubo post-eruption, 1991

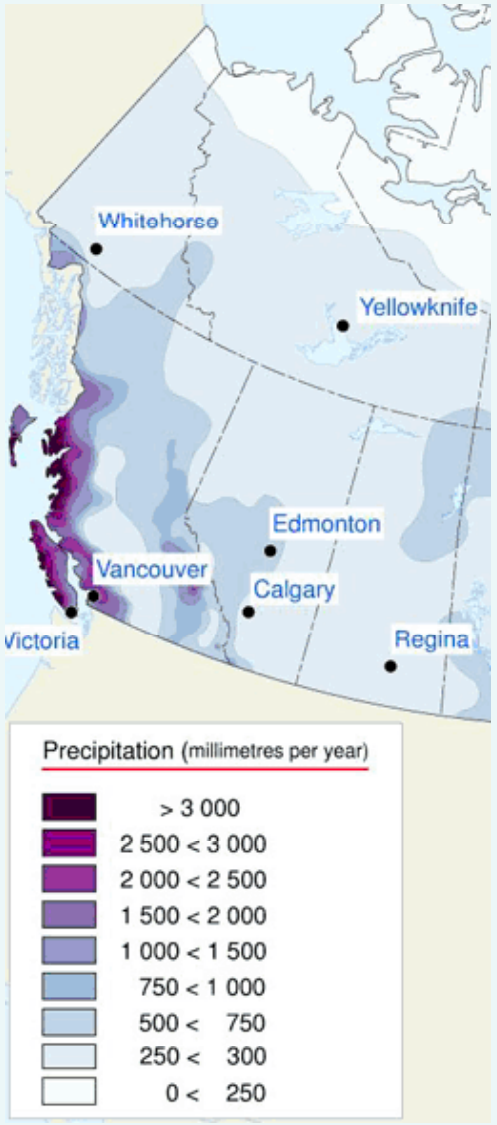
Components of the climate system – the lithosphere

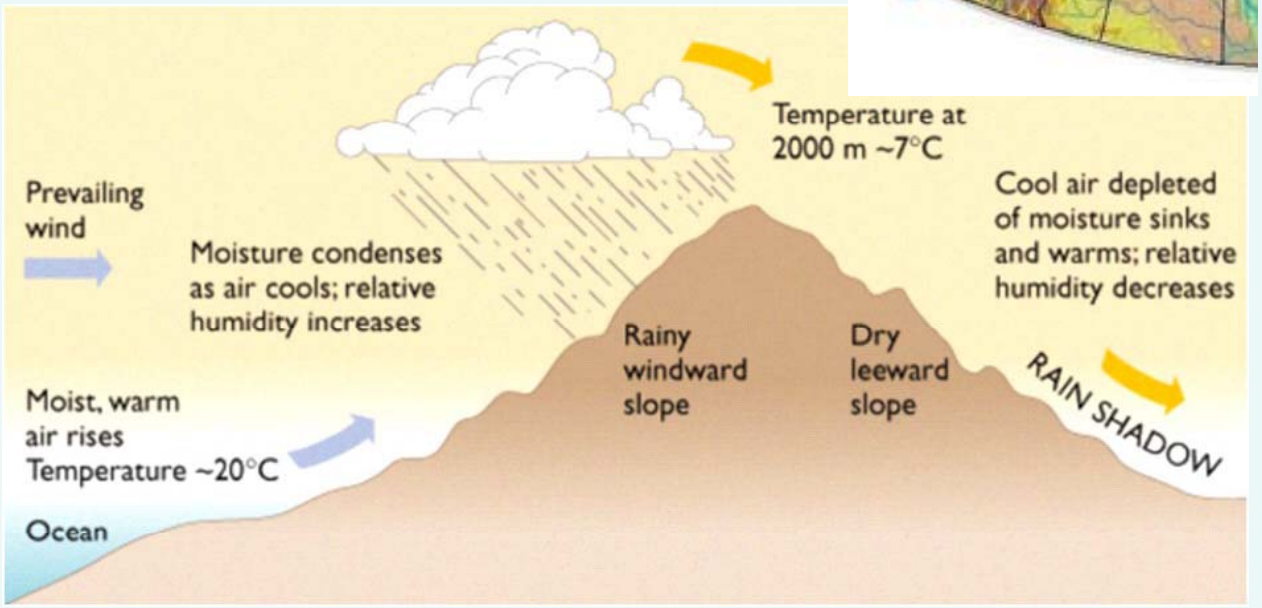
- Topography and orographic effect

  wettest climate –
  - West of Coastal Mts
  - West of Rockie Mts

This effect also affects <u>global climate</u>

Topographic map vs. *Precipitation map*

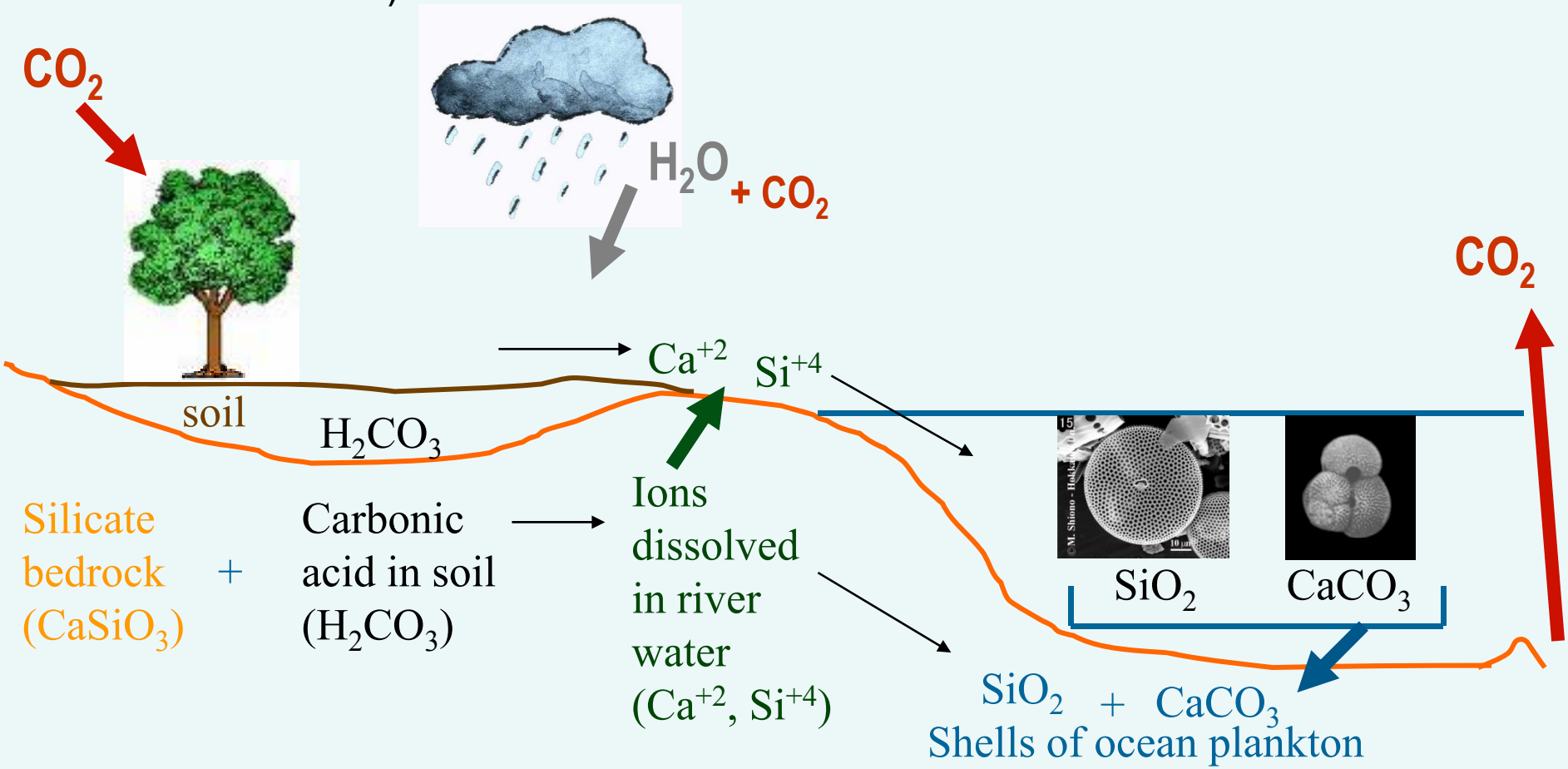




Weathering - link between lithosphere & atmosphere

CO_2 moves: 1) from atmosphere to lithosphere → chemical weathering

2) from lithos. back to atmos. → volcanism



Chemical weathering -

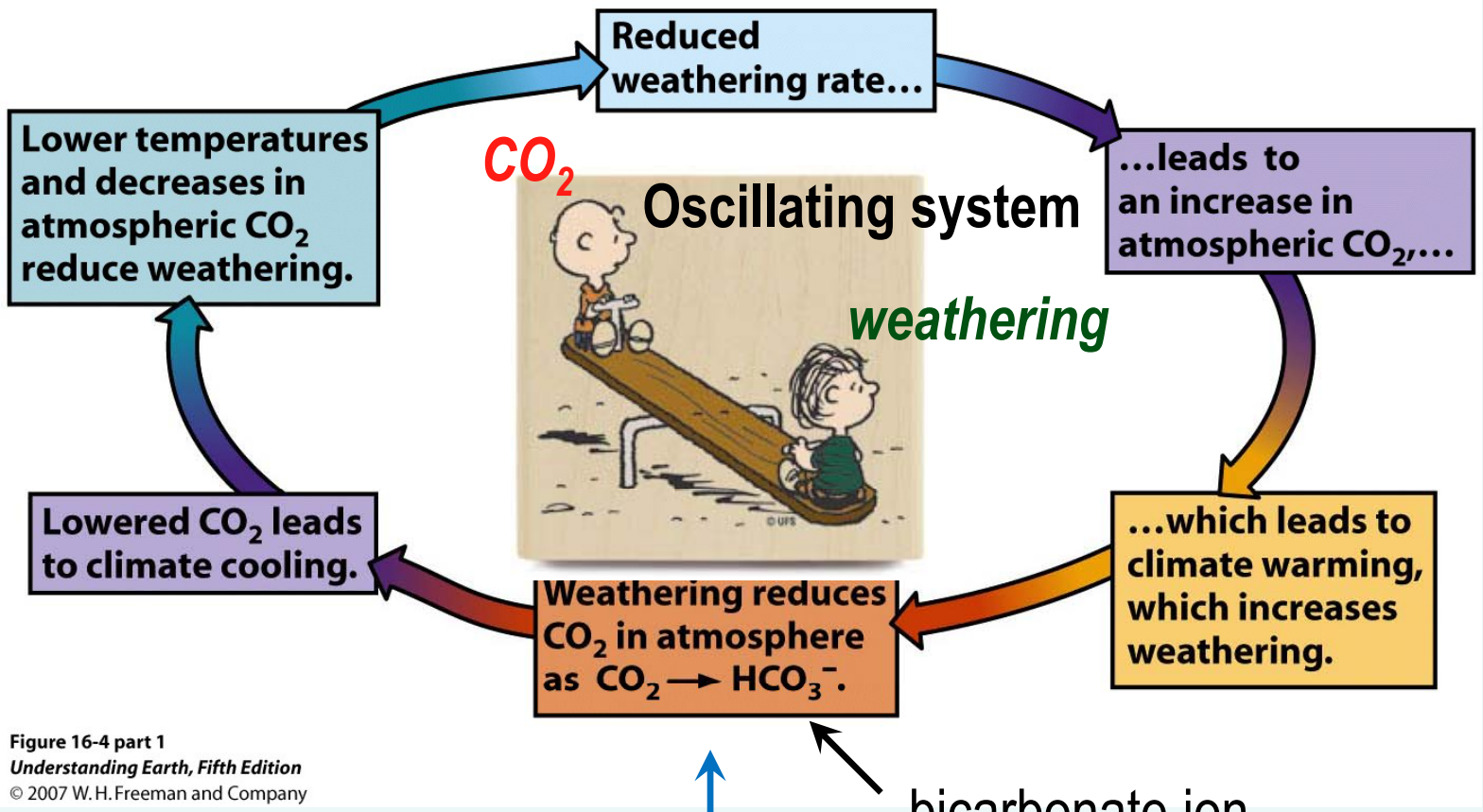


Figure 16-4 part 1
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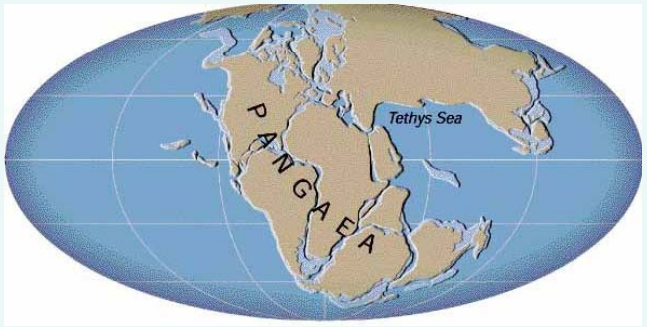
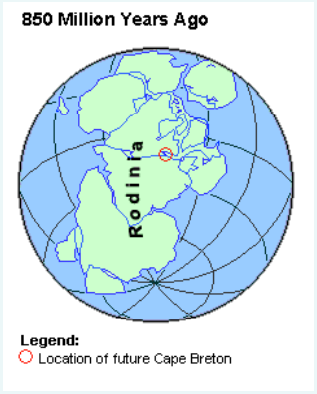
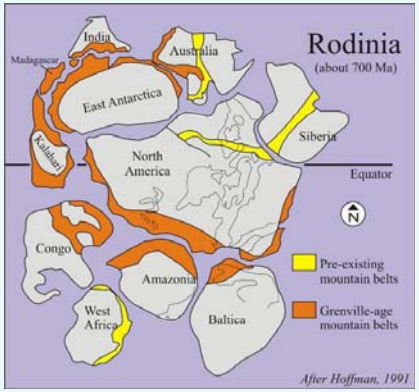
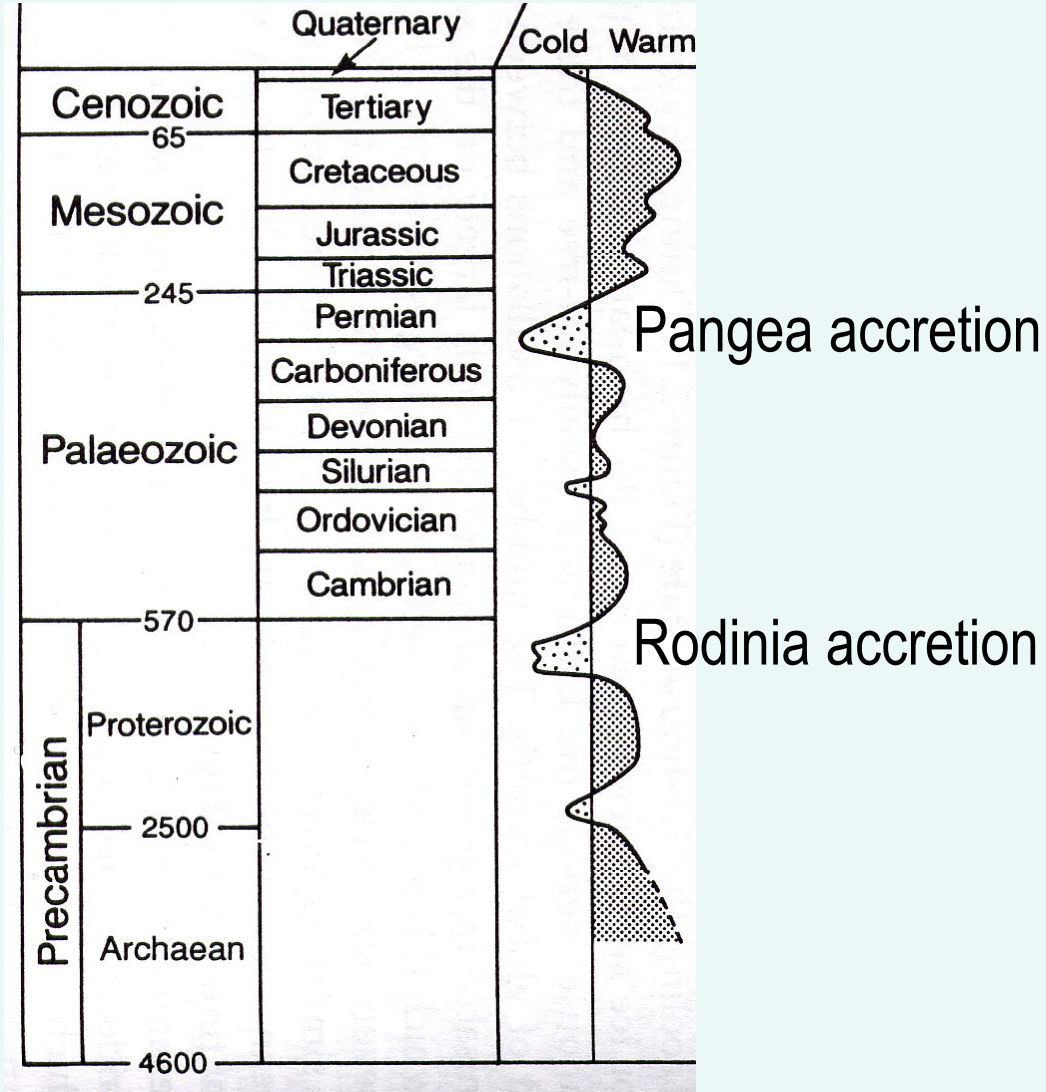
Components of the climate system – the lithosphere

Some workers suggest that icehouse-greenhouse cycles are related to cycles of supercontinent accretion and break-up



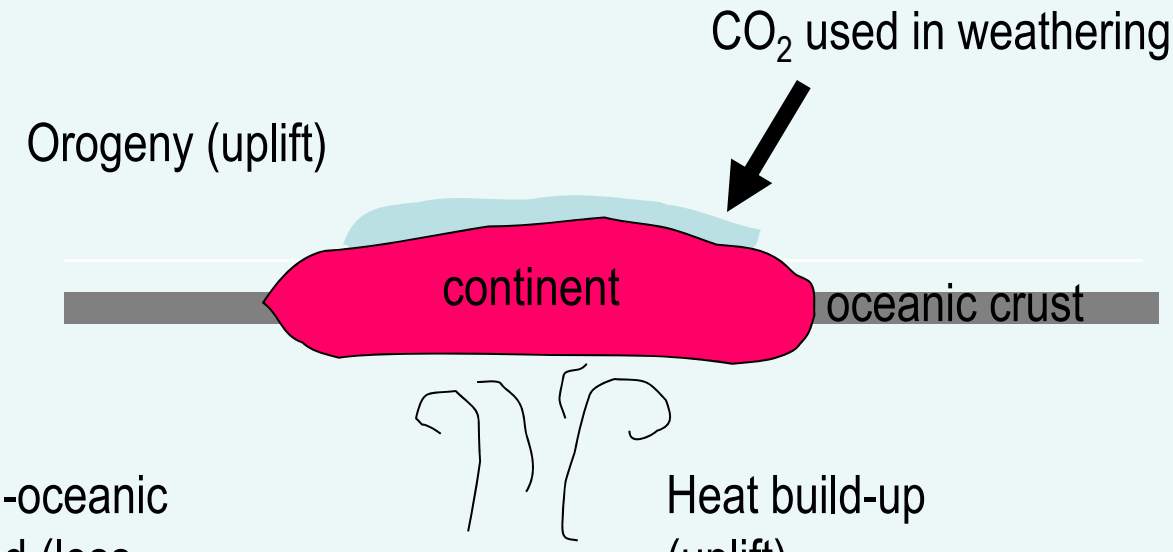






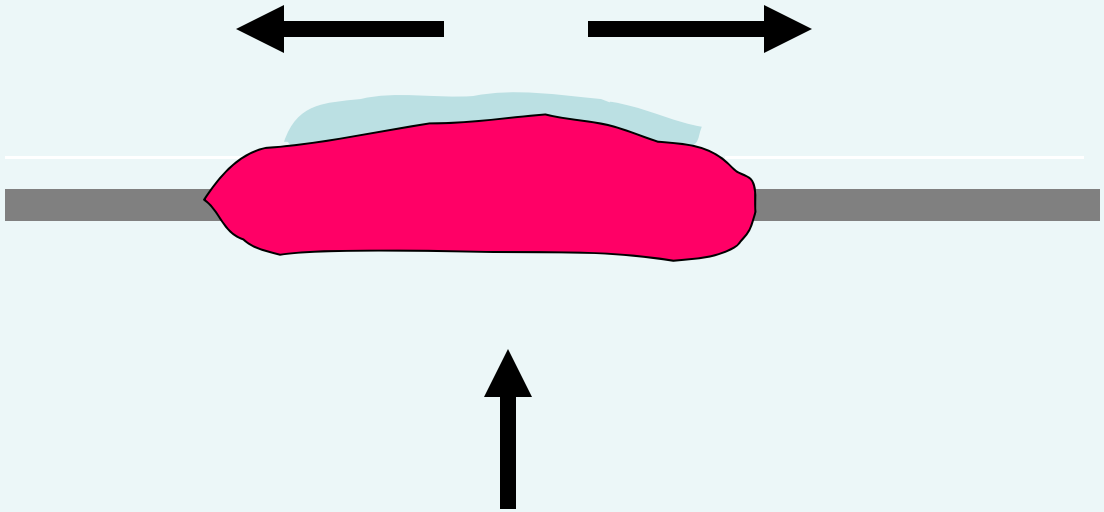
Tectonic-scale climate change

Supercontinent assembly

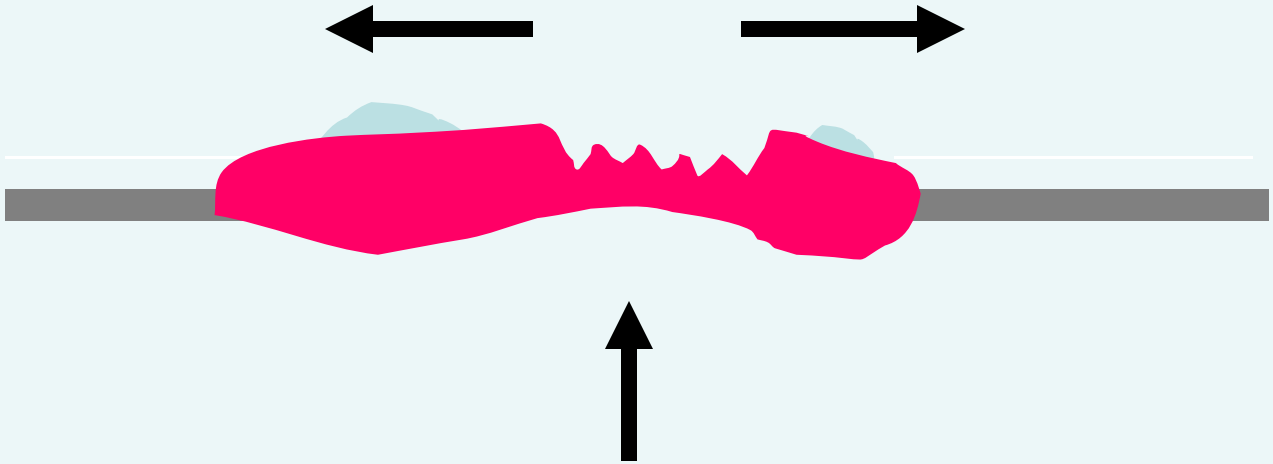


Result: COOLING (icehouse world)

Supercontinent break-up

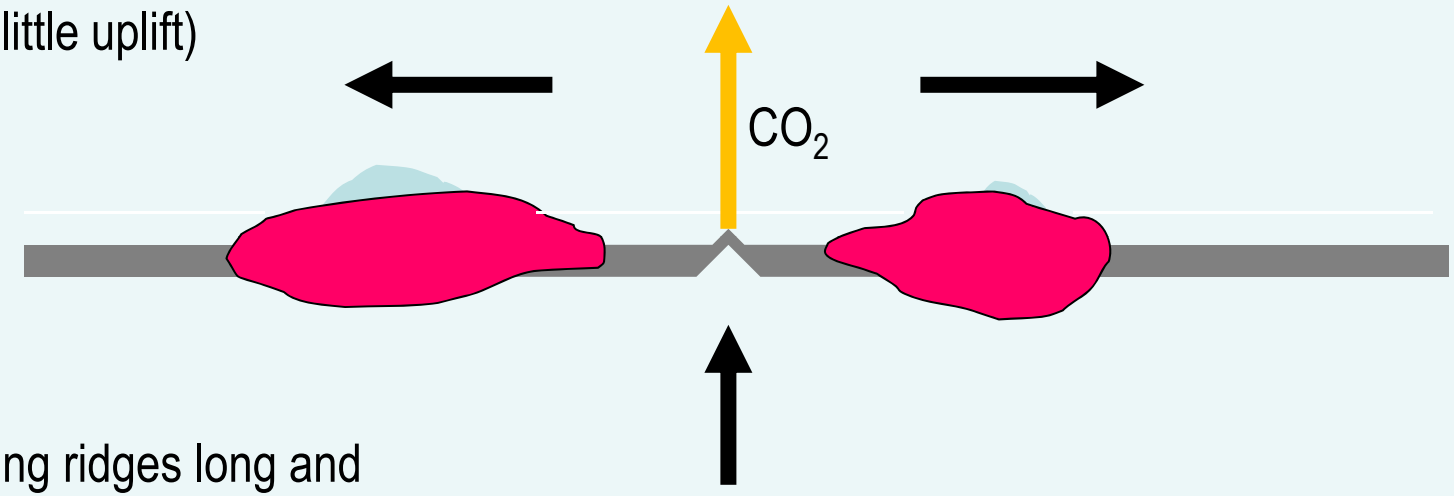


Supercontinent break-up



Supercontinent break-up

No continent-continent collision (little uplift)



Spreading ridges long and active (volcanic CO_2 emission high)

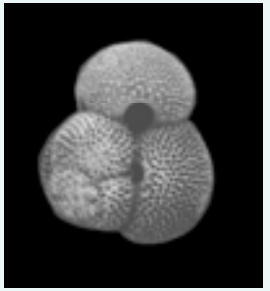
Result: WARMING (greenhouse world)
& deglaciation

Components of the climate system – the biosphere

Amount of energy used by living organisms is relatively small -
(0.1% of solar energy flux is used by plants for photosynthesis)

However by its interaction with the atmosphere, hydrosphere and lithosphere, the biosphere can affect the climate.

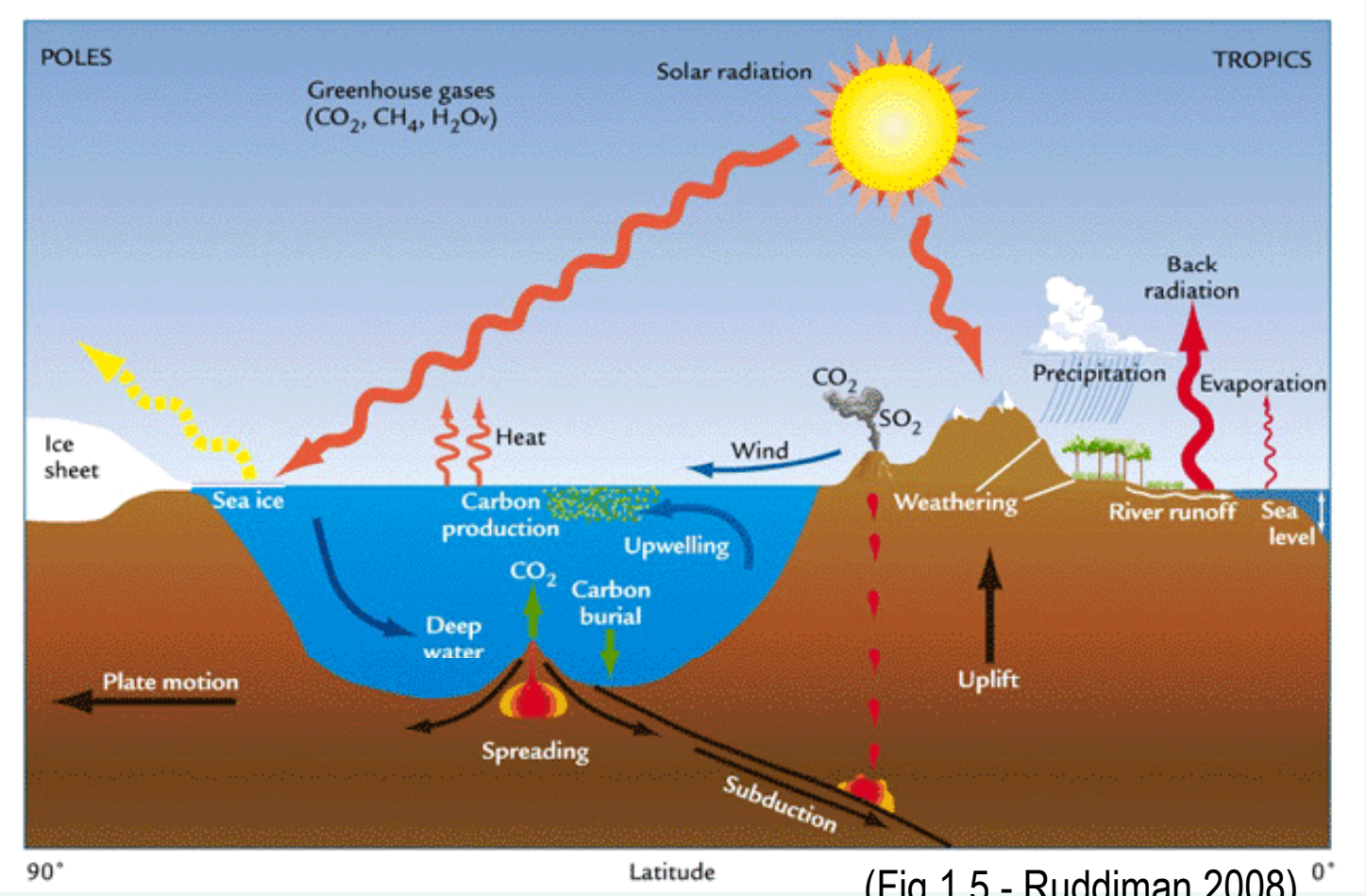
e.g.:
- vegetation traps surface moisture which increases T
- through transpiration, vegetation also emits water vapour in atmosphere
- some marine organisms extract CO_2 from seawater and store this greenhouse gas in the lithosphere



- effects of humans ... *we'll come back to that!*

Summary of interactions between components of climate system

Component's role = f(store & transfer E)



(Fig.1.5 - Ruddiman 2008)

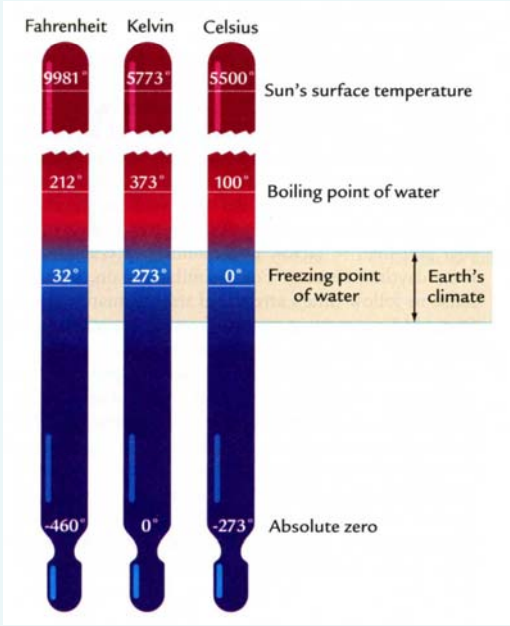
Measuring climate change

How can climate variations be detected?

Instrumental records only go back a few 100s yrs

If Earth formed 1 yr ago,
1st thermometer
appeared 2 s ago!

… must use other tools



Paleoclimatology – the study of past climate through proxy data

GOAL: understand *past* climate in order to understand *present* and predict *future* climate

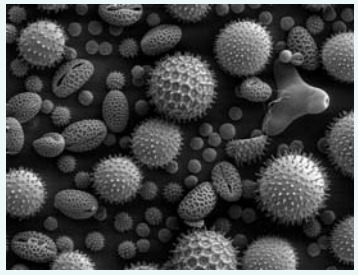
Paleoclimatology basics

Proxy data – indirect evidence from natural recorders of climate variability such as:

1. seafloor sediment

2. ice cores

3. others : tree rings, pollen, coral, volcanic ash, …



Measuring climate change

1. seafloor sediment
   - layered deposits (time)
   - biota reflects ocean conditions

Since 1960's, many deep-sea drilling programs

Joides Resolution – drill ship

sediment core logging

drill rig

Measuring climate change

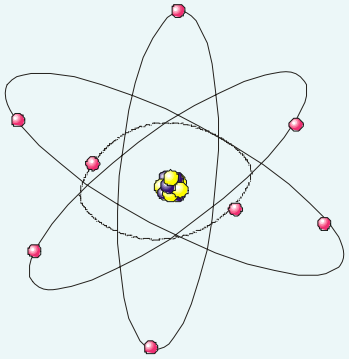
1. seafloor sediment - assumptions:

   - There is a direct link between air and water temperature.
   - Marine organisms distribution and abundance are affected by ocean T
   - Change in climate will be reflected by these organisms as they die and and get buried on the ocean floor sediment

Further, the $^{18}O/^{16}O$ ratio of the oxygen contained in the minerals ($CaCO_3$, SiO_2) forming the hard parts of these organisms can also be used to estimate periods of glacial activity (i.e. T)

Measuring climate change - oxygen isotope

In nature, not all oxygen atoms have 8 neutrons – isotope



The ratio → **heavier** oxygen isotope $\frac{^{18}O}{^{16}O}$ = $\frac{1}{500}$

lighter oxygen isotope

How can this ratio help us decipher past climate?

1. Lighter ^{16}O evaporates more easily from oceans →
oceans become ^{18}O enriched (vs. clouds)

2. Heavier ^{18}O precipitates more easily →
rain returns ^{18}O to surface and cloud is further enriched in ^{16}O

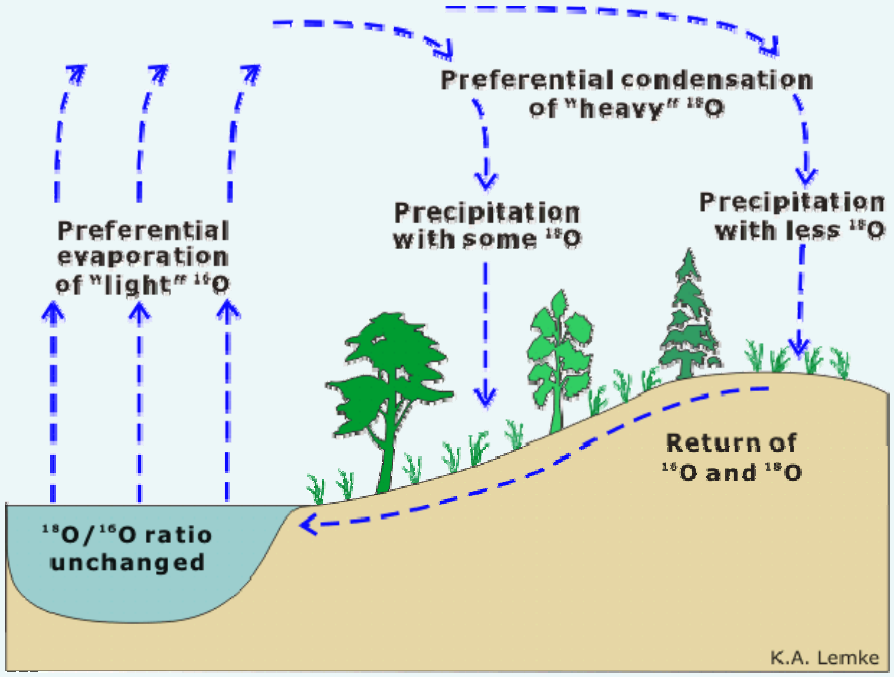
3. During periods of glaciation, ^{16}O is trapped in ice →
oceans are further enriched in ^{18}O (vs. interglacial - warm period)

Isotope fractionation (division based on mass)

Measuring climate change - oxygen isotope

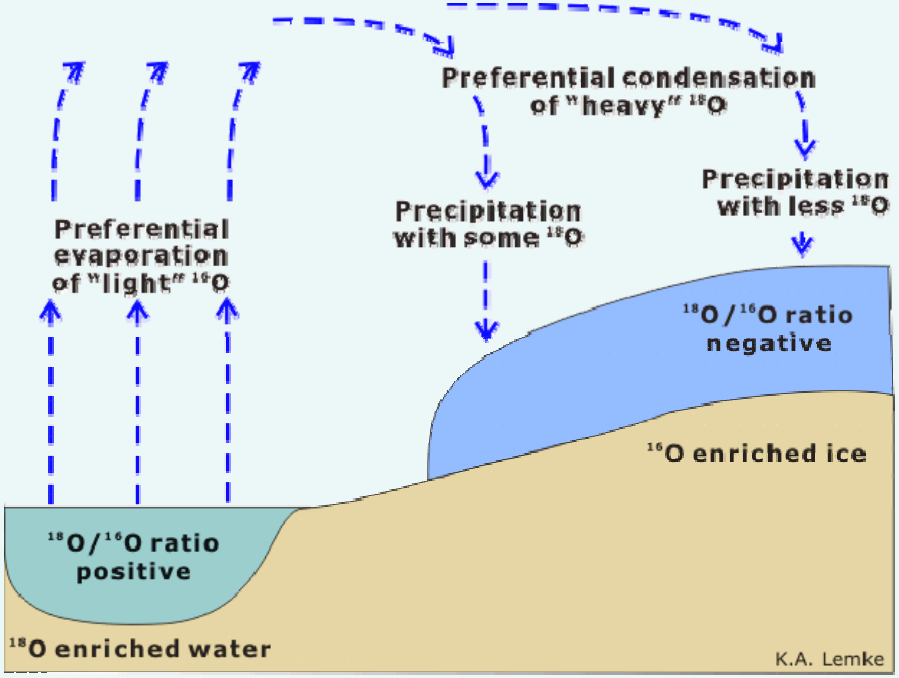
Oxygen isotope ratios ^{18}O / ^{16}O can help estimate past volumes of ice-sheets

Warm period



'Normal' ^{18}O / ^{16}O ratio

Glacial period



Oceans are <u>^{18}O enriched</u>
i.e. + ‰ ^{18}O values
(vs. standard mean of 0 ‰)

2. ice cores

- Oxygen in the water molecules can be analysed to determine their $^{18}O/^{16}O$ ratio from which T can be estimated

- In addition, gas bubbles trapped in the ice are samples of the past atmosphere and can also be analyzed (CO_2, CH_4, SO_2, …)

- Ice cores are layered (precipitation vs.time record)
+ if ash layers → absolute date

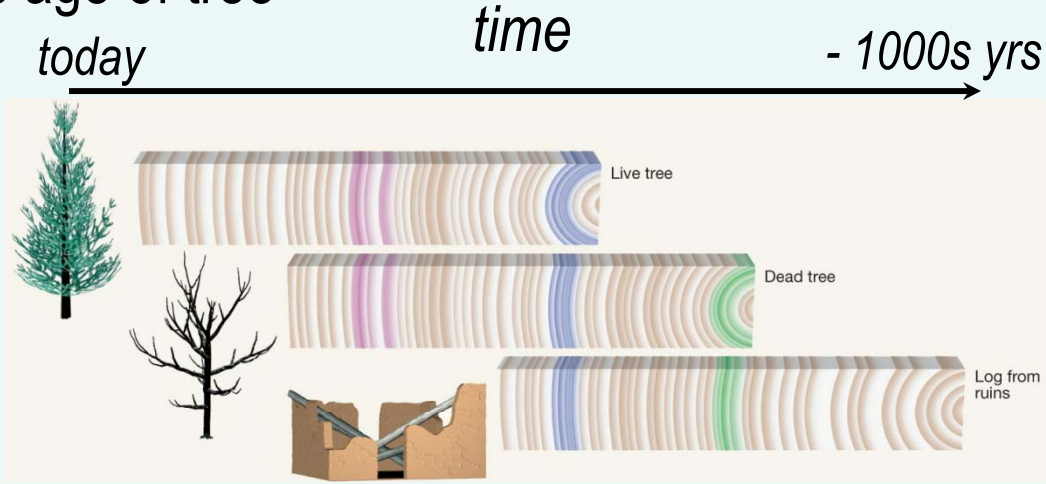
3. Tree rings

• Seasonal growth rings (pale / dark); favorable vs. harsh climate

• Distribution of species can indicate: T, humidity, soil type, insolation, wind

• Time → counting rings gives age of tree

• Cross dating techniques → extend time scale

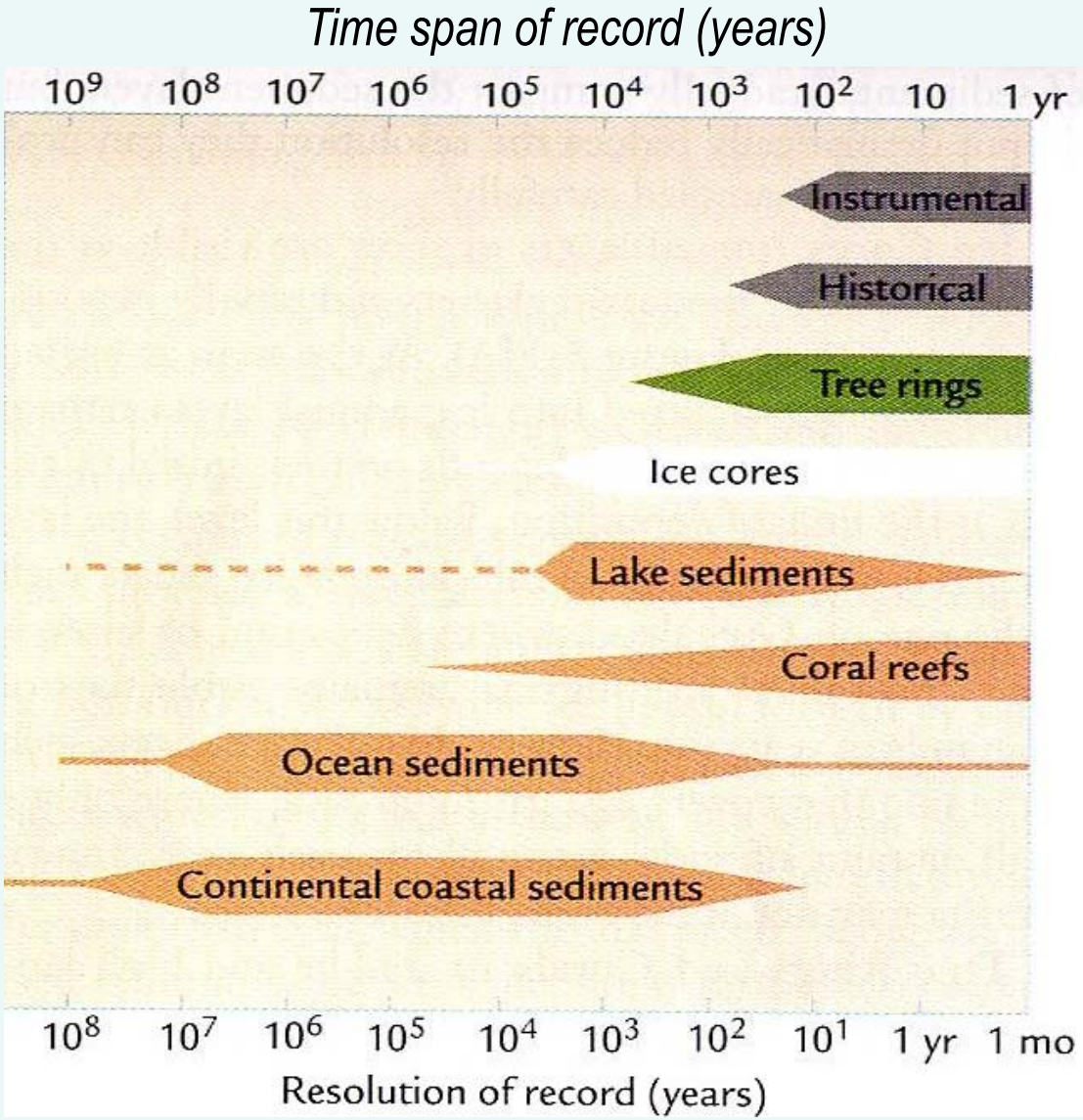


Measuring climate change

Usefulness of climate proxies

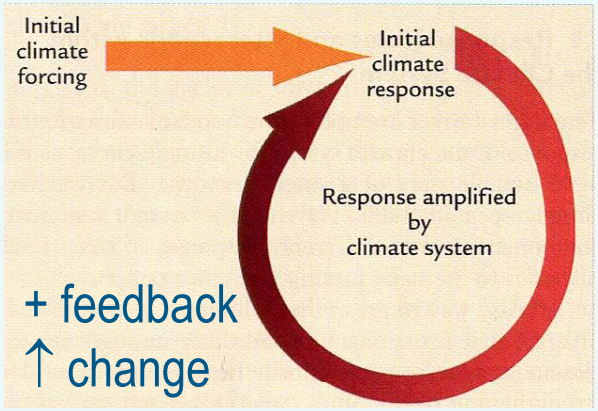
Tree rings and ice cores - high resolution, but only go back 1000s to 10 000s yrs

Sedimentary record proxy - <u>longest record</u> ~ Ga, most useful on full geologic scale

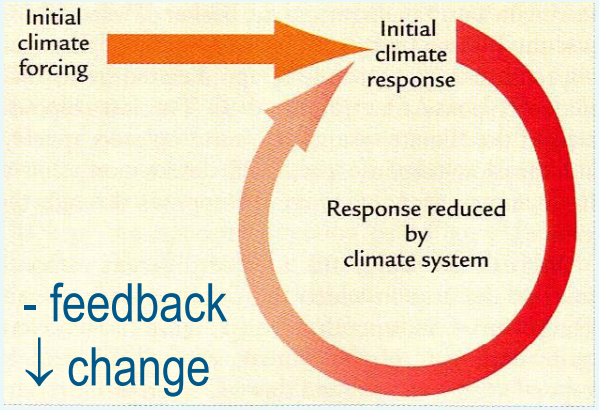


Inducing variation in the climate

Interaction between the various internal components of the climate system may either amplify (positive feedback) or suppress (negative feedback) climate changes that are underway.



POSITIVE → e.g., decreased insolation → cool climate → glacier growth → increased albedo → more solar E reflected → even cooler climate → glacier growth, etc.



NEGATIVE → e.g., greenhouse warming → increased evap. & cloud cover → → less solar radiation → cooling

Fig. 1-11 Ruddiman 2008

Feedback effects

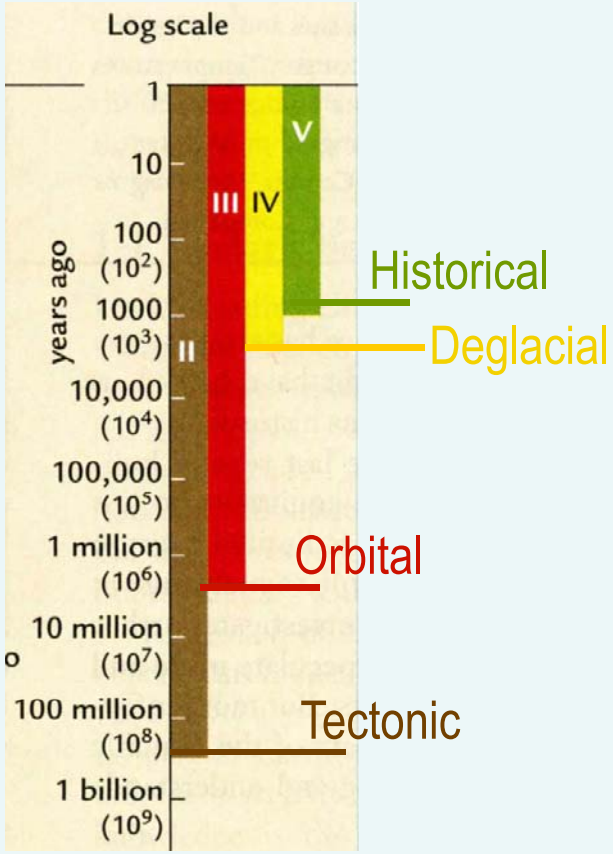
The FEEDBACK GAME – can you figure it out!?

Factors	*Effect on T*	*+ or - feedback*	*Why?*
↑ in water vapor			
↑ in plant growth			
↑ cloud cover			
↑ in ice cover			

… very complex and often more than one-sided, eg. clouds

Inducing climate variation

Time scales of change



Possible causes (and ~time scale)

see section: component of climate system – lithosphere

1. Tectonics – latitude of continents and supercontinent assembly/breakup cycles (millions of yrs)
2. Volcanism (months to yrs)

next 4 slides and movies

3. Orbital variations (10's to 100 thousand yrs)
4. Solar activity (11 and 22 yrs cycle)

movies

5. Milky Way spiral arm encounters (~140 million-year cycle)
6. Humans (~ last 100 yrs)

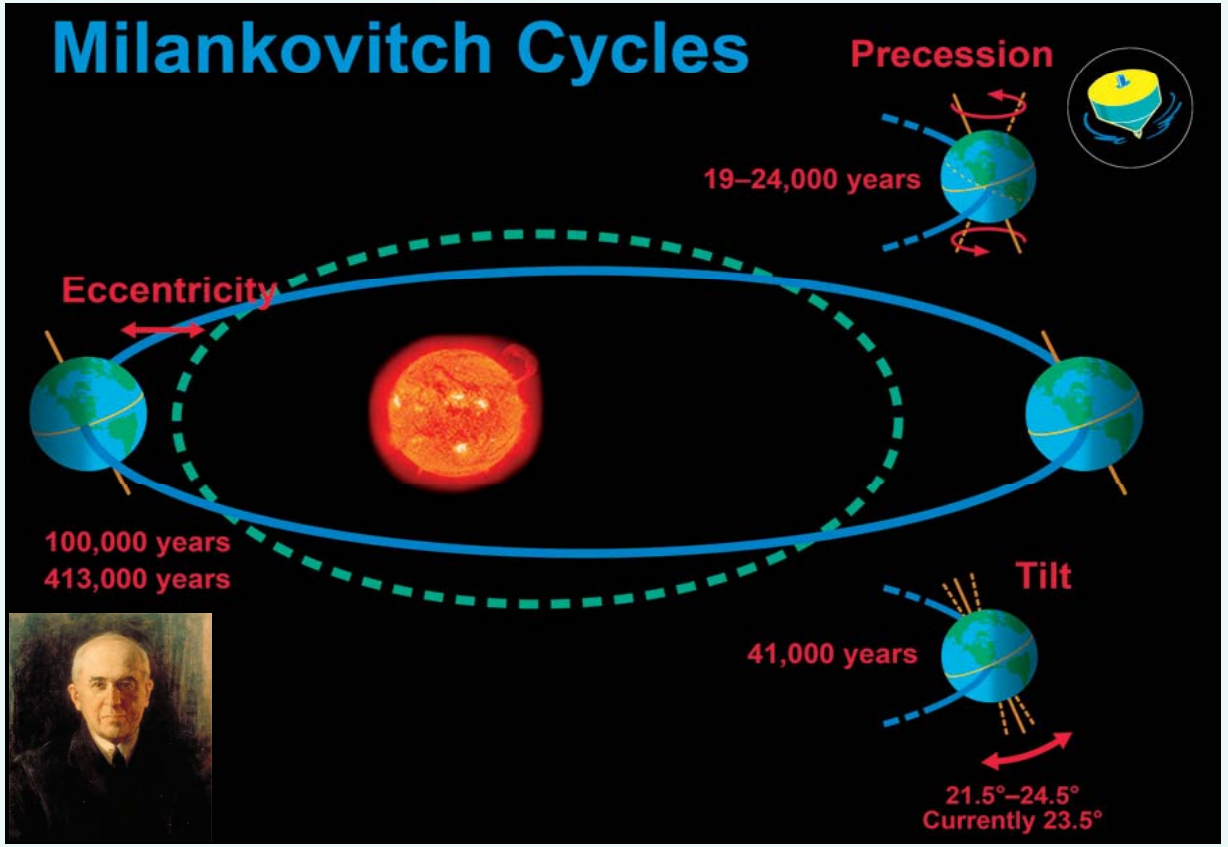
Inducing climate variation – orbital variations

Orbital changes:

- Eccentricity
- Tilt
- Precession

↓

All affect contrast between seasons (relative insolation)



General rule –

Lower seasonal contrast →

WARMER winters (more snow) and COOLER summers (less melt) →

Promotes ice sheet growth (if other conditions are also favorable)

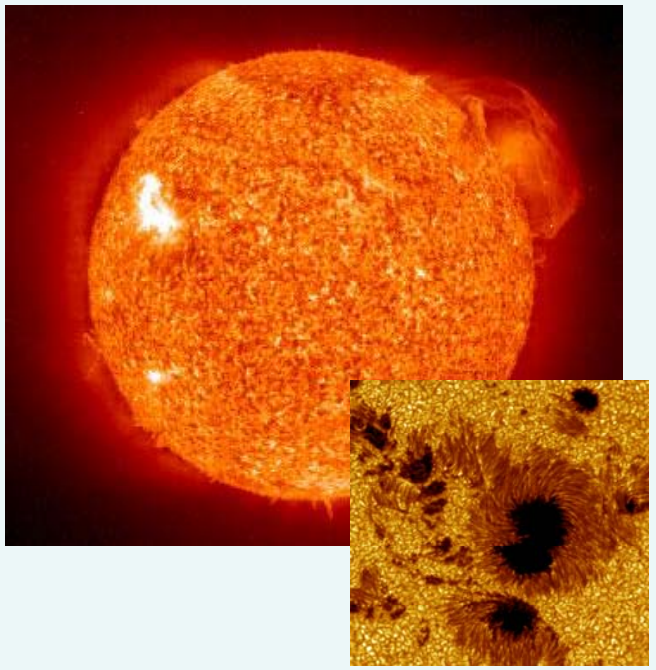
Inducing climate variation – solar activity

Sun → sole external E source powering our climate system

Sun → variable star with fluctuating E output

↓

Logical consequence:
varying Sun = varying climate

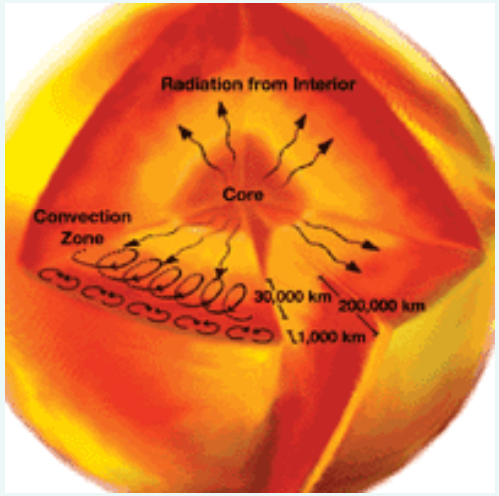


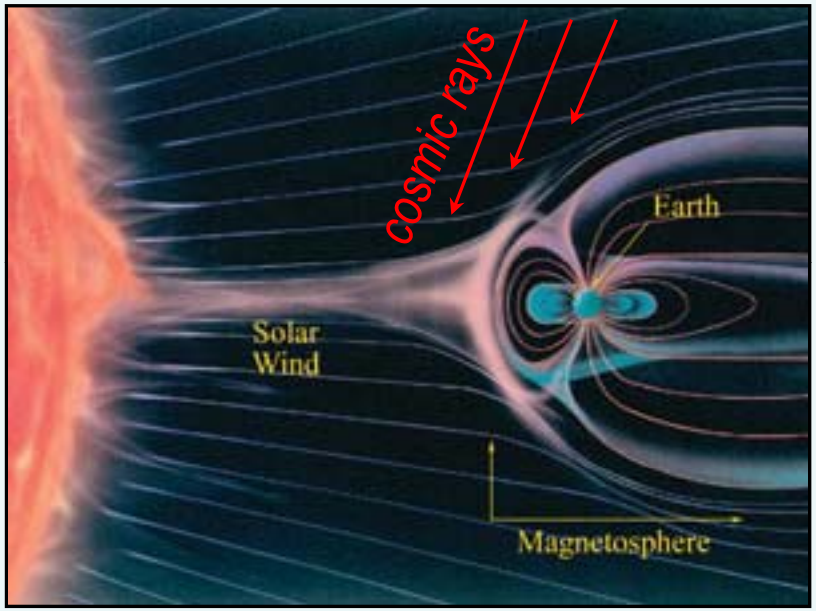
Sunspots: region on Sun's surface marked my intense magnetic activity; observable as dark spots on the Sun's surface.

Sun's activity is high → # sunspots ↑ (max. ~ every 11 yrs)

Inducing climate variation – solar activity

Solar wind: stream of charged particles emitted by the Sun. Solar wind expand the heliosphere (magnetic bubble surrounding our Solar system) and increases with Sun activity (sunspots).





Heliosphere and **Earth's magnetic field** both shield the Earth from incoming galactic cosmic rays

Cosmic rays: energetic particles originating from space. Some reach the Earth's atmosphere (90% are protons). Possibly linked to cloud formation.

Inducing climate variation – solar activity

Solar activity vs. Earth's climate – proposed sequence of events:

Solar activity

gives off the solar wind

expands heliosphere

that reduces cloud-forming cosmic rays

giving lower cloudiness (albedo)

and more light on earth

making a **warmer Earth**

Inducing climate variation – humans (anthropogenic cause)

Let's go to the movies!

1. An inconvenient truth (Al Gore, 2007)

5 min. excerpt

2. The great global warming swindle (various scientists, 2007)

15 min. excerpt

3. The cloud mystery (Henrik Svensmark, 2008)

17 min. excerpt

Inducing climate variation – humans (anthropogenic cause)

Questions to keep in mind while you watch the three movie excerpts:

1. Main ideas presented by each movie
2. CO_2 as Δ climate driver$\rightarrow$ arguments FOR and AGAINST
3. Sun's activity and cosmic ray flux as Δ climate driver$\rightarrow$ arguments FOR and AGAINST

1. An inconvenient truth (Al Gore, 2007)

www.climatecrisis.net

2. The great global warming swindle (various scientists, 2007)

www.youtube.com

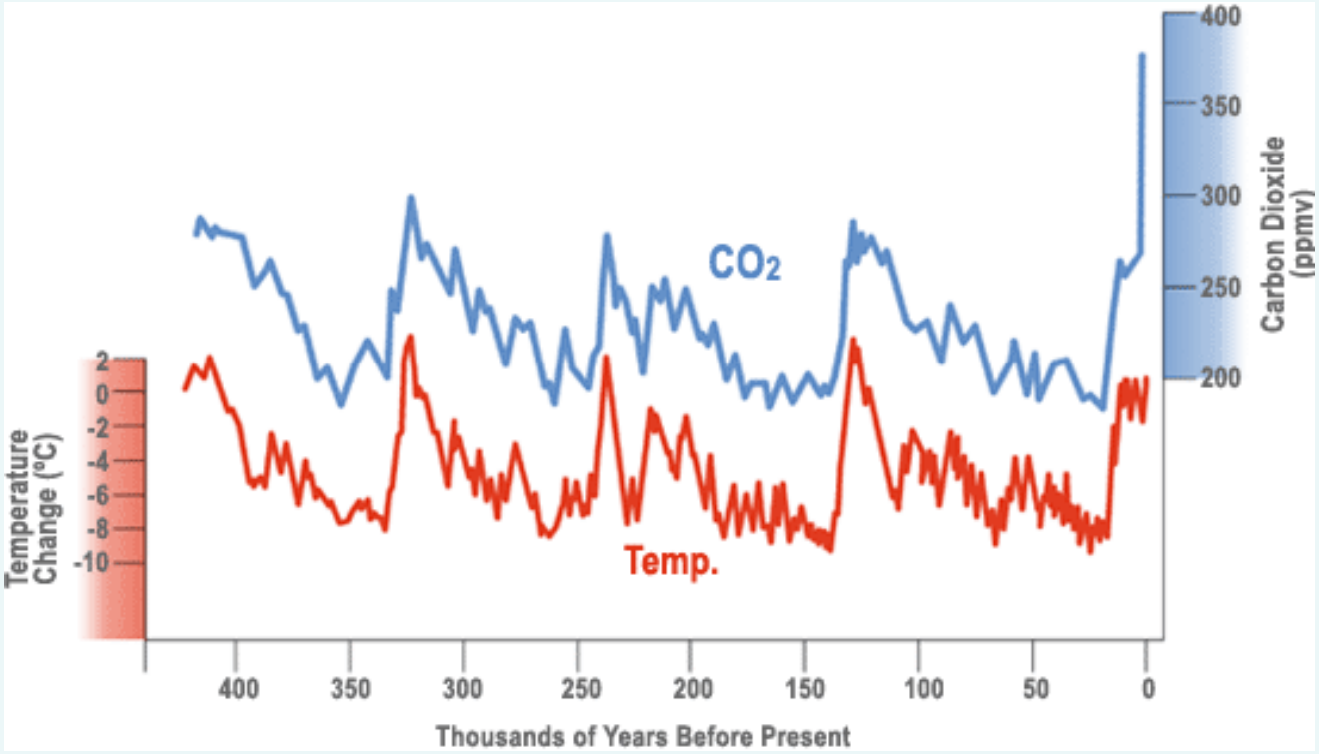
3. The cloud mystery (Henrik Svensmark, 2008)

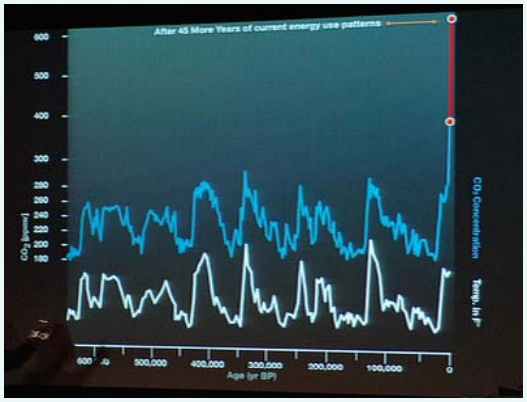
www.thecloudmystery.com

The next few slides, are a selection of graphs (8) presenting some of the data that is central to the climate change debate.

Use the notes you took in class during the presentation of the movie excerpts, the internet references provided, and the following graphs in parallel to summarize the various points of view on the roles of CO_2 (anthropogenic and natural), and cosmic ray flux as possible drivers of climate change.

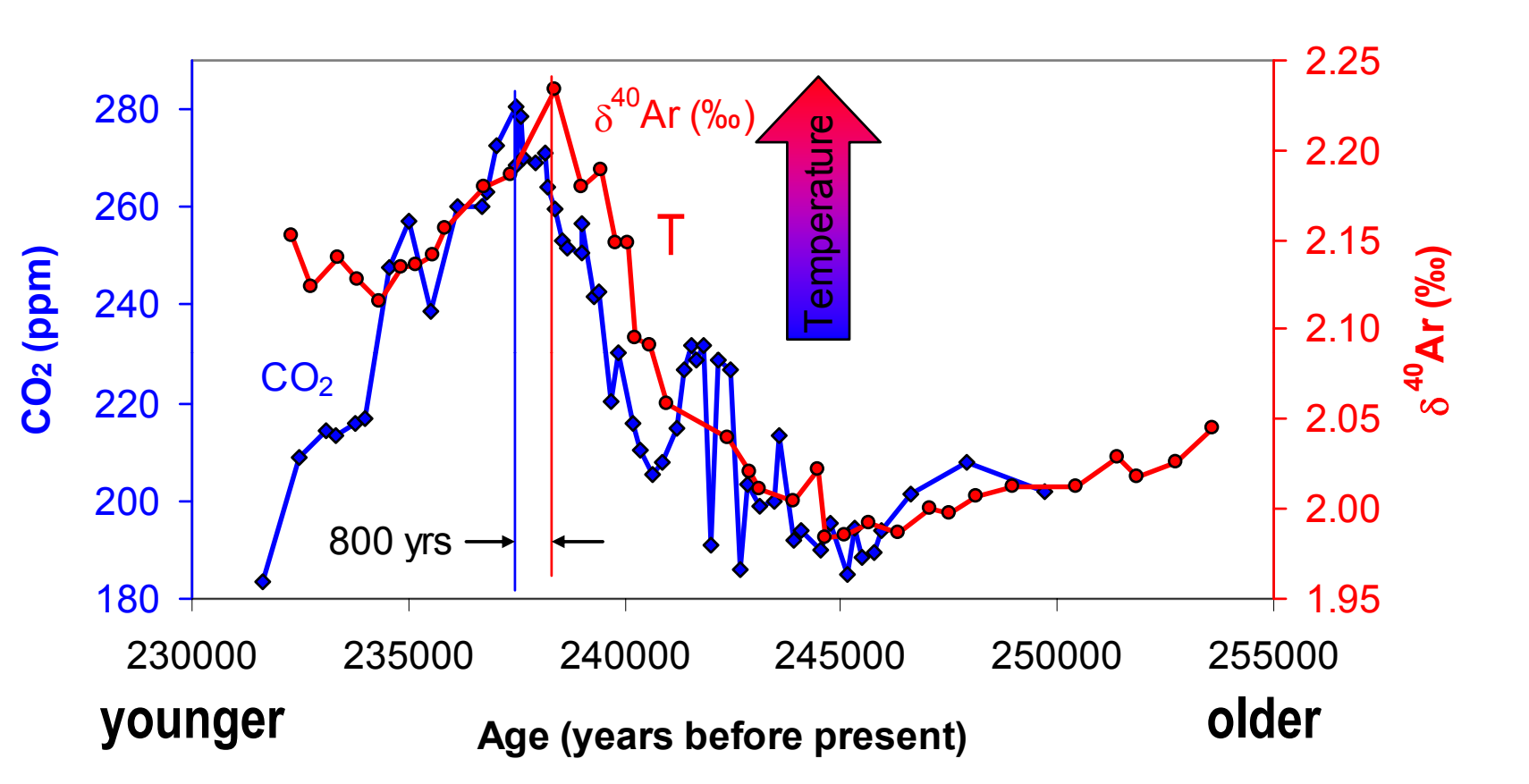
CO_2 and T vs. time over the last 650 000 yrs – as presented by Al Gore





Gore's slide is based on original data from Vostok ice core (Antarctica) published by J.R. Petit et al. in Nature (June 1999).

CO_2 and T vs. time – finer resolution → CO_2 lags behind T by about 800 yrs



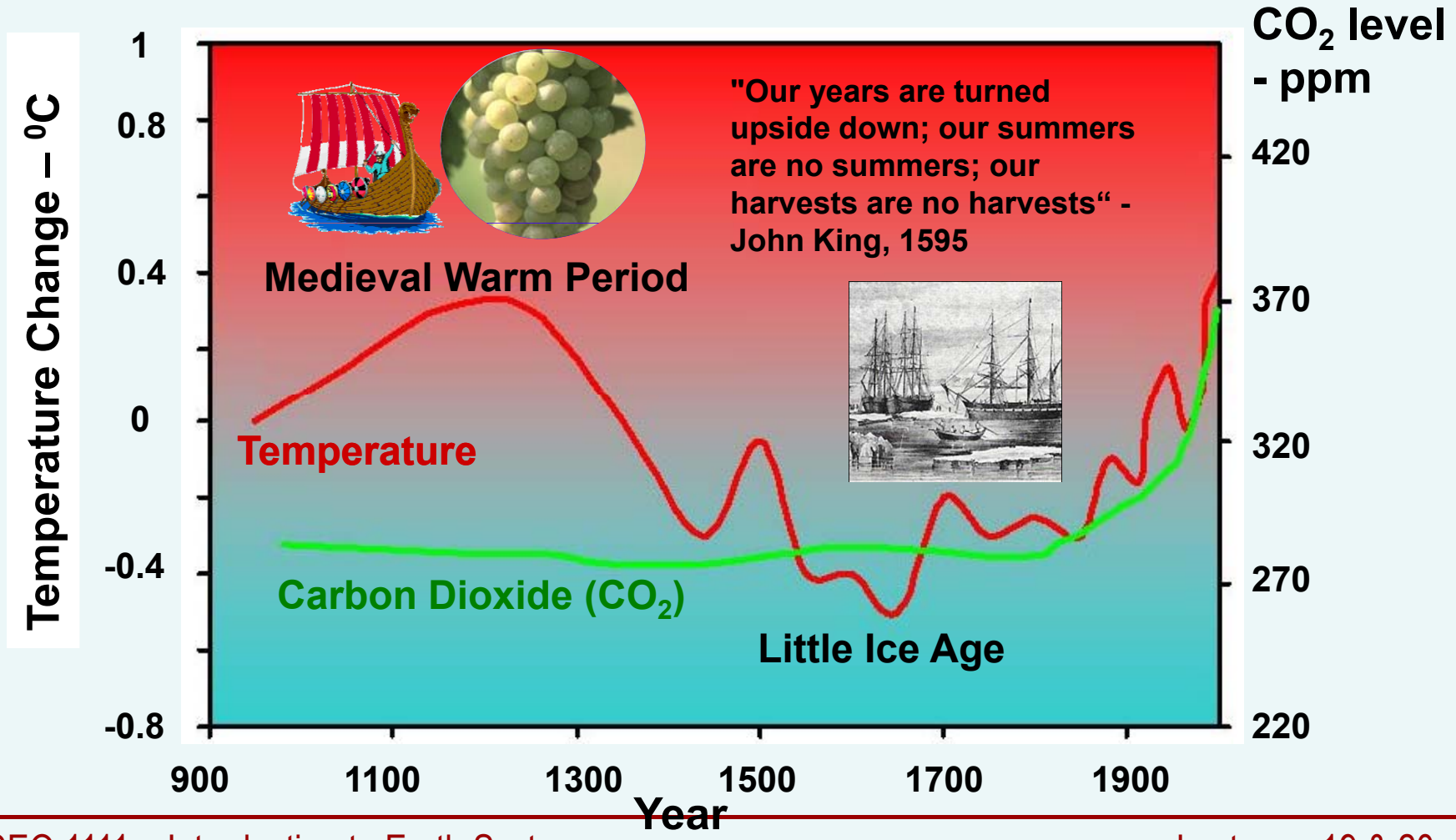
"This confirms that CO_2 is not the forcing that initially drives the climatic system during a deglaciation. Rather, deglaciation is probably initiated by some insolation forcing."

Caillon et al., 2003, Science, 299, 1728

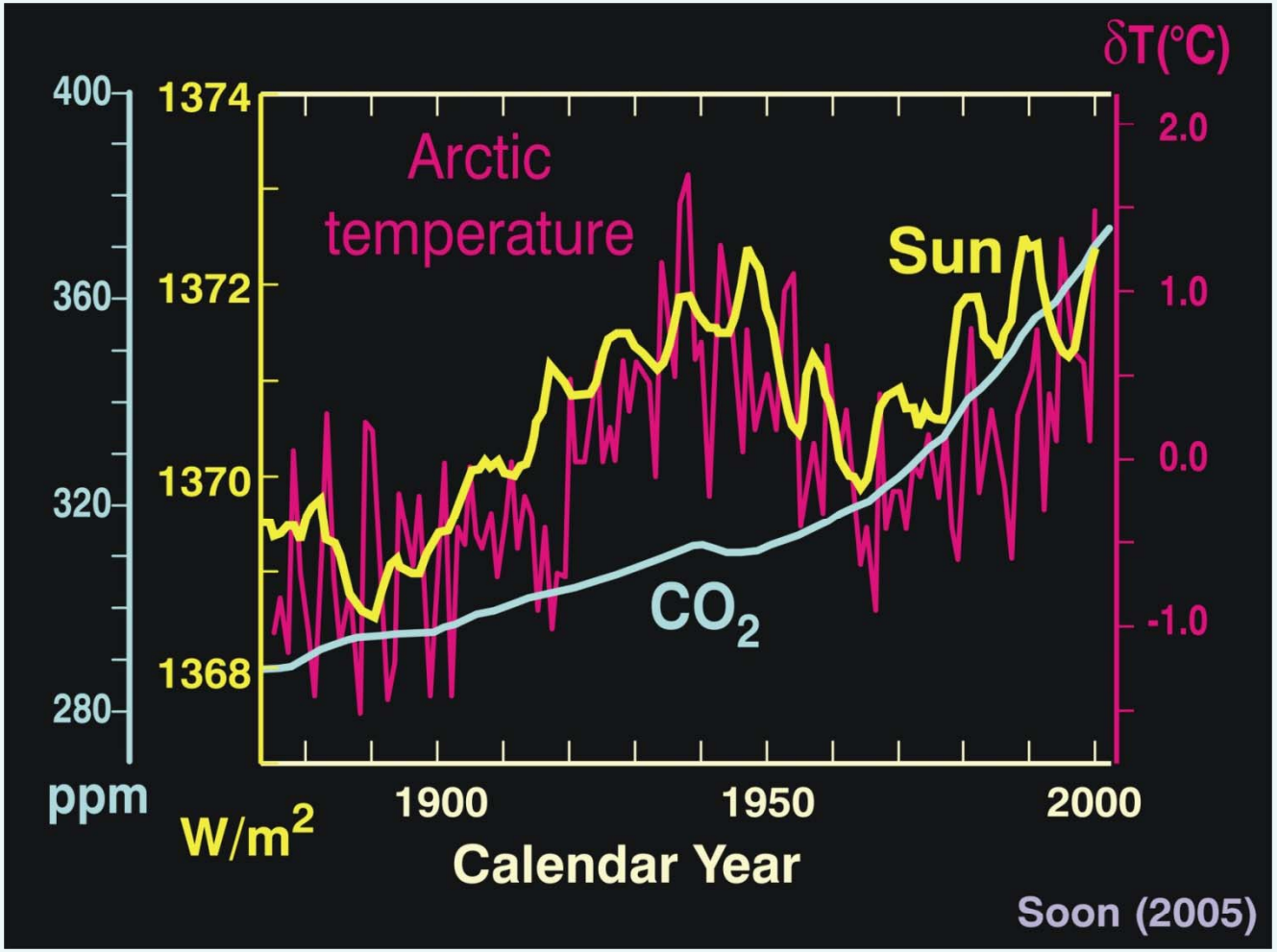
CO_2 and T vs. time – the last millennium

Note 1: low CO_2 during medieval warm and high CO_2 during little ice age

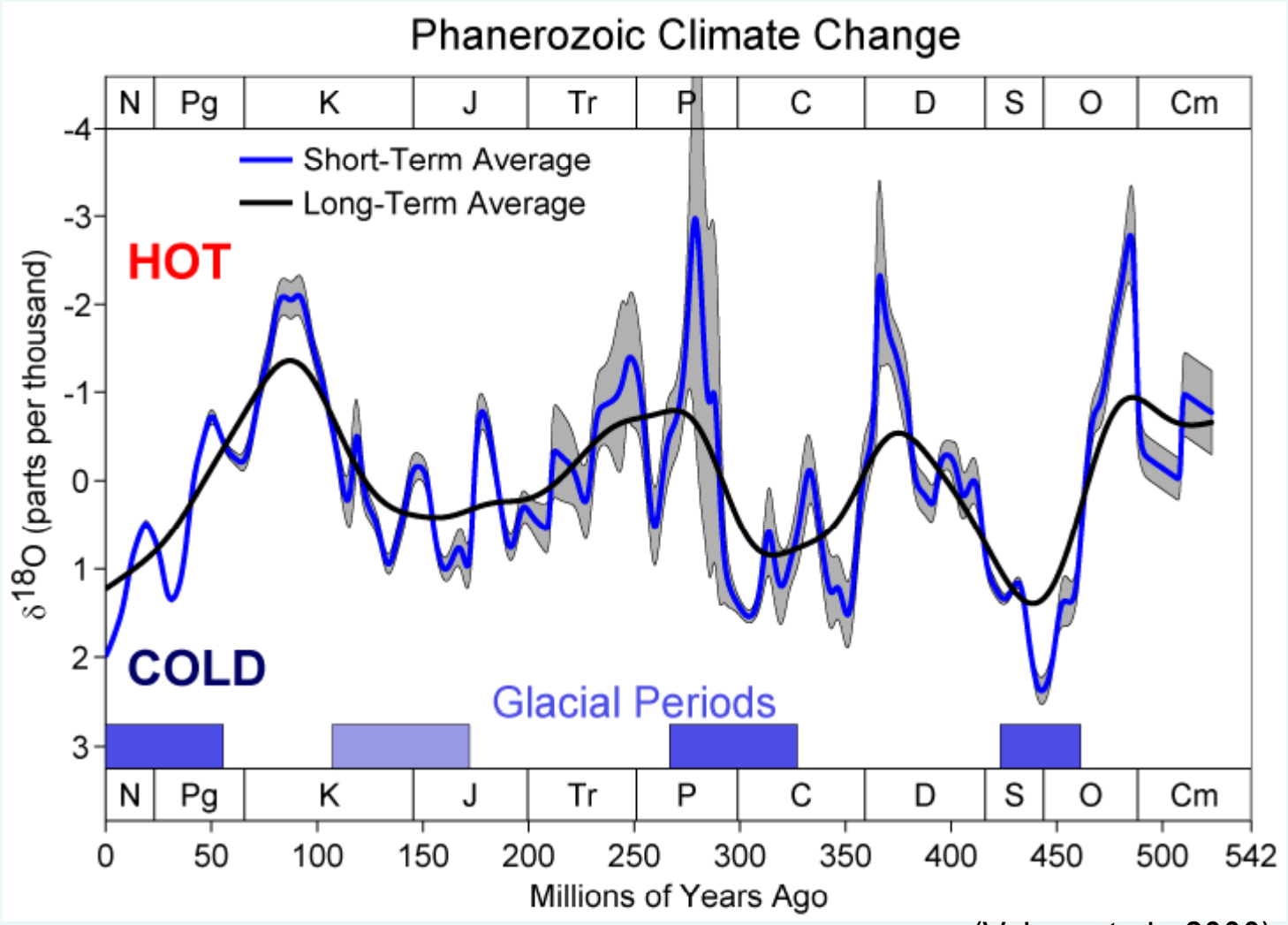
Note 2: are present day T so anomalous (even in this very short time span)?



CO_2 , T , and solar activity vs. time – the last century

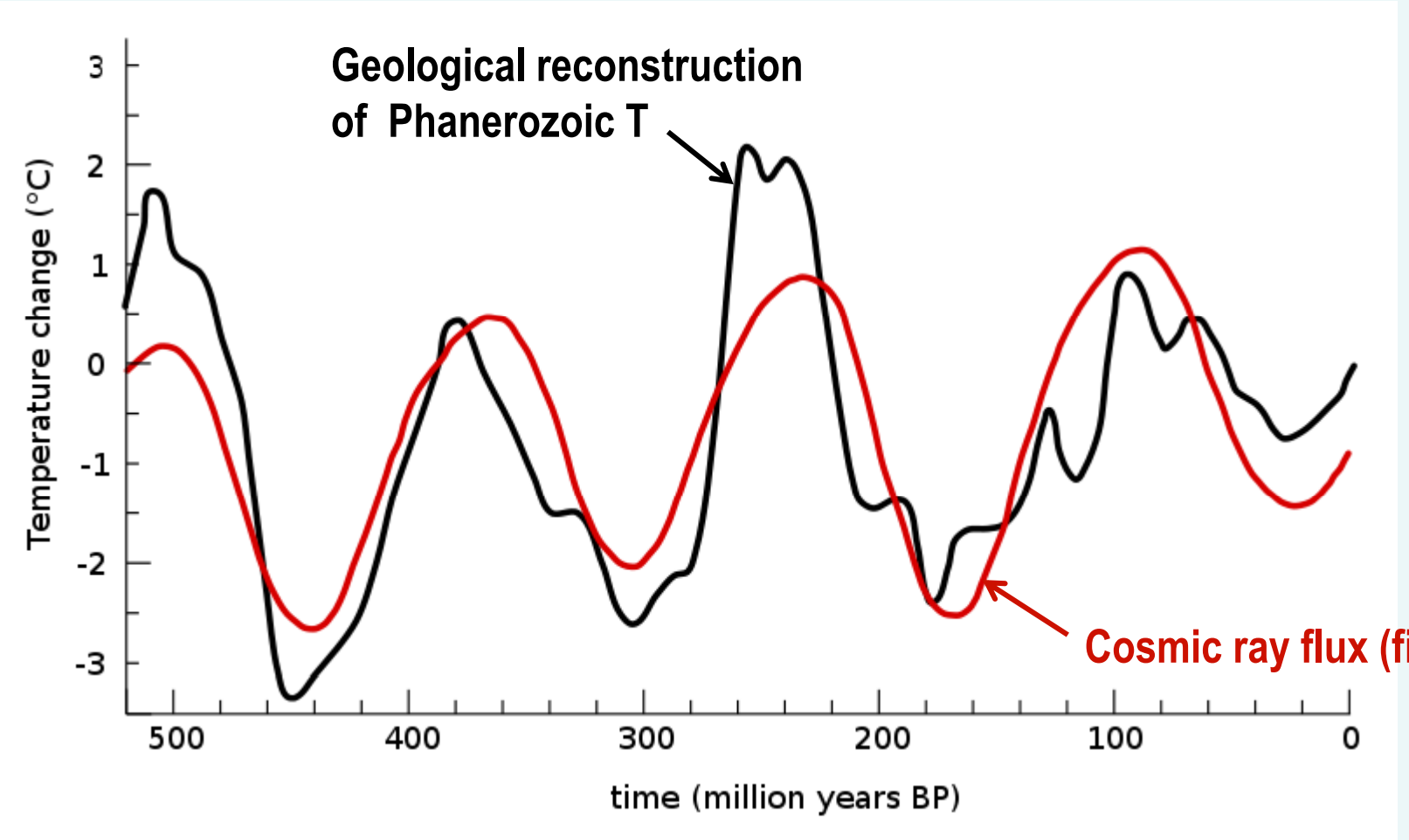


Paleotemperature reconstruction and glacial periods of the Phanerozoic



(Veizer et al., 2000)

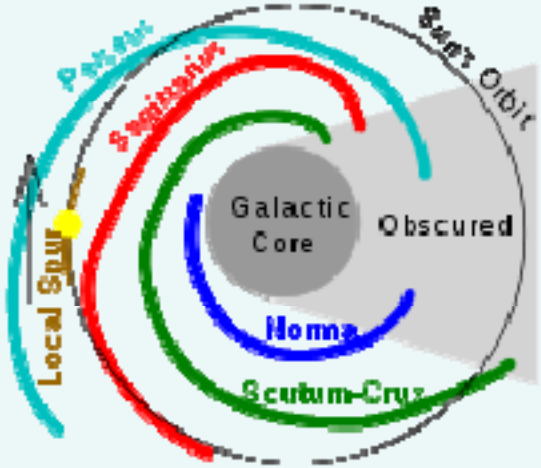
T and cosmic ray flux vs. time – last 500 Ma (geologic scale)

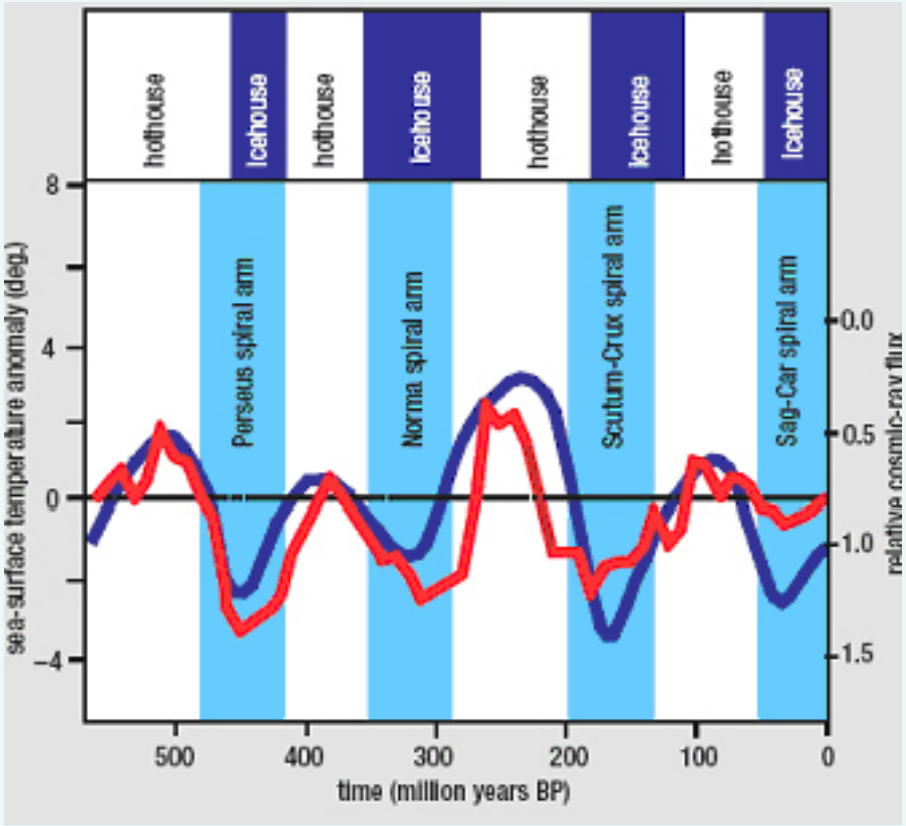


Nir J. Shaviv, NJ, Veizer, J. *GSA Today*, **vol 7**, Issue 7 (July 2003)

T and cosmic ray flux vs. time – last 500 Ma (geologic scale)

Note: cosmic ray flux increases as the Solar system crosses the various spiral arms of the Milky Way (our galaxy)

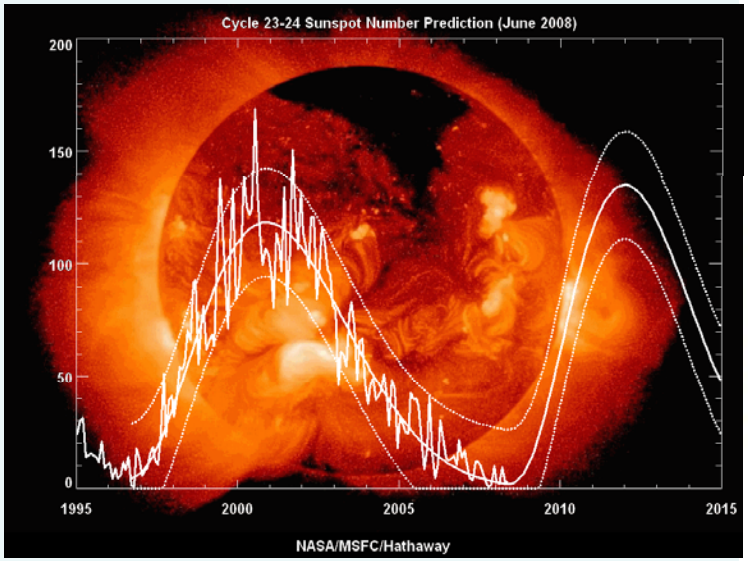


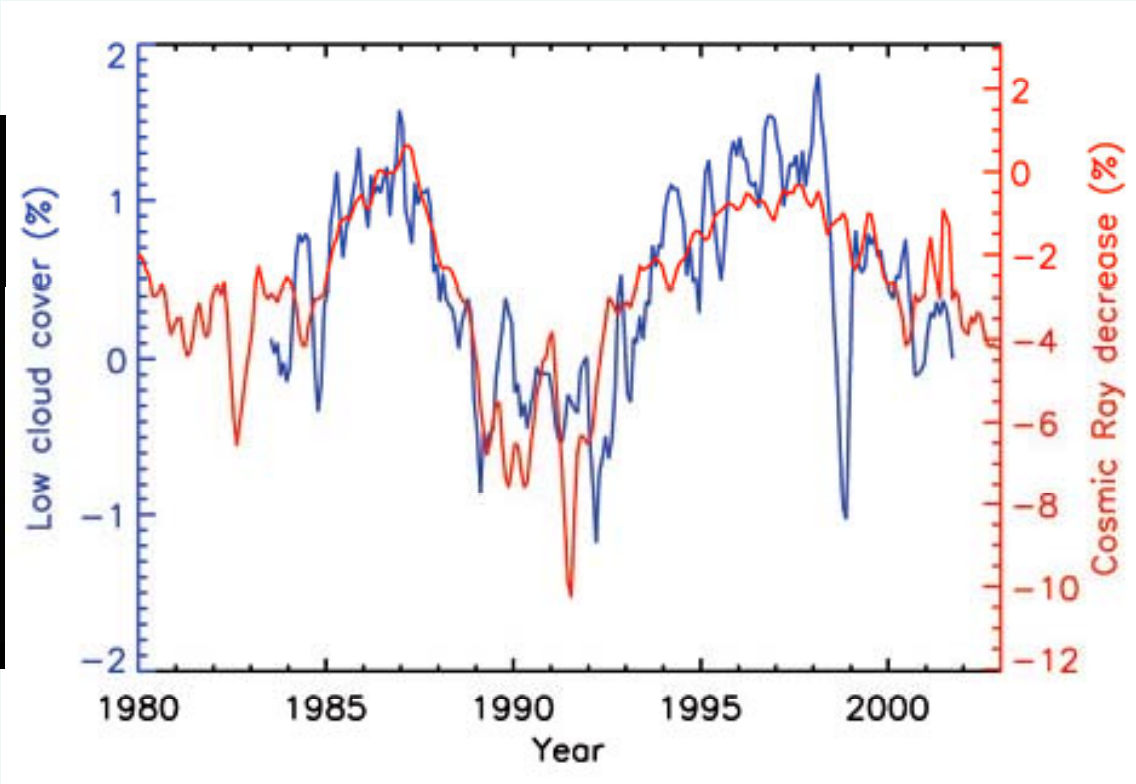


Svensmark, H. A&G; vol. 48 February 2007

Low cloud cover and cosmic ray flux vs. time – ~ last 25 yrs

Sun spot cycle (11 yr period)

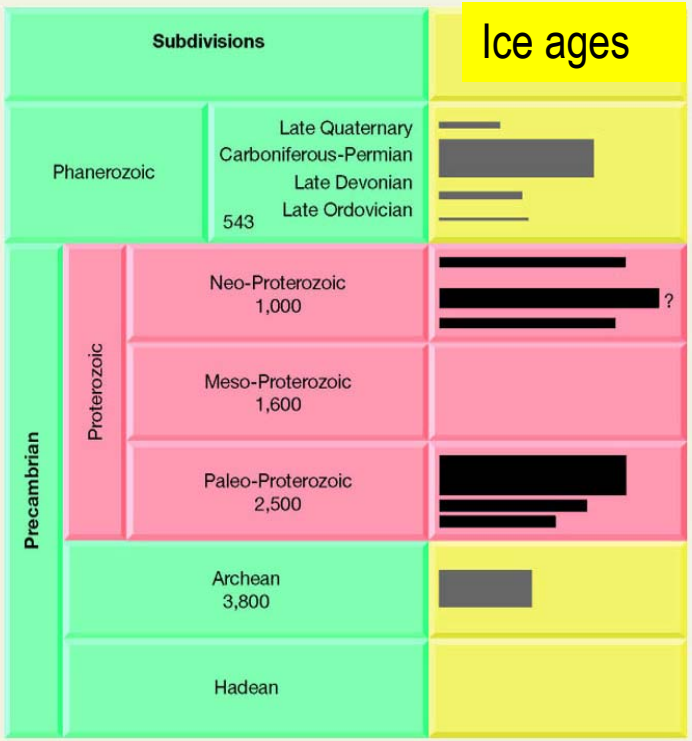




Svensmark, H. A&G; vol. 48 February 2007

Numerous intervals of global refrigeration –

Glaciers and ice sheets more extensive than today



◆ **Figure 12.C** Major glacial episodes in Earth history as indicated by horizontal bars.

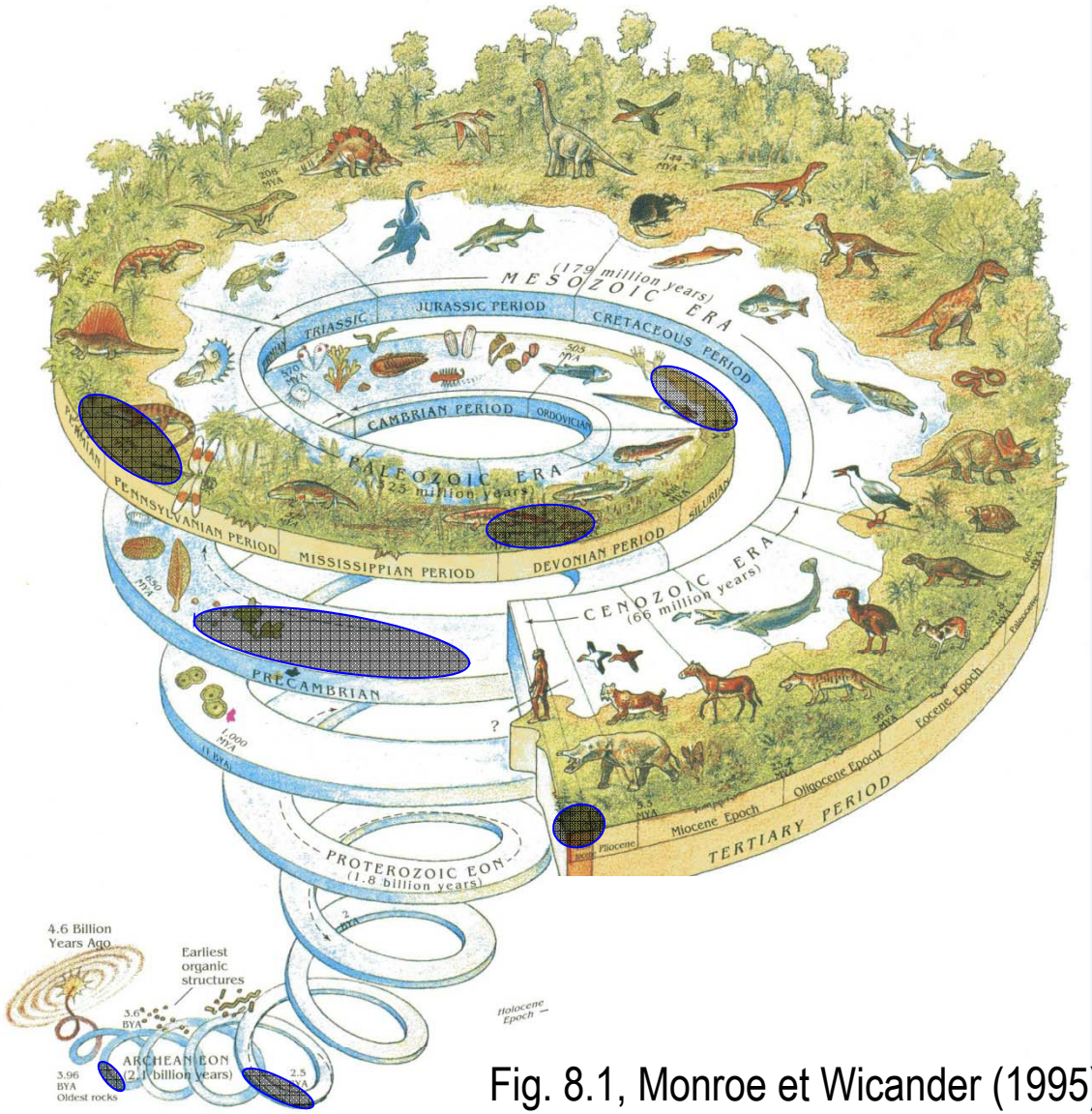


Fig. 8.1, Monroe et Wicander (1995)