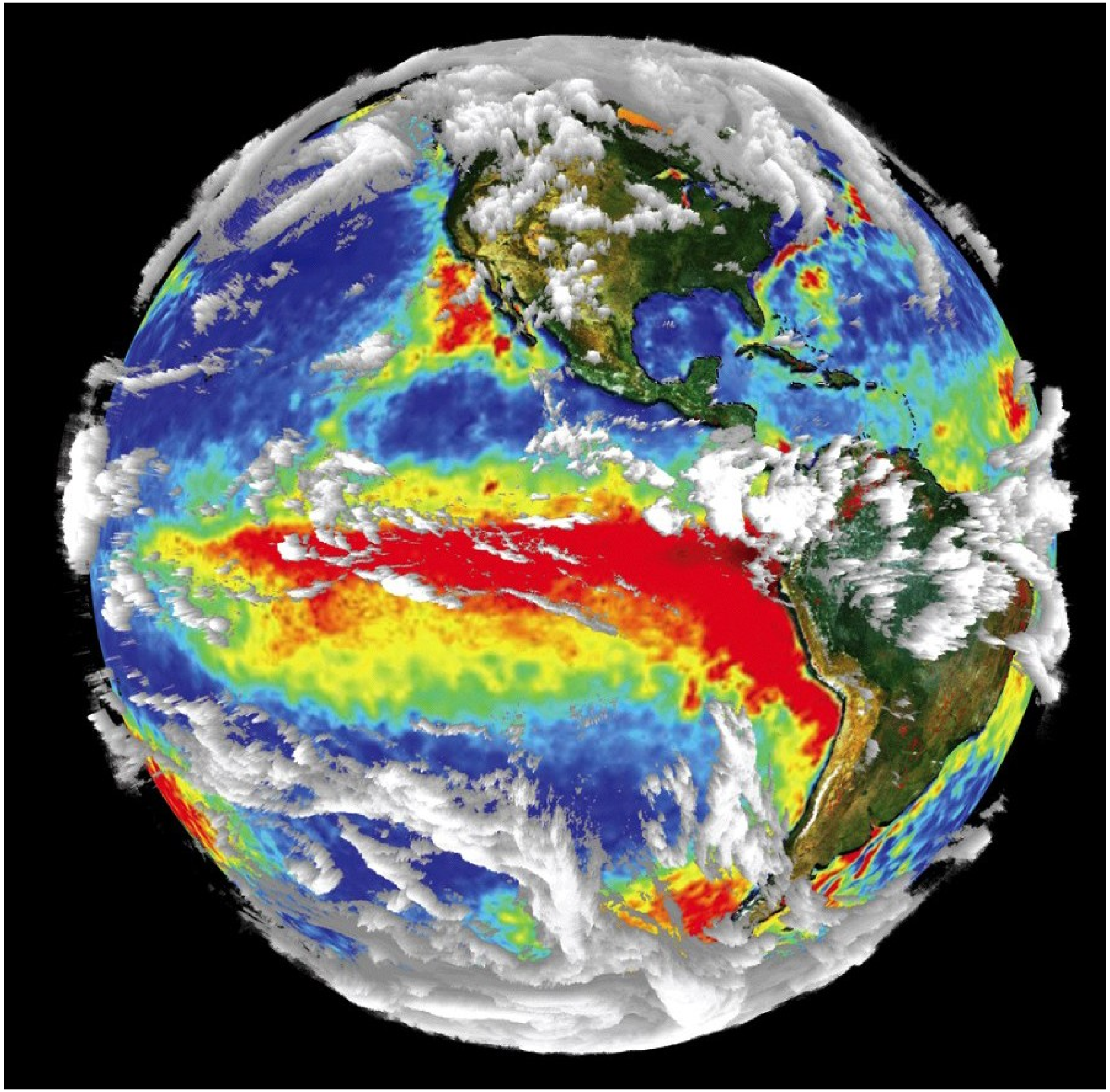
Climate

Geology 1

G. Bertotti

We have created mountains, plains, topography

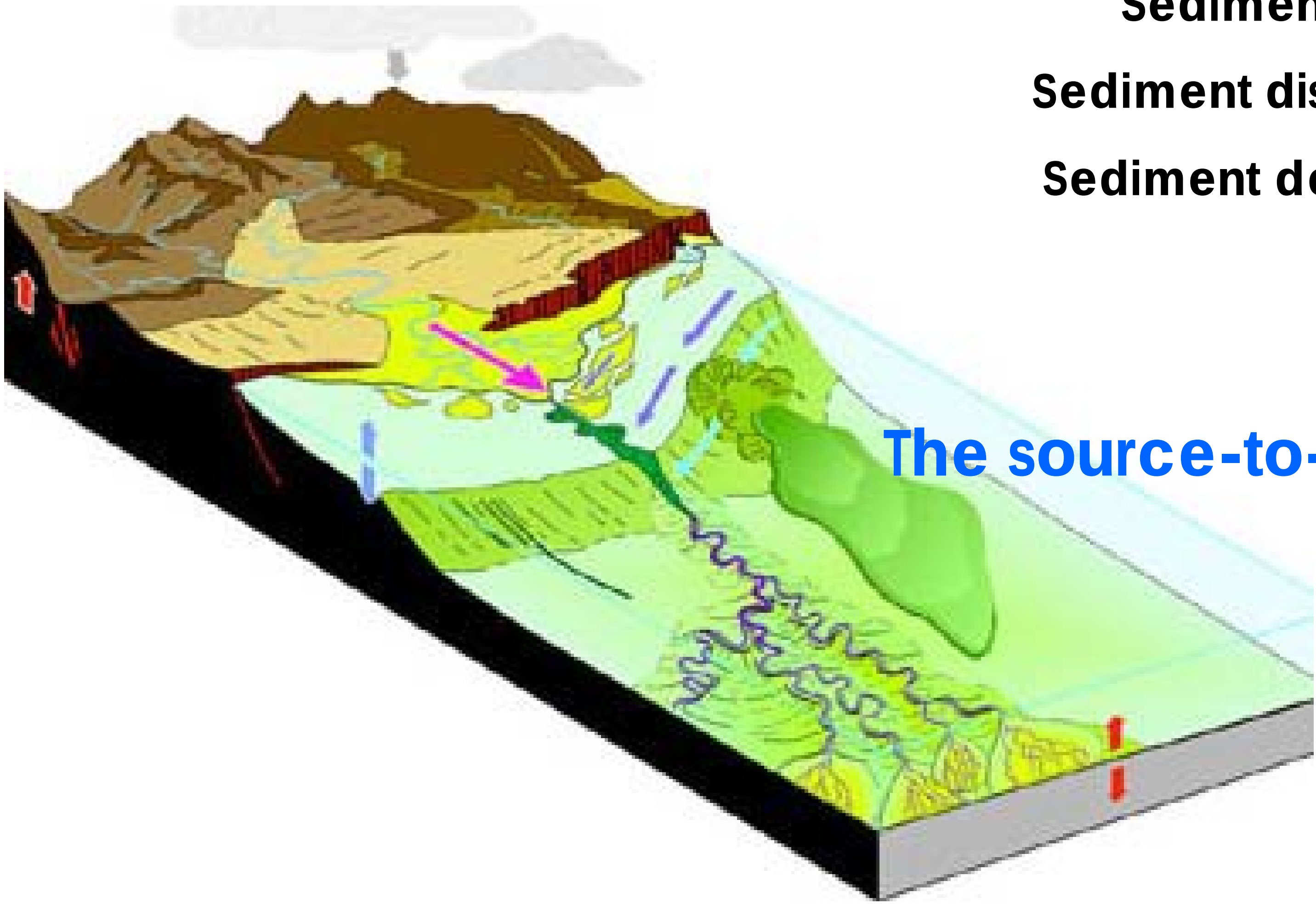


Sedimentary systems

Sediment factory

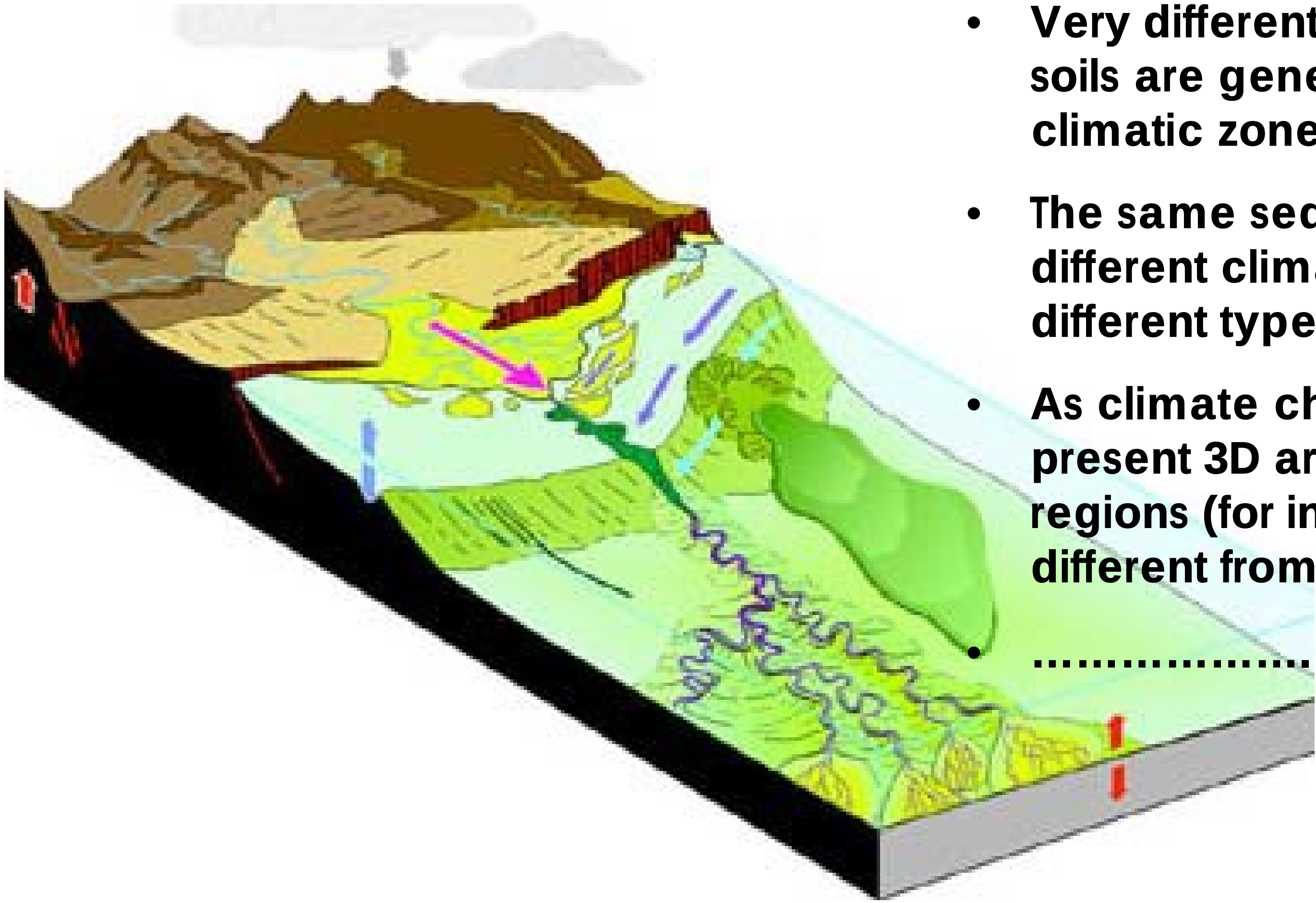
Sediment distribution

Sediment deposition



The source-to-sink approach

Climate has a major impact on processes taking place in all components

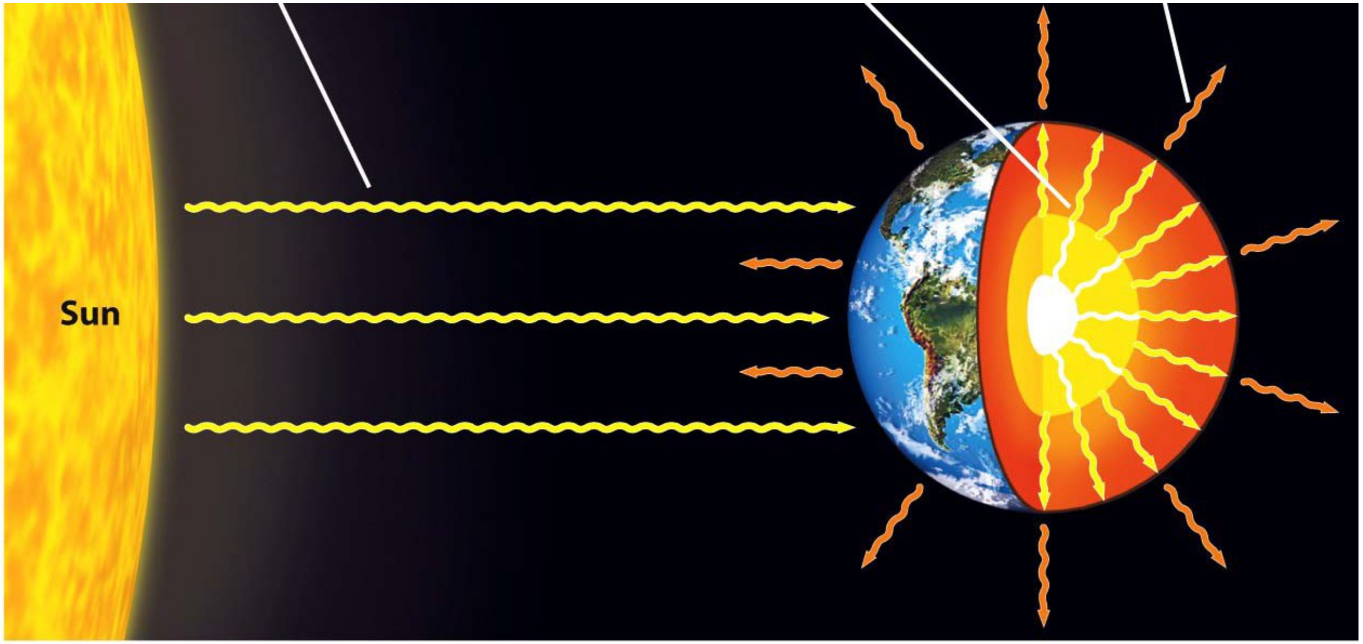


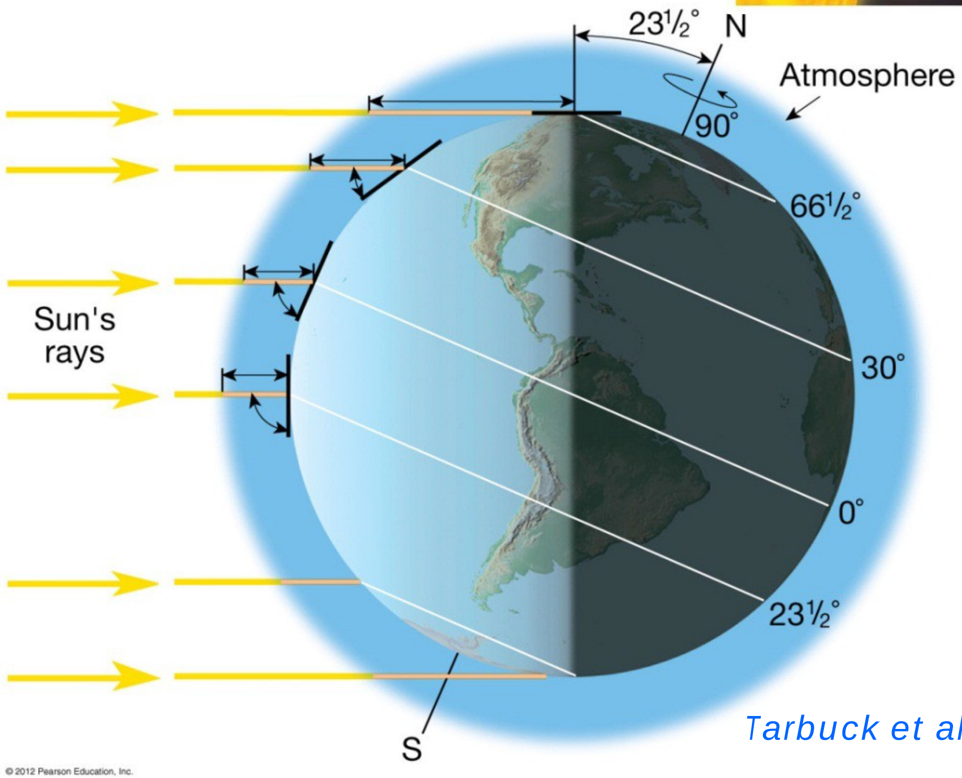
- the same mountain in different climates produces very different sediments
- Very different amounts and types of soils are generated in different climatic zones
- The same sediments deposited in different climatic zones produce different types of rocks
- As climate changes through time, the present 3D architecture of rocks and regions (for instance deltas) is different from the one in the past
- ………………..

A two component system:

The energy coming from the sun

The interactions with the Earth



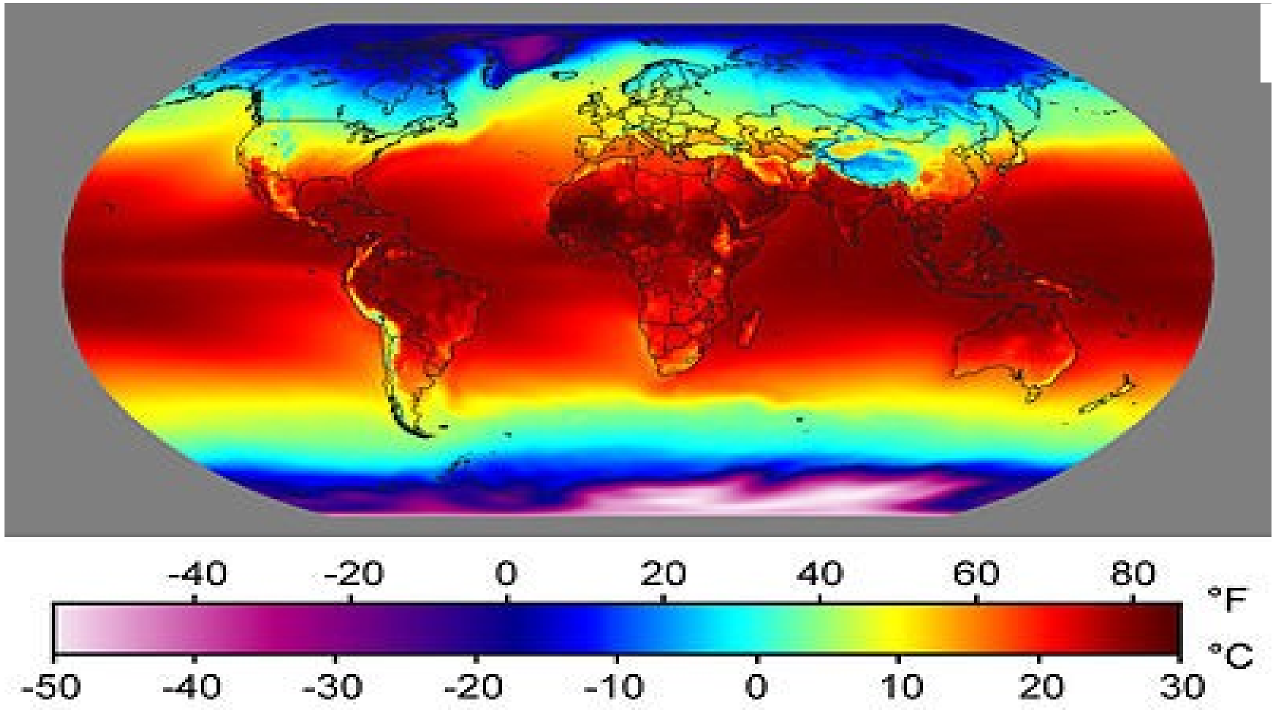


Tarbuck et al.

First-order temperature distributions

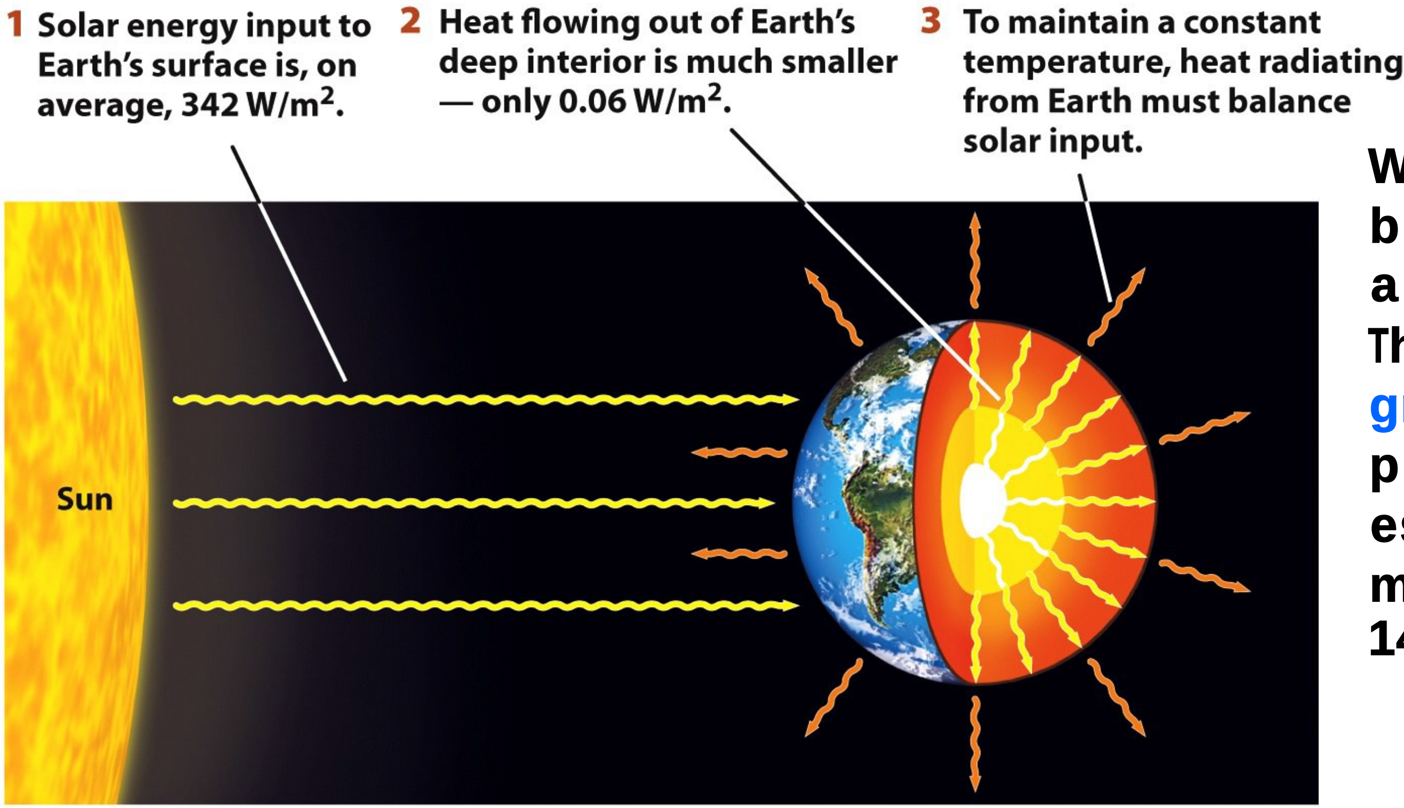
Because of the spherical shape of the Earth, different parts of the planet receive different amount of energy.

Temperatures vary across the globe



Annual mean temperatures

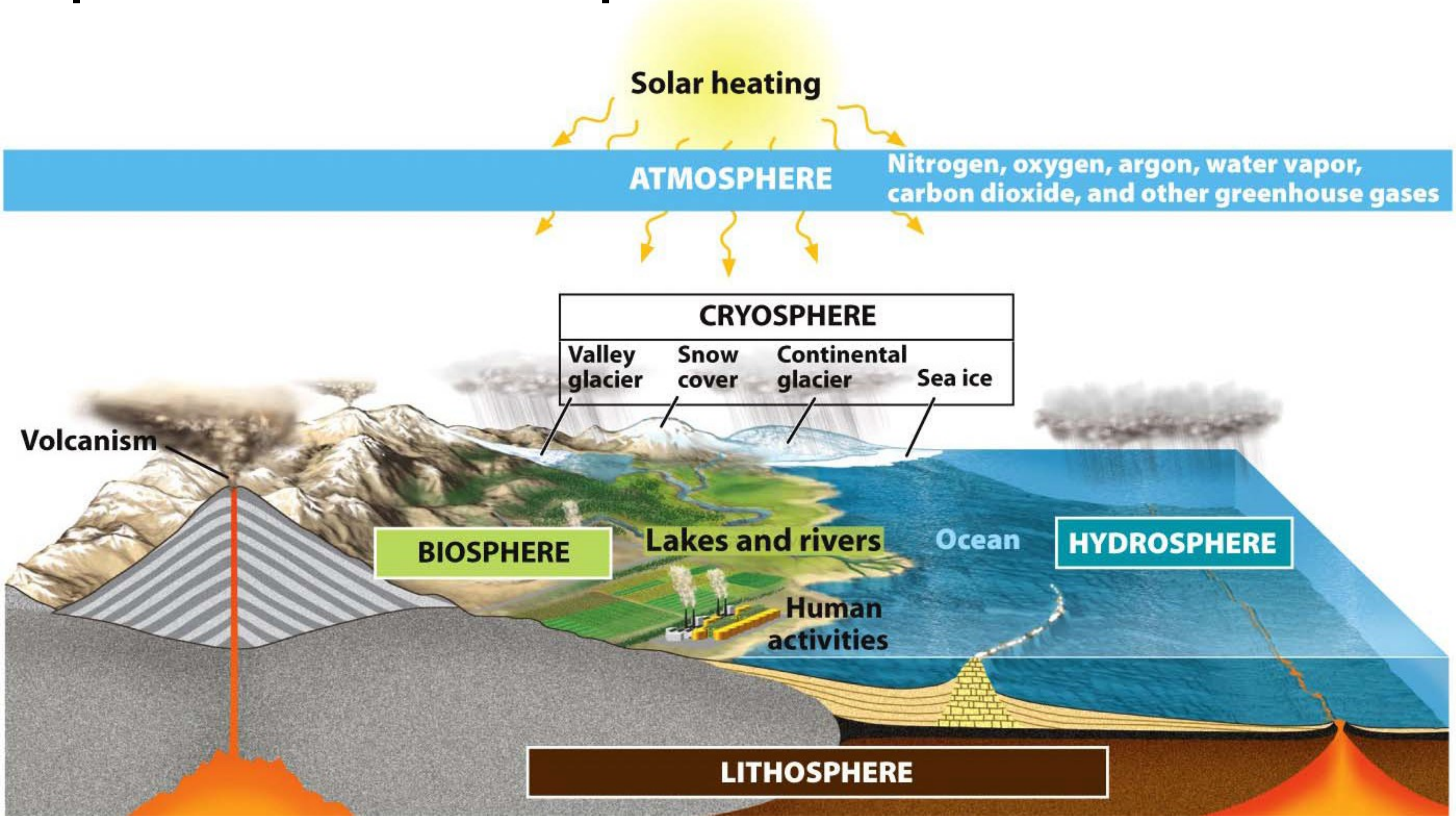
Average temperatures are roughly constant through time, the energy arriving to the Earth's surface and released by it must be in balance



Without atmosphere balance would be achieved for a T=-19°C

The atmosphere, with its greenhouse gases prevents part of the energy to escape leading to much more pleasant average of 14°C

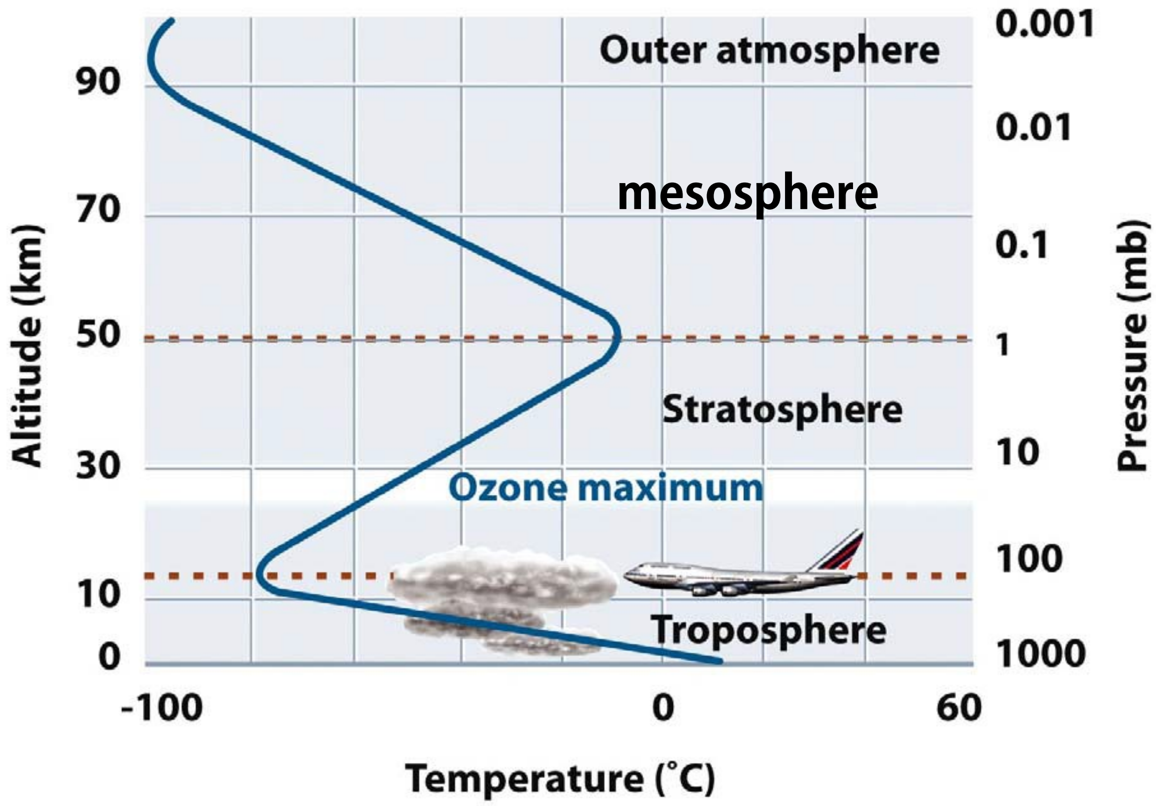
Descending towards the Earth surface energy interacts and impacts with different components



1) Atmosphere
2) Hydrosphere
3) Biosphere
4) Lithosphere
5) cryosphere

The atmosphere

A layer of gases (mostly in the troposphere) surrounding the Earth and retained by the Earth's gravity



The Ozone (O_3) layer: stops UV rays from the sun, causing T decrease

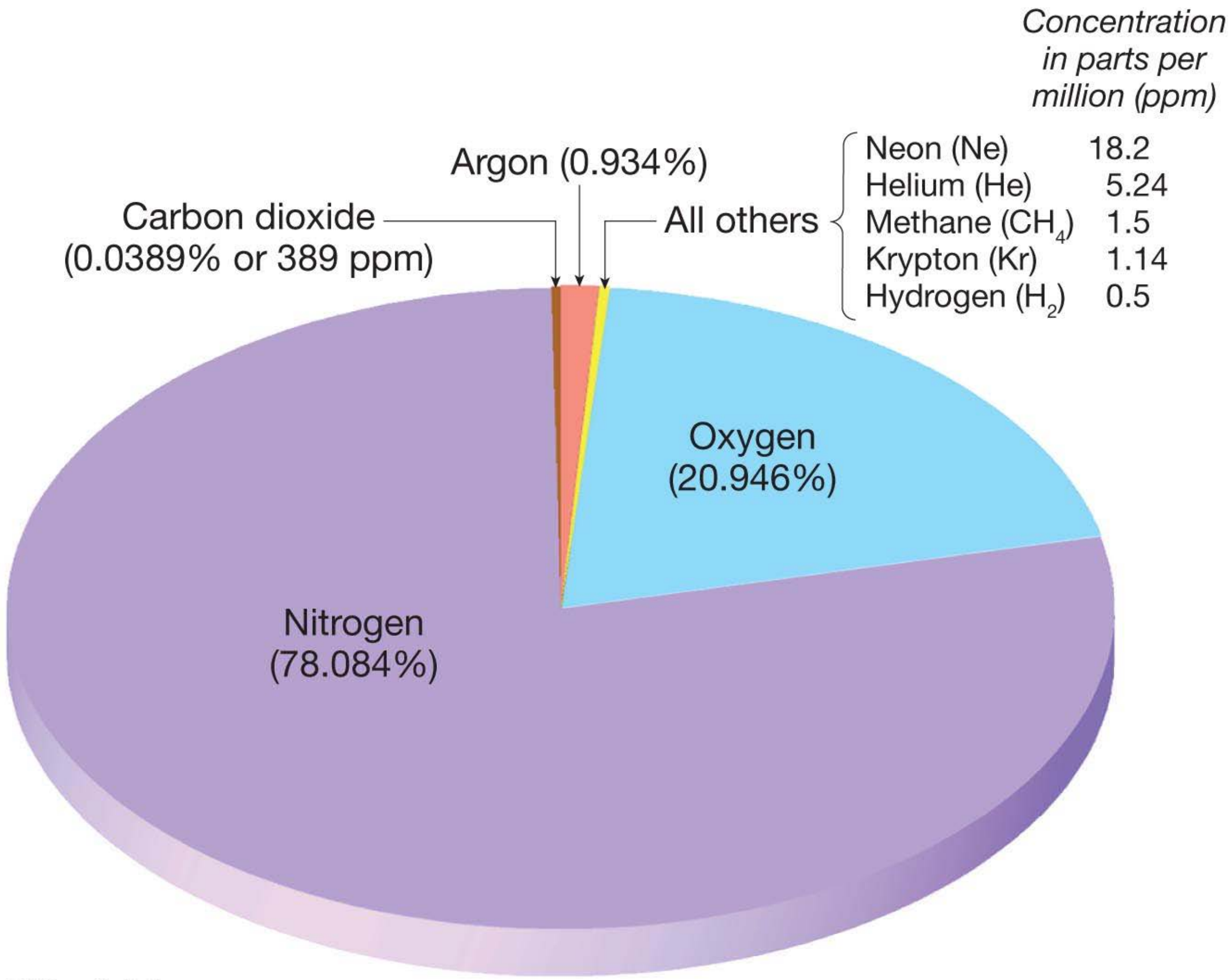
Temperature changes controlled by the ozone layer and Earth radiation. This causes a stratification of the asthenosphere with not much mass moving through it

The composition of the atmosphere

Main components: not so important

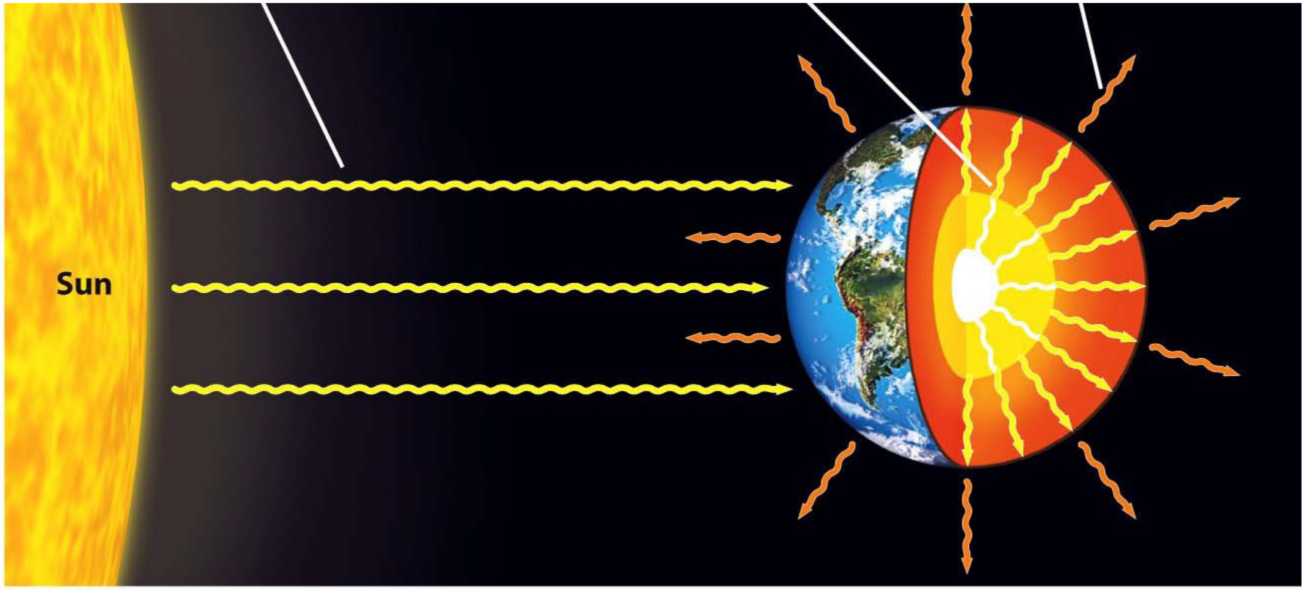
Water vapour: controls precipitation, absorbs heat from Earth...

CO_2: very important in absorbing heat from Earth

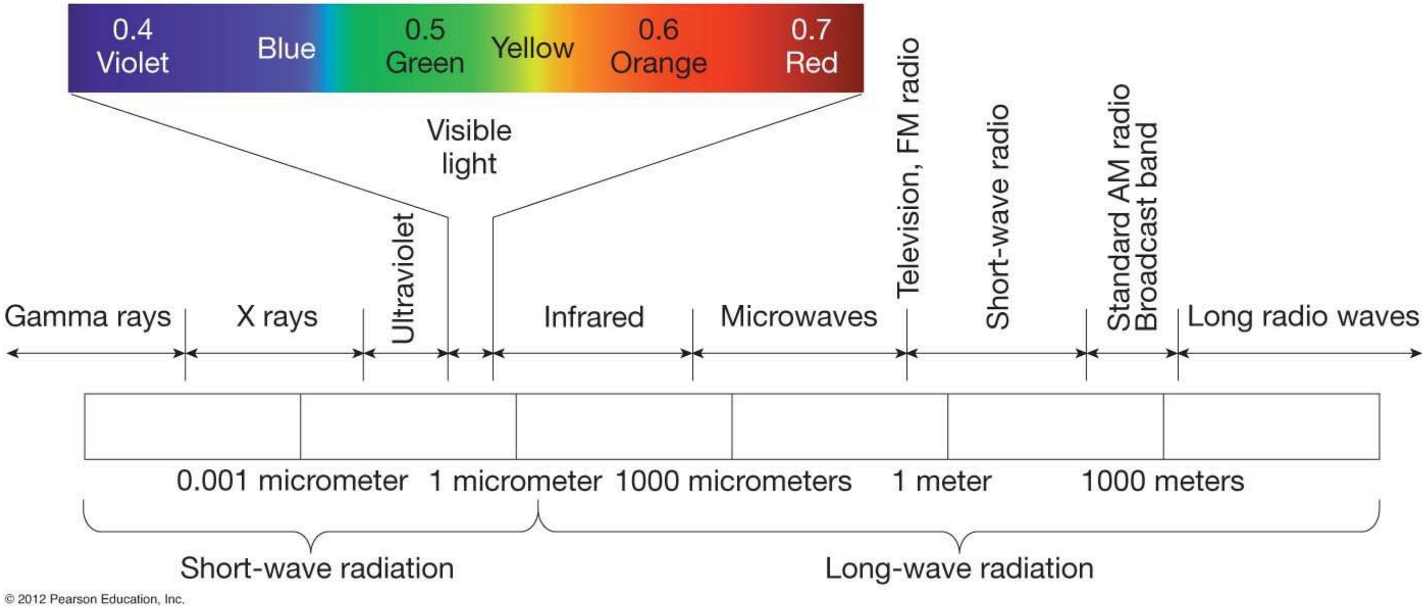


Sun radiation and interactions with atmosphere

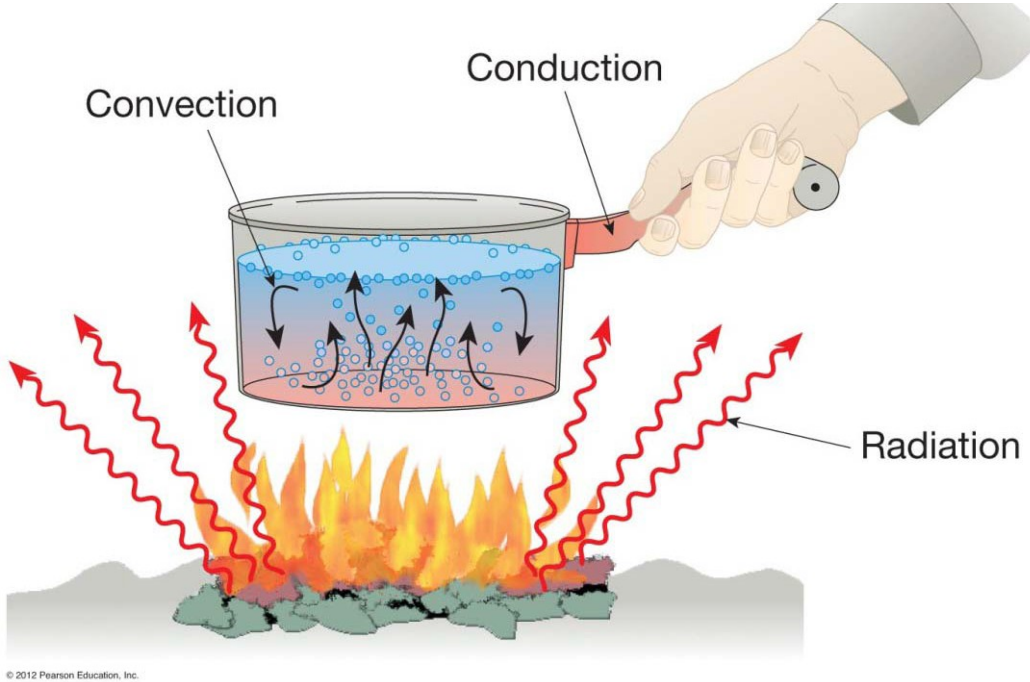
Three important notions to be retained



1) Radiations include a very large variety of wave lengths



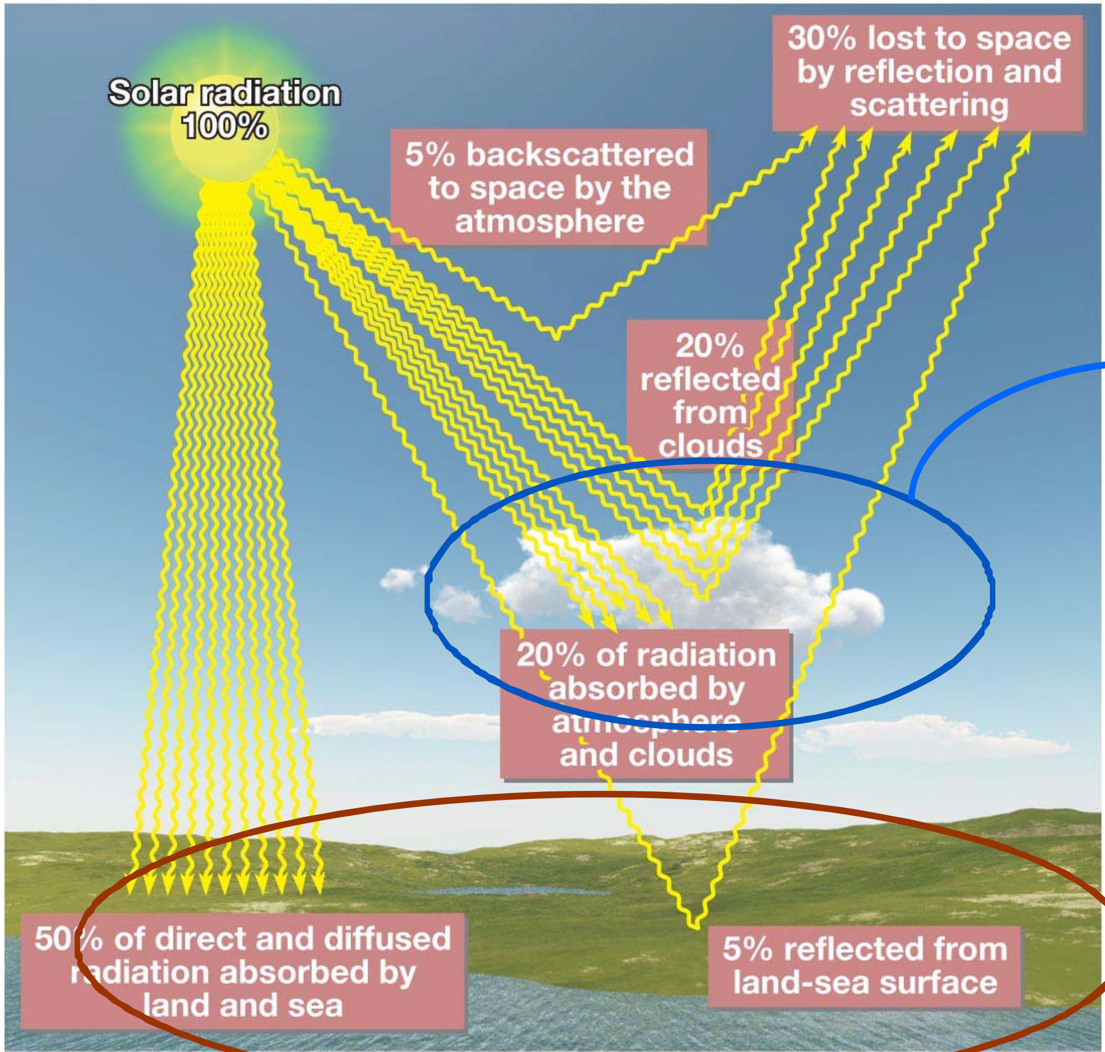
2) Heat can be transmitted in three ways: conduction, convection and radiation. Radiation is crucial in Sun-Earth interactions



3) 4 important rules control radiation

- **All objects absorb and emit radiant energy**
- **Good absorbers are also good emitters (e.g. Earth surface – gases are selective: the atmosphere is a poor absorber of light)**
- **Hotter objects radiate more energy per unit area than cold objects**
- **the hotter the radiating body, the shorter the emitted wavelength (the wavelength of Sun radiation is much shorter than that of the *Earth. Light for the sun and infrared for the Earth)***

The fate of Sun radiation



Tarbuck et al.

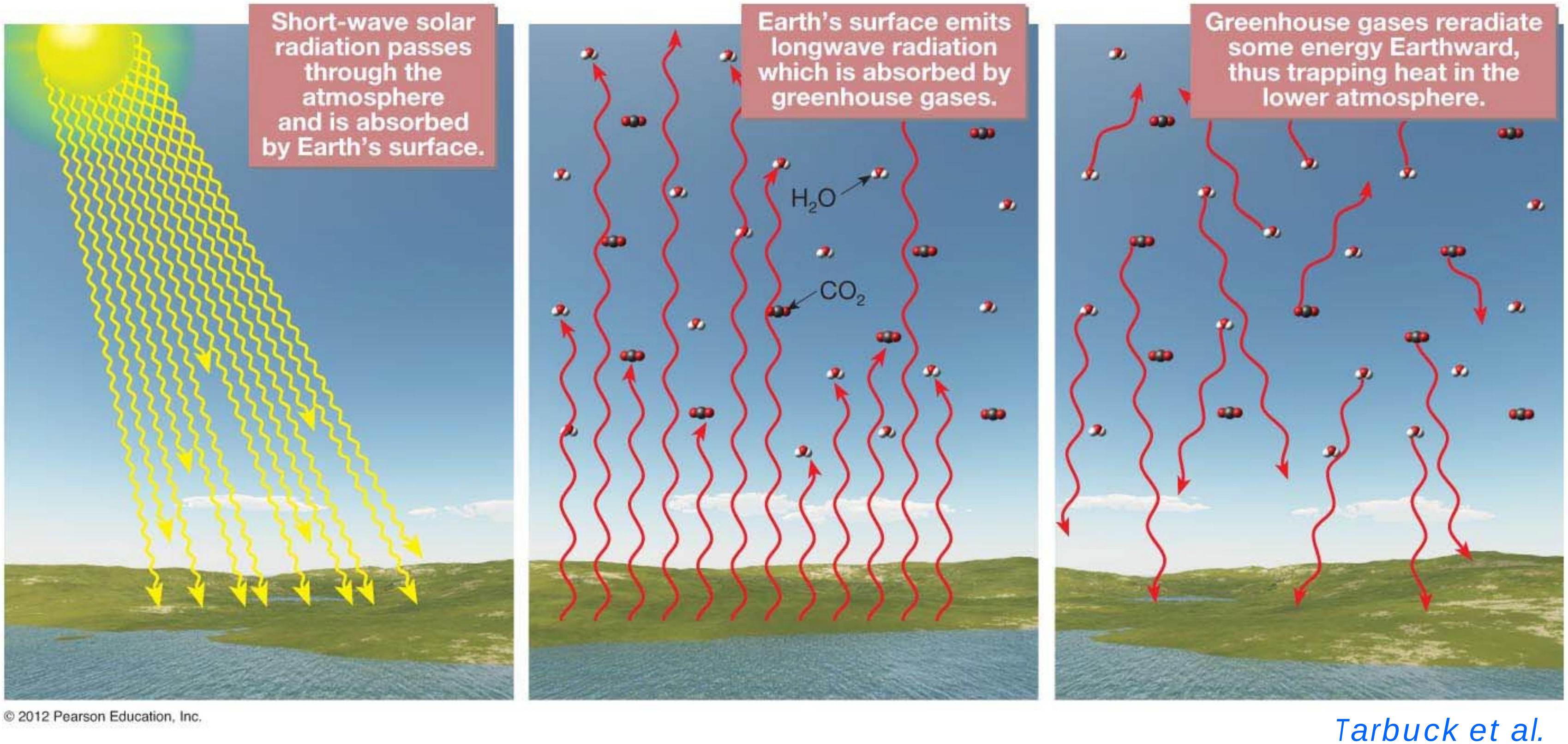
This can change

Radiation arriving on the Earth is reflected or absorbed

(can also change)

What happens to the energy reaching the Earth?

The green-house effect



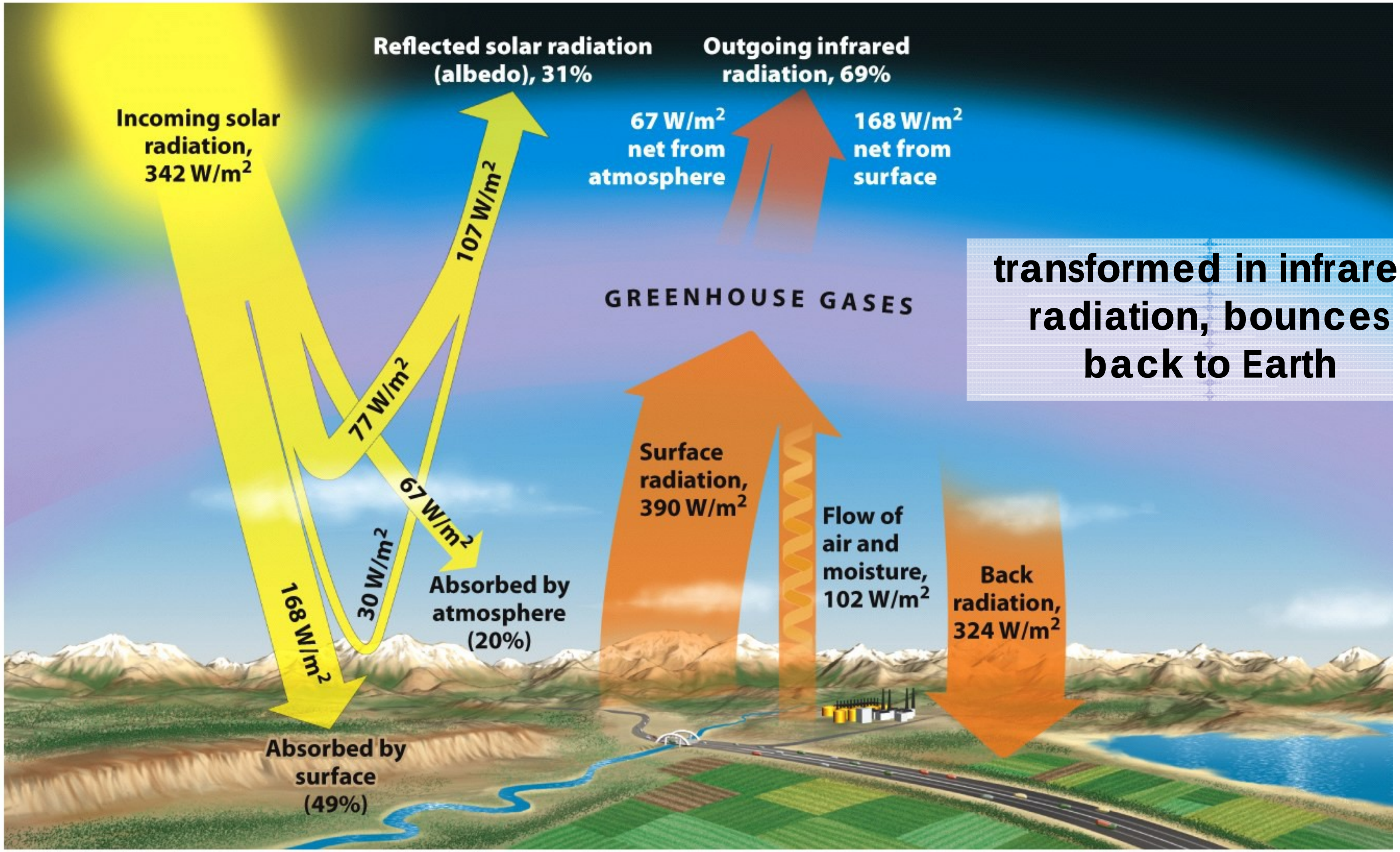
Tarbuck et al.

A crucial and delicate balance for our planet

The effect of greenhouse gases: another representation

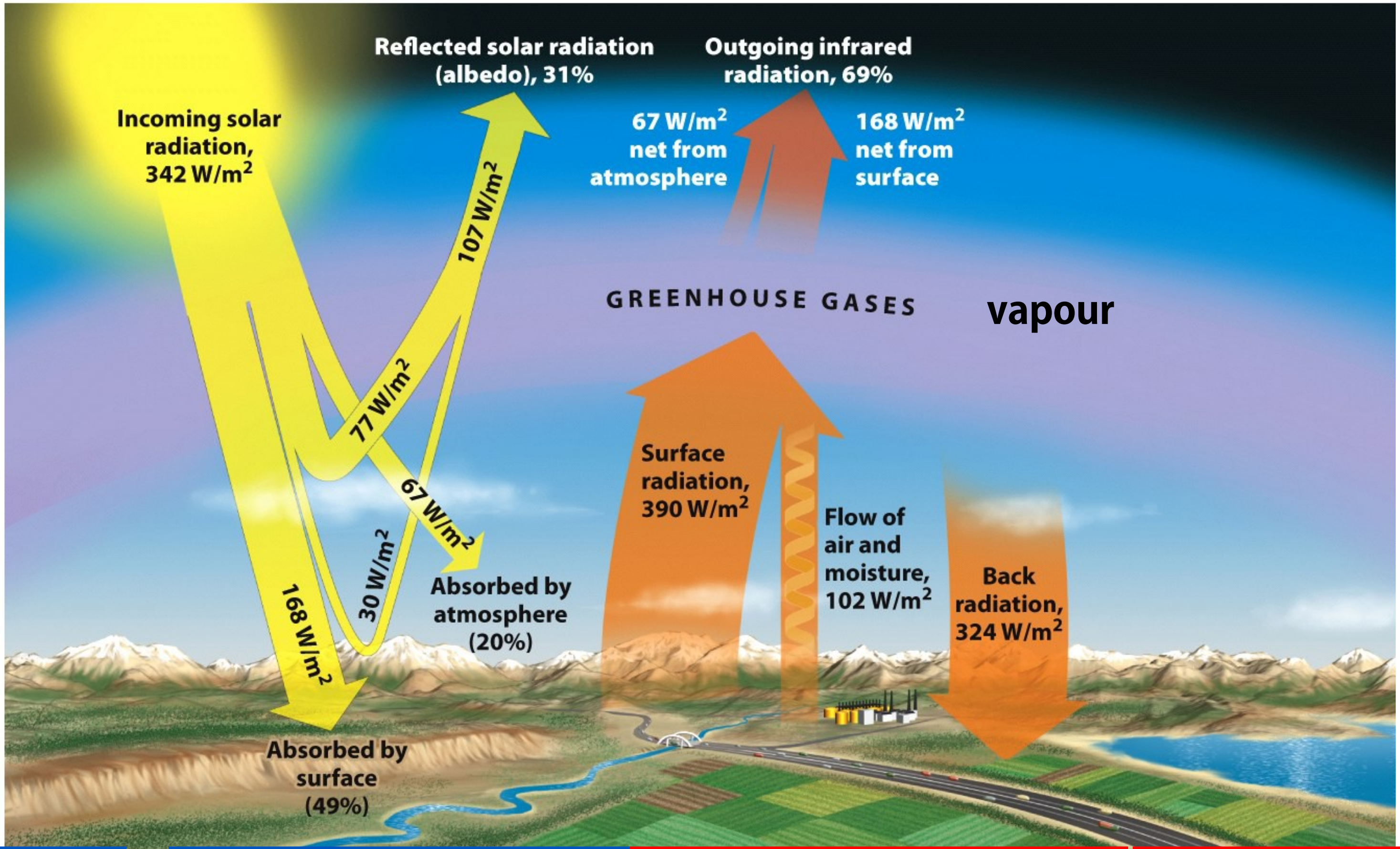
returned directly to the atmosphere

input (342W/m²)



transformed in infrared radiation, bounces back to Earth

The system is kept in balance by a powerful but delicate system of feed-backs: 1) water-vapour, 2) albedo 3) radiation and 4) plant growth



Water vapor.

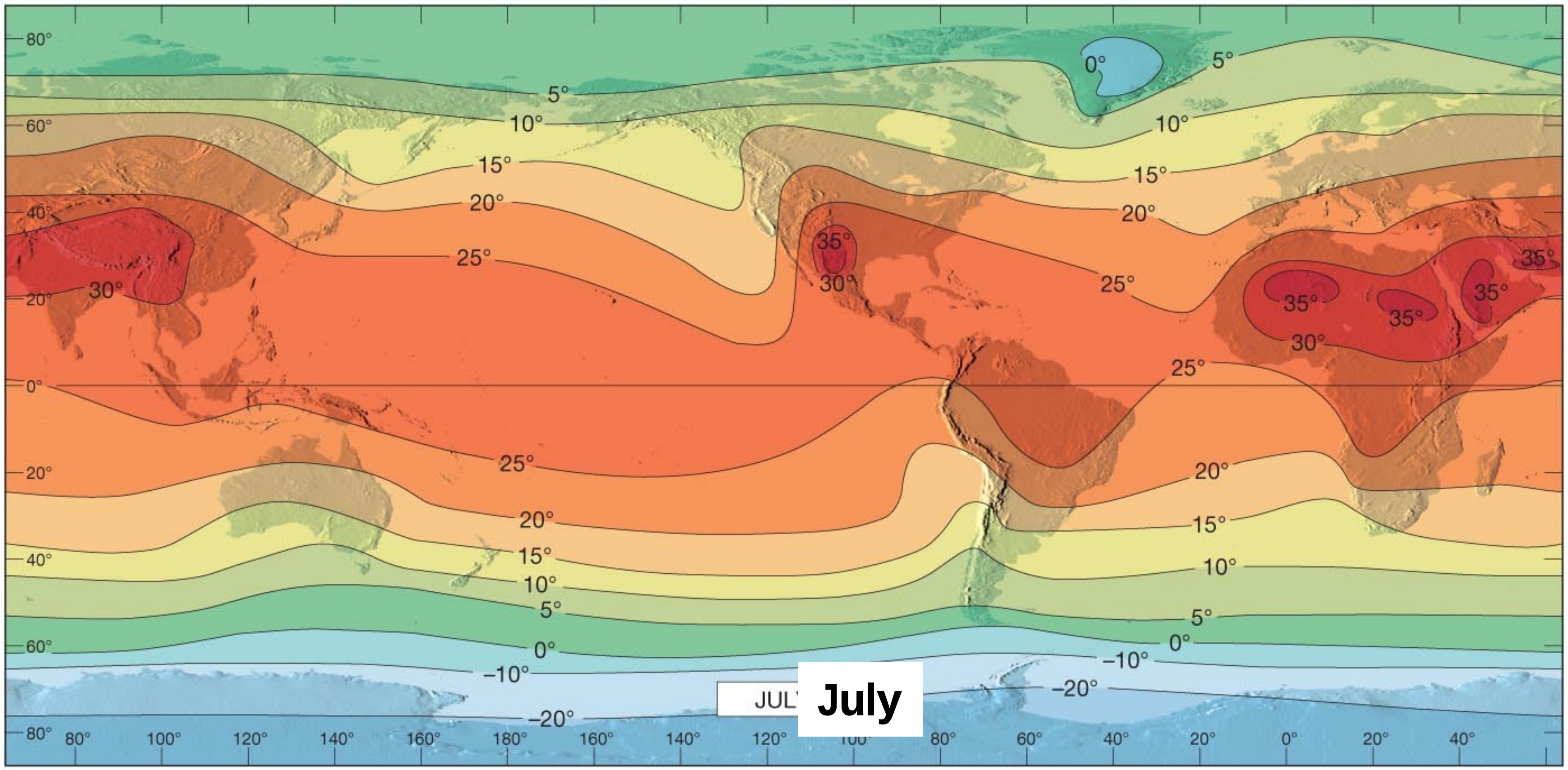
A rise in T increases vapor → increase in T

Albedo. Increases with increasing ice/snow, more energy goes back to space, T decrease

Radiation. Increase in T increases radiation back to space, decreasing T. Stabilizing effect

Plant growth (2 effects). More plants, more CO_2, higher T. But more plants, also removes CO_2 as they are converted to organic-rich layers

Resulting temperature distributions



Tarbuck et al.

Important changes along domains with the same latitude!

- **The effect of continents,**
- **The effect of ice caps**
- ..

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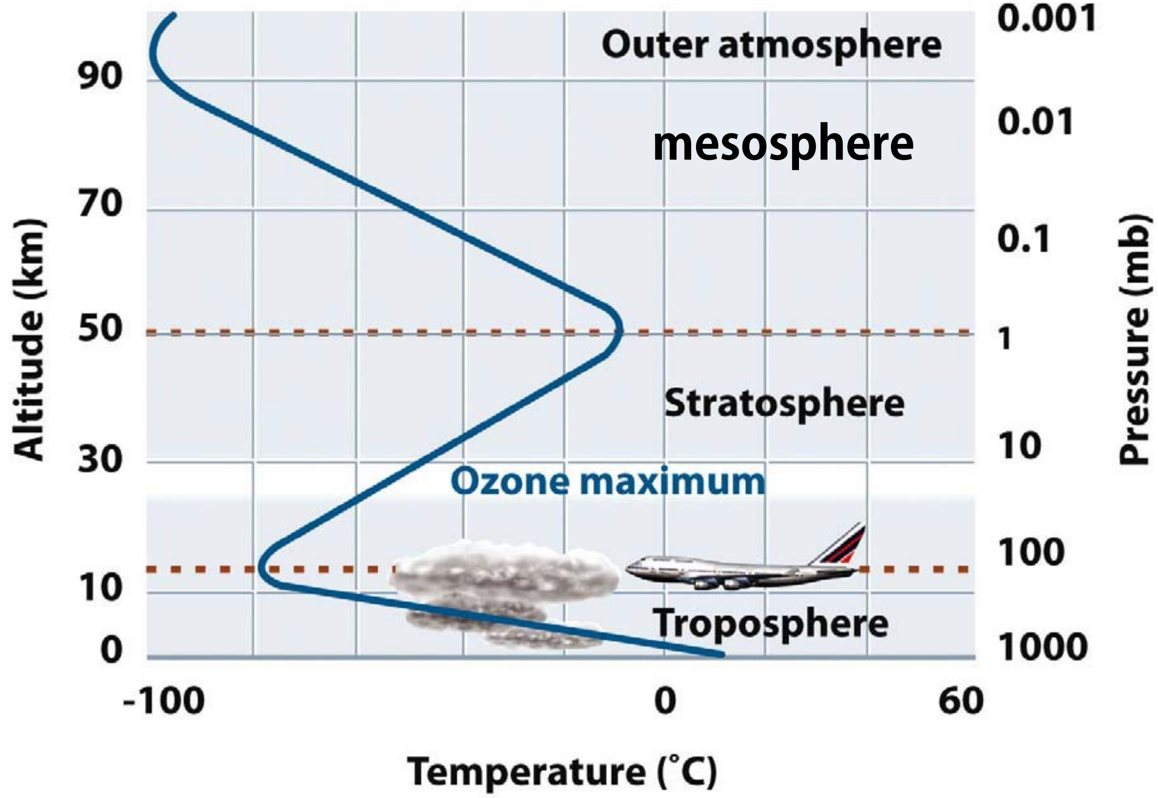
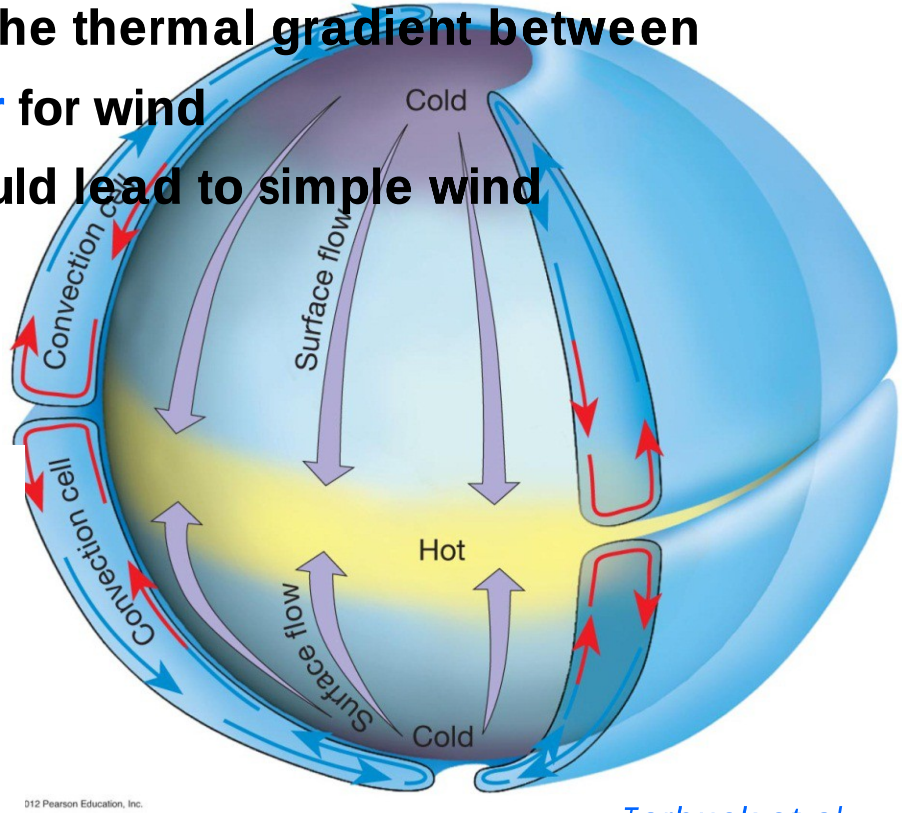


Large temperature differences at the surface of the Earth!

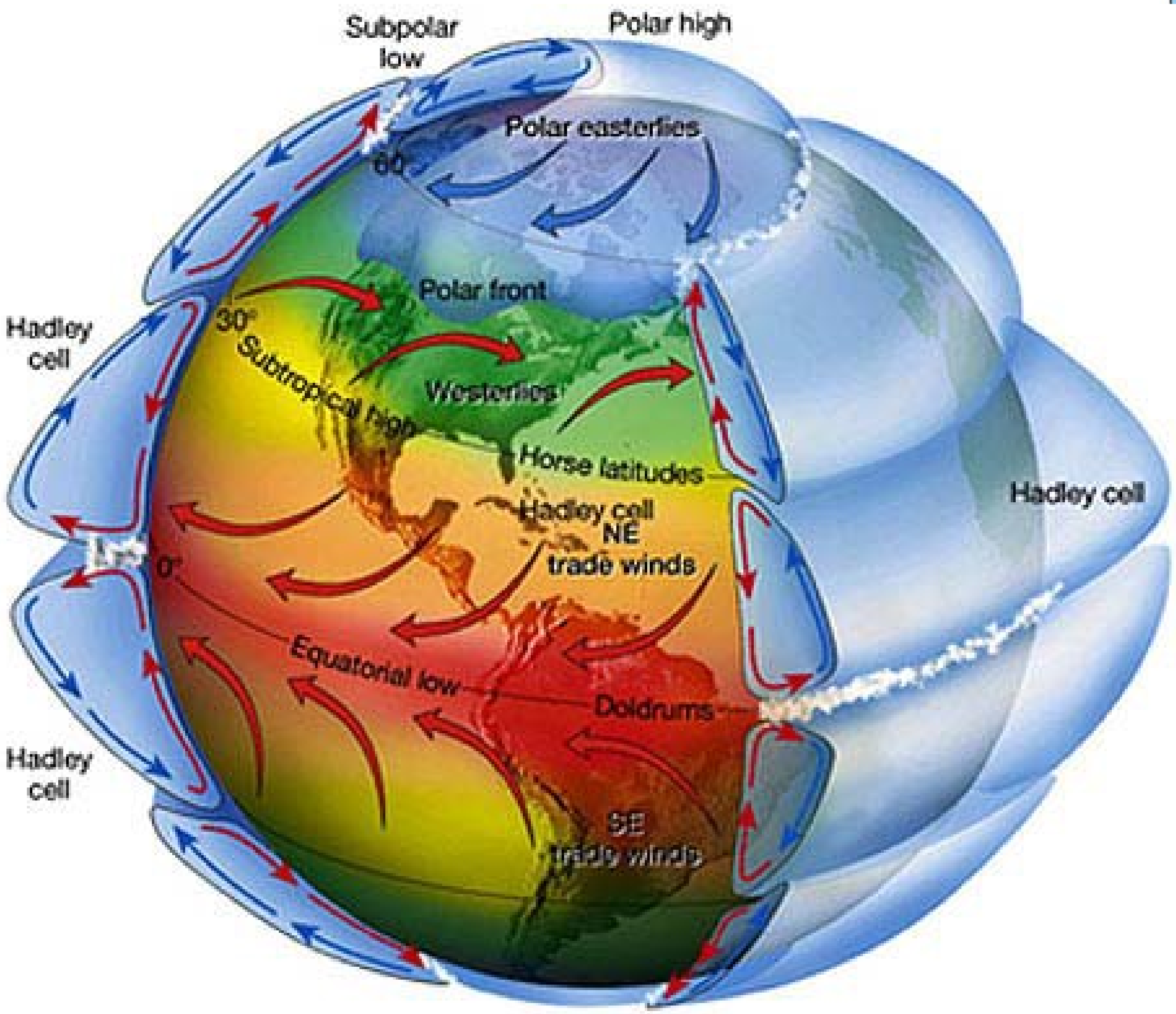
The troposphere enters in action and winds form

Winds and atmospheric circulation

The thermal gradient between the equator and the pole is the main driver for wind circulation. In a non-rotating Earth, this would lead to simple wind patterns

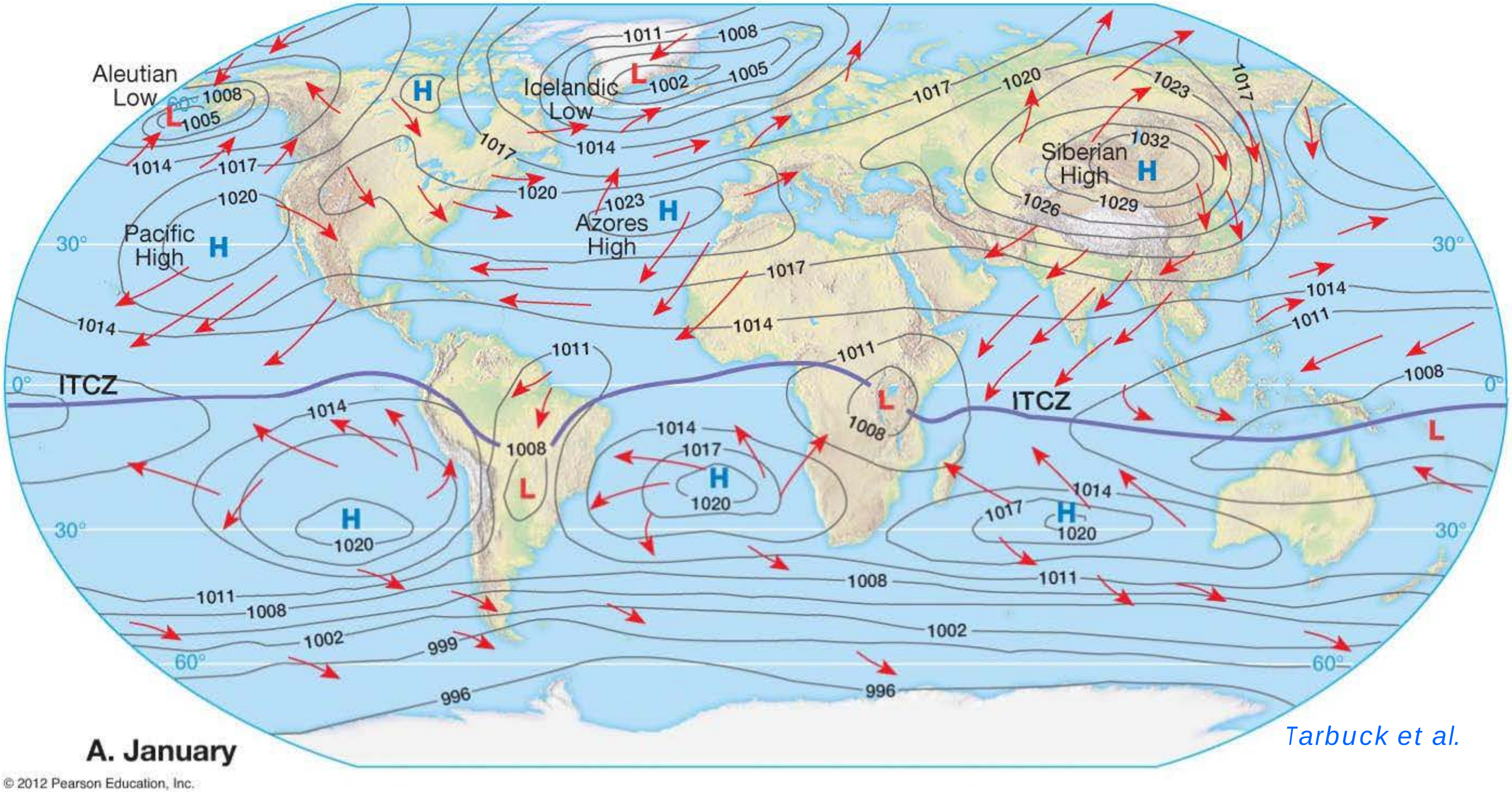


Tarbuck et al.



Because the Earth rotates, Coriolis' force becomes relevant and 3+3 cells are formed

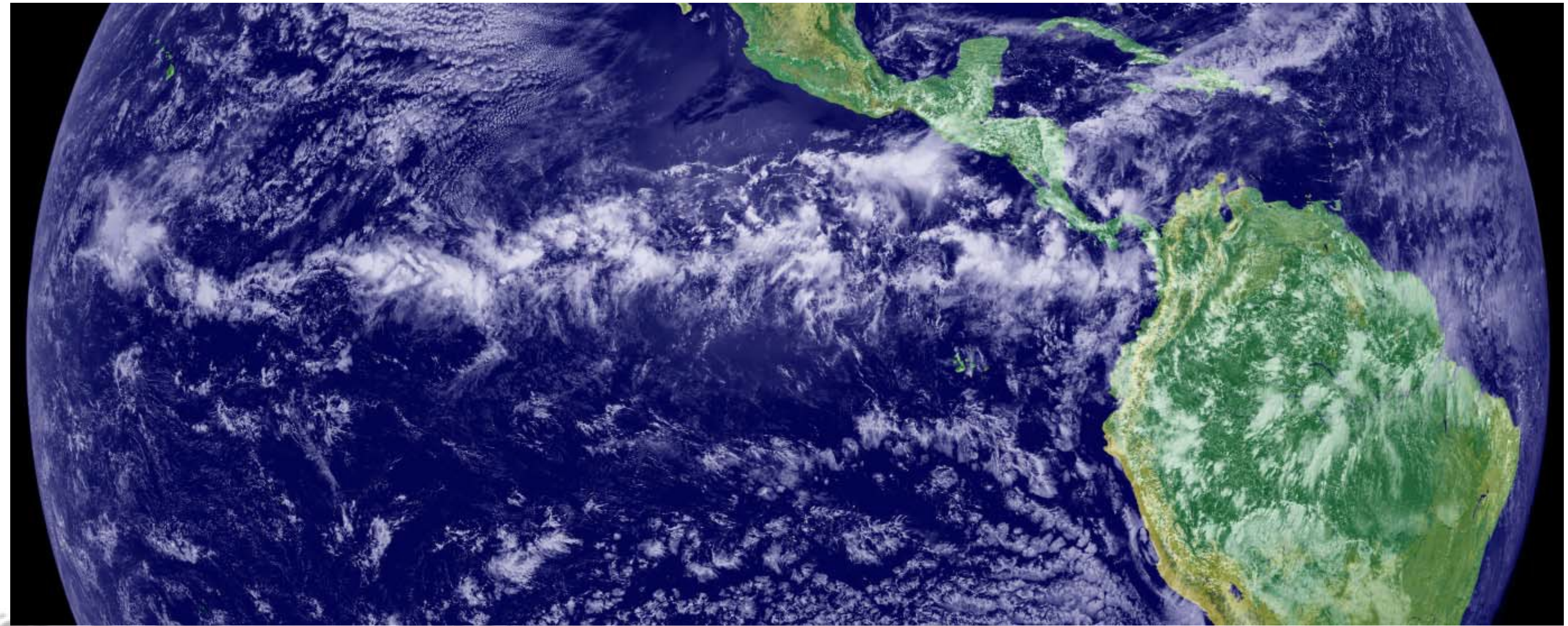
Things are more complicated: continental masses play a big role

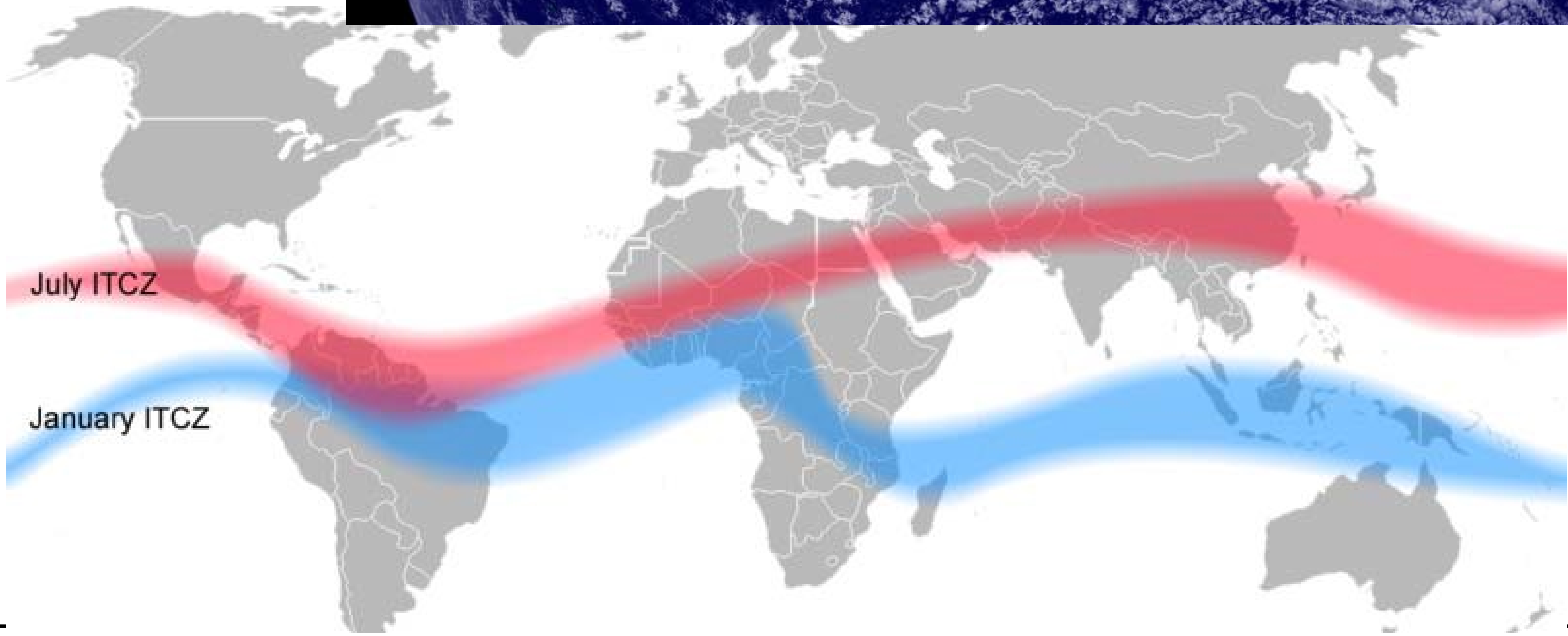


Tarbuck et al.

Surface pressures and wind patterns (January)

The intertropical convergence zone (ITCZ)





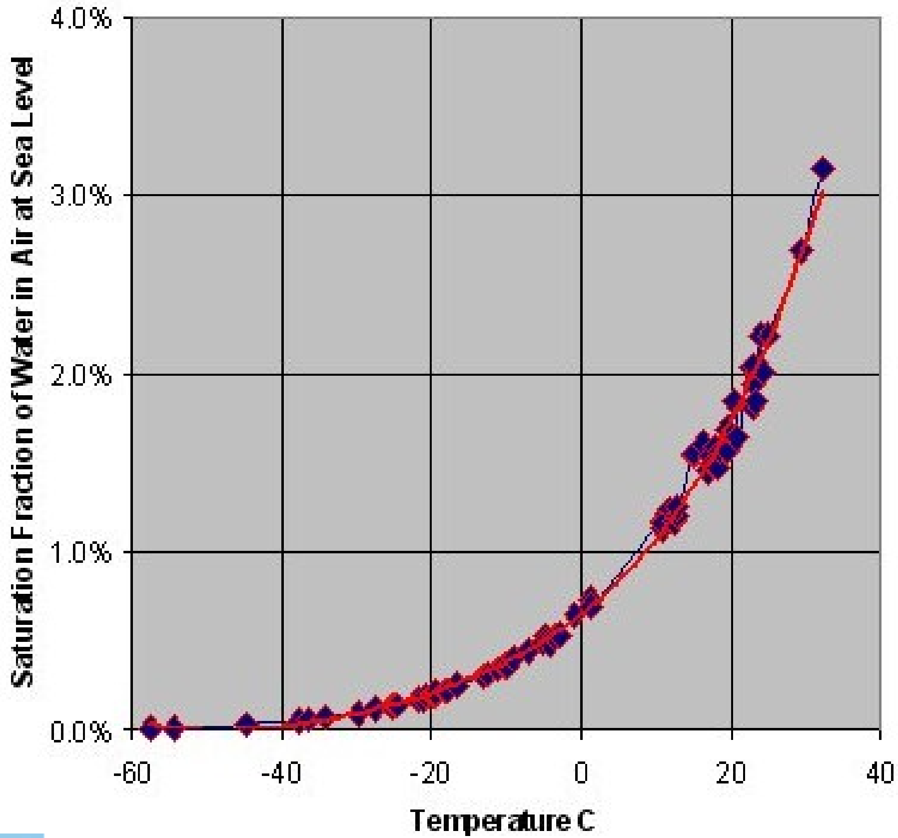
The position of the ITCZ changes during the year and during the geological history

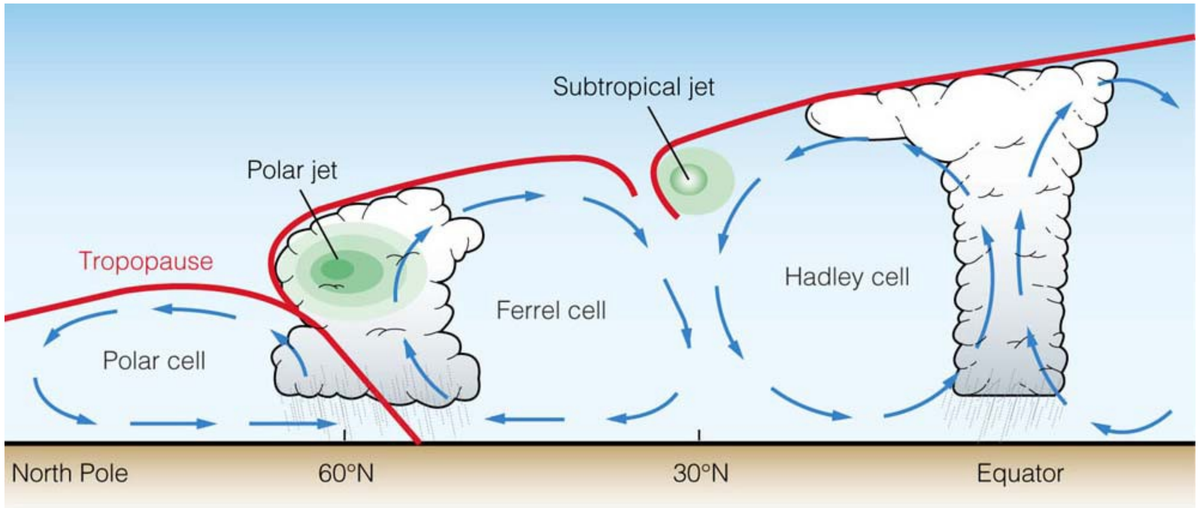
Precipitations :

conditioned by vertical movements of air masses

The amount of water dissolved in air is directly proportional to air temperature

When air cools, precipitations occur

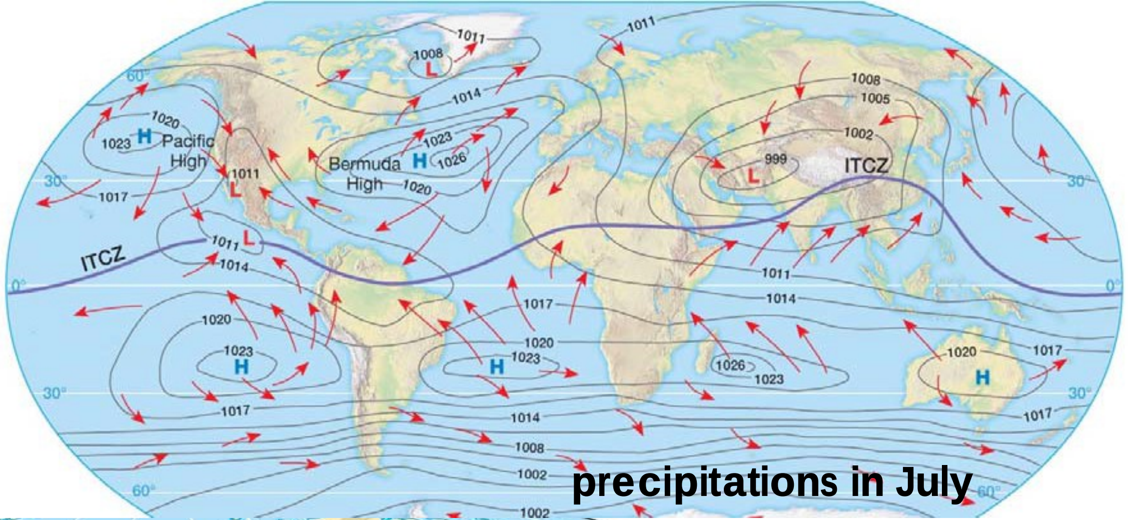




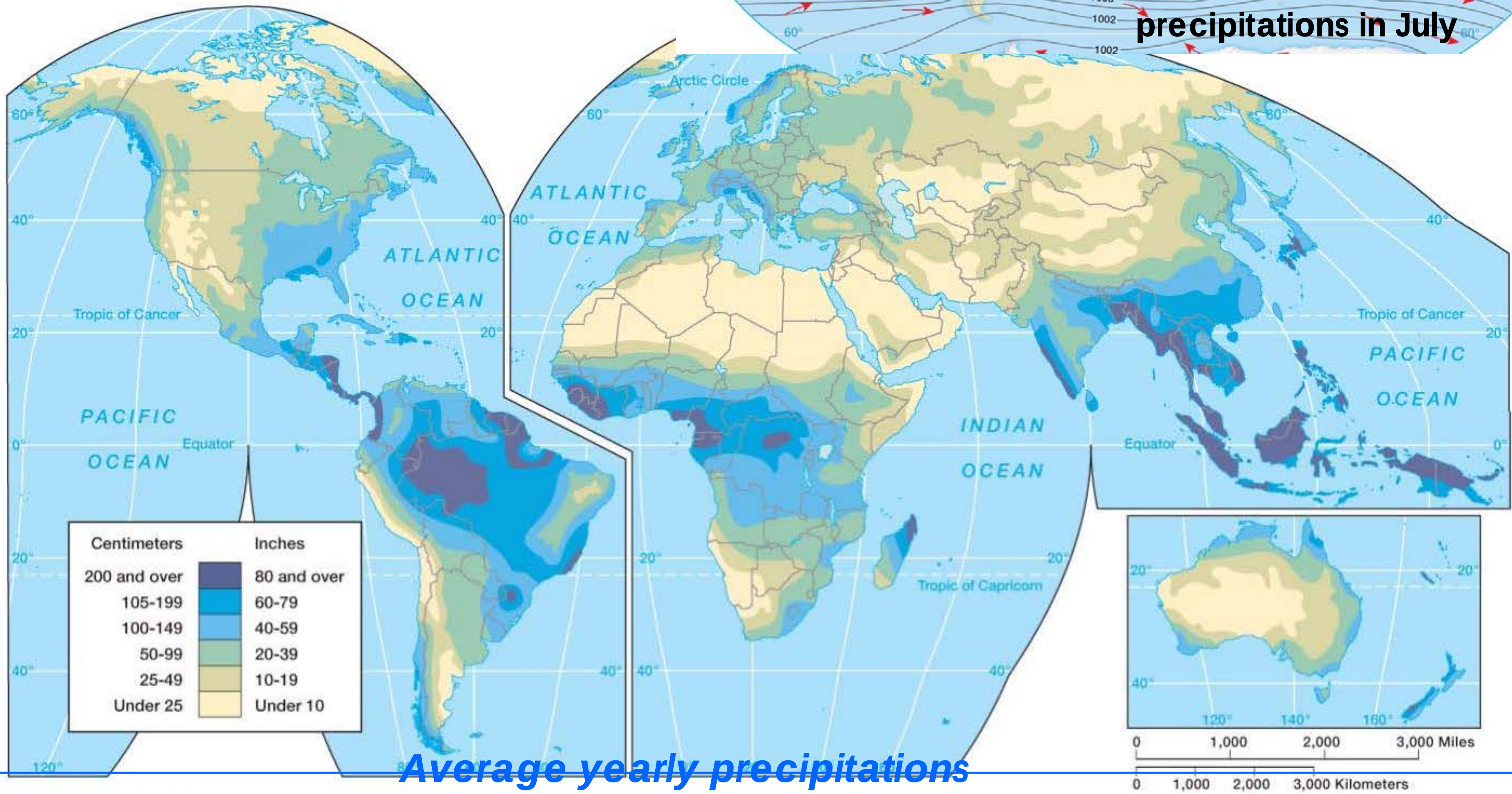
In low-pressure domains, air masses rise and cool.

If the air is humid, precipitation occurs

Low-pressures and precipitations



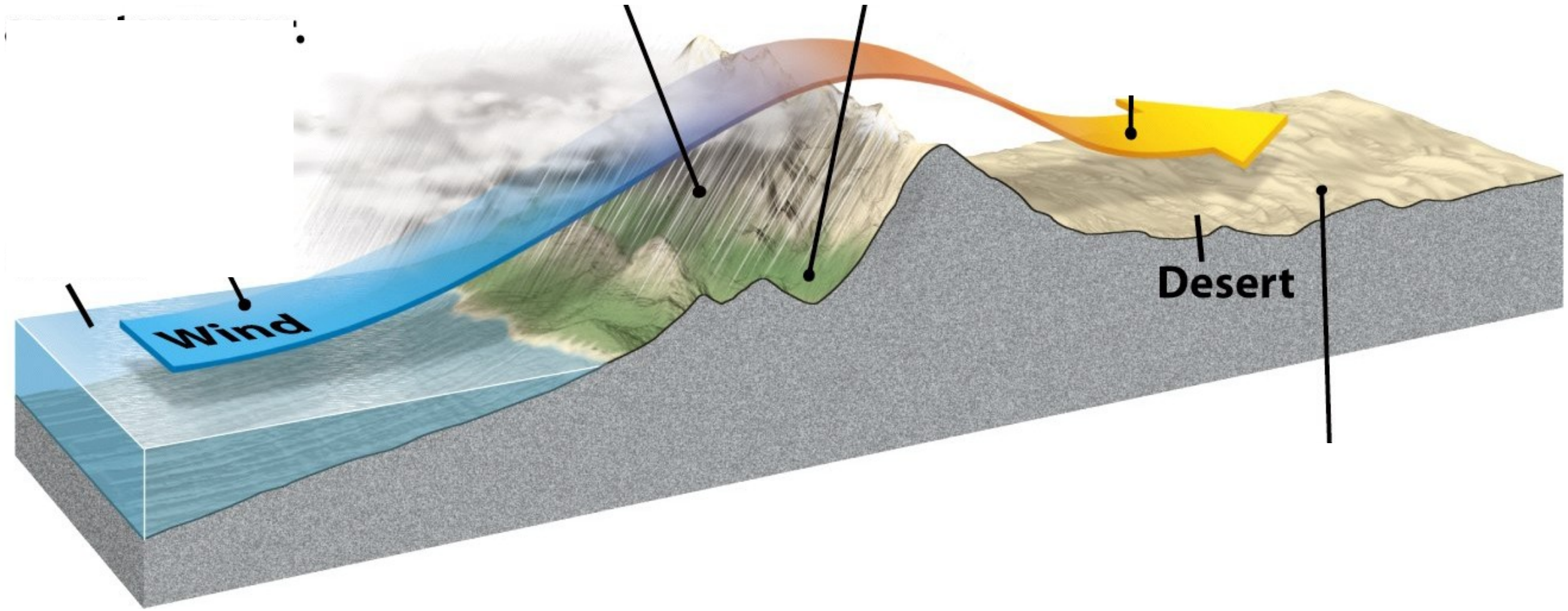
precipitations in July



Average yearly precipitations

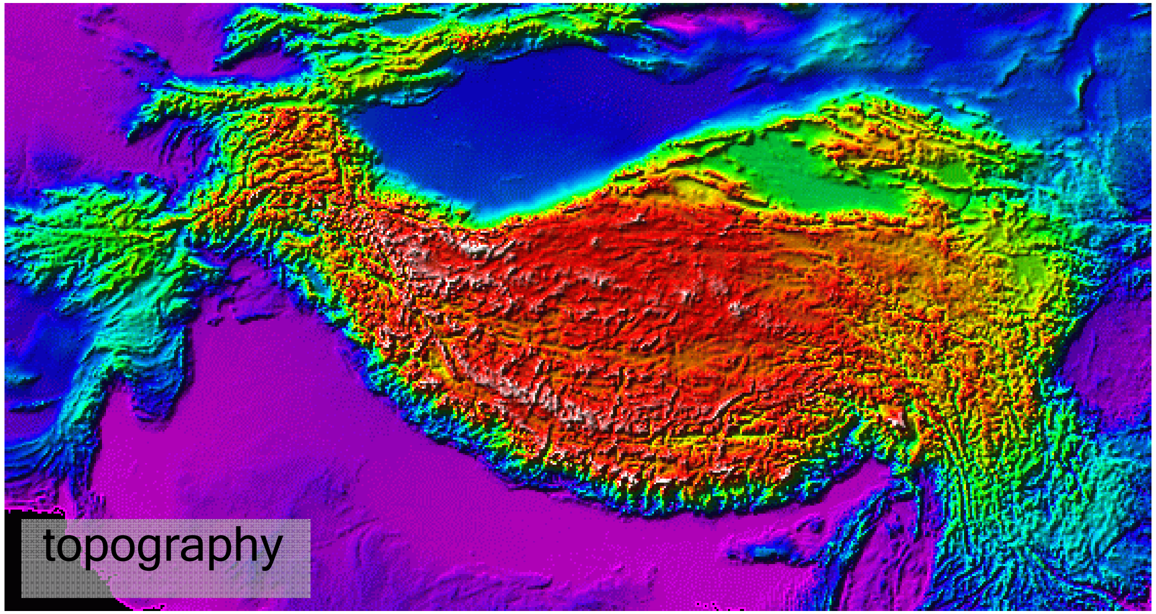
Precipitations

Surface topography (mountains) is another factor which causes air to rise, ► cool and determine precipitations

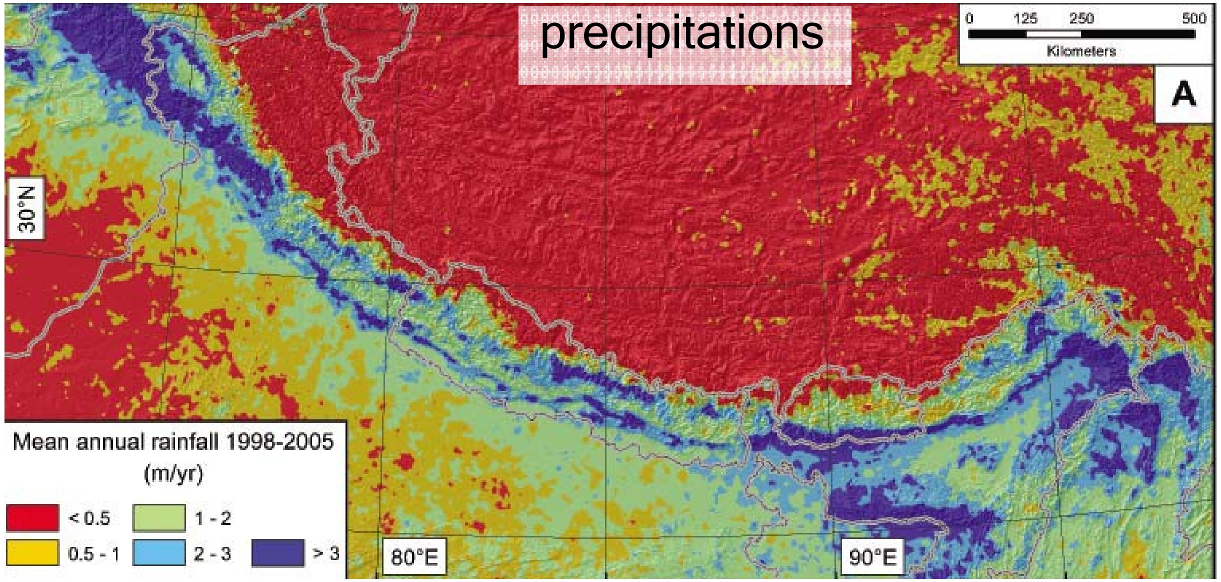


Precipitation occur on the wind-side of the belt.
A rain shadow develops on the other side of the mountain
The domain behind it is arid

The Himalaya is the right place



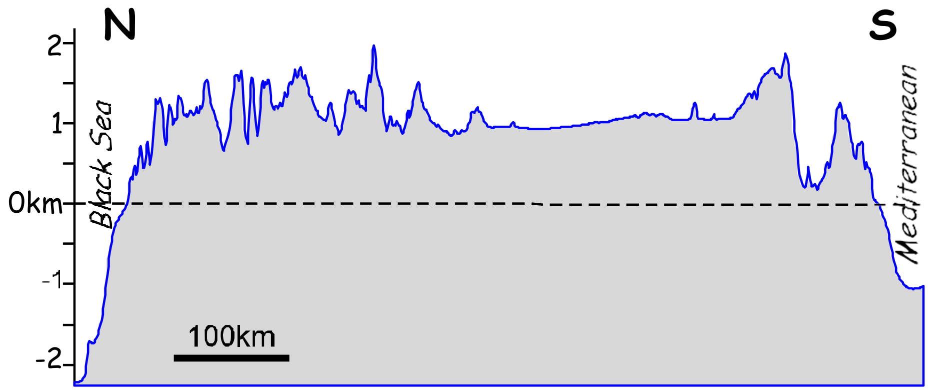
All water falls on the southern side of the Himalaya leaving Tibet dry

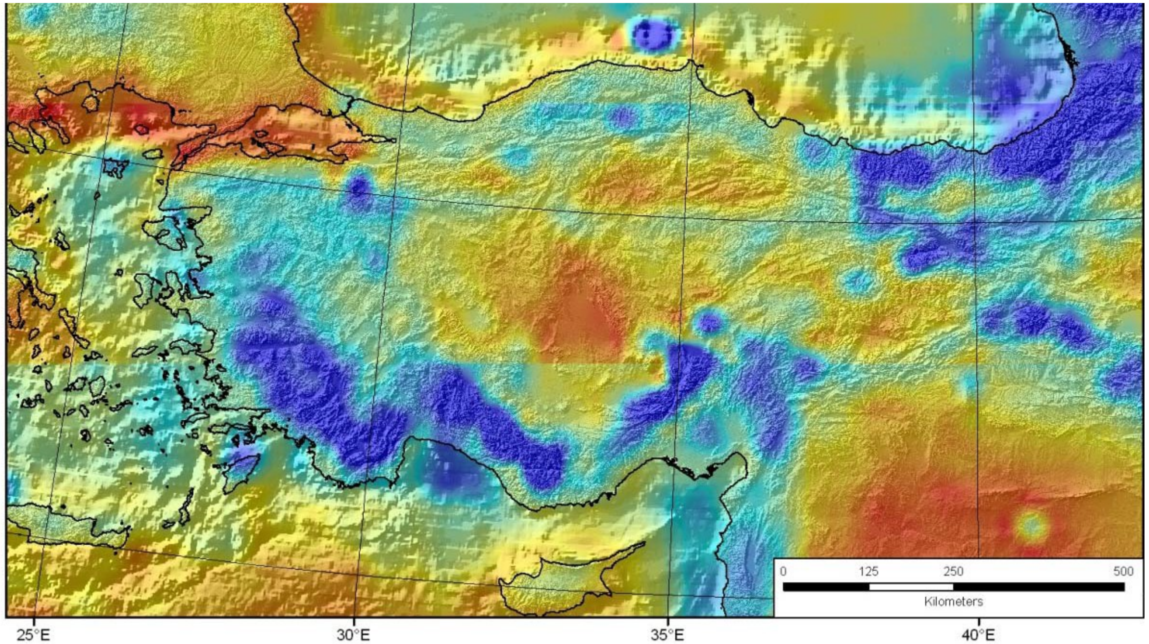


The onset of monsoonal wind circulation in SE Asia is coeval with the uplift of the Tibetan plateau

Who is the chicken, who is the egg?

Another great example: Anatolia

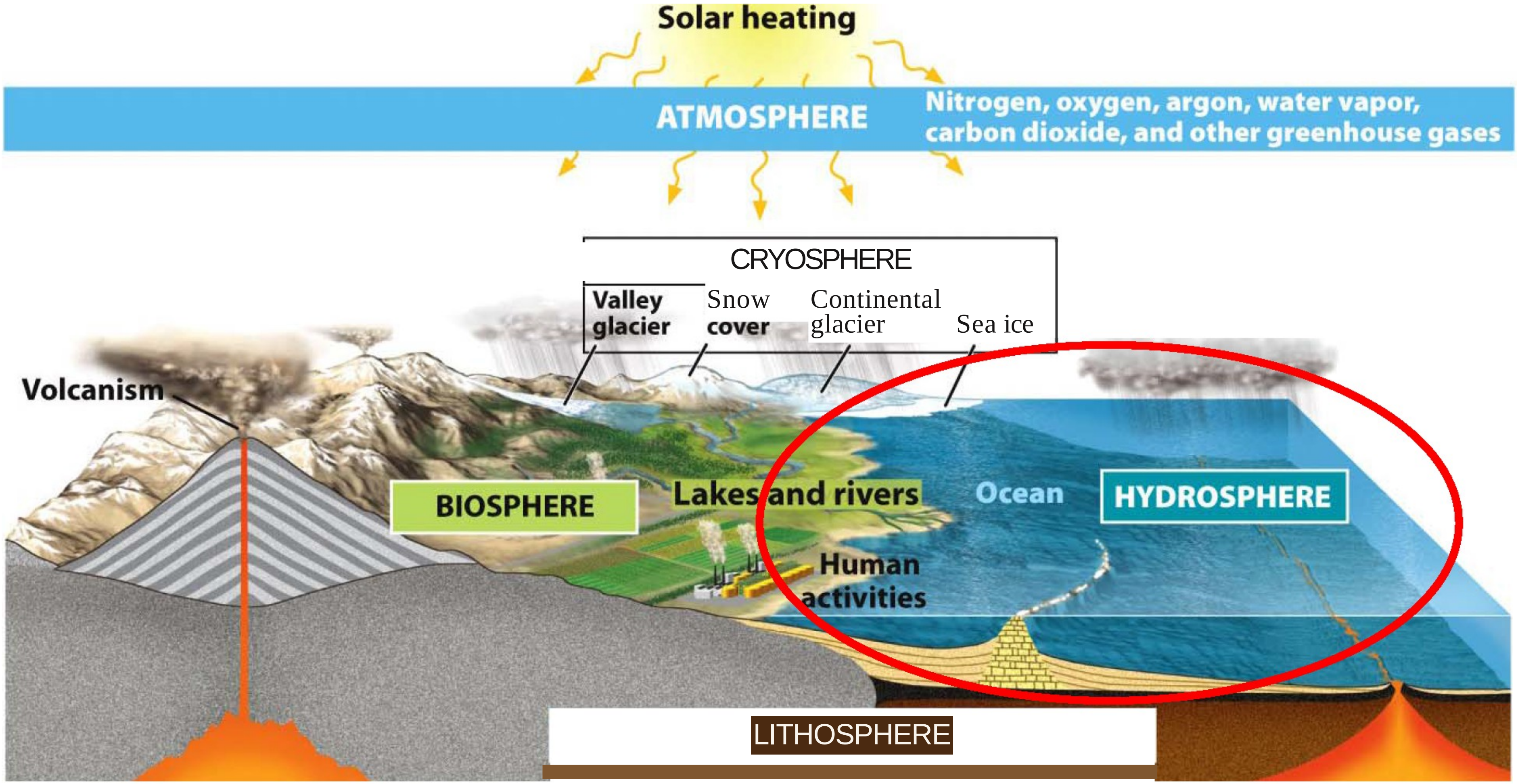




Most humid air is blocked in the southern domain (Taurus mountains) and, to a less extent, by the northern ridges

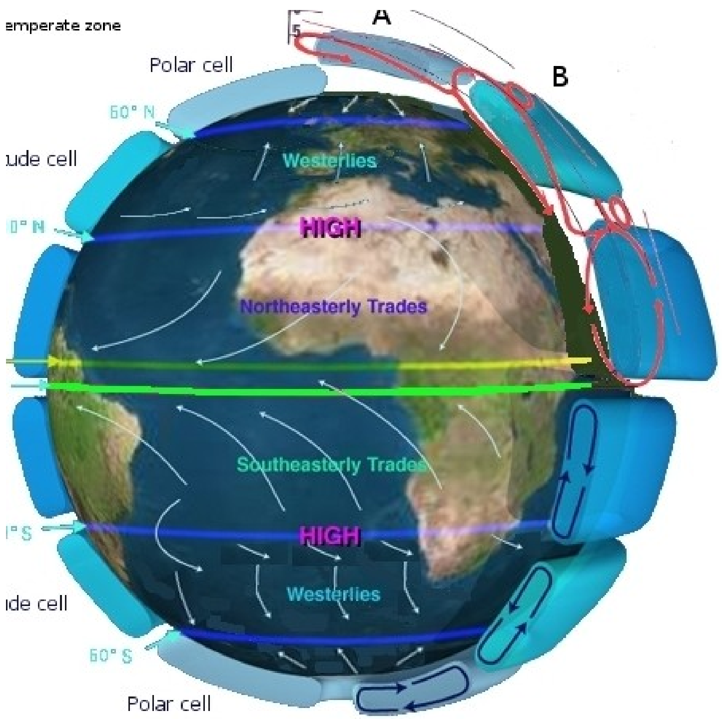
The Anatolia plateau in between is (semi)arid

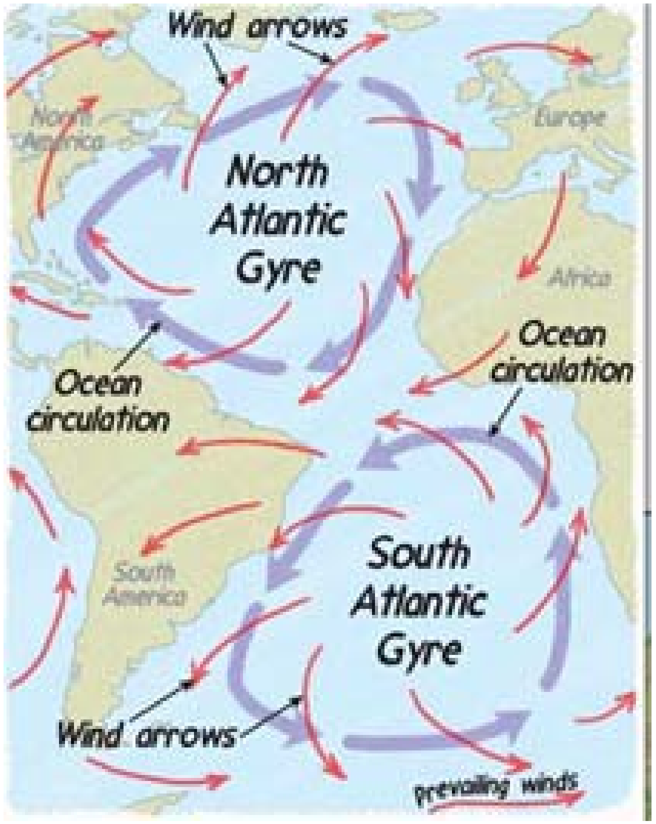
We continue our descent



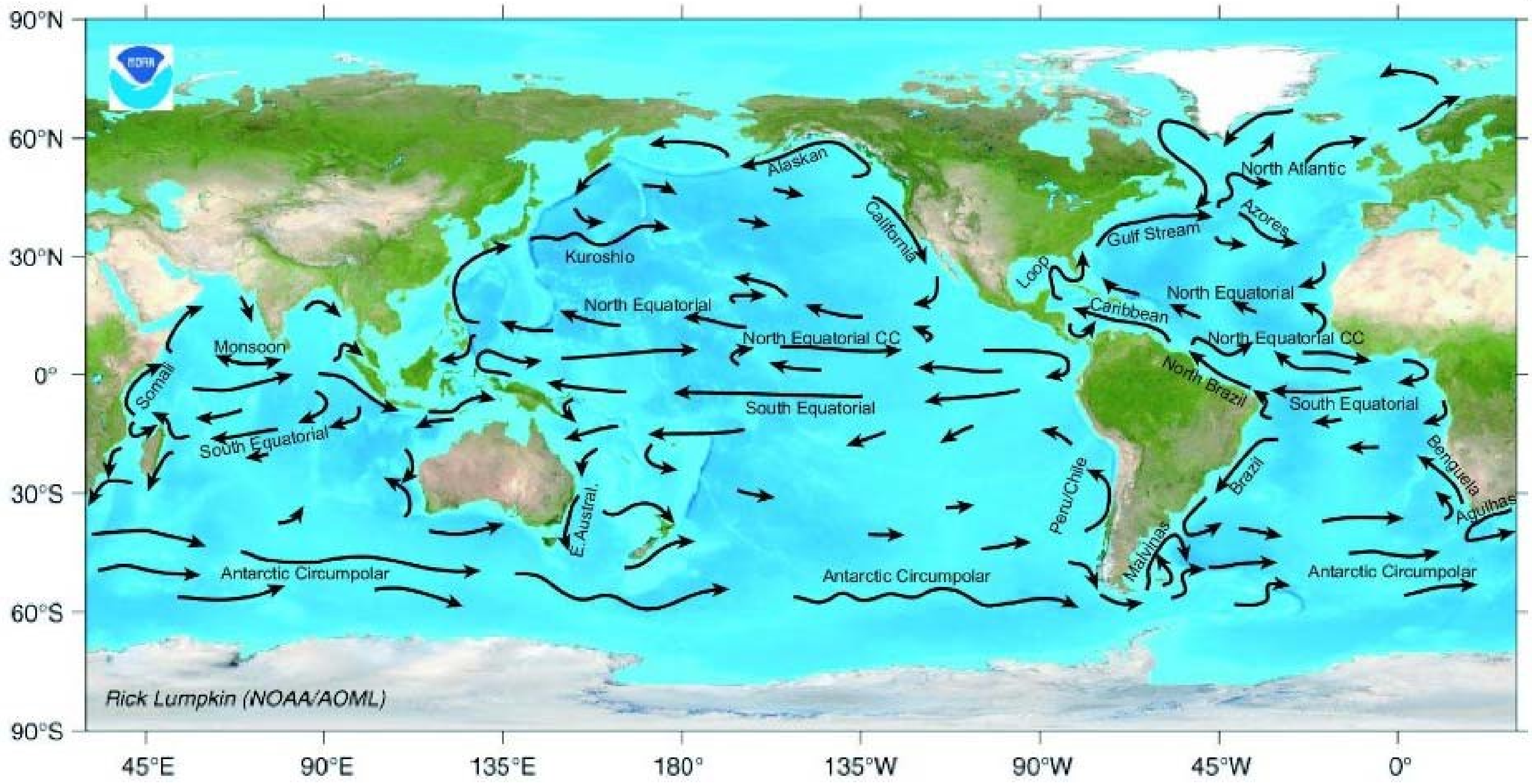
Ocean circulation

Wind circulation and temperatures are also the driving forces steering large scale ocean currents.



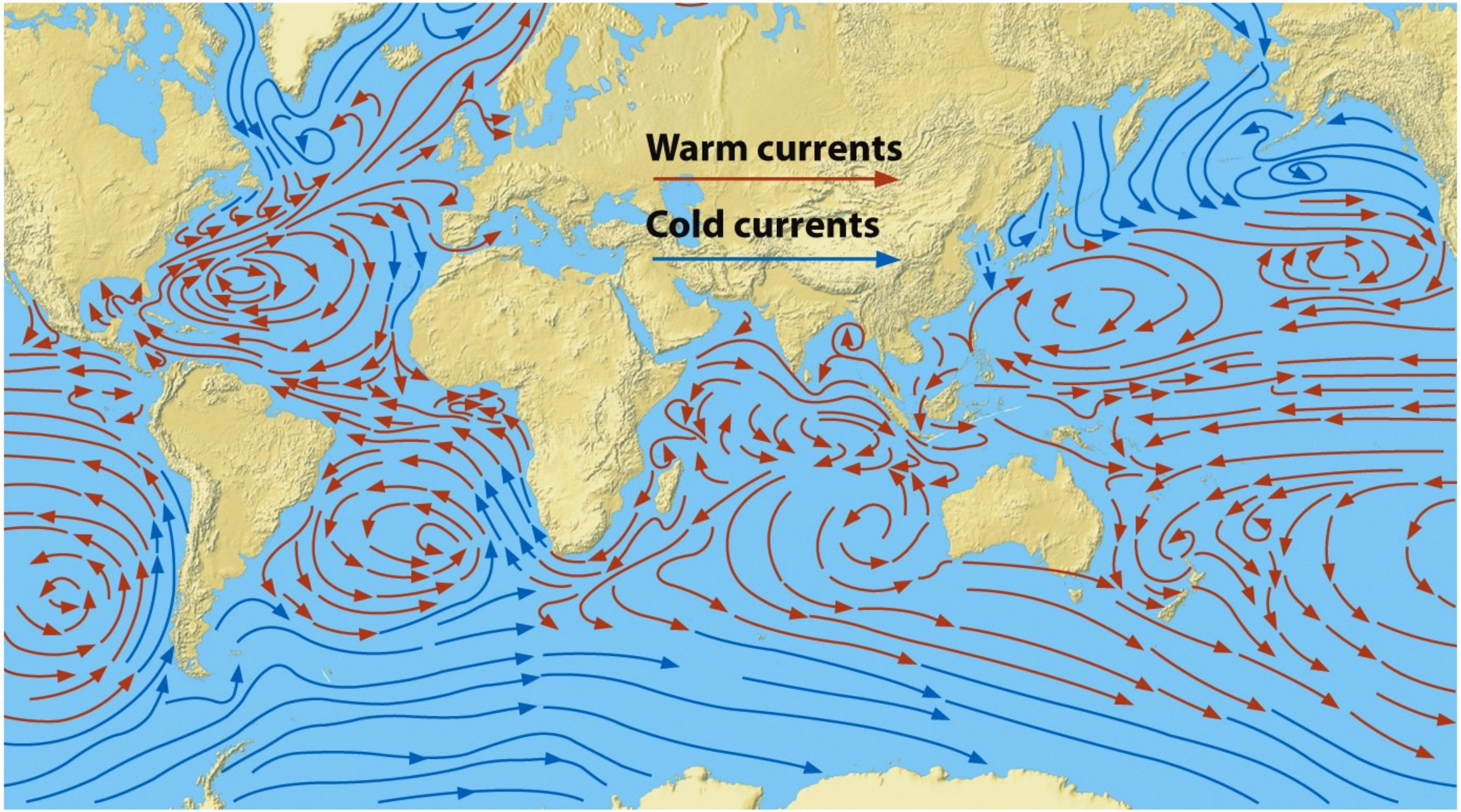


Differently from winds, their trace is deviated by continents amplifying the N-S component of movement



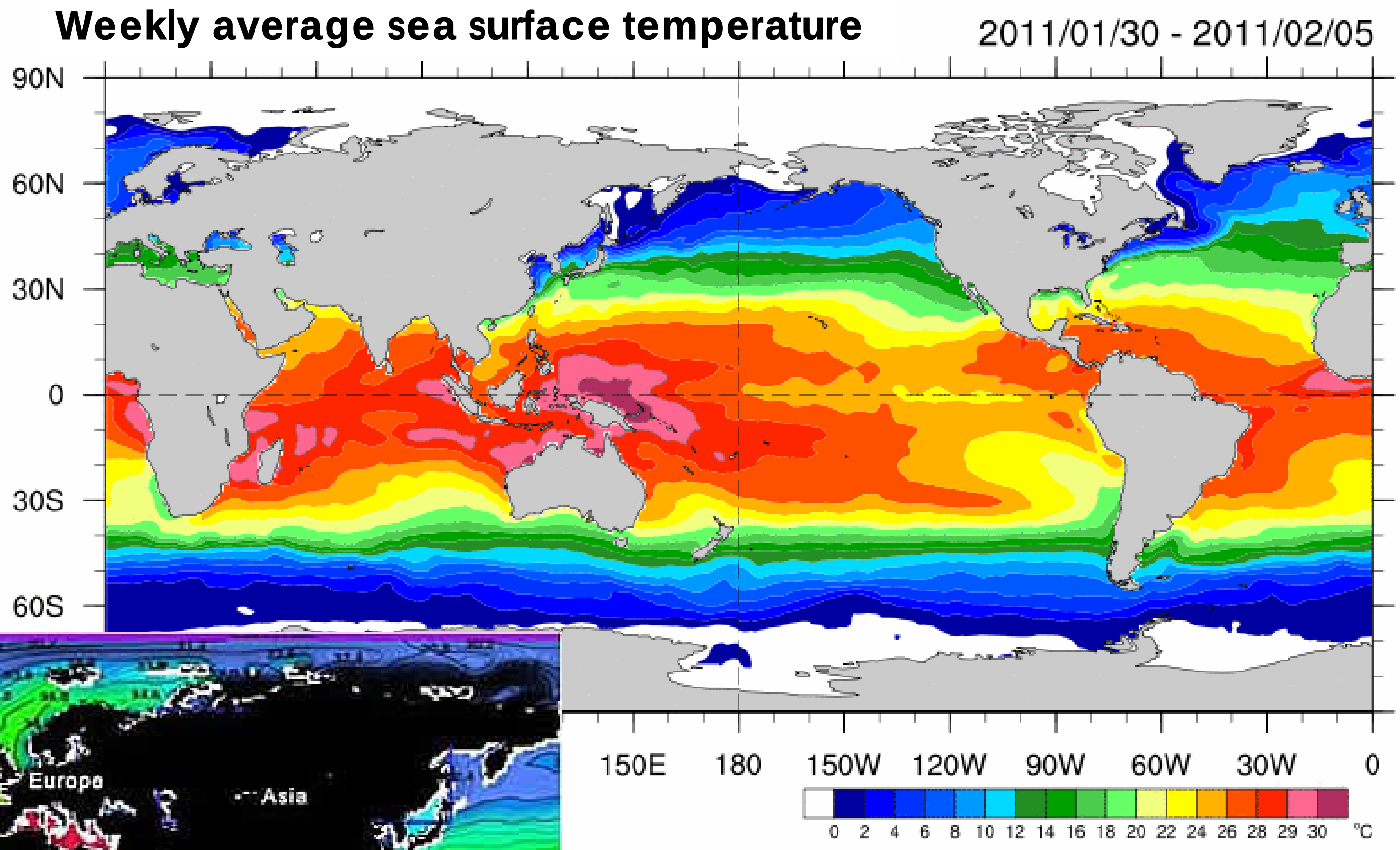
During their movement, currents transport heat, salt etc and interact with the surroundings

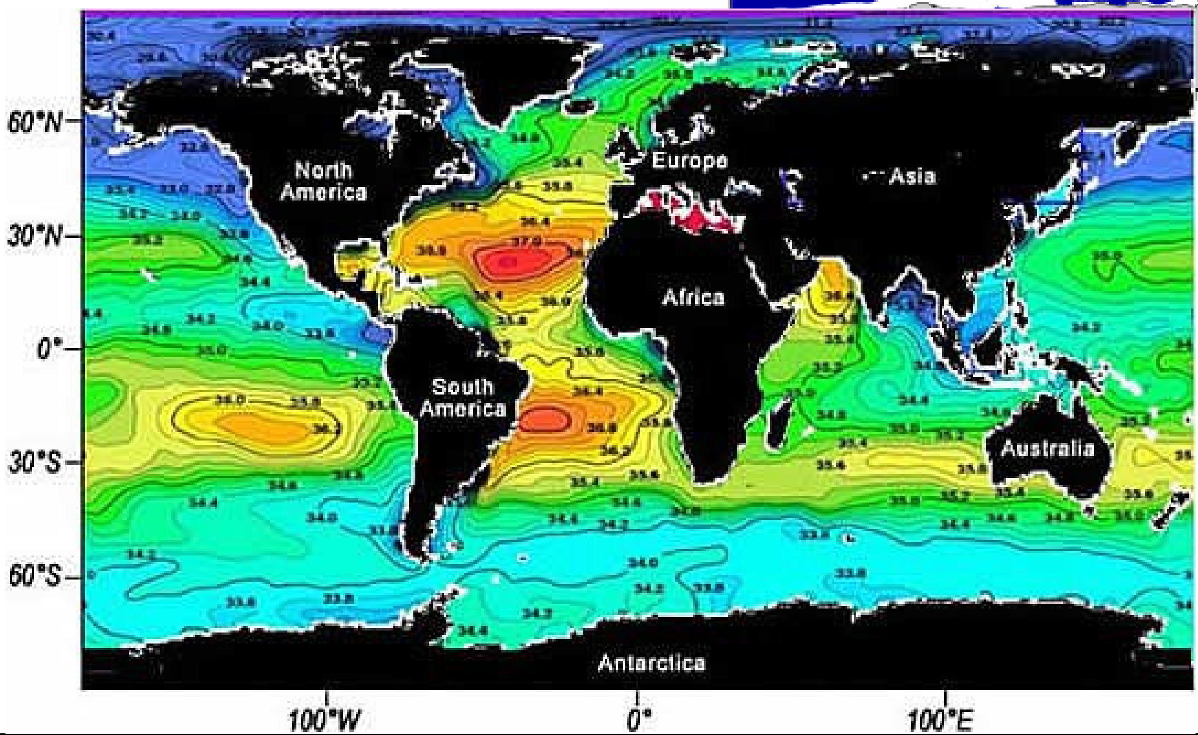
Moving across latitudes, water changes temperatures ► density, thereby causing vertical movements of the water masses



Big E-W asymmetries!

Temperatures





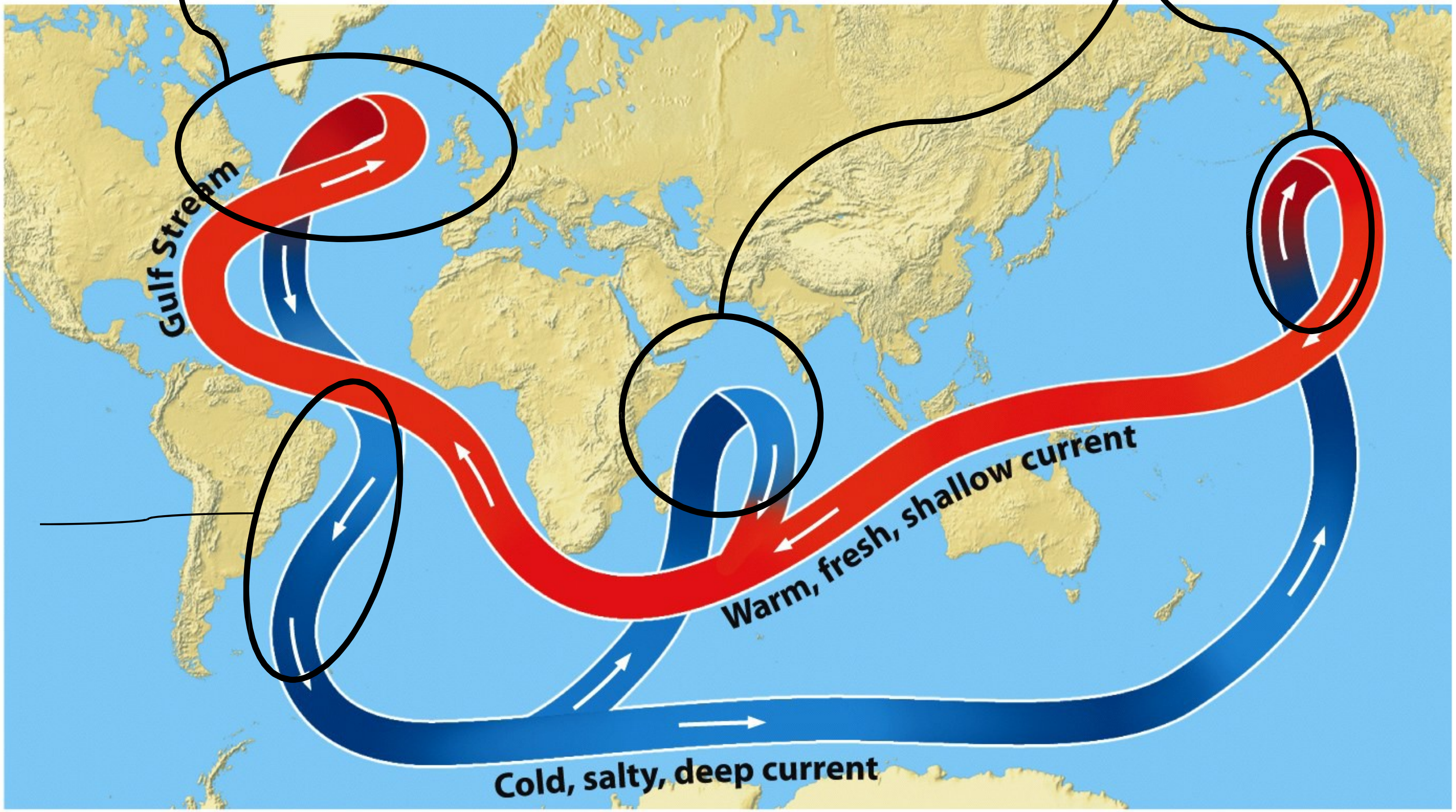
salinities

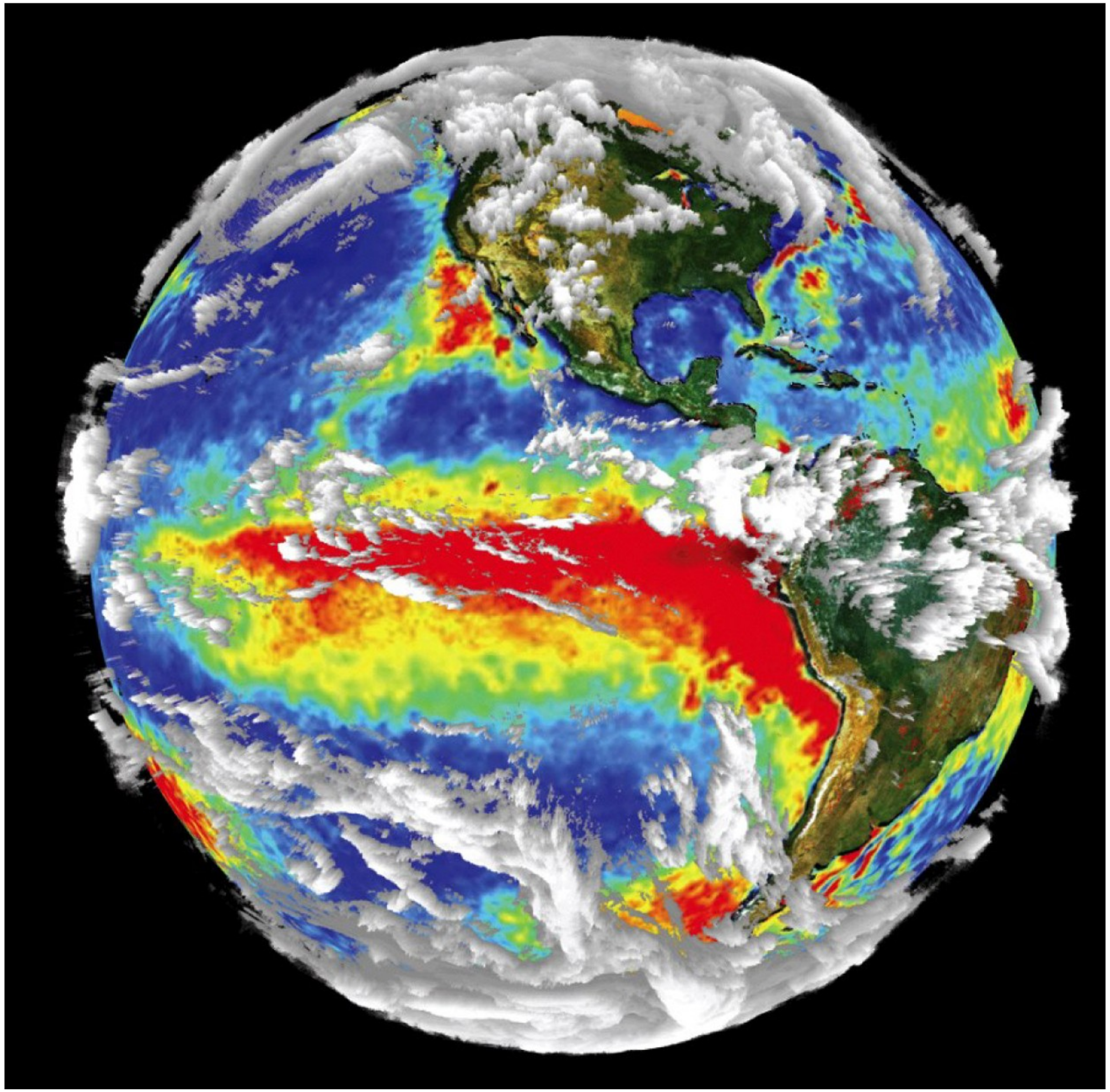
The first order pattern of currents: driven by density differences (temperature and salinity)

Waters arriving in the N Atlantic and more saline (because of less river input)

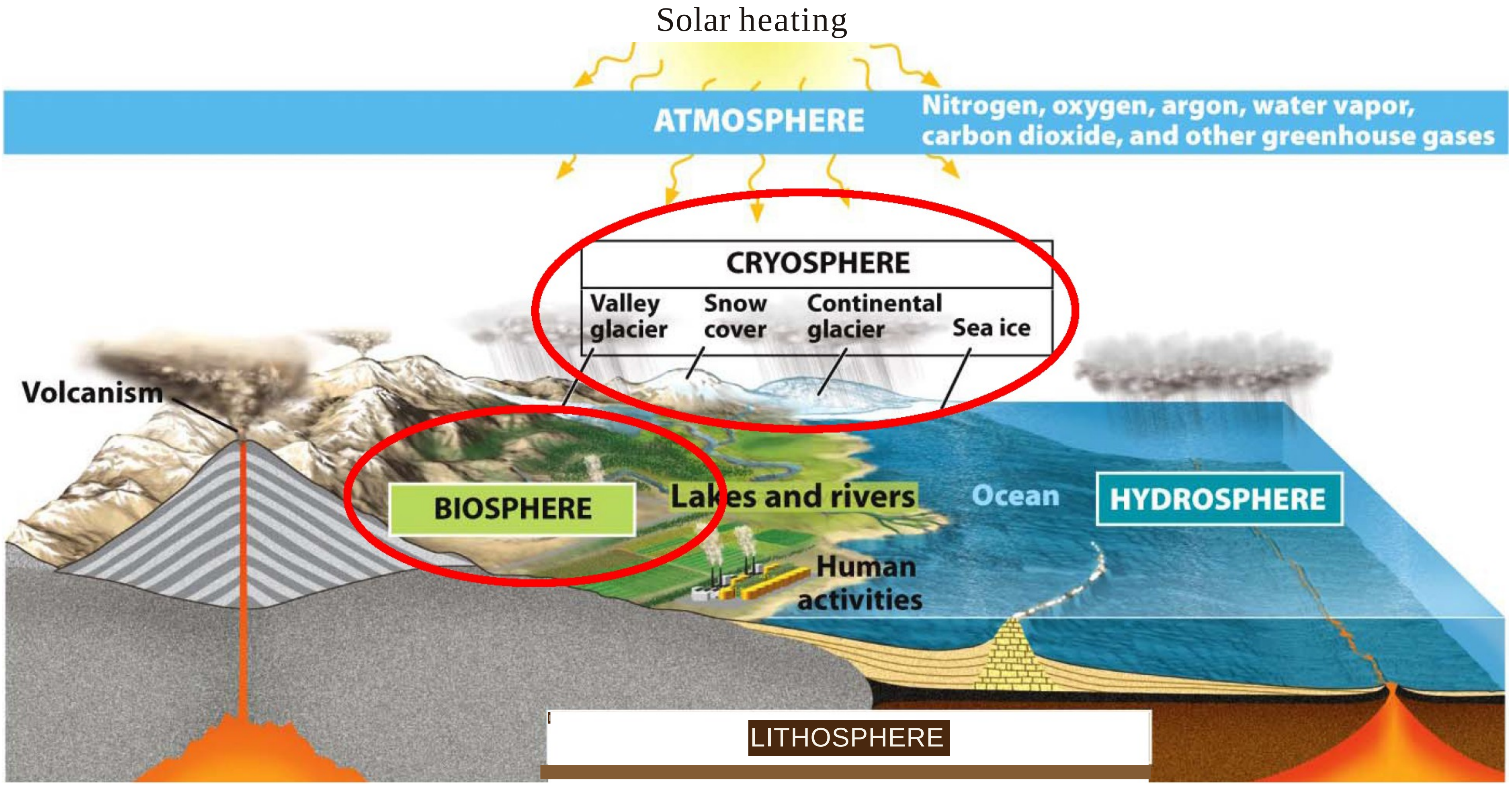
Upwelling zones (very important for nutrients distribution)

Heavy water moves southward (thermoaline circulation)



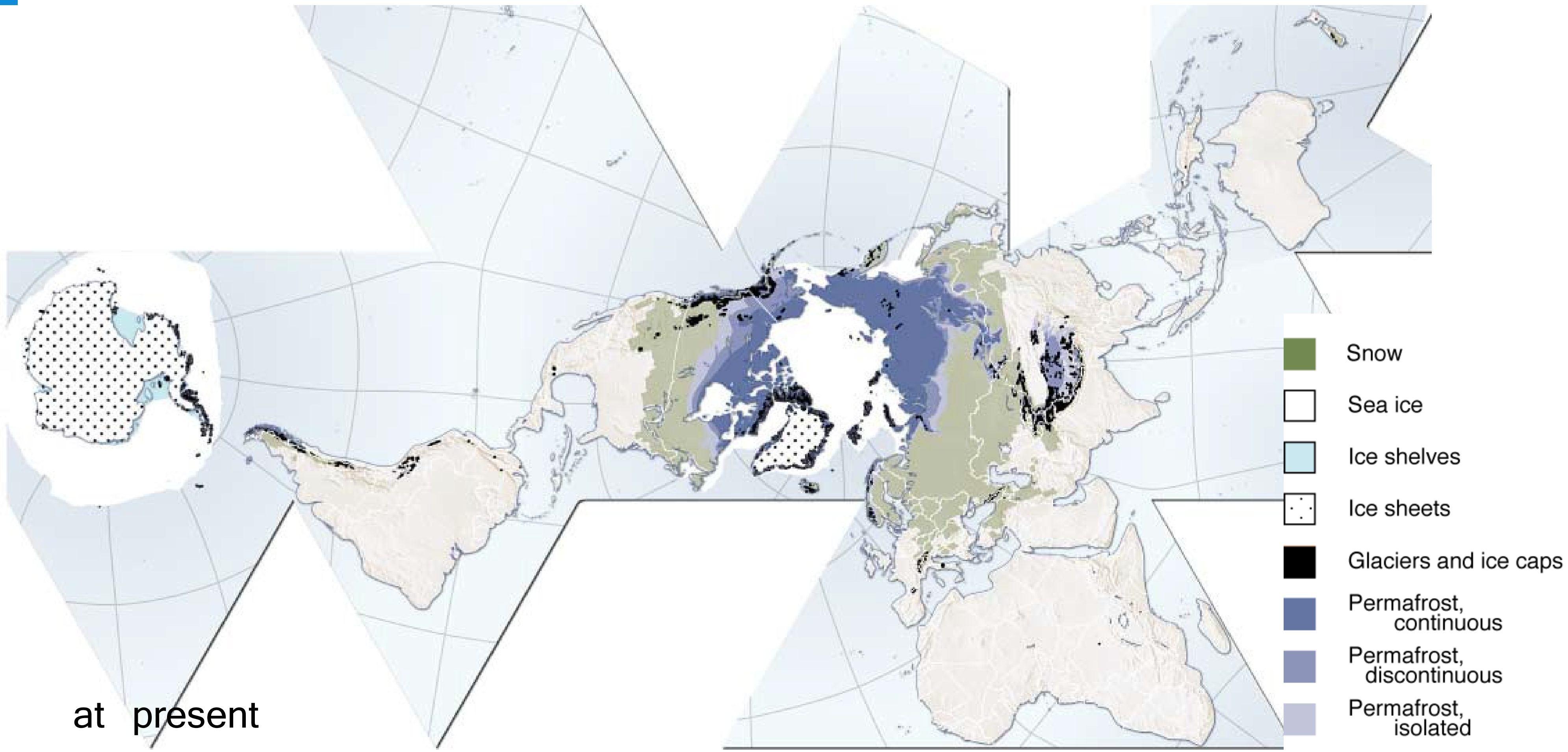


Some more components of the climate system

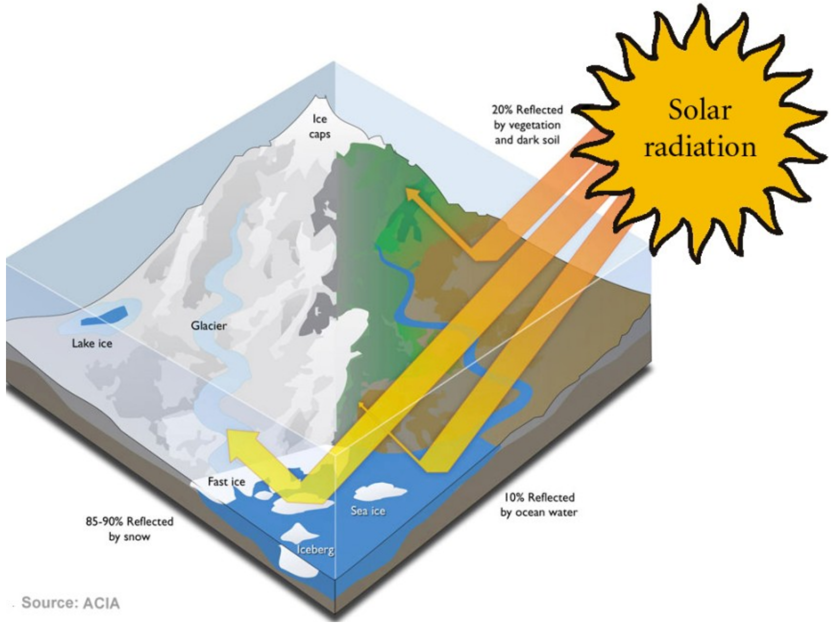


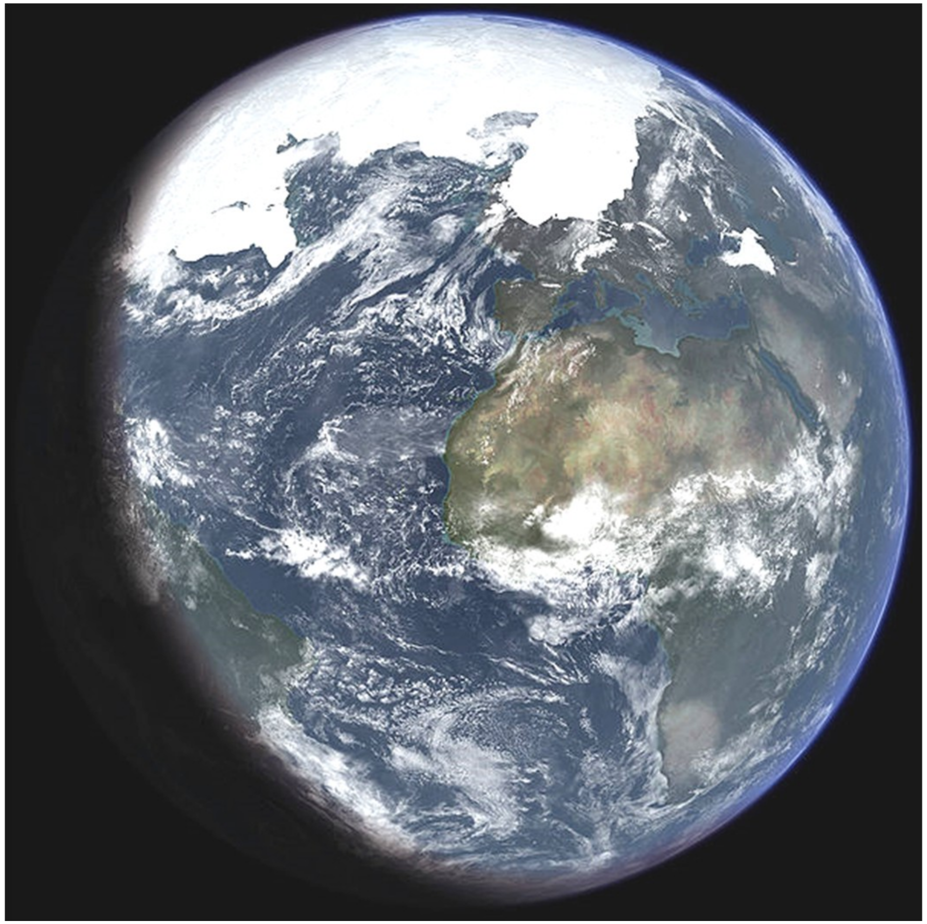
Cryosphere

The part of the water cycle which is stored in glaciers and snow



Glaciers are of crucial importance because they control i) the albedo effect (the proportion of light/energy which is reflected back into the atmosphere), ii) the sea-level (amount of waters in the oceans)





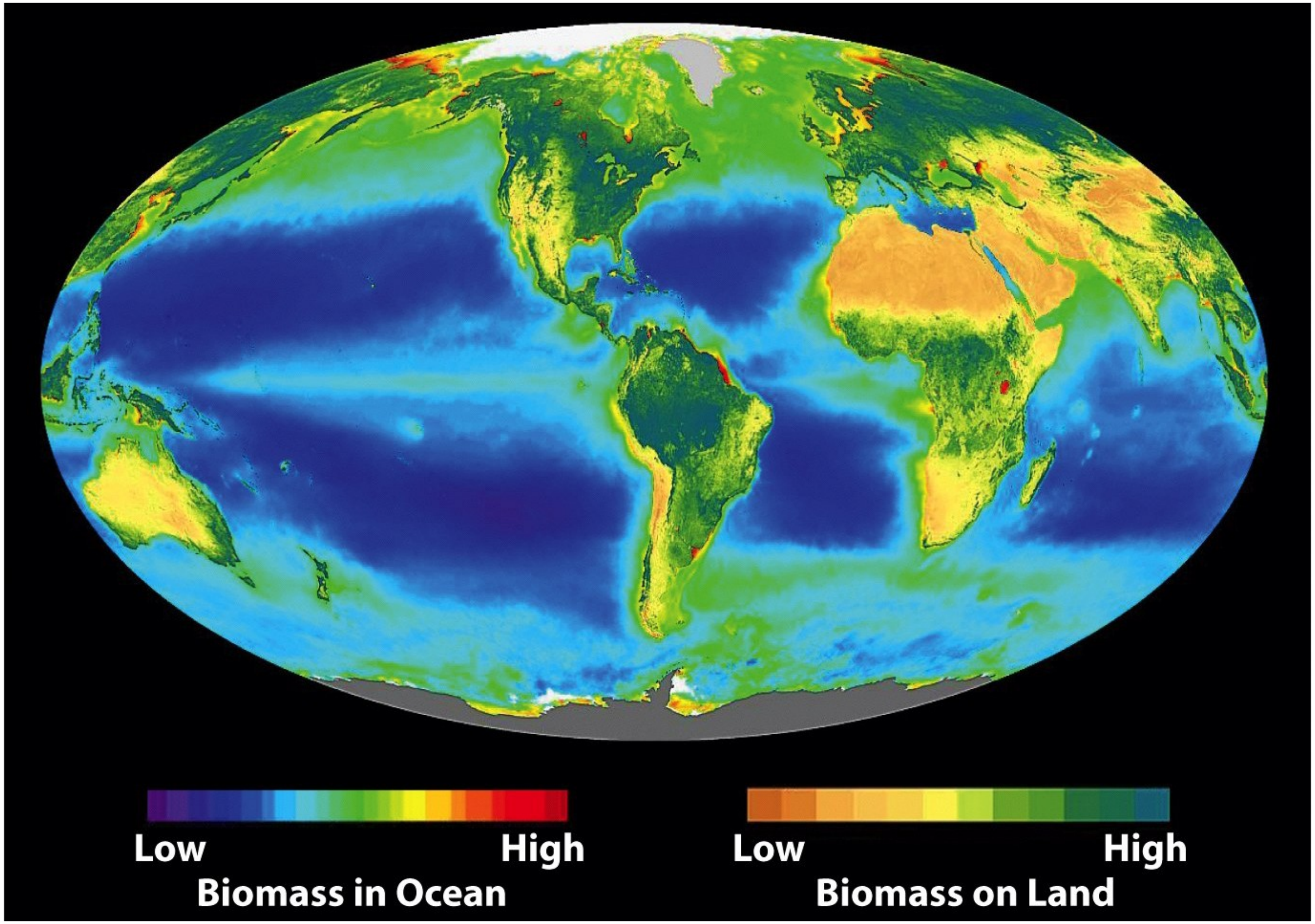
Because temperatures change, the volume of glaciers change with all consequences

Sea-level 10.000 yr ago (last ice age) >30% of the surface of the continents was covered with ice (now ~10%).

As a result, sea level was ~120m lower than at present

Biosphere

- all organisms living near Earth's surface
- plants and animals
- microbes, marine and terrestrial



Major influence on:

- **Albedo**
- **CO² exchanges and sequestration**

Putting all things together one has the climate

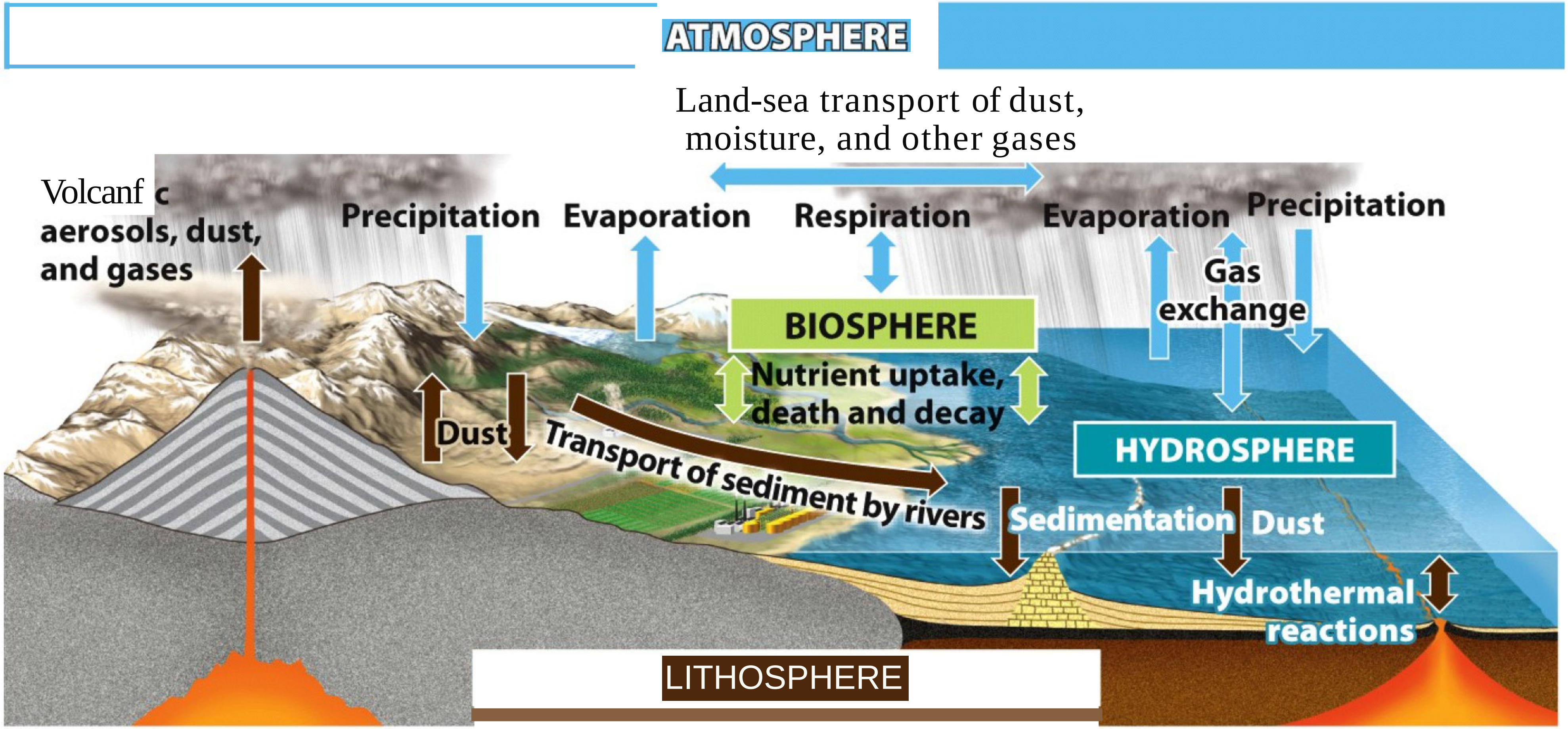
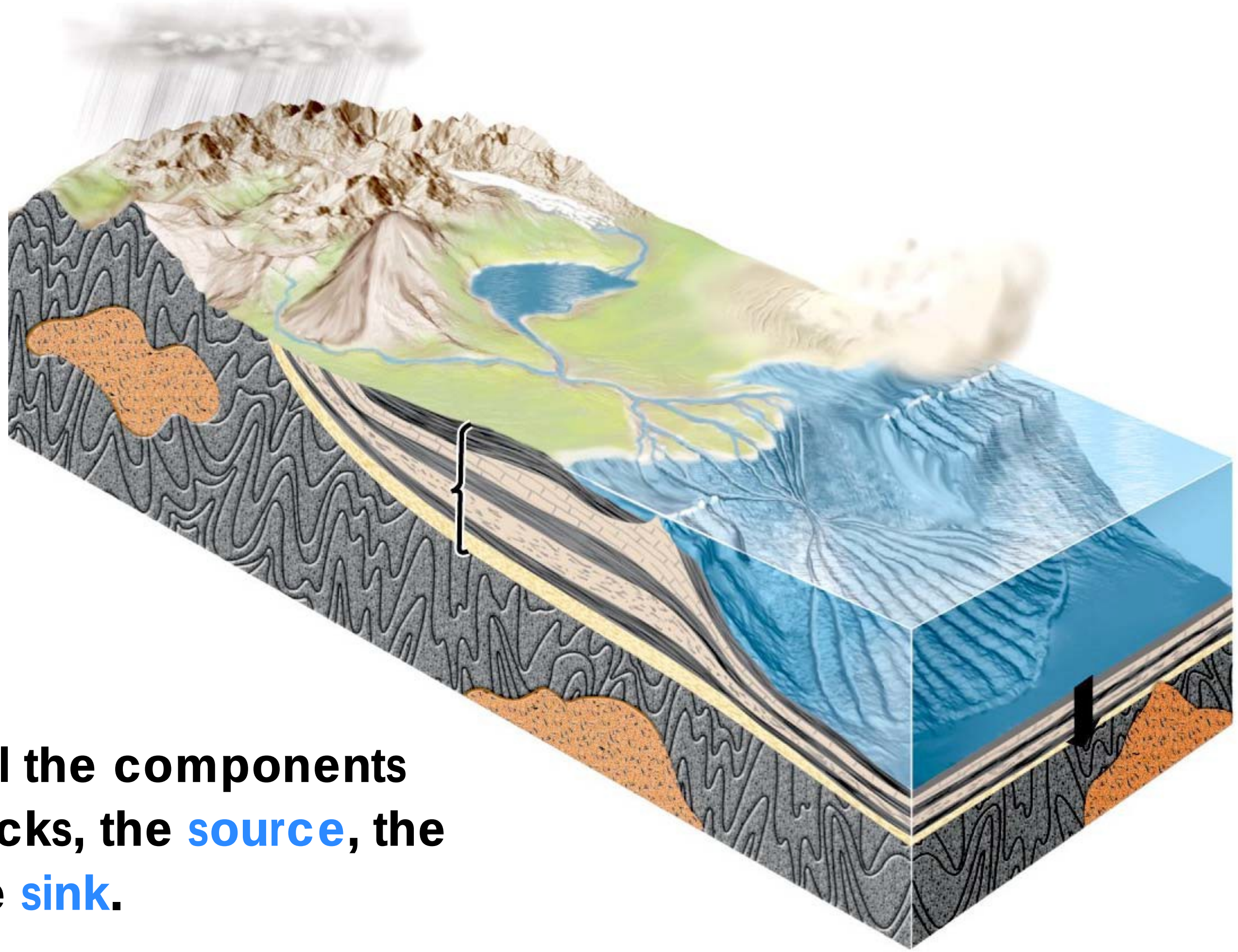


Figure 1S.14
Understanding Earth, Sixth Edition

Climate are the weather conditions (temperatures, humidity, atmospheric pressure, wind and rainfall) over a longer times span (>10s of years)

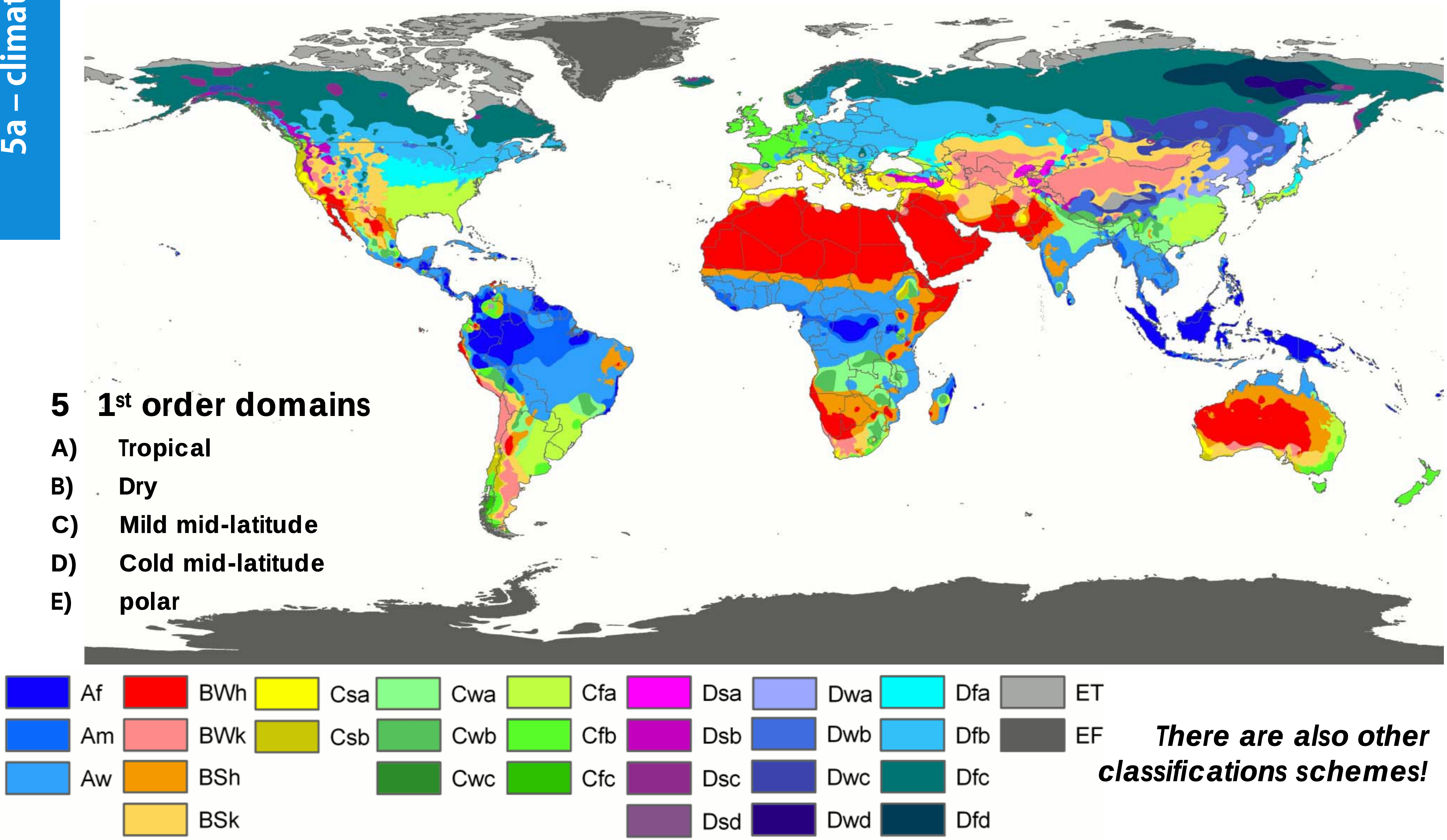


Climate system impacts all the components controlling sedimentary rocks, the source, the distributary system and the sink.

Most of our resources are in sedimentary rocks, and most of our communities live on sedimentary rocks

Climate is crucial

Climate zones in the Earth



5 1st order domains

A) Tropical
B) Dry
C) Mild mid-latitude
D) Cold mid-latitude
E) polar

There are also other classifications schemes!

Tropical climates (A): constant high temperatures (at sea level and low elevations) during the entire year at T>18° C.

Subdivisions: Tropical rainforest (Af), Tropical monsoon (Am), tropical wet and dry savanna climate (Aw)

In dry (arid and semiarid) climates (B) precipitation is < potential evotranspiration

Different letters indicate the magnitude of difference between the two. A second letter indicates temperatures

In Temperate/mesothernmal climates (group C) have summer average T>10°C and average winter T = -3-18° .

the second letter indicates the precipitation pattern: w= dry winter, s=dry summer and f=significant precipitations during all seasons. Subdivision: Dry-summer subtropical Mediterranean climates (Csa, Csb), Humid subtropical (Cfa, Cwa), oceanic climates (Cfb, Cwb, Cfb)

Continental/microthermal climates (group D) have T>10° in the warmest months and coldest month T<-3°) Typical for the internal parts of continents

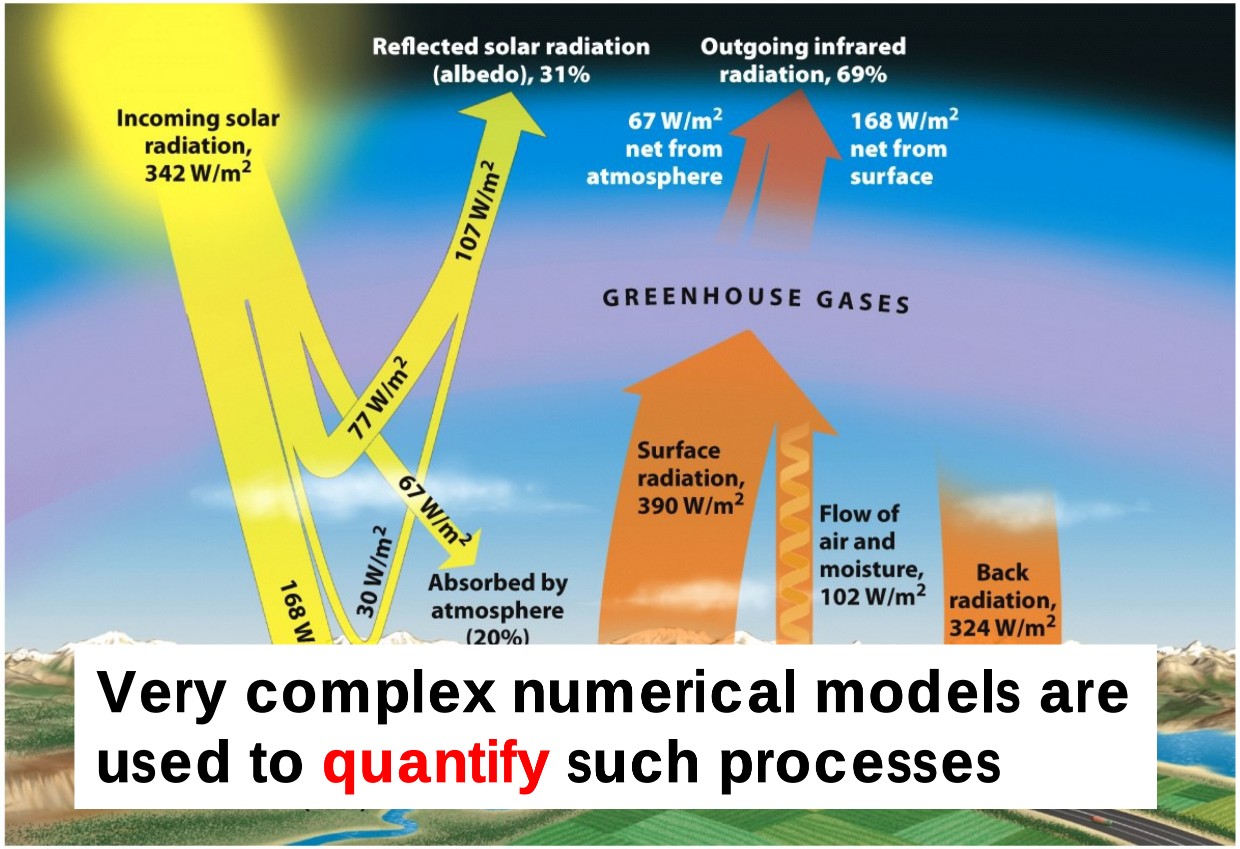
Hot summer climates (Dfa, Dwa, Dsa), warm summer continental (Dfb, Dwb, Dsb), continental subarctic or taiga climates (Dfc, Dwc, Dsc), continental subarctic with severe winters (Dfd, Dwd)

Polar climates. Have average T<10° during all months of the years

Tundra climate (ET), ice cap climate (EF).

Climate change

Climate system changes through time



Very complex numerical models are used to quantify such processes

- **changes in the incoming energy**
- **changes in the radiation distribution**

Complex non-linear relations characterized by positive and negative feed-backs

- **how to "disturb" the system**
- **how to go back to normal**

The example of CO_2

- **Increases greenhouse gas > increases T > increases water evaporation > clouds > absorption > T increase**

but

- **Clouds also reflect sun radiation. More clouds > less radiation reaching the Earth > lower T**

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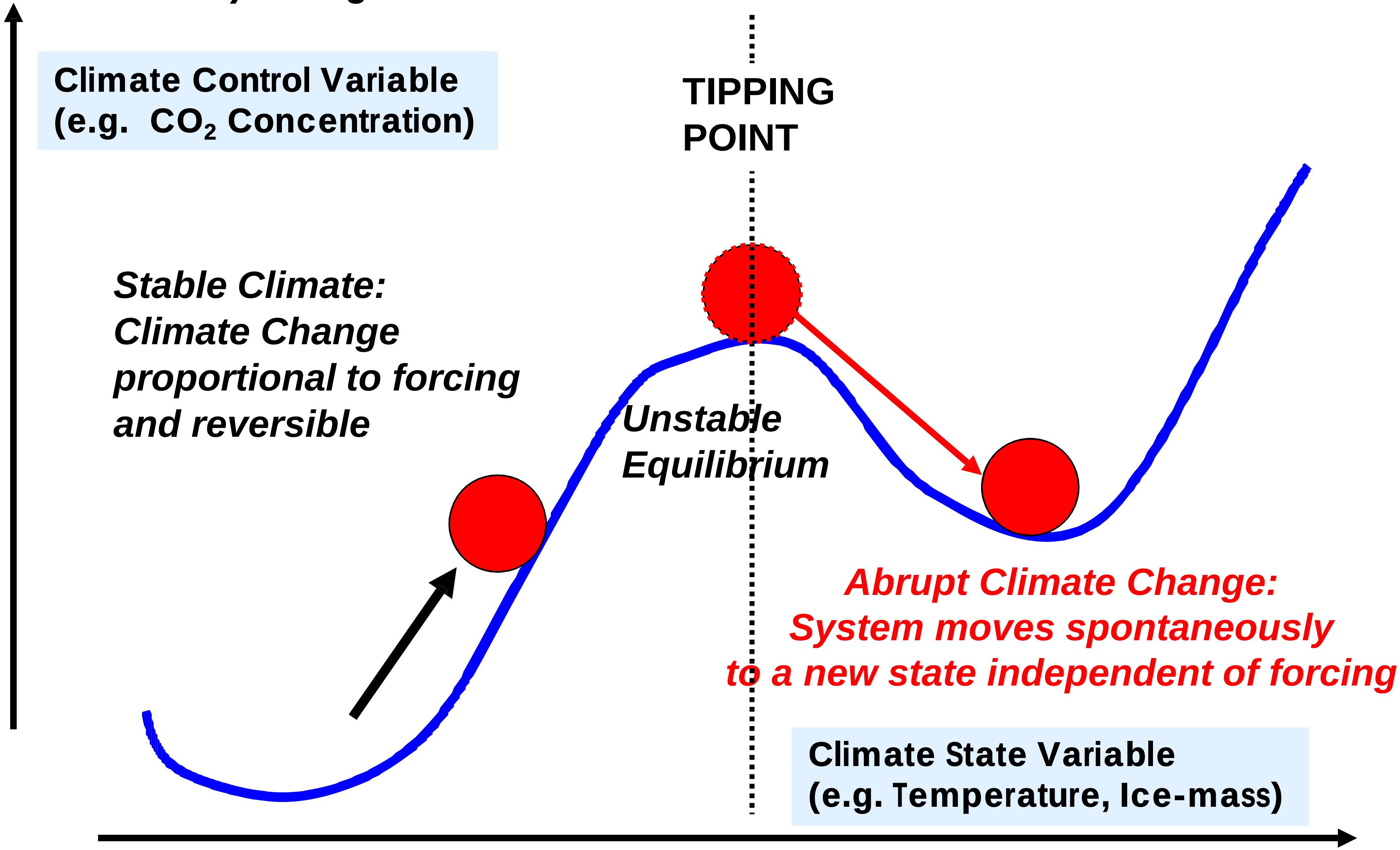
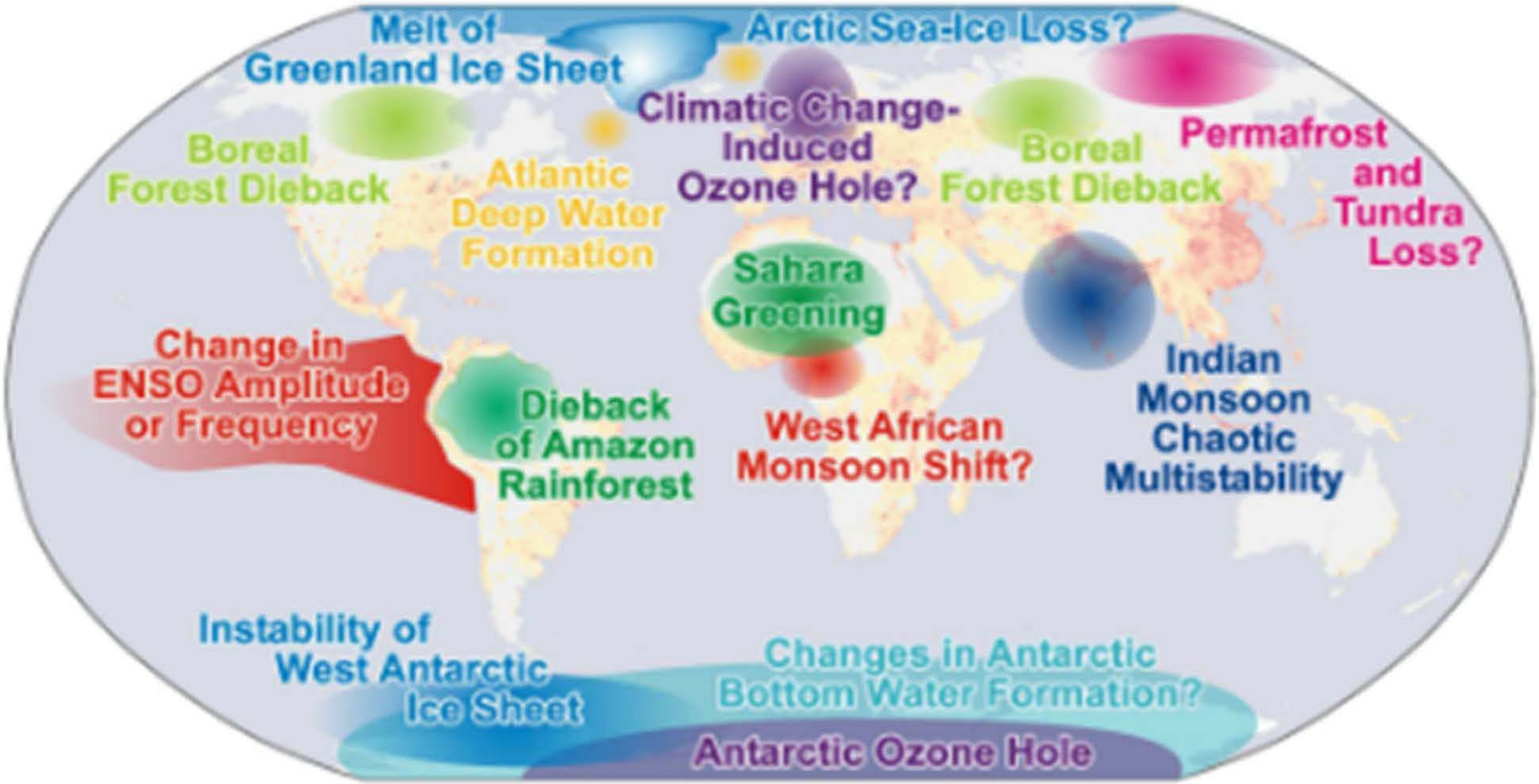
All these interactions are strongly non-linear and characterized by tipping points, points where small "normal" steps create large (maybe irreversible) changes



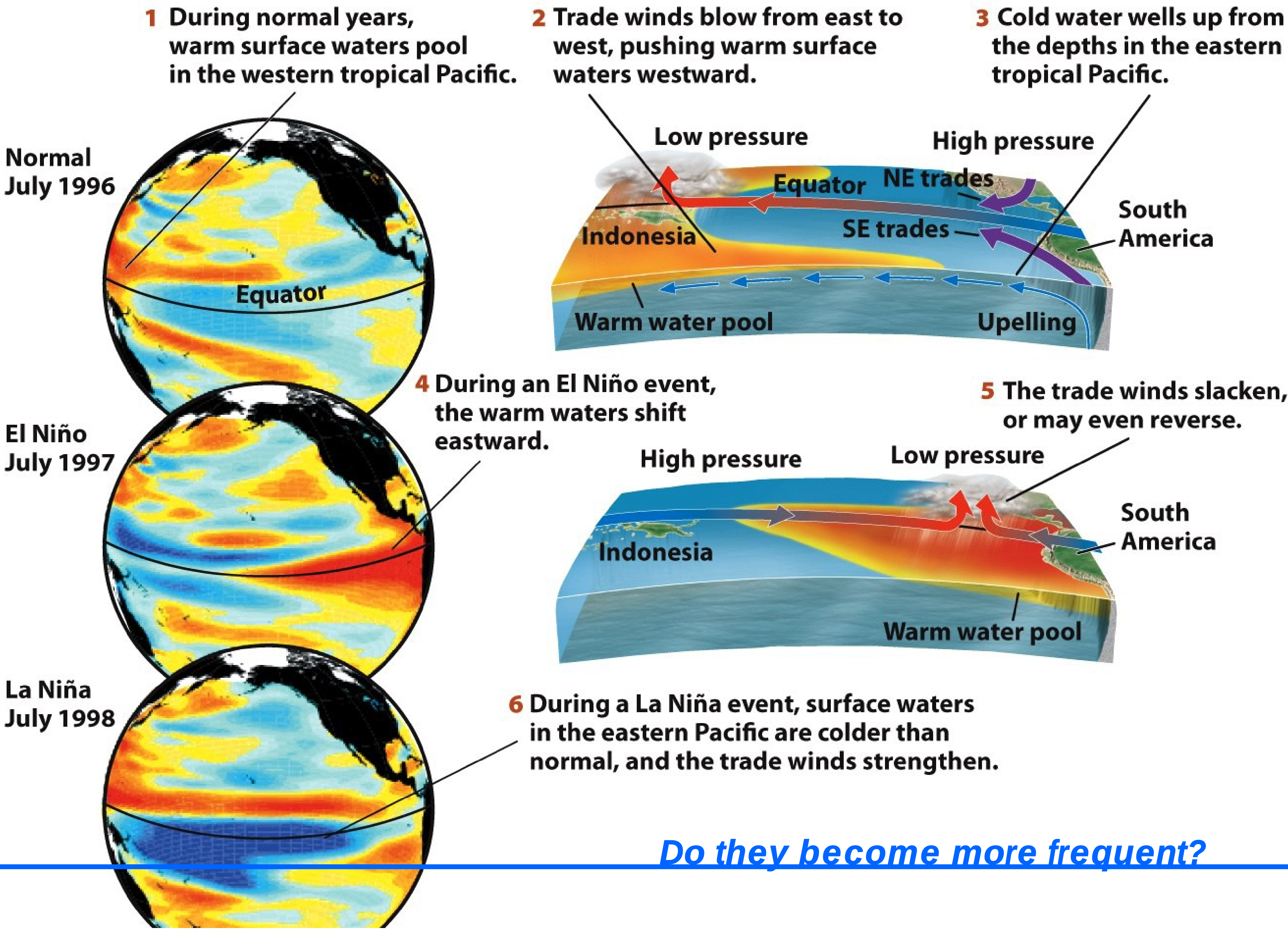
Systems sensitive to tipping points



Multiscale climate change

- seasonal time scale (El Niño)
- 10^1-10^2yr, human activity (?)
- 10^2-10^4yr time scale (astronomical ciclicity)
- at the 10^6 yr time scale (plate tectonics and other)
- at the 10^7-10^8yr scale (the evolution of the Earth)

Short time lengths: El Niño



Do they become more frequent?

The human scale: global change

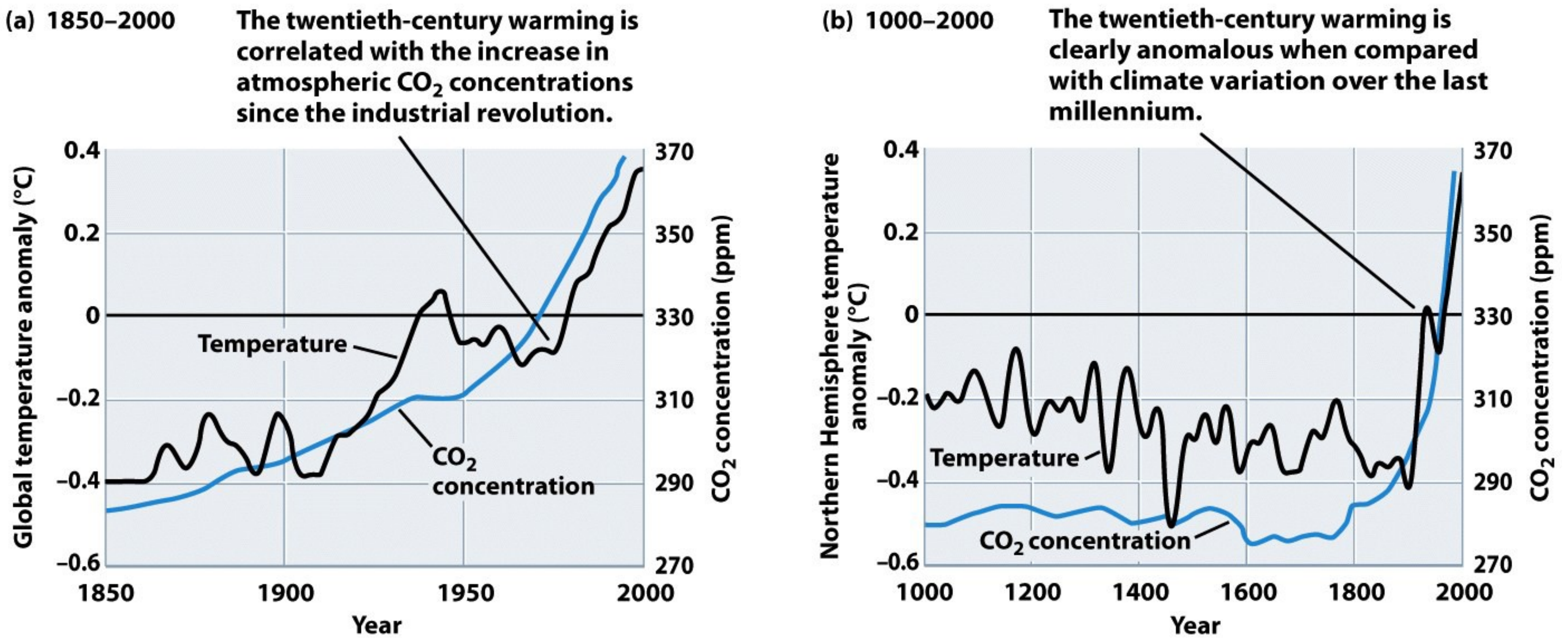
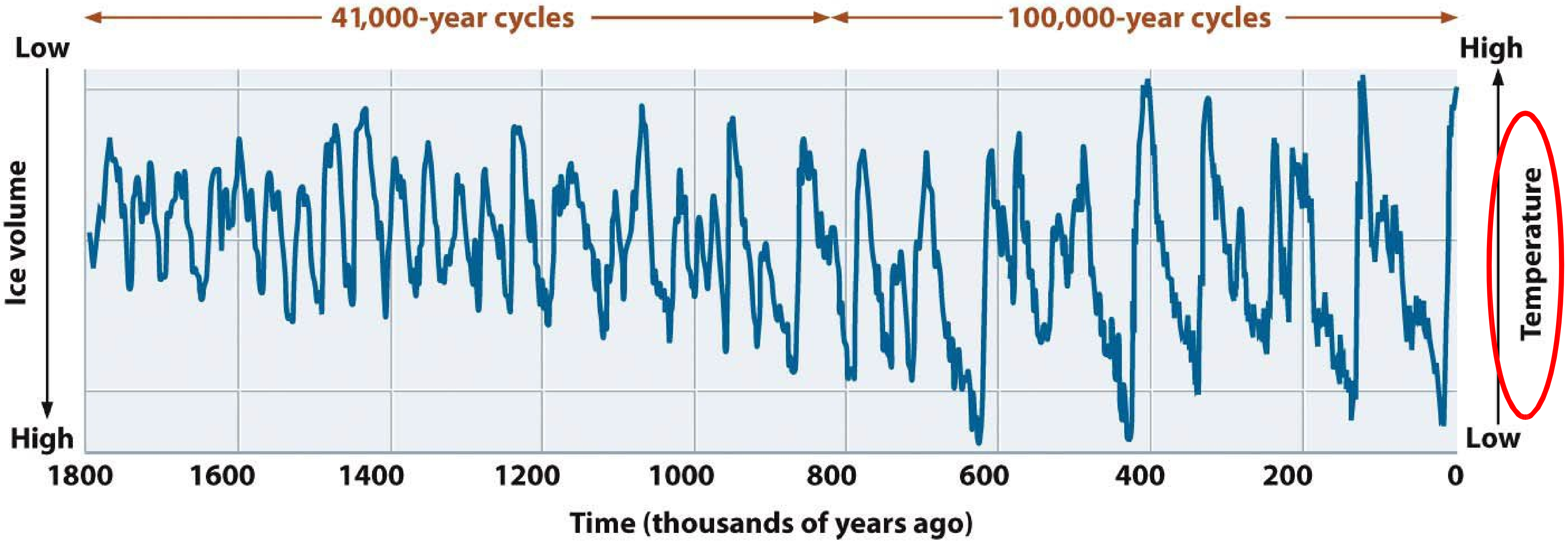


Figure 15.19
Understanding Earth, Sixth Edition

A clear correlation between the CO_2 content and temperature

The increased CO_2 is clearly related to human activity

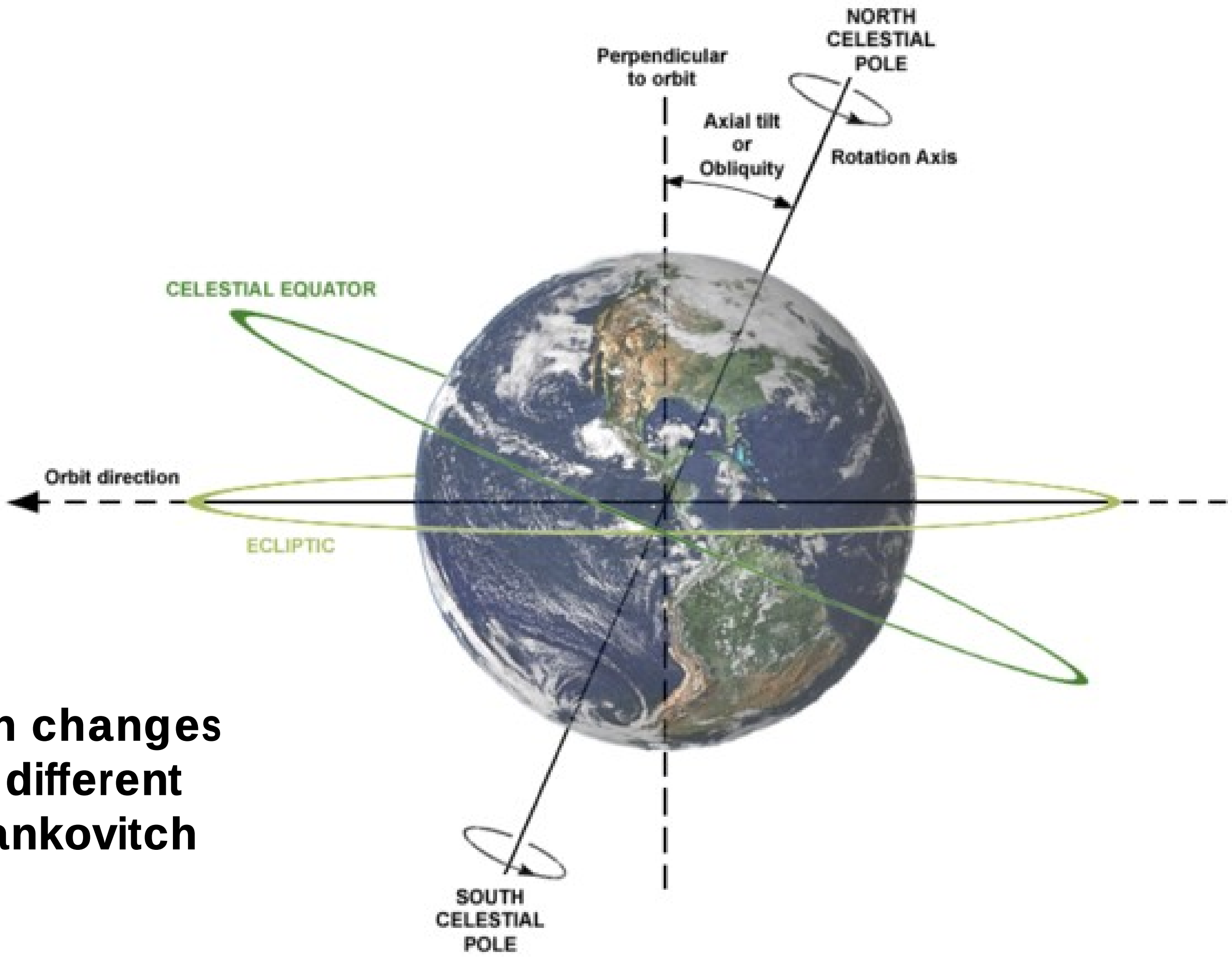
Other things are also going on at a slightly larger time scale: 10^3-10^4yrs



Milankovitch (astronomical) cycles:

23 kyr - precession
41 kyr - tilting
100 kyr - eccentricity

The position of the Earth with respect to the sun influences the amount of energy received by each part of the planet

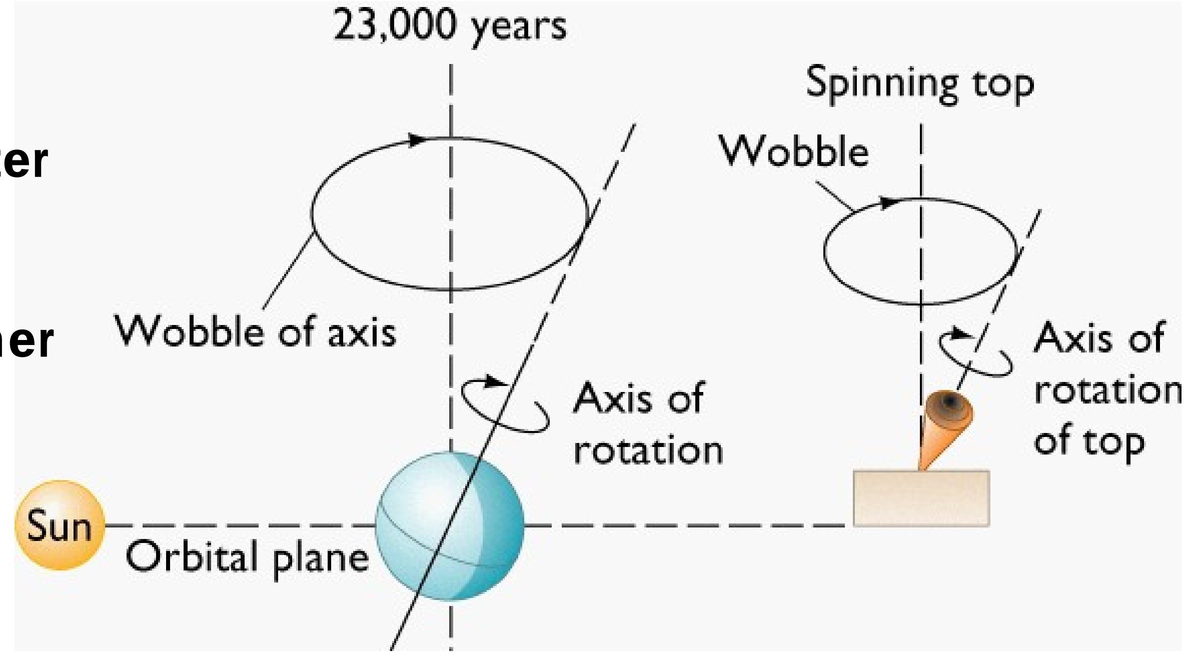


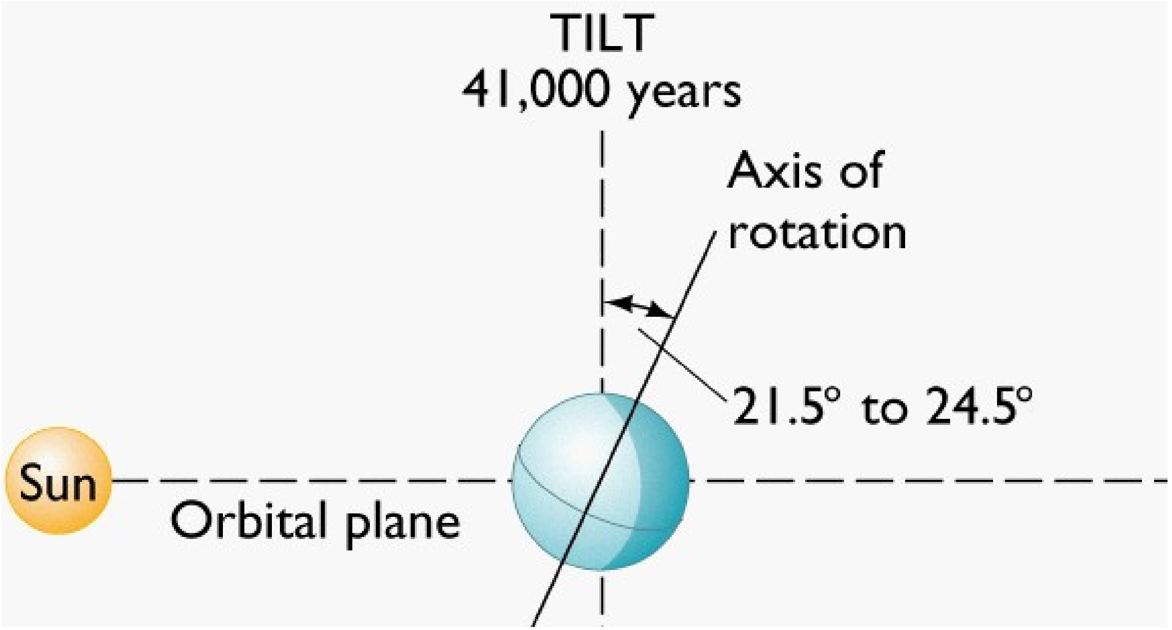
The position of the Earth changes through time imposing different cyclic oscillations (Milankovitch cycles)

Precession

Now:
summer 7 days longer than winter

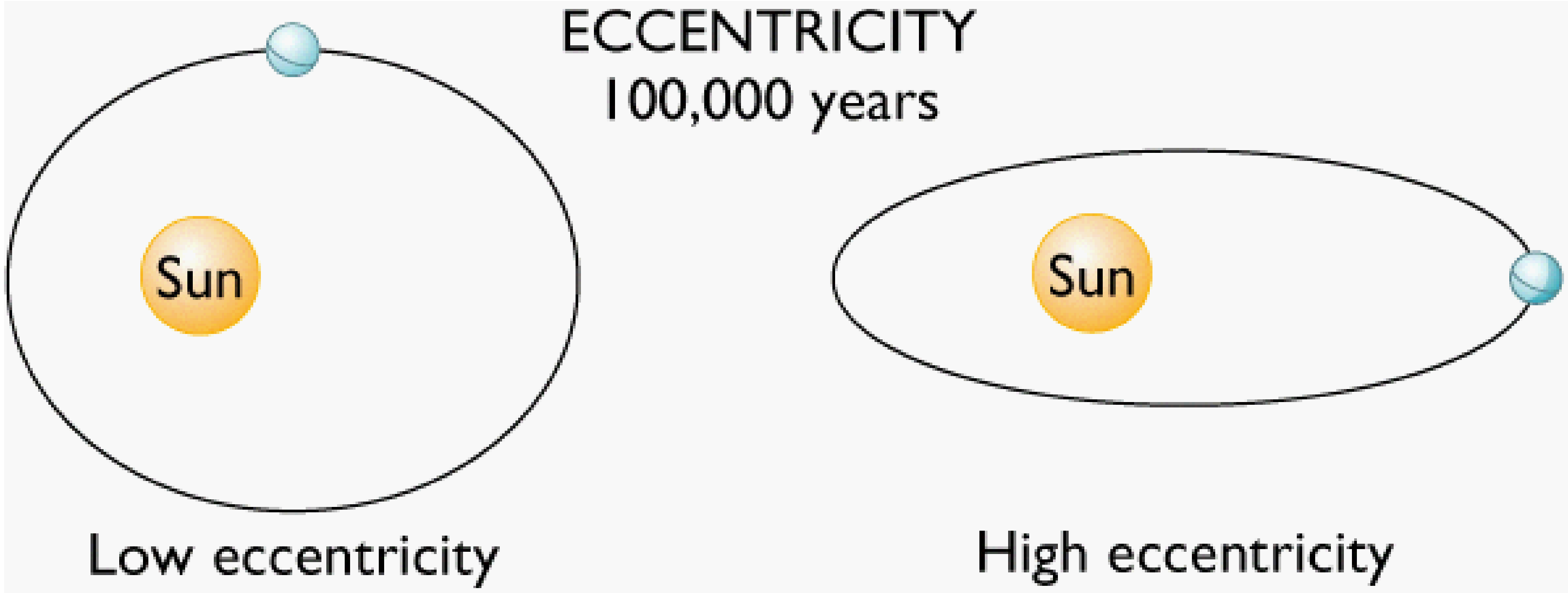
11 000 y BP:
Winter 7 days longer than summer





Tilting

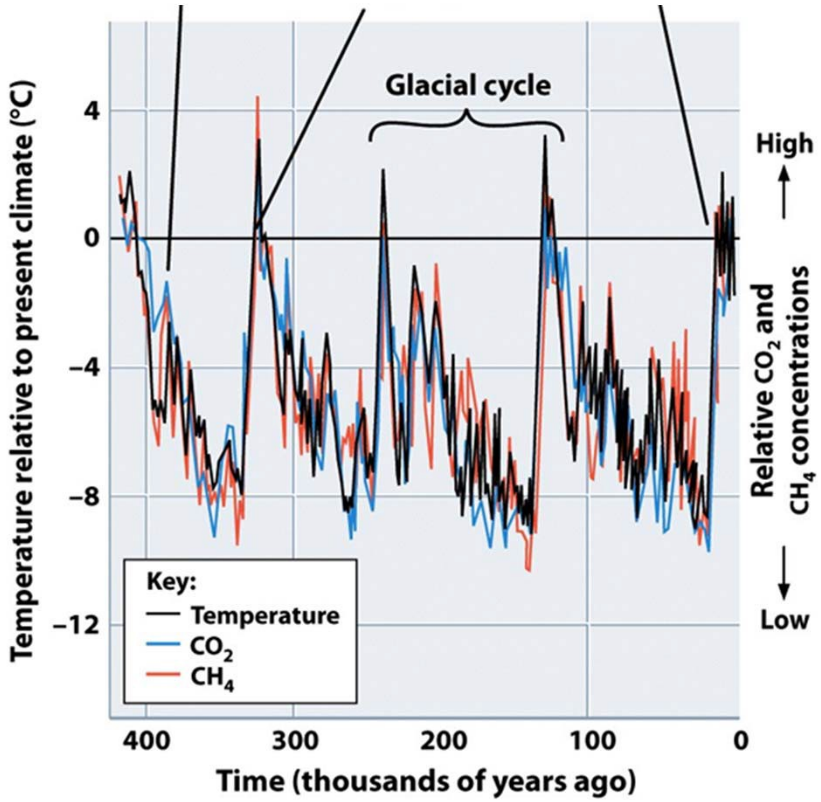
The shape of the orbit of the Earth around the sun changes

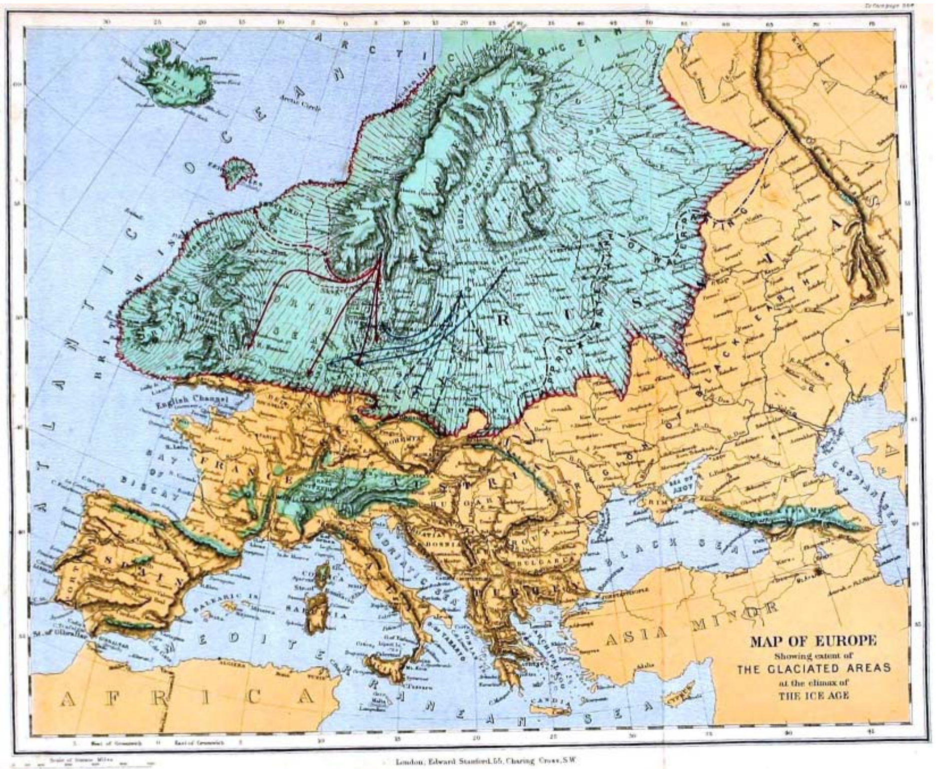


Long and cold winters favouring ice ages

Changes in temperatures have major effects on the entire Earth system. Cooling period correspond to glaciations (interglacial the time between)

Glaciations change sea-level, the albedo and the entire budget of greenhouse gases





The last glaciation peaked at 18000 (=18kyr) and ended ca. 12000years ago.

Even continuous successions can be interrupted by quite sudden events.

the Bonarelli level

Events at the 10^6yr scale

10^6yr time scale: The Cr t[illegible]

(E) Sea level changes and continental glaciation (Ridgwell, 2005)

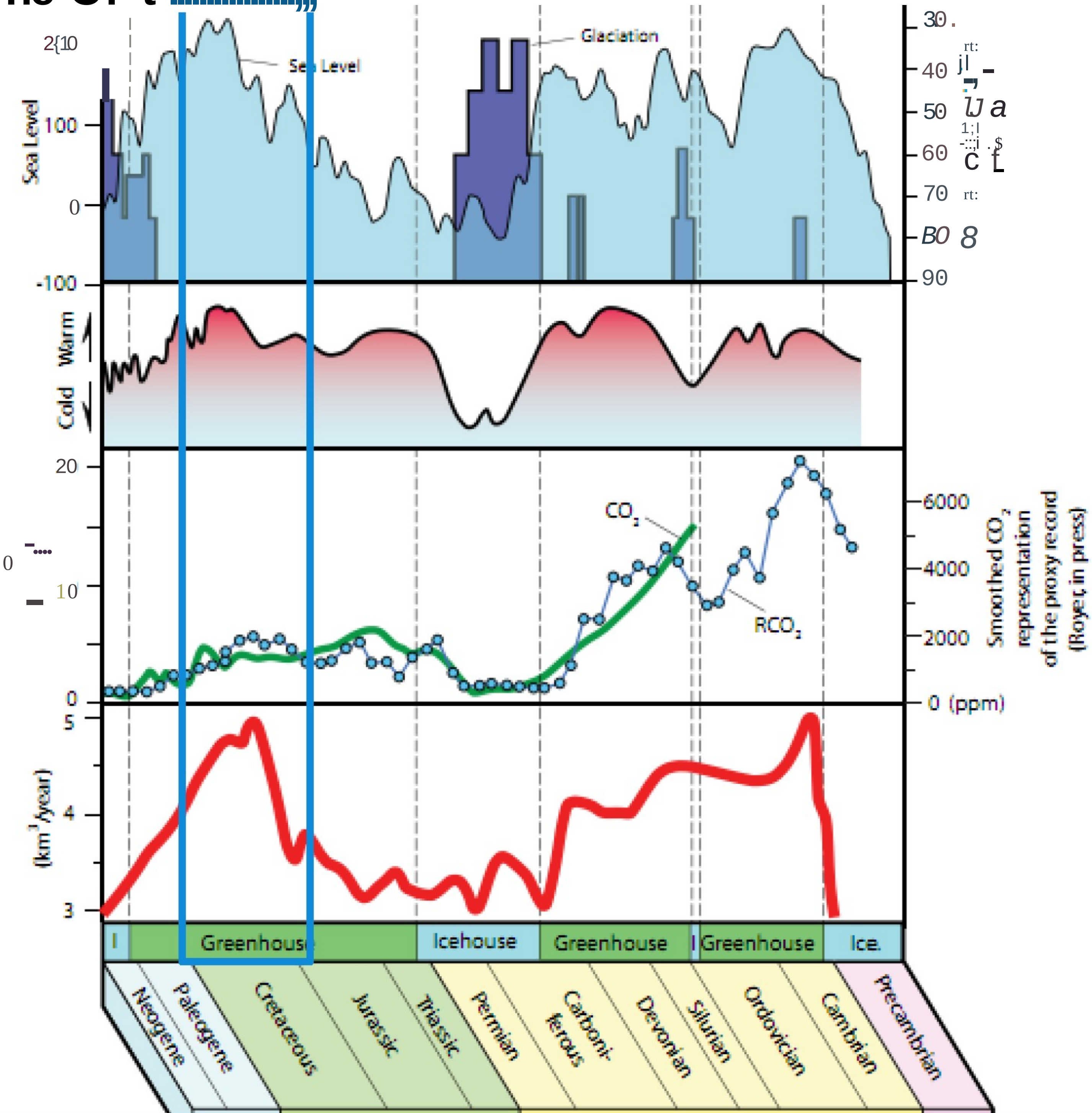
(D) Temperature (Frakes et al., 1992)

(C) Carbon dioxide

ratio of mass of atmospheric CO_2 at a past time to that at present (Berner, in [illegible])

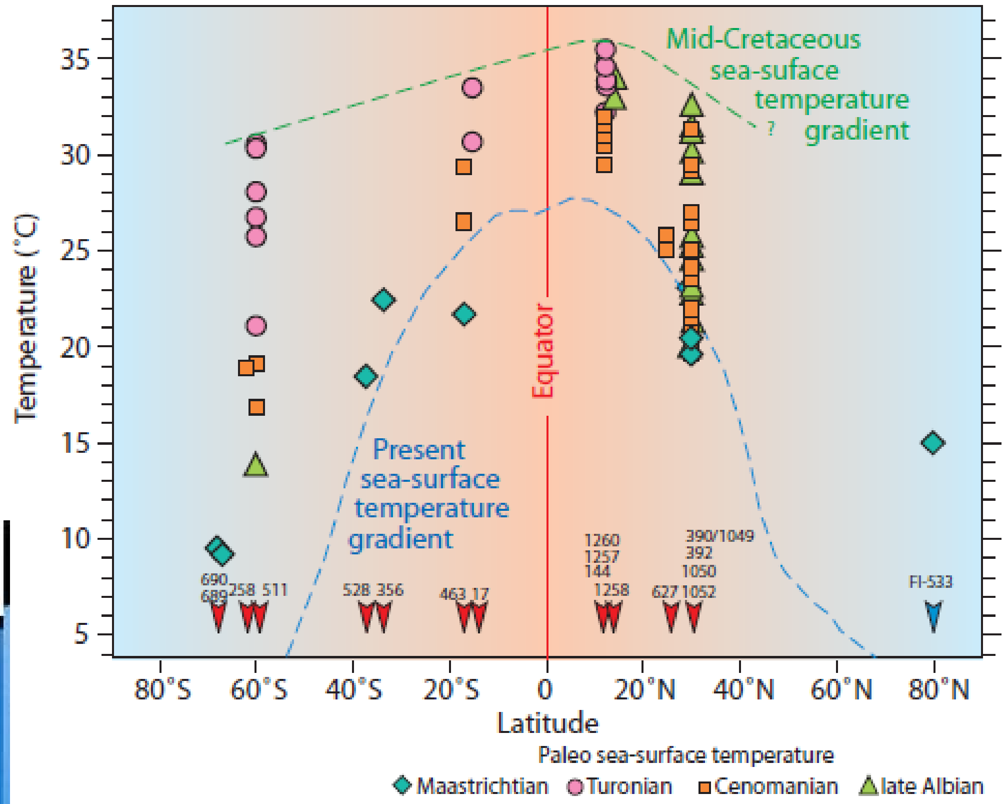
(B) Production rate of oceanic crust (Stanley, 1999)

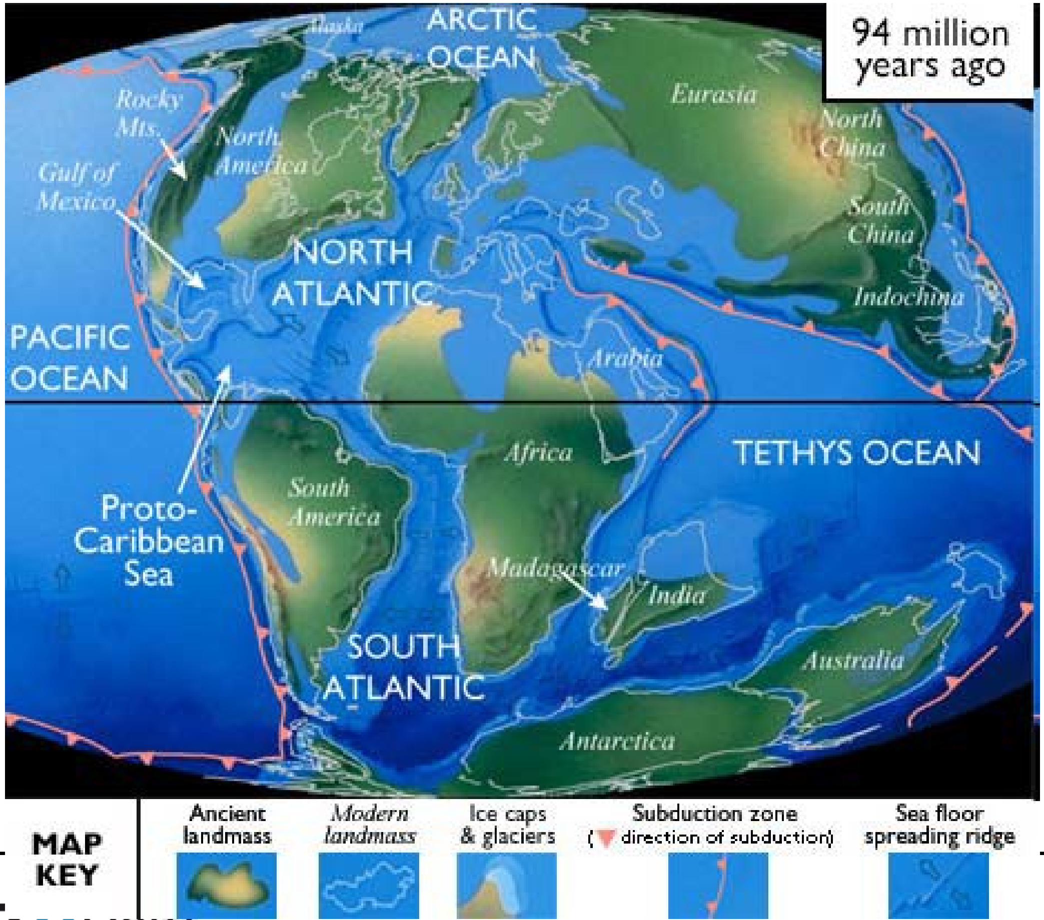
(A) Climate mode (Frakes et al., 1992)



Generally high temperatures coupled with very low N-S thermal gradients.

One of the result is sluggish oceanic circulation



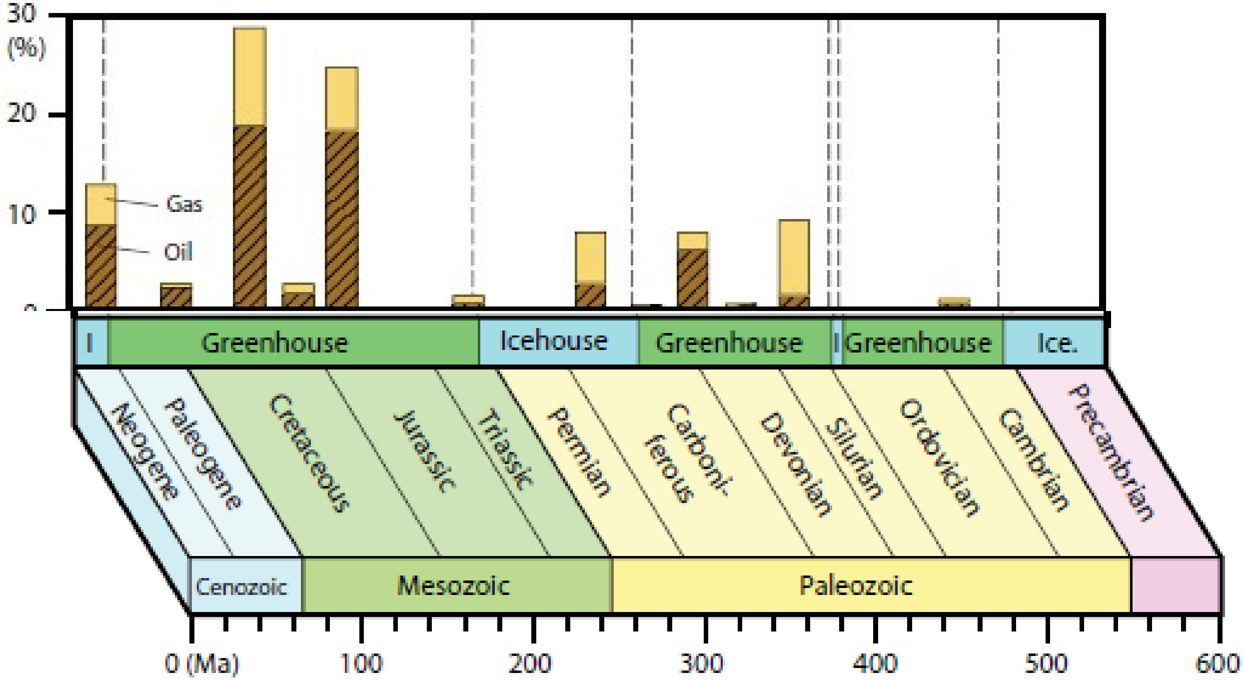


A large part of the oceans was extending in E-W direction thereby preventing effective circulation water masses

> Perfect time for the deposition of sediments rich in organic content

Consequences on sedimentary patterns and ….. global oil reserves

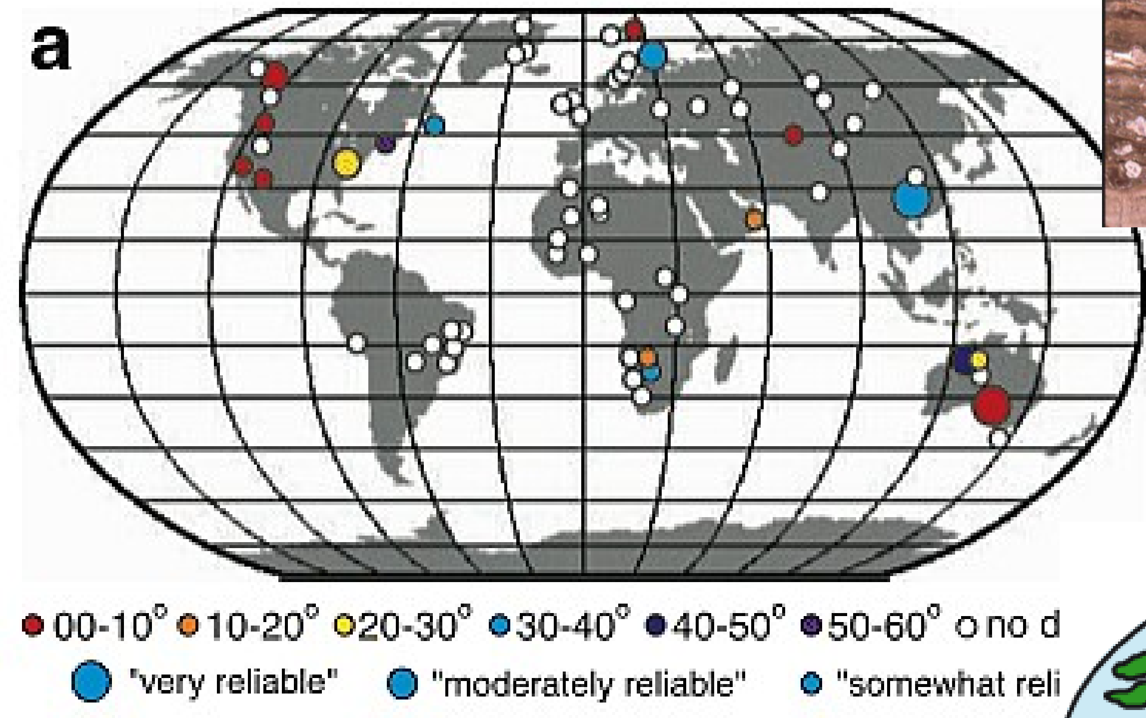
(G) Percent of world's original petroleum reserves generated by source rocks (Klemme and Ulminshek,1991)



Going deeper in time and towards even longer time-lengths

The snowball Earth

Glacial deposits have been found in places which at 650Ma were at tropical latitudes



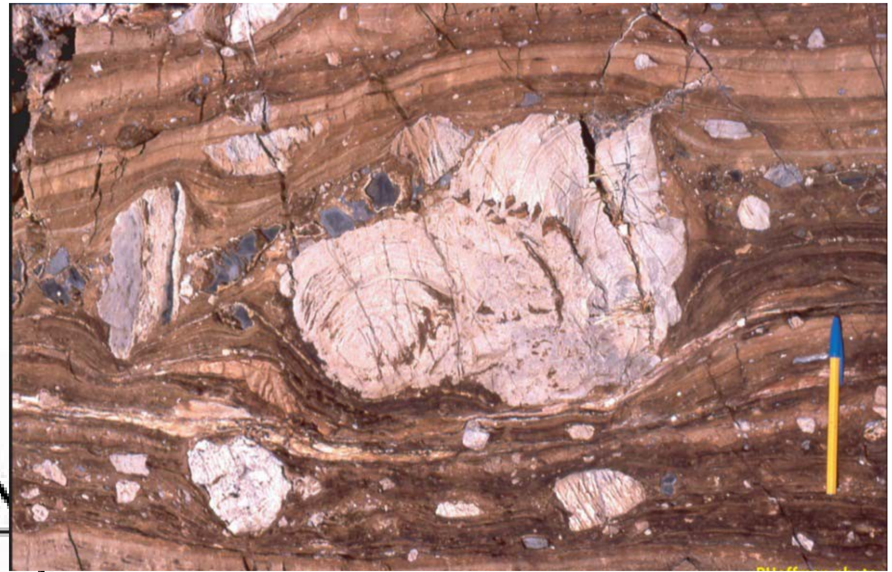
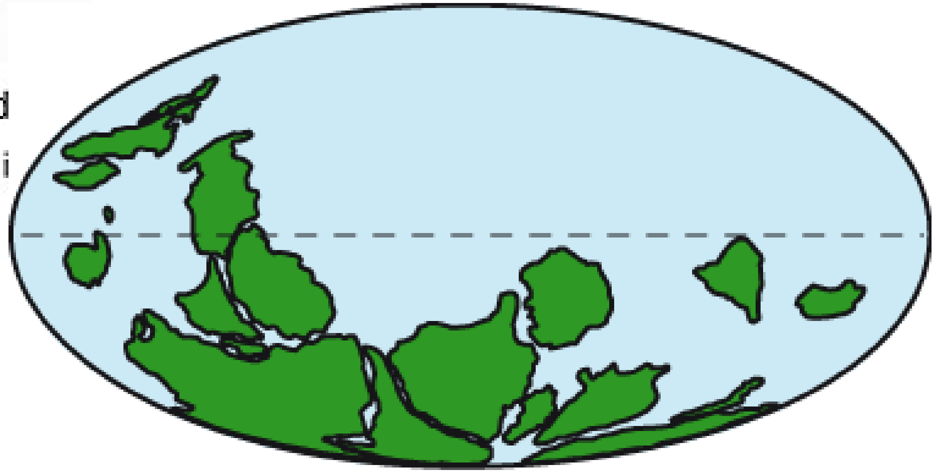
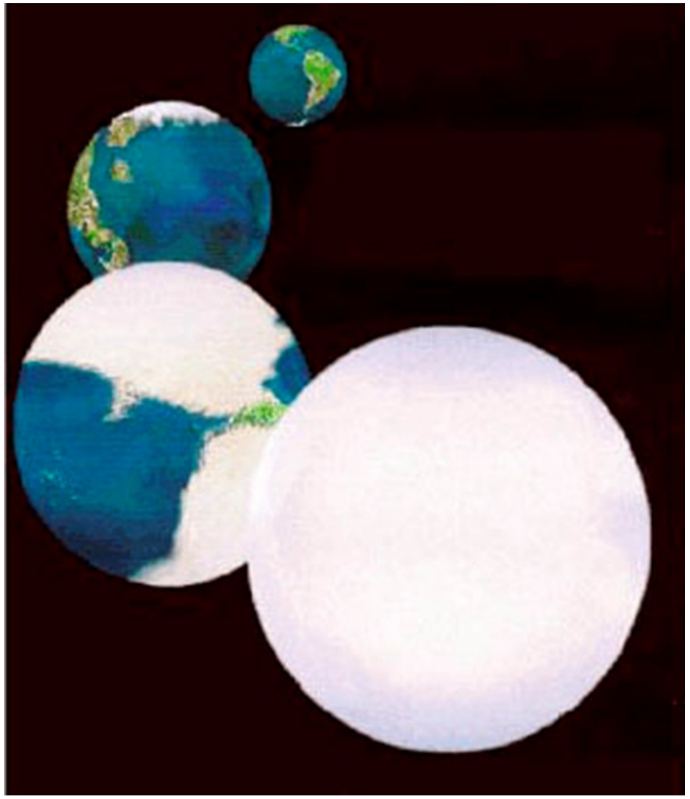


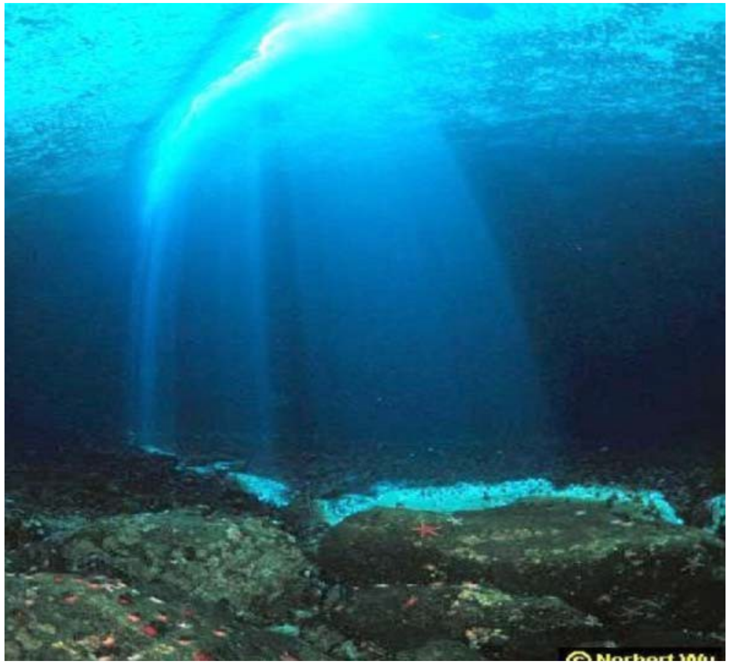
Plate tectonics had gathered a large mass of continents in polar regions





The development of large ice masses started feed backs, increasing albedo, decreasing temperatures ...

The entire Earth was probably covered with ice.



During: Glaciers on land and sea: little light and life

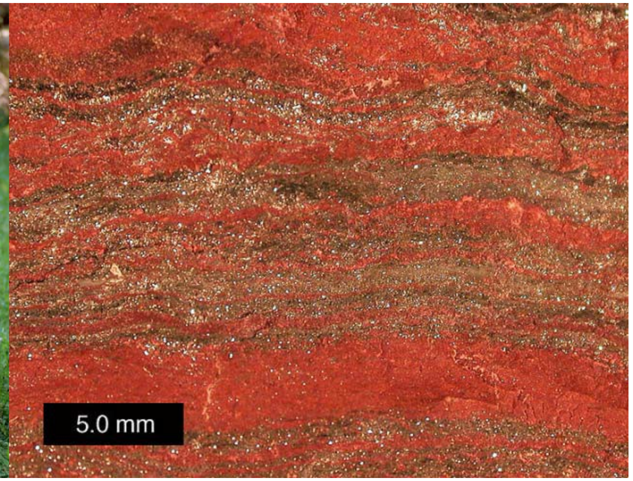
Gradual (slow) accumulation of CO_2 was eventually enough to re-establish the green house effect and bring back temperatures to normal. Or increase of volcanic activity?

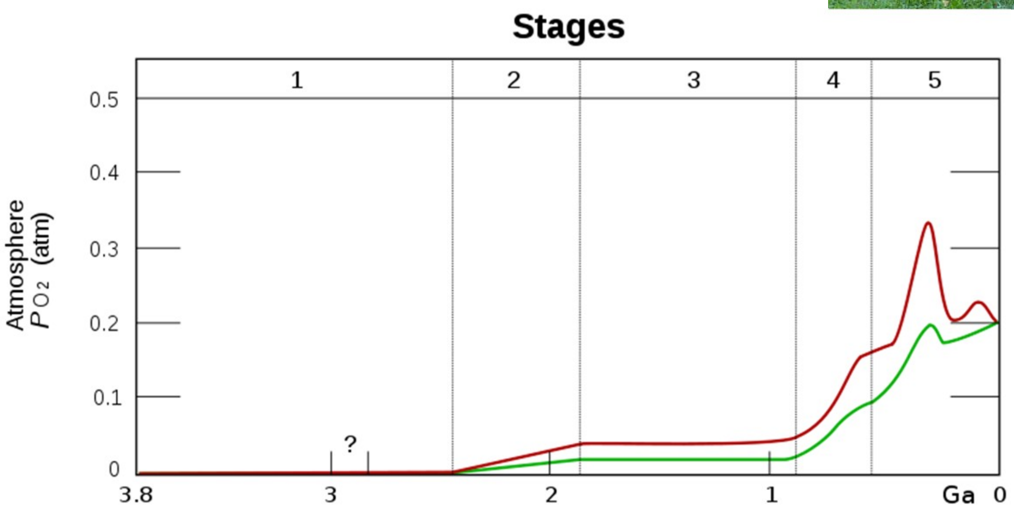
melting of oceans produced huge discharge and nutrients were brought to the sea triggering an explosion of life

Banded iron formations: the history of the Earth and its atmosphere

Sedimentary rocks with fine alternations of Fe-oxides and shales, mostly of pre-Cambrian age (especially 2.4Gy).

Are major source of Fe-ore





Stage 1 (3.85–2.45 Ga): Practically no O_2 in the atmosphere.
Stage 2 (2.45–1.85 Ga): O_2 produced, but absorbed in oceans & seabed rock.
Stage 3 (1.85–0.85 Ga): O_2 starts to gas out of the oceans, but is absorbed by land surfaces.
Stages 4 & 5 (0.85–present): O_2 sinks filled and the gas accumulates

Related to the biologically-induced appearance of O_2 which could oxidize the large amounts of Fe erupted by volcanoes

Another period of BIFs was during the snow-ball Earth

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