Climate 1:
The Climate System

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CLIMATE AND "WEATHER"

Common sense often leads us to confuse the two things; the necessity to define separately climatology and meteorology is not completely clear and a simple widely accepted distinction between the two disciplines is essentially based on the different temporal scale.
Actually, the different objectives imply a clearer cut separation of method and general theoretical formulations.

The definition of **weather** is very simple: *it is the state of the system (particularly of the atmosphere) at a precise moment.*

Instead, the definition of **climate** is more complex: in fact, climate is *represented by the mean state and variations over time of the same system*; but since climatic phenomena have variations that occur on different time scales, from 1 day to 1 million years or more, it is not possible to consider them all contemporarily, but it is necessary to focus on a time scale of interest and each time consider the phenomena that have typical variations on longer time scales as constant, and those that have variations on shorter time scales as rapid casual fluctuations of the system.

CLIMATE AND TIME-SPACE PARAMETERS

- What meteorological parameter should be chosen to represent climate?

- On what time scale (years, decades, centuries) should the arithmetic mean operation be performed, that elementary statistics suggests as being the most natural for quantitative determination of this type of parameters?

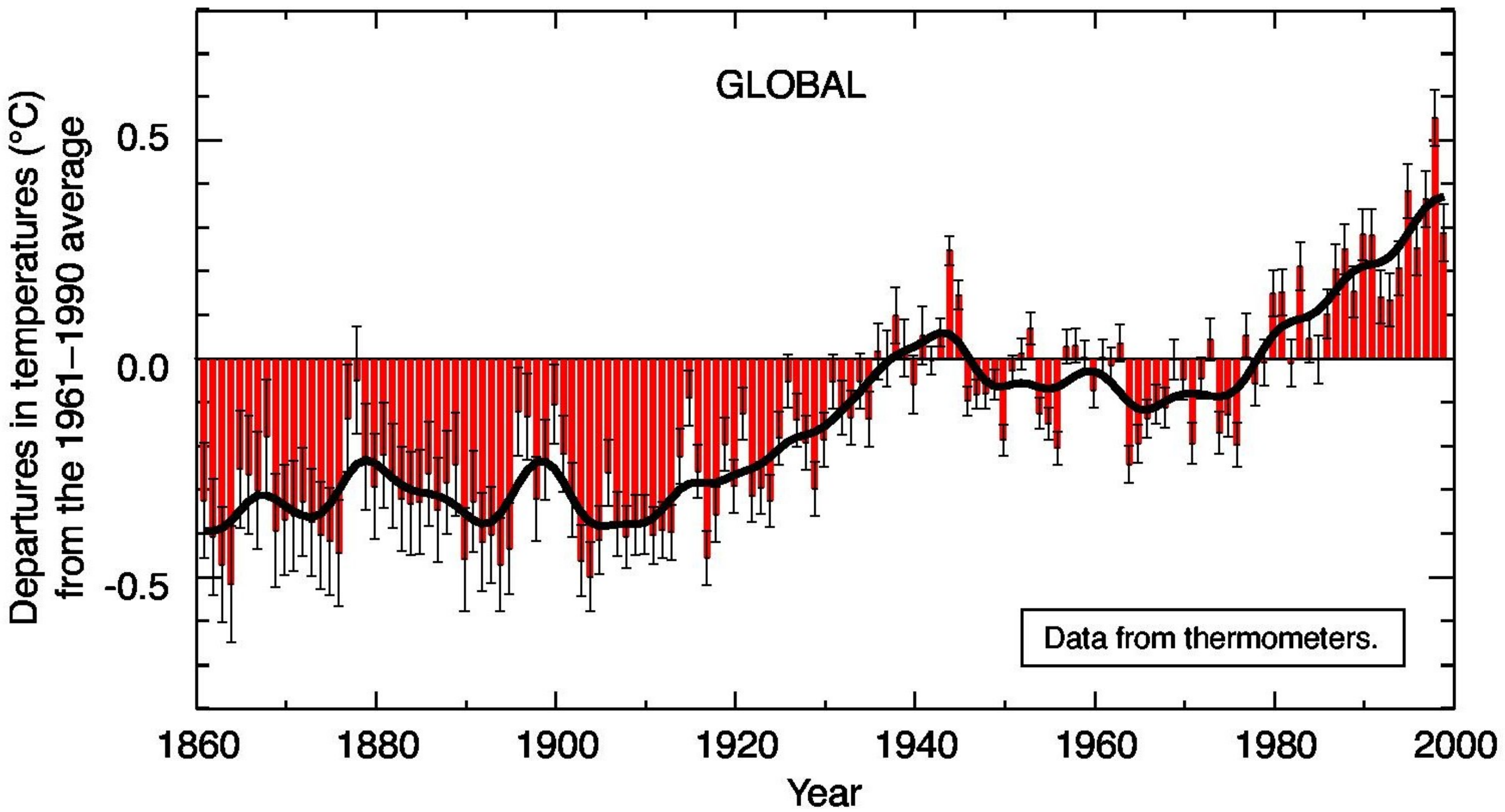
- Are there significant space scales to connect to different climate characterizations?

- No observation is “better” a priori than the others to represent climate; one answer may be a targeted choice based on the subject being studied.

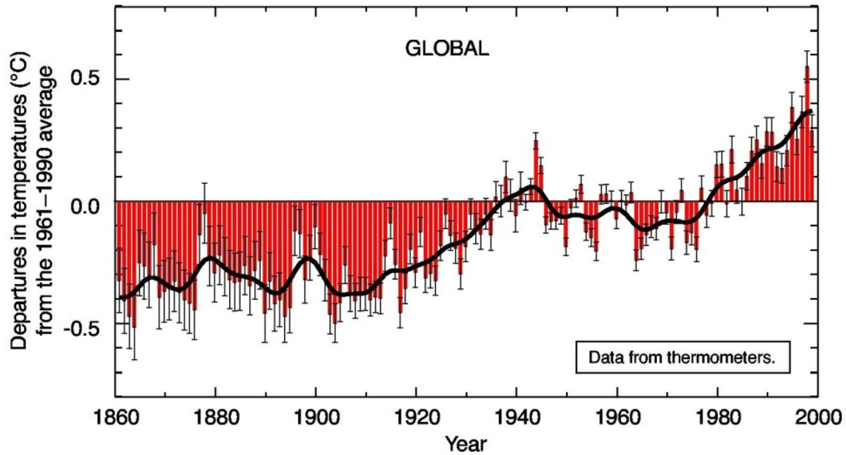
- In that case the answer is obtained by trial and error, and by improving algorithms and conceptualizations with experience.

- For this situation a rather simple physico-mathematical scheme may exist on which to build a theory of the phenomenon in a traditional way. Therefore, the precision and completeness of the experimental data to work on is even more important.

100 years


GLOBAL
Departures in temperatures (°C)
from the 1961–1990 average
0.5
0.0
-0.5
1860
1880
1900
1920
1940
1960
1980
2000
Year
Data from thermometers.

DATA ON THE EVOLUTION OF PAST CLIMATE



INSTRUMENTAL DATA

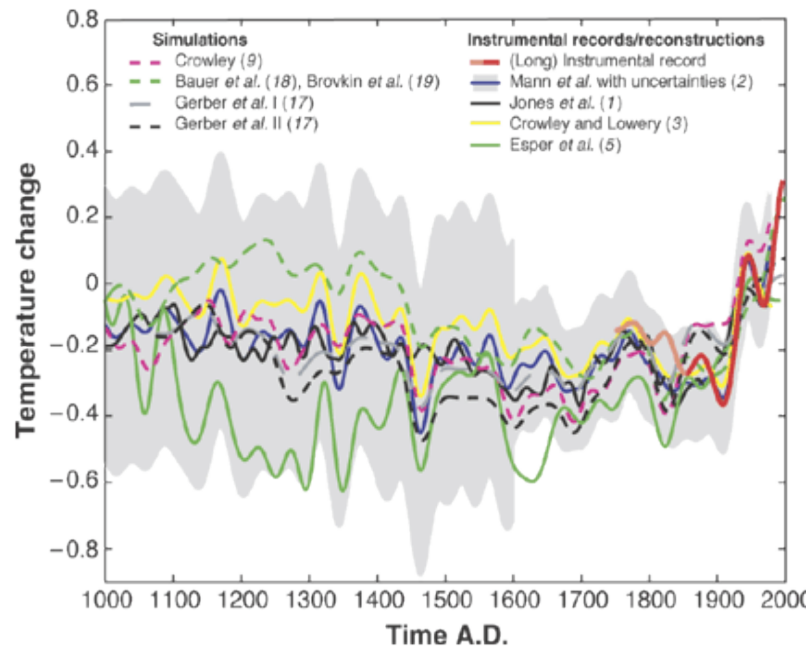
More precise reconstruction of the short-term variations (after homogenization!)
Limited over time (the series have been available since the tools began to be used)

Suitable to study **short** and **mid-term climate change**

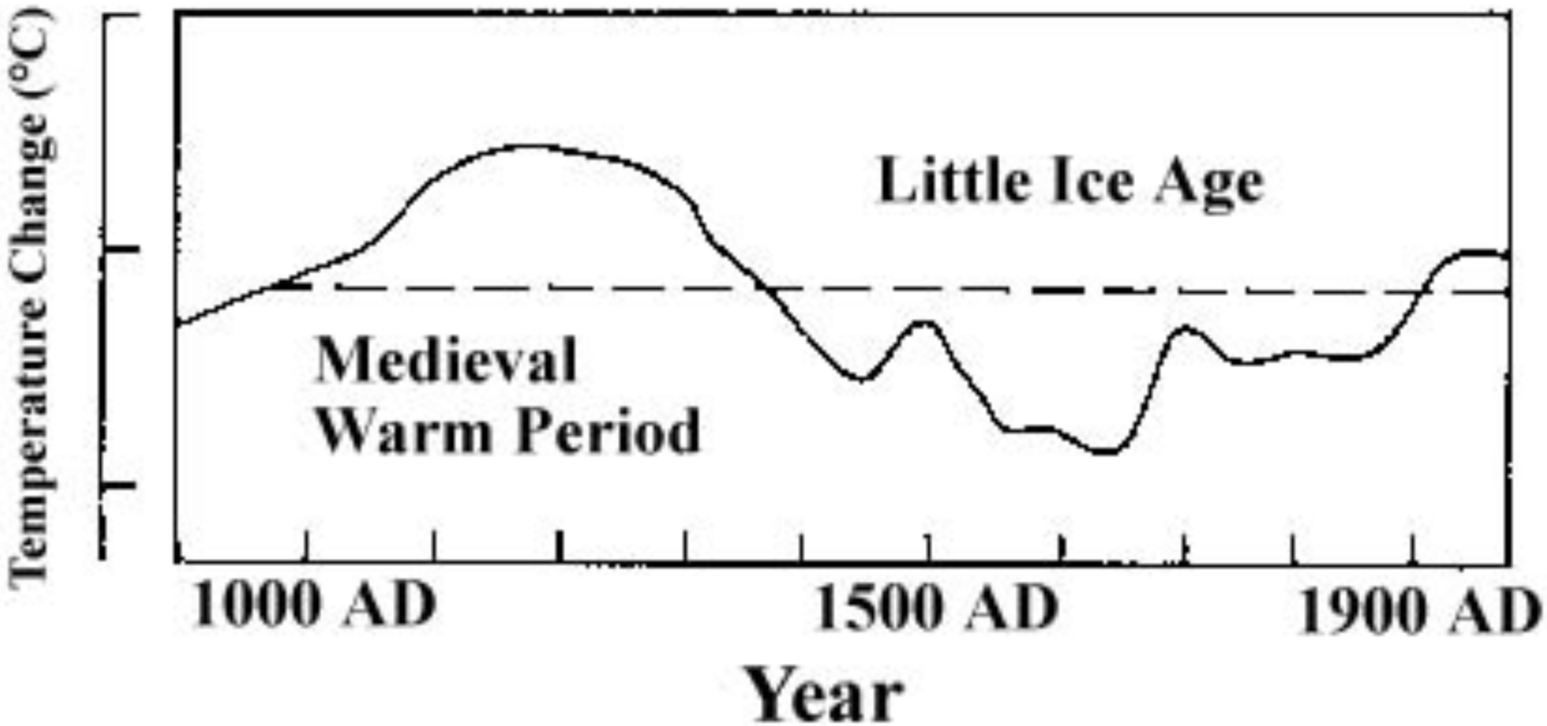
Suitable to study long-term climate change (up to geologic scales)

They provide information on the climate in **past ages**
They are **less accurate** than instrumental data

PROXY DATA

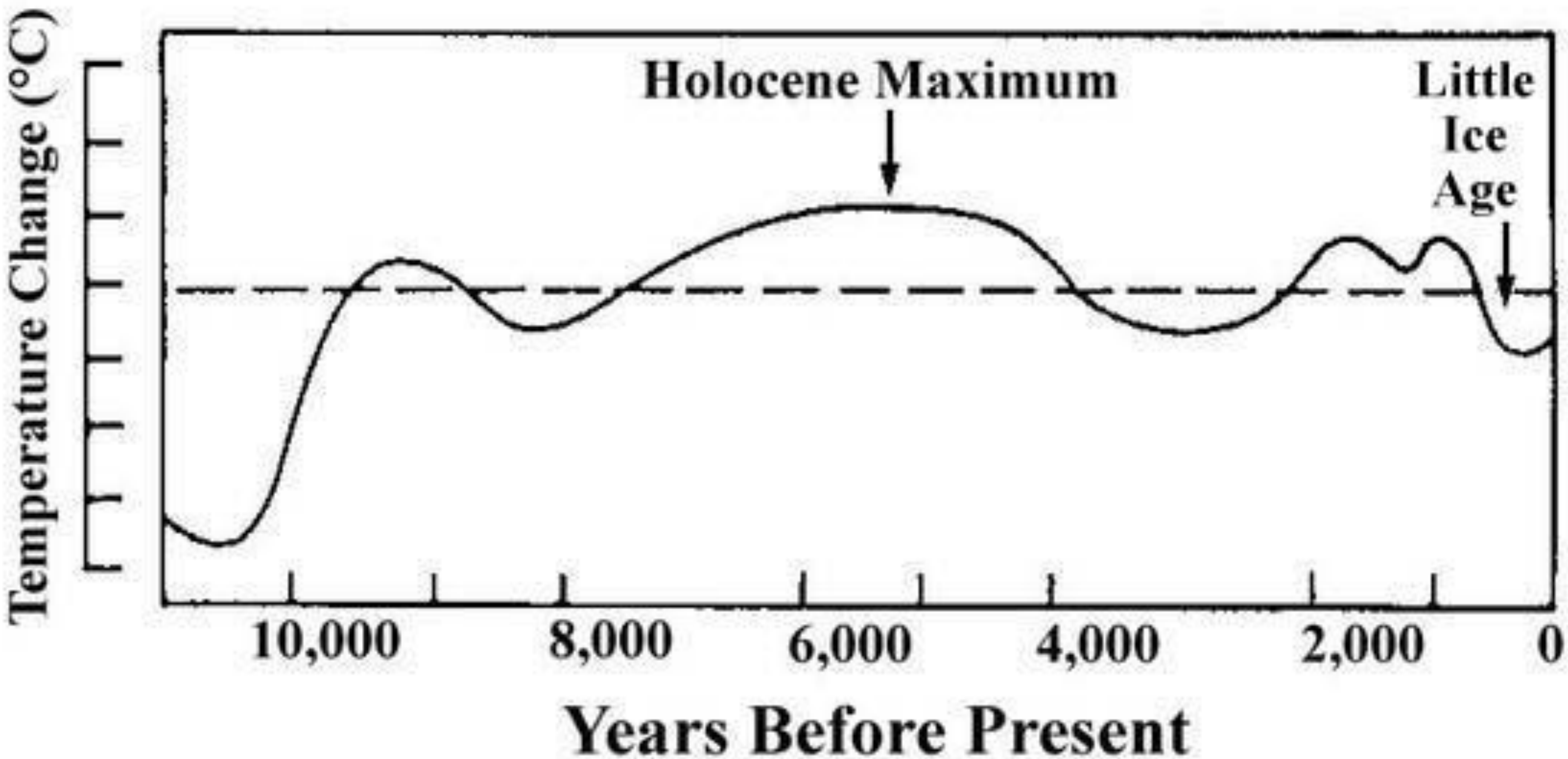


1,000 years

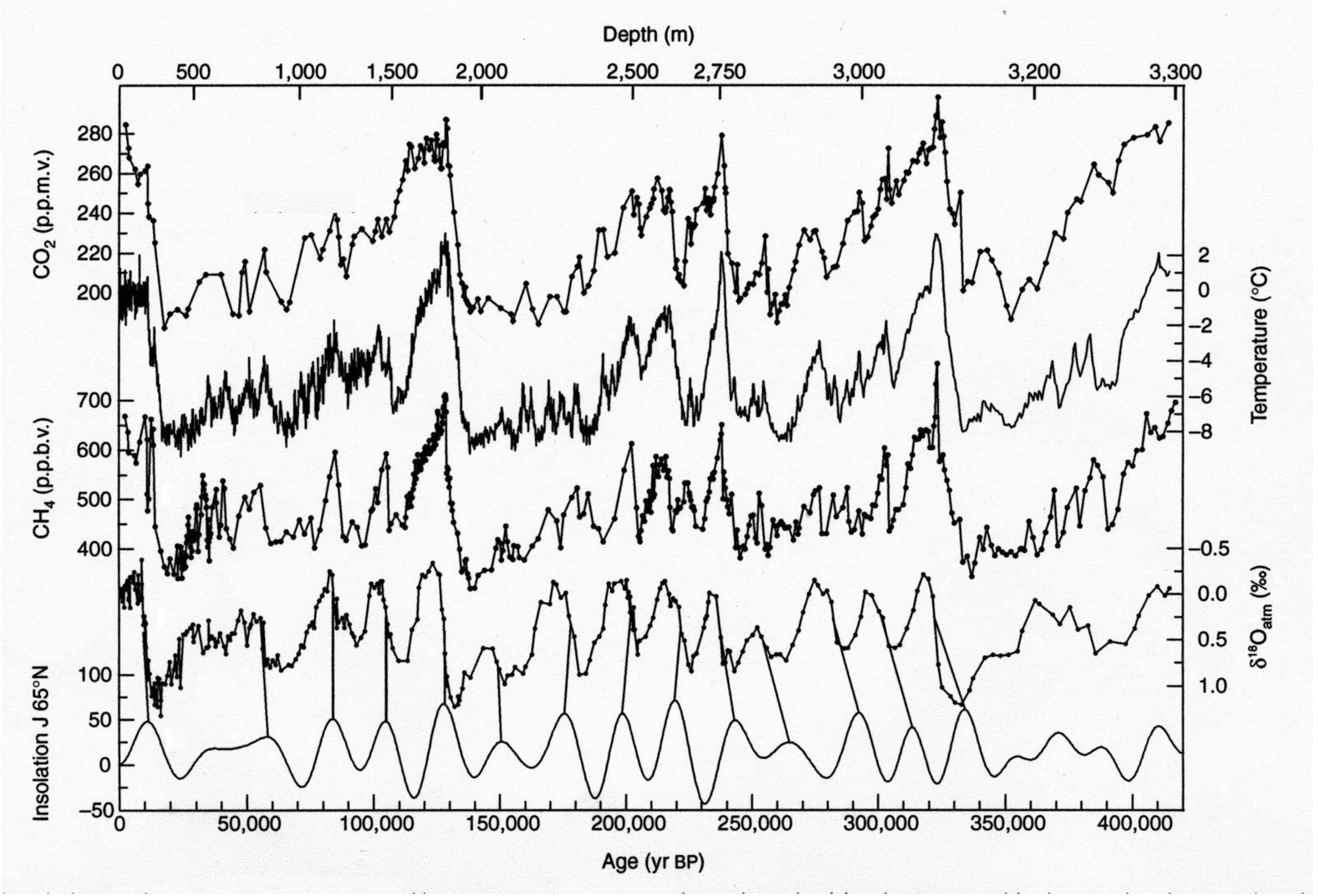


Temperature Change (°C)
Little Ice Age
Medieval
Warm Period
1000 AD
1500 AD
1900 AD
Year

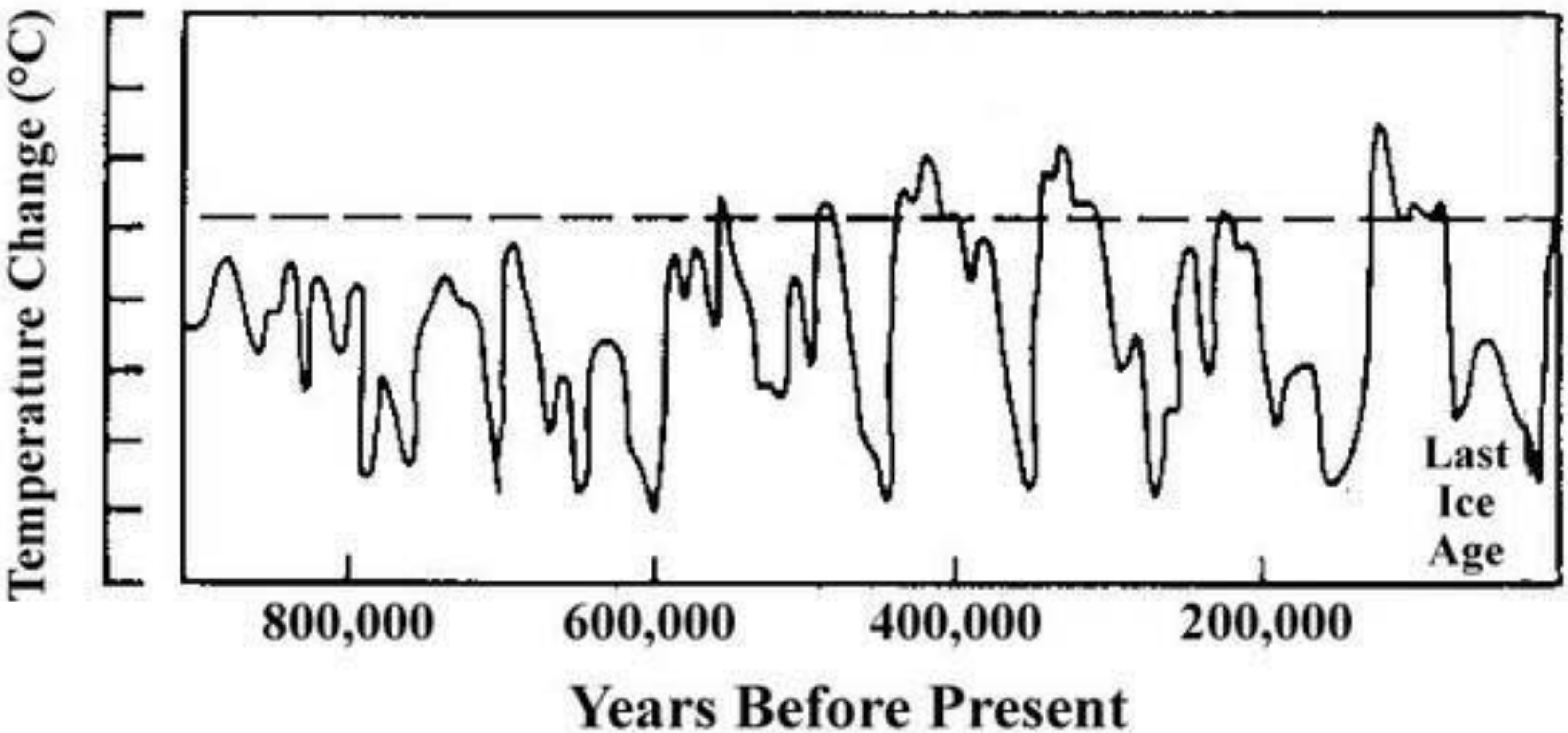
10,000 years


Holocene Maximum
Little Ice Age
Temperature Change (°C)
10,000
8,000
6,000
4,000
2,000
0
Years Before Present

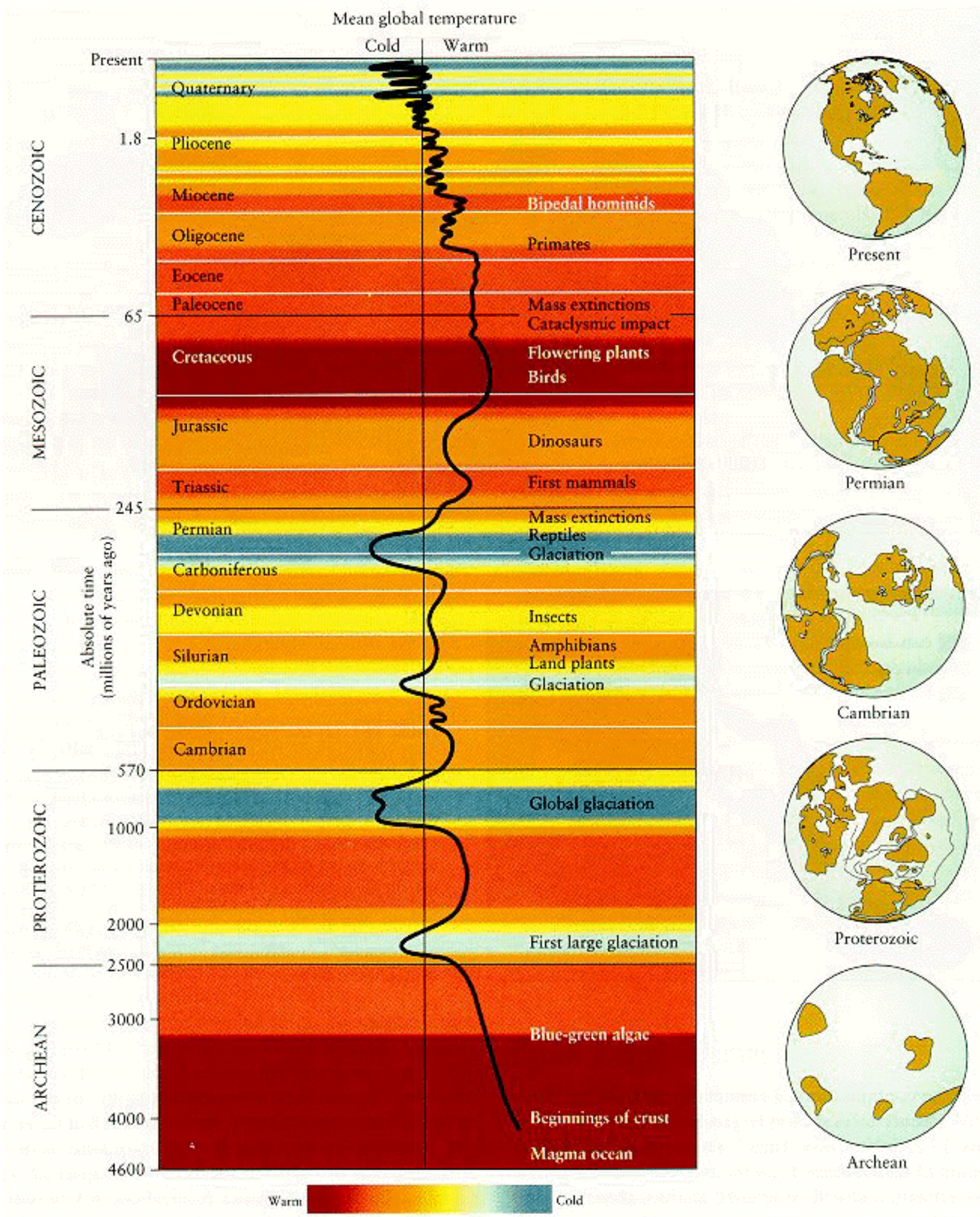
420,000 years



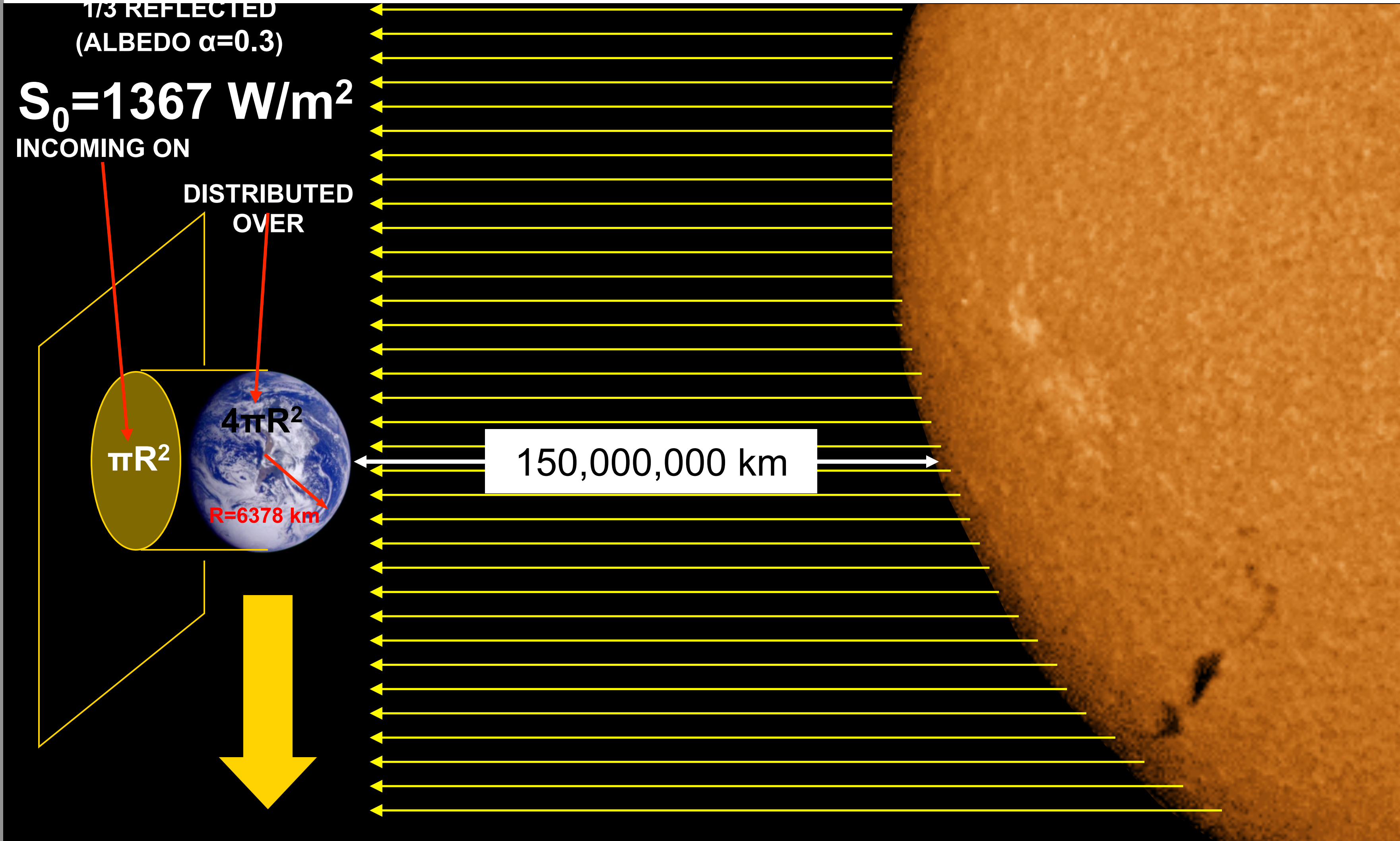
1 million years



4.5 billion years



SOLAR RADIATION



THE MEAN RADIATION ABSORBED BY OUR ATMOSPHERE IS

$$(1-\alpha)S_0/4 = 240\ W/m^2$$

RADIATION BALANCE

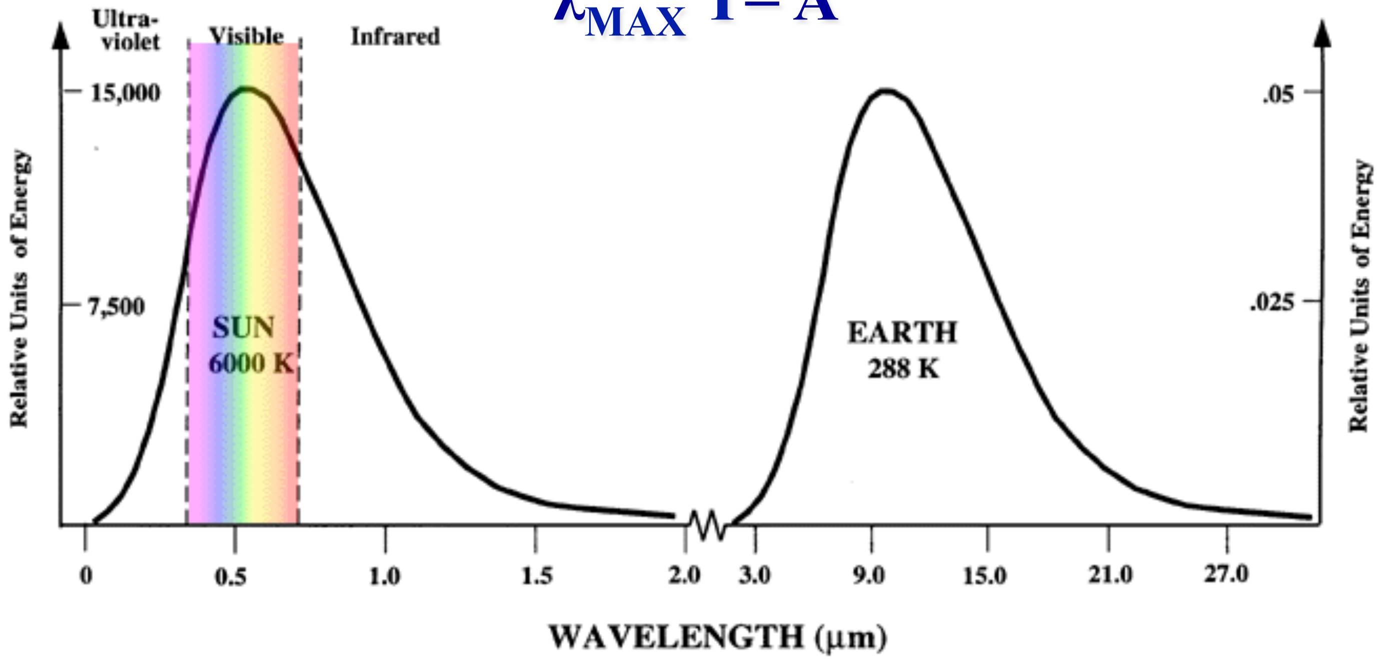
EVEN THE EARTH, AS EVERY BODY HAVING A TEMPERATURE ABOVE ABSOLUTE ZERO (-273°C), **EMITS RADIATION**!!

THE RADIATION WAVELENGTH EMITTED DEPENDS ON TEMPERATURE:

$$\text{Total Energy} = \sigma T^4$$

THE RADIATION EMITTED DEPENDS ON TEMPERATURE:

$$\lambda_{MAX} T = A$$



THUS THE SUN AND THE EARTH EMIT IN TWO DISTINCT BANDS OF THE SPECTRUM

RADIATION BALANCE

ENERGY ABSORBED = ENERGY EMITTED

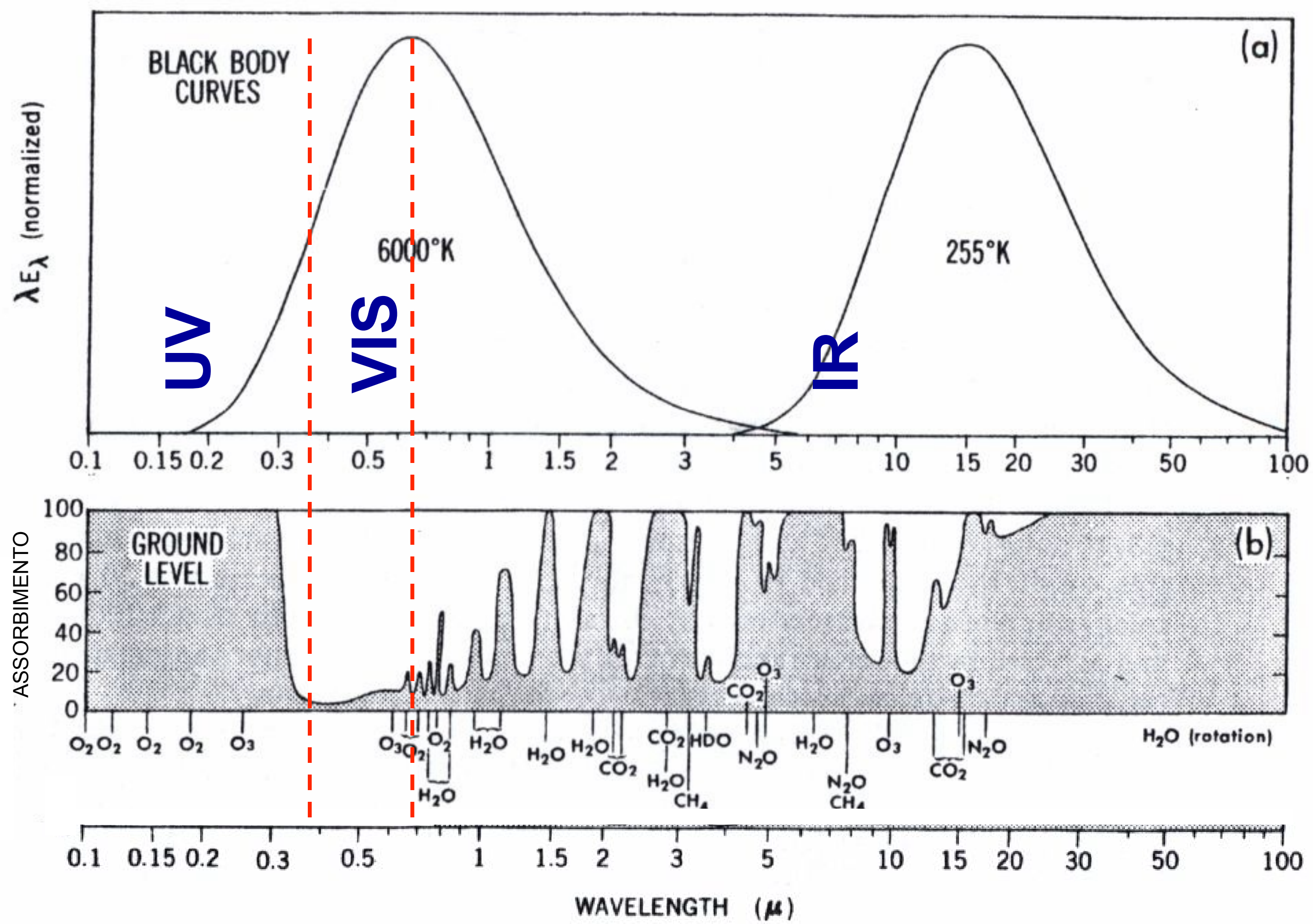
That is

$$\frac{S_0}{4}(1-\alpha) = \sigma T^4$$

$$T = \sqrt[4]{\frac{S(1-\alpha)}{4\sigma}}$$

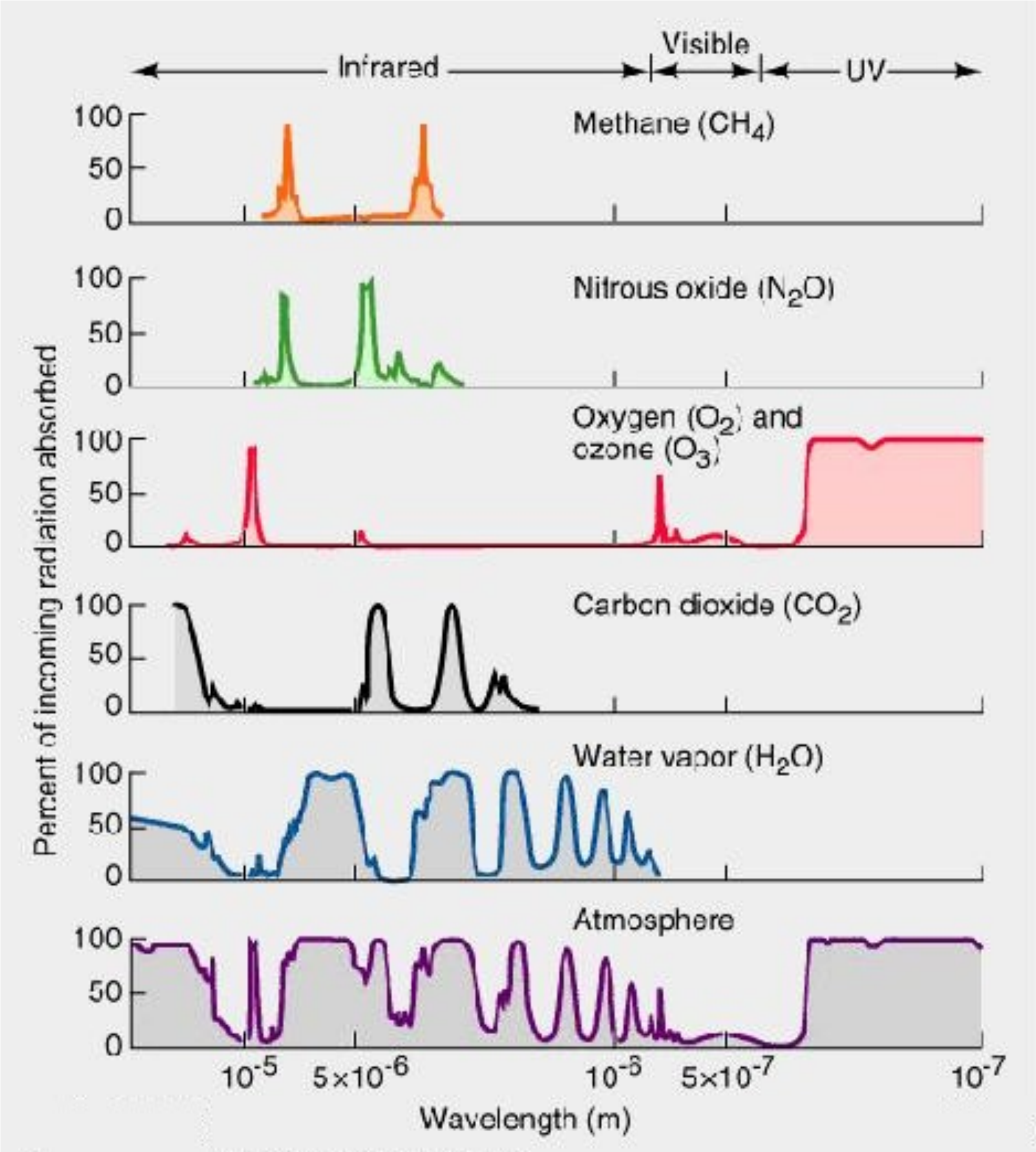
T = 255 K = -18 °C

THE ATMOSPHERE



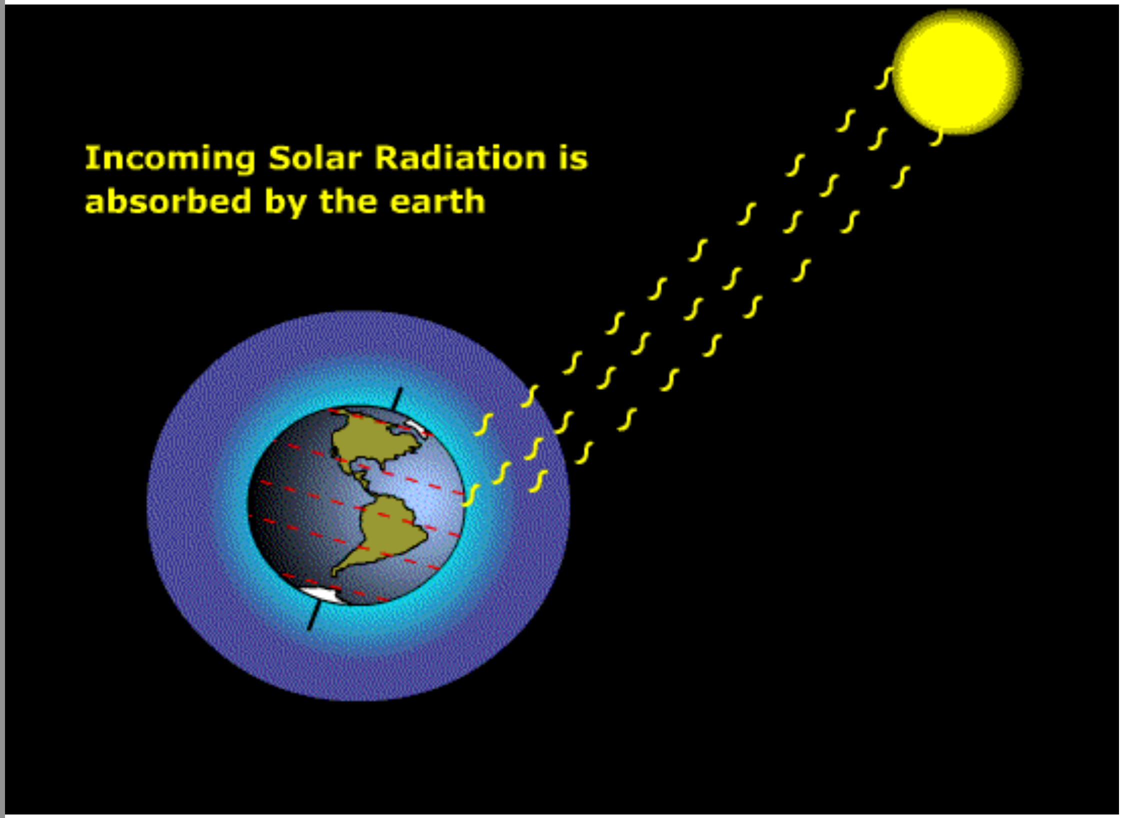
The atmosphere is transparent enough to visible radiation, but it has a great ability to absorb infrared radiation.

EARTH'S ATMOSPHERE TRANSMITTANCE



The consequence is that **only a small part of the radiation emitted by the earth's surface and the lower layers of the atmosphere can leave our Planet, while most is absorbed by the surrounding atmosphere.** Naturally, it also emits infrared radiation, a large part of which is reabsorbed by the ground and the underlying atmosphere**.**

This phenomenon of infrared radiation entrapment is called:

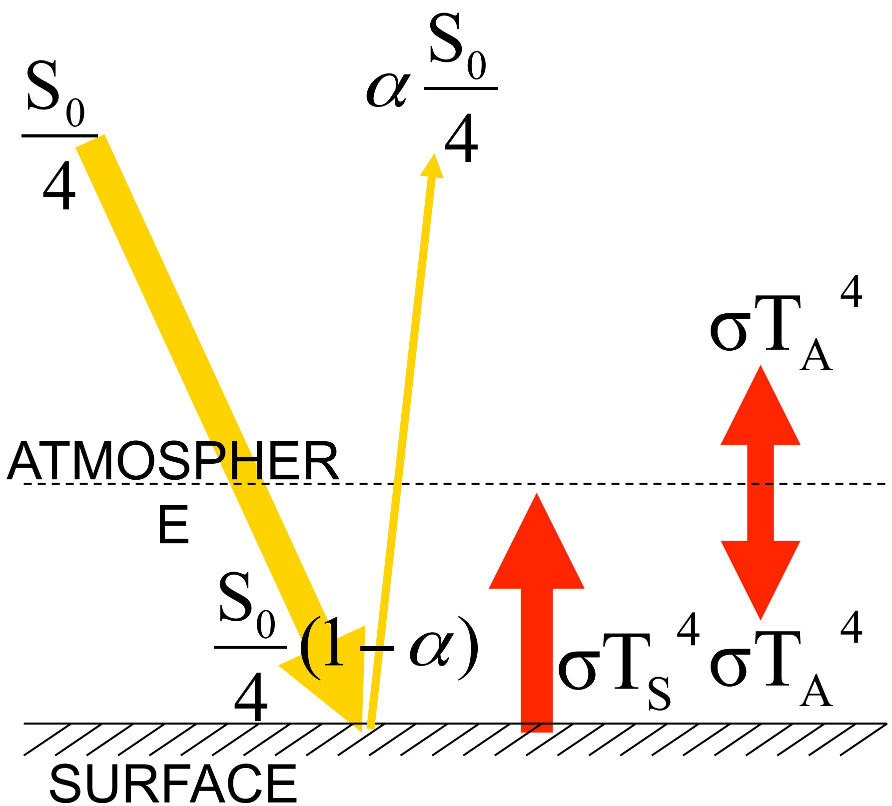


GREENHOUSE EFFECT

GREENHOUSE EFFECT MODEL

Working hypothesis:

- The ground emits as a black body;
- The atmosphere is transparent to solar radiation and opaque to terrestrial radiation



THE SURFACE BALANCE IS:

RECEIVES $\frac{S_0}{4}$ **OF WHICH ABSORBS** $\frac{S_0}{4}(1-\alpha)$

RECEIVES σT_A^4

GIVES σT_S^4

BALANCE: $\frac{S_0}{4}(1-\alpha) + \sigma T_A^4 = \sigma T_S^4$

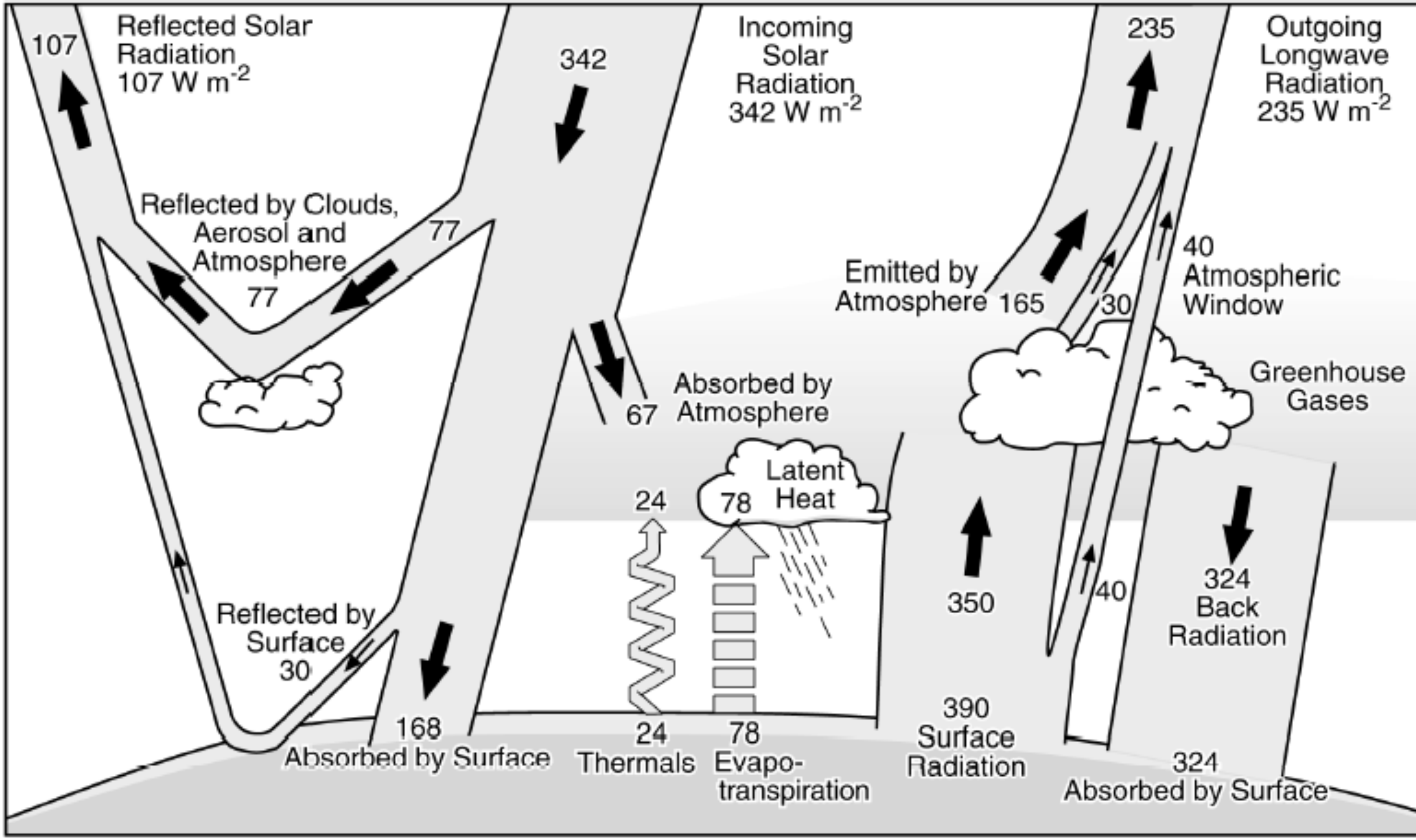
THUS

$$T_S = \sqrt[4]{\frac{S_0}{4\sigma}(1-\alpha) + T_A^4}$$

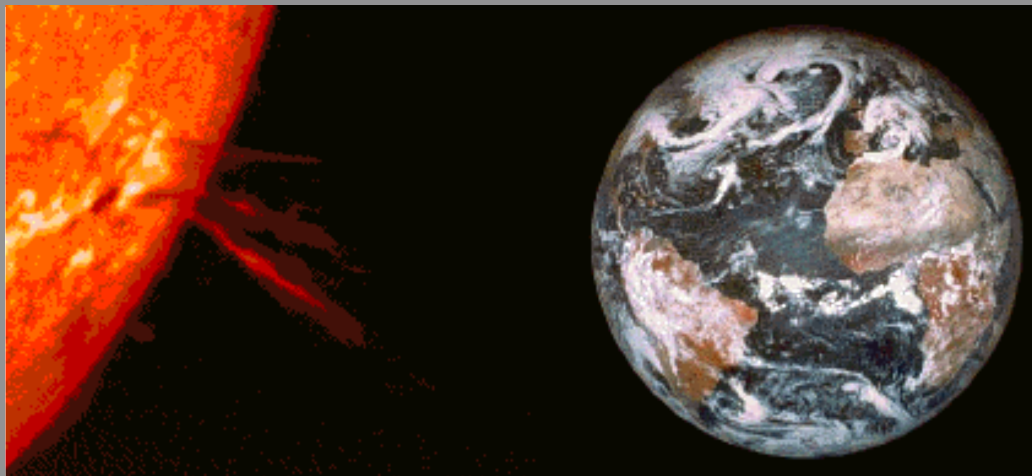
GREATER THAN THAT OBTAINED WITHOUT CONSIDERING THE CONTRIBUTION OF THE ATMOSPHERE

$$T_S = \sqrt[4]{\frac{S_0}{4\sigma}(1-\alpha)}$$

ENERGY BALANCE

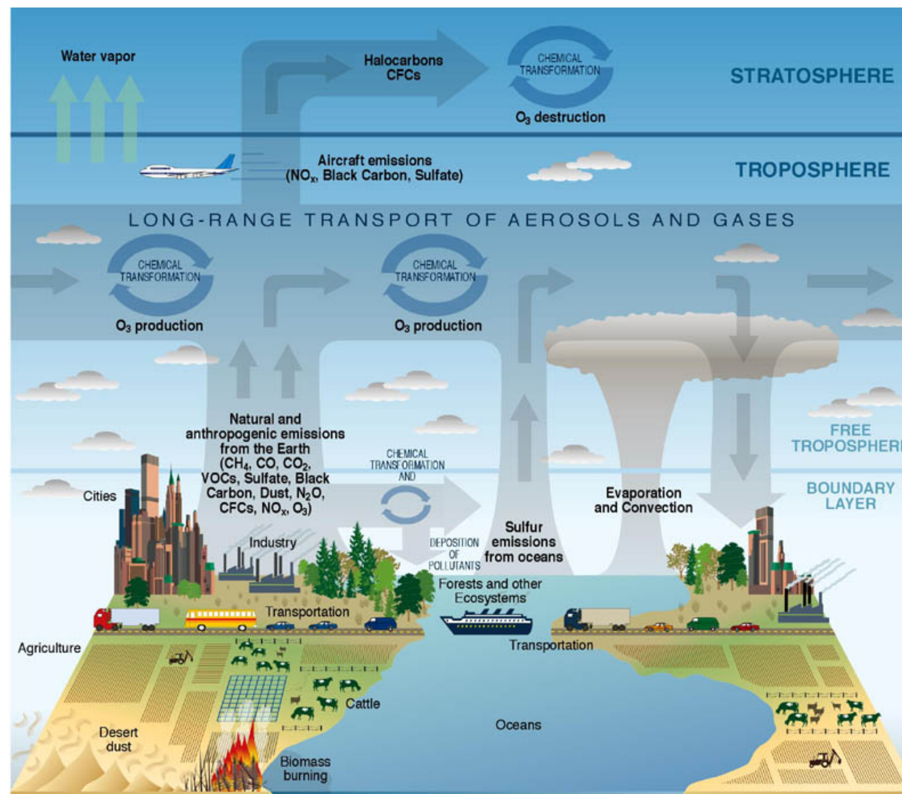


WHY DOES THE CLIMATE CHANGE?



Because the amount of radiation that reaches the top of the atmosphere changes

Because the composition of the atmosphere changes



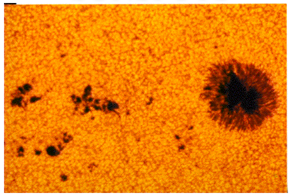
RADIATION CHANGES AT THE TOP OF THE ATMOSPHERE

CAUSES

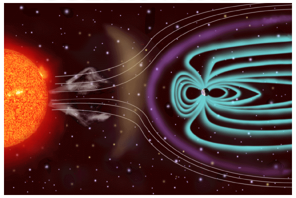
ASTROPHYSICAL PROCESSES

SOLAR ACTIVITY

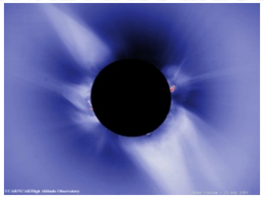
SUNSPOTS



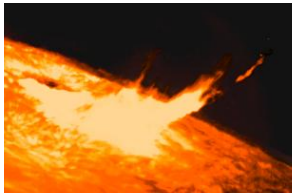
SOLAR WIND



CORONAL MASS EJECTIONS



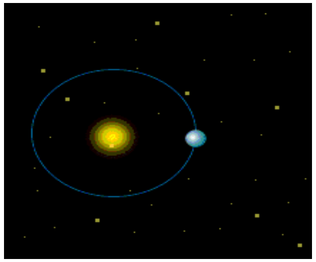
FLARES



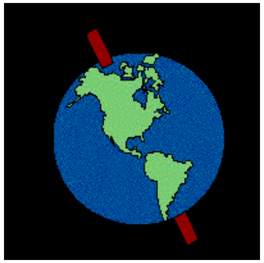
ASTRONOMICAL PROCESSES

MILANKOVITCH THEORY

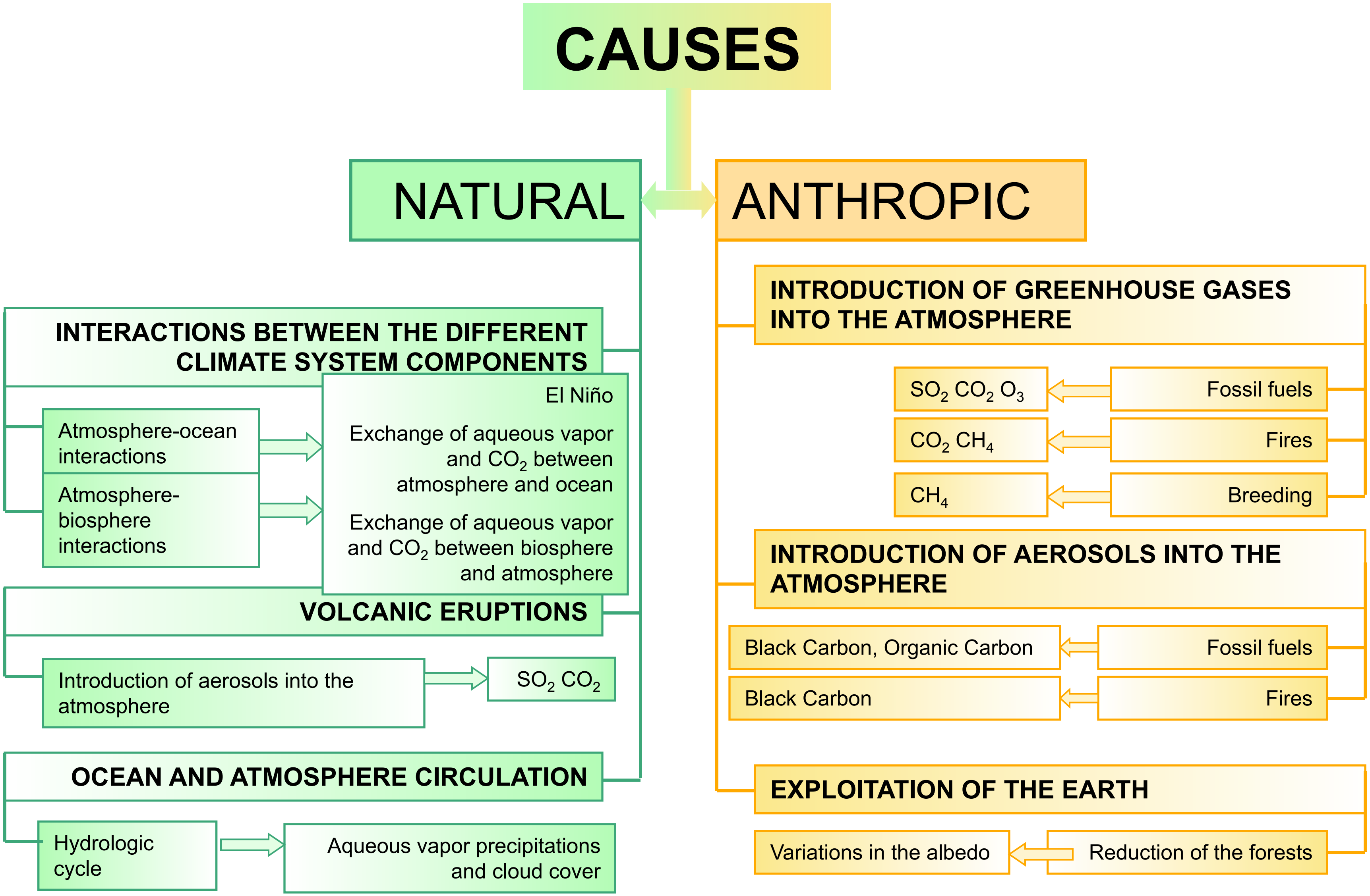
VARIATIONS IN THE EARTH'S ORBIT



VARIATIONS IN THE EARTH'S AXIS



VARIATIONS IN ATMOSPHERIC COMPOSITION



THE CLIMATE SYSTEM

From a climatic point of view the Earth can be divided into 5 components

ATMOSPHERE
(gaseous component of the climate system, is the most rapidly changing one over time)

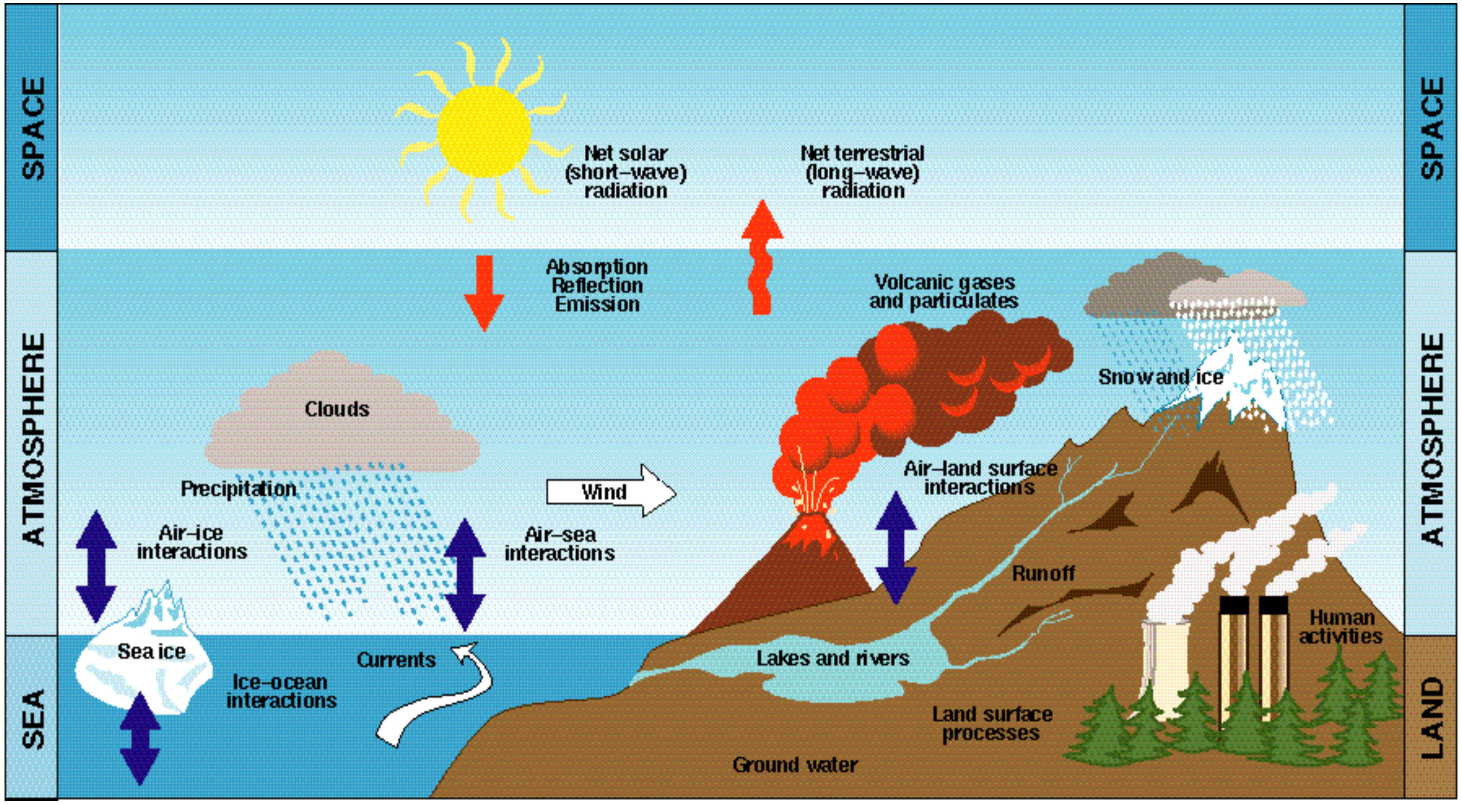
CRYOSPHERE
(includes glaciers, snowfields, and ocean ices)

LITHOSPHERE
(orographic structure of the Earth, it changes very slowly over time)

HYDROSPHERE
(oceans, seas, rivers and lakes)

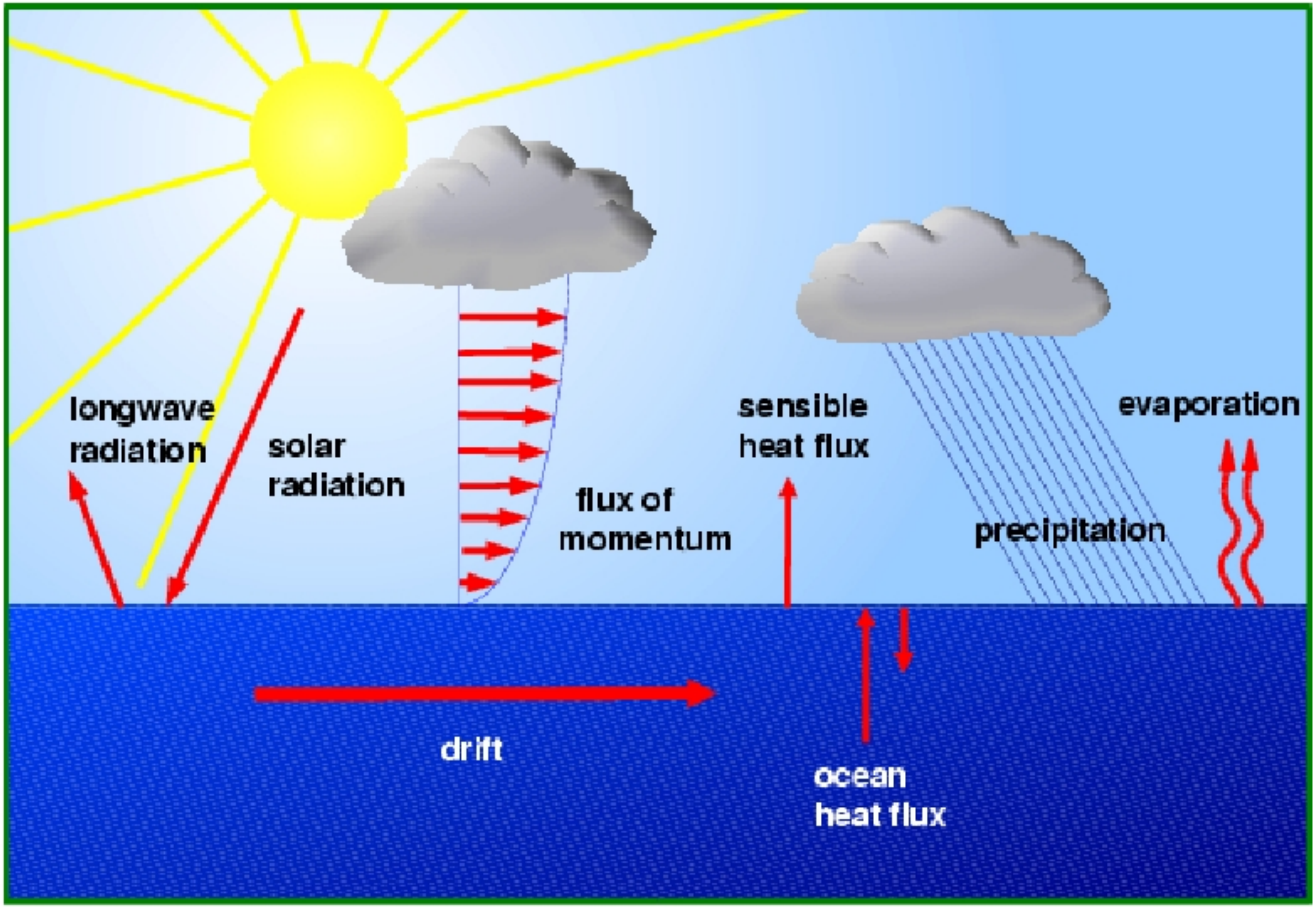
BIOSPHERE
(flora, fauna, human activity)

The external energy sourse provided by the sun should also be considered

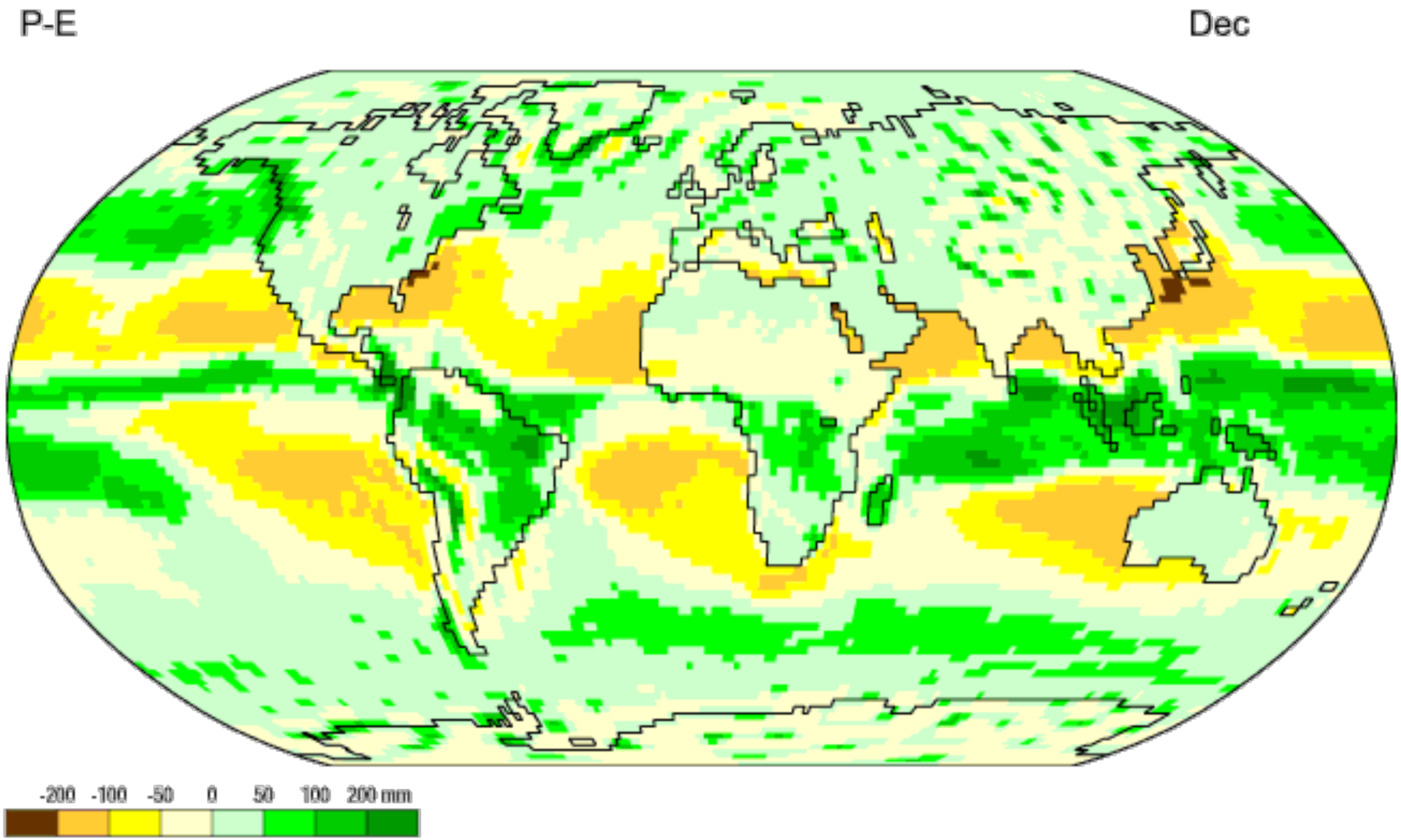


OCEAN-ATMOSPHERE INTERACTIONS

The ocean and the atmosphere interact through the heat fluxes and aqueous vapor that determine the dynamics of the two fluids

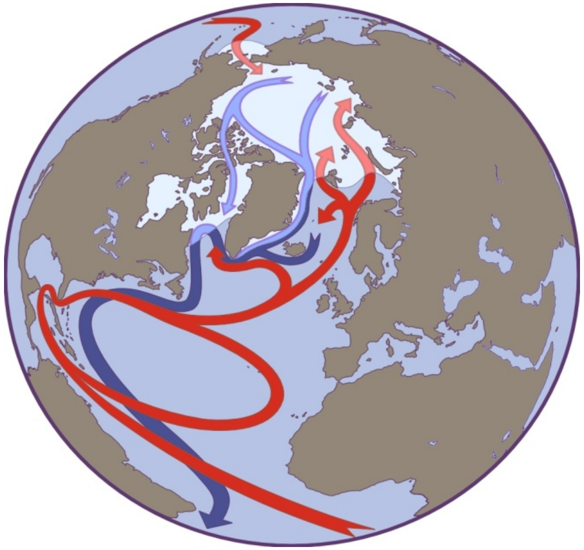


PRECIPITATION-EVAPORATION



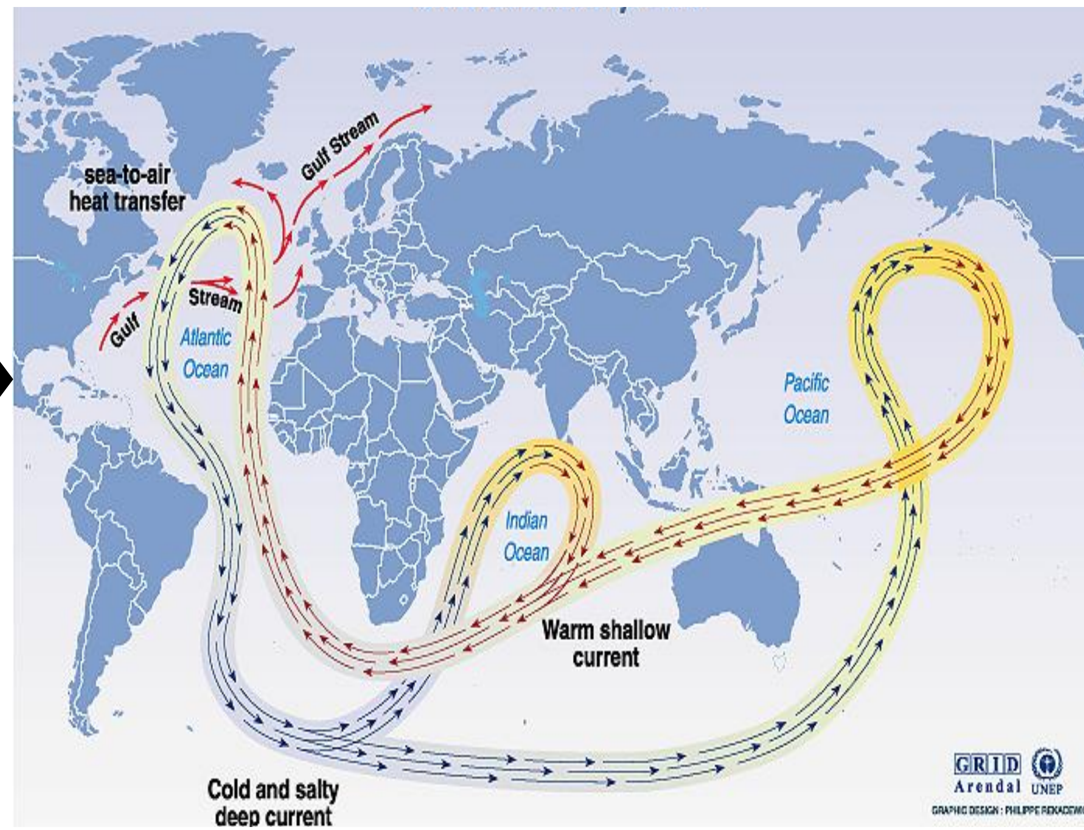
Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

OCEAN CIRCULATION



The general oceanic circulation is schematically described by the so-called one "conveyor belt." The Gulf Stream reaches the marginal seas, it releases heat into the atmosphere and sinks to the bottom of the ocean.

The deep current connects the masses of water of the oceans. The mixing time of the oceans has a 1,000-year time scale.



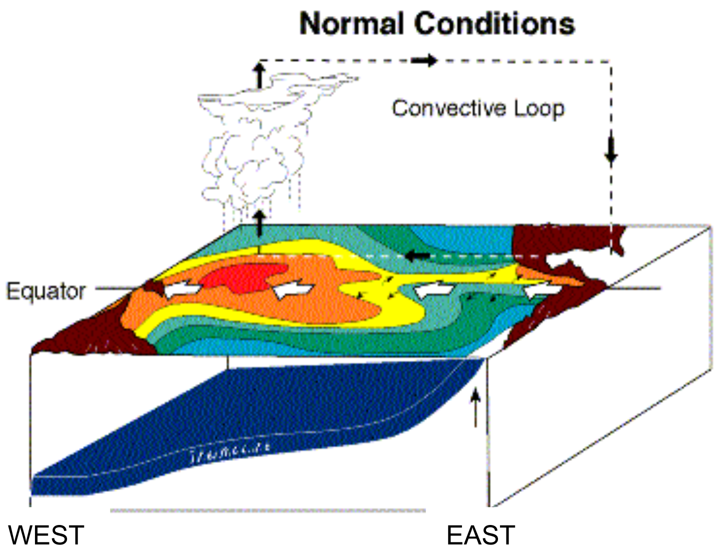
EL NIÑO

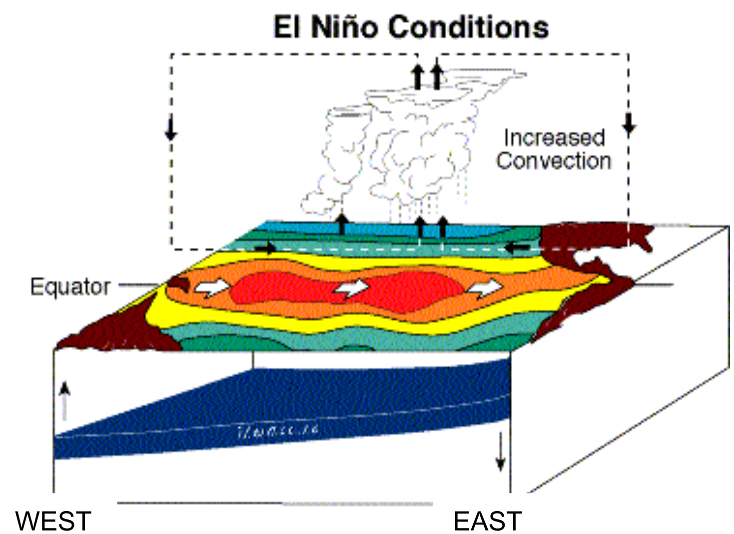
In normal, non-El Niño conditions

- Trade winds blow westwards.
- Sea surface is about 1/2 meters higher at Indonesia than at Ecuador.
- SST is about 8 degrees C lower in the east supporting marine ecosystems fisheries.
- West Pacific regions are wet, while the east Pacific is relatively dry.

During El Niño

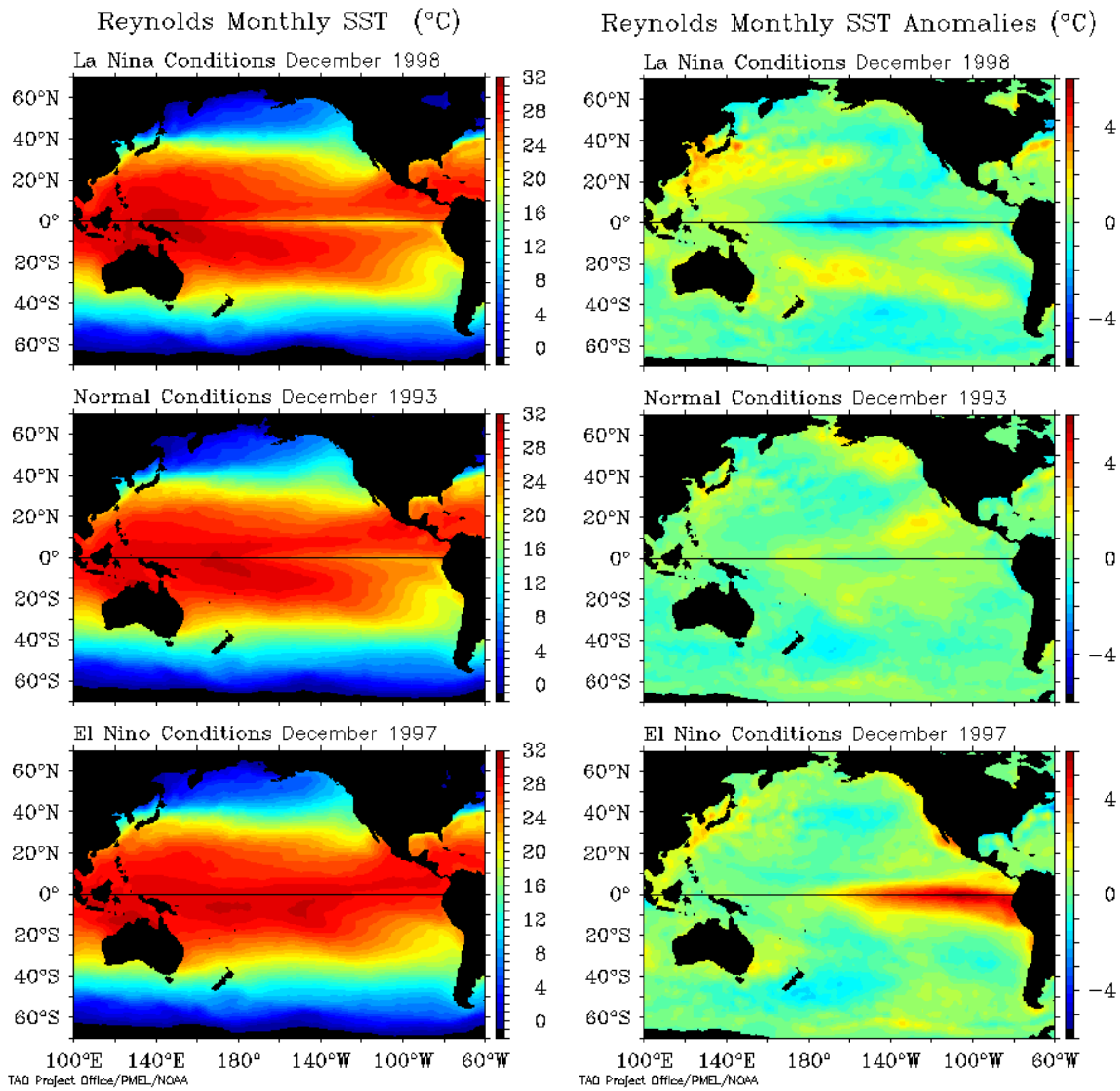
- Trade winds relax in the western Pacific
- Depression of the thermocline in the eastern Pacific and elevation of the thermocline in the west.
- Rise in SST and a drastic decline in primary productivity.
- Rainfall follows the warm water eastward, flooding in Peru and drought in Indonesia and Australia.
- Large changes in the global atmospheric circulation.





NOAA/PMEL/TAO

EL NIÑO



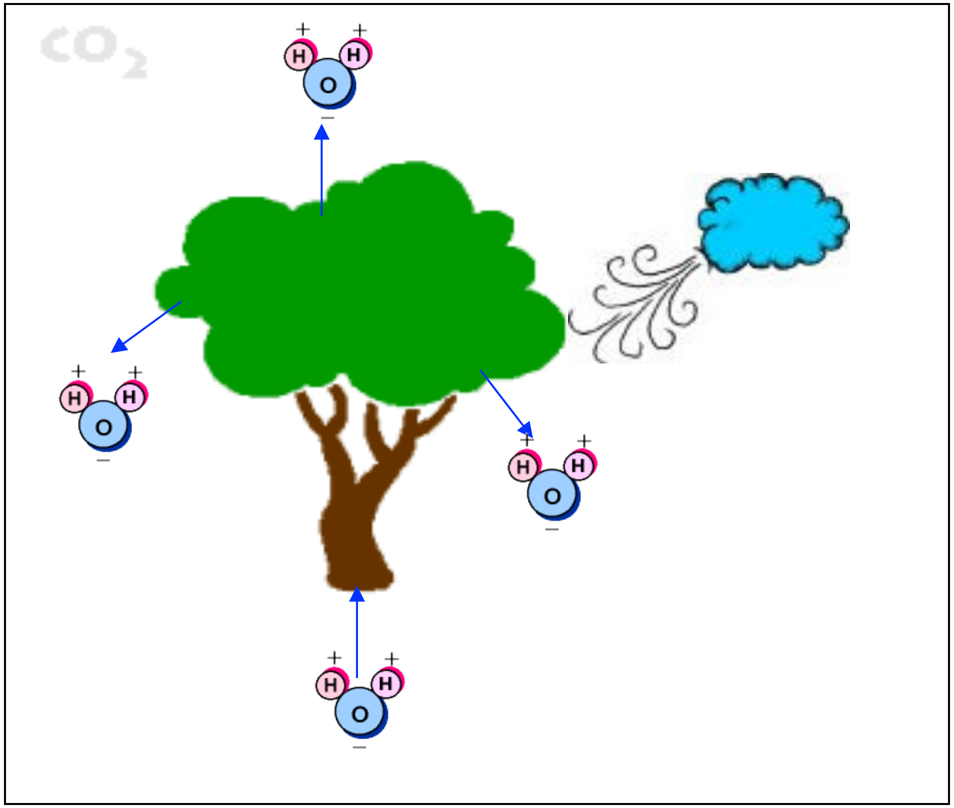
La Niña (cold) Conditions
December 1998

Normal Conditions
December 1993

El Niño (warm) Conditions
December 1997

ATMOSPHERE-BIOSPHERE INTERACTION

Vegetation influences the climate in different ways



PHOTOSYNTHESIS

Trees **absorb carbon dioxide** (CO_2), holding back the carbon (C) from the CO_2 molecule and **release oxygen** (O_2) into the atmosphere. The biosphere contributes to the removal of CO_2 from the atmosphere.

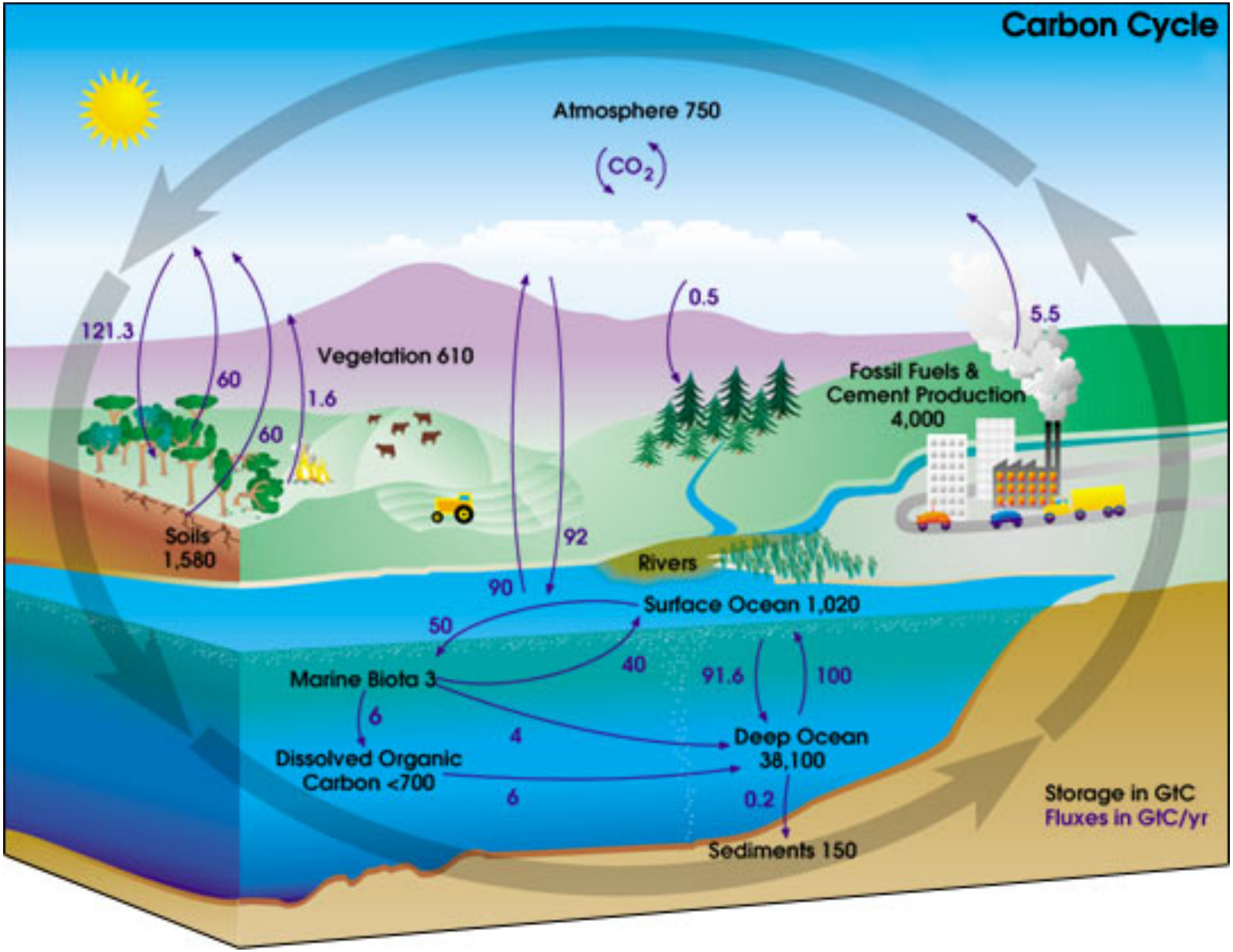
EVAPORATION

There is more evaporation in forested, because the tree roots absorb water from the ground and transfer it to the atmosphere in the form of vapor.

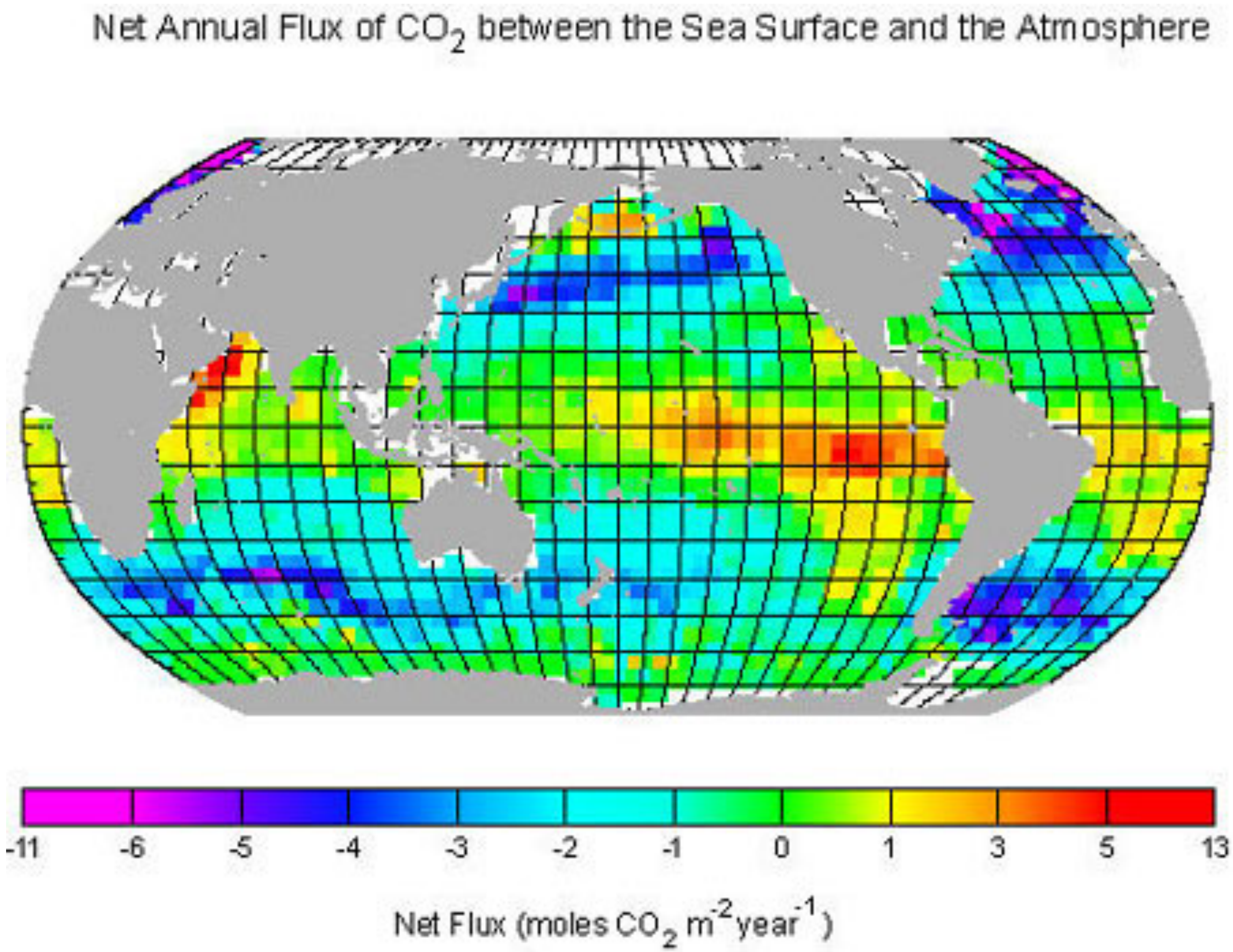
RADIATIVE BALANCE

The reflecting power of the vegetation (albedo) is lower than that of the ground.

THE CARBON CYCLE



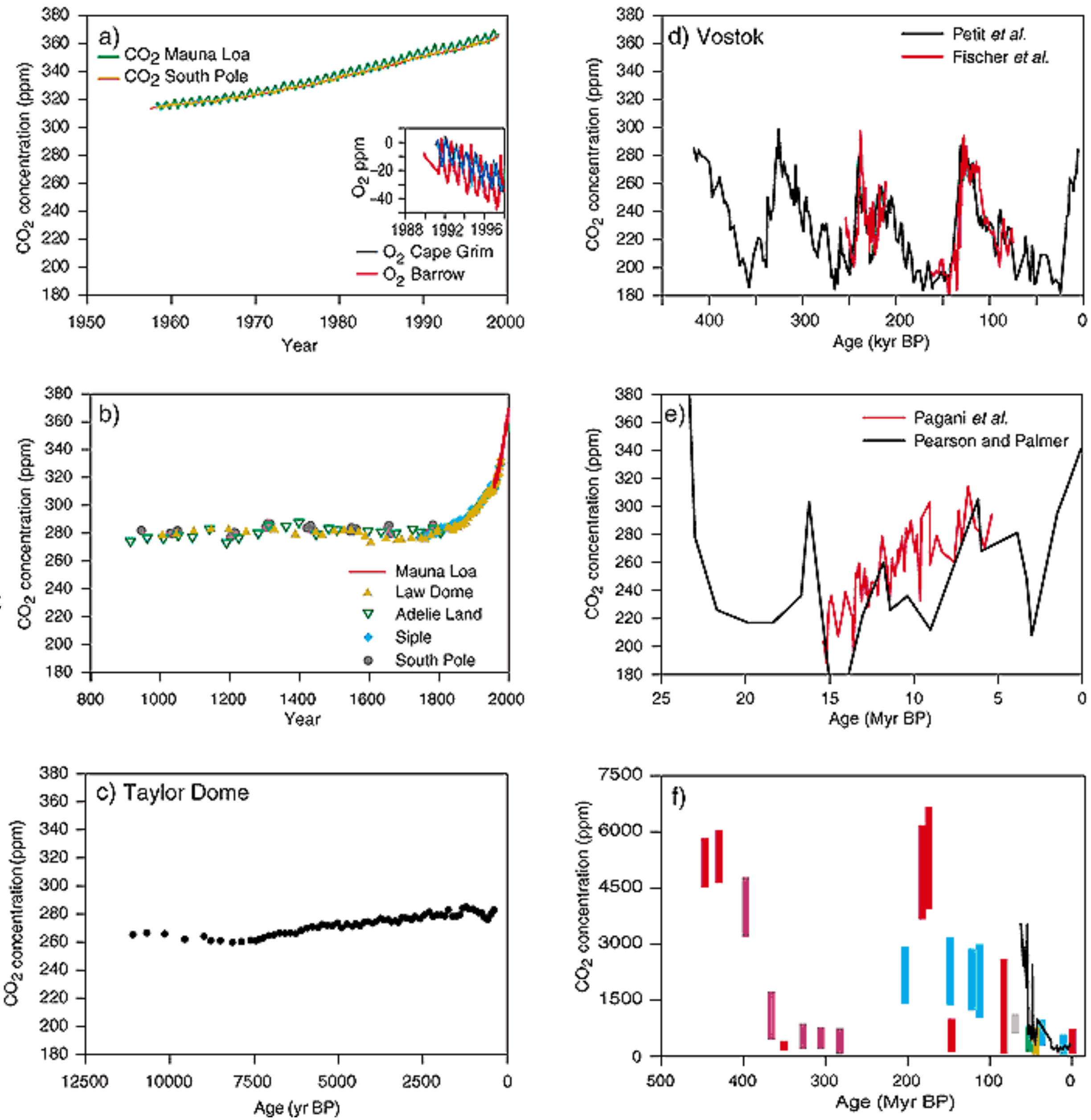
ATMOSPHERE-OCEAN CO_2 EXCHANGE



CONCENTRAZIONI DI CO_2

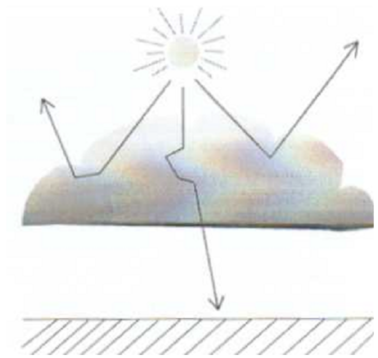
Variation of the concentration of atmospheric CO2 on various time scales.

(a) Direct Measures.
(b) Antarctic Ices.
(c) Taylor Dome Coring of the Antarctic ice.
(d) Vostok Coring of the Antarctic ice
(e,f) Concentrations deduced with geochemical methods.

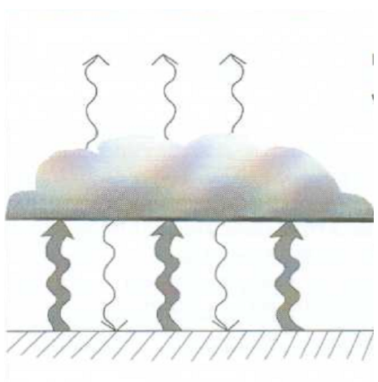


RADIATIVE EFFECTS OF CLOUDS

- Clouds cause an increase in the albedo (cloud albedo forcing).
- Clouds cause a greenhouse effect (cloud greenhouse forcing).



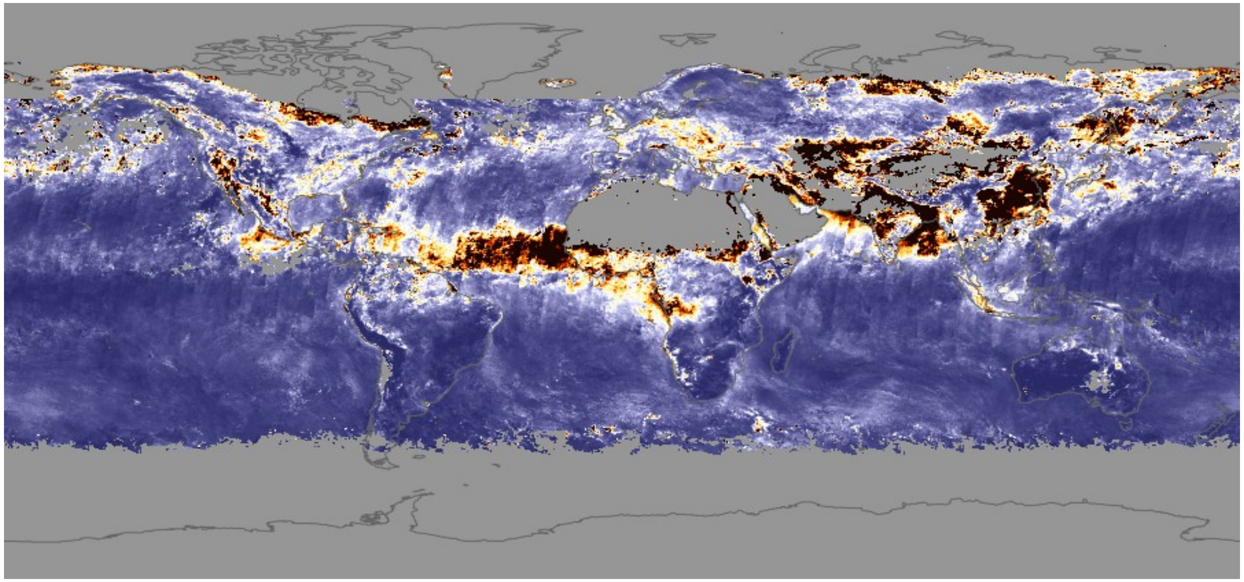
- It is estimated that clouds increase, on average, the outgoing flux of solar radiation by around -48 Wm^{-2} on a global scale.



- It is estimated that clouds decrease, on average, the outgoing flux of infrared radiation by around -31 Wm^{-2} on a global scale.

Thus, the effect of clouds on the net radiative flux is -17 Wm^{-2}, i. e. a global mean effect of atmosphere cooling

AEROSOLS

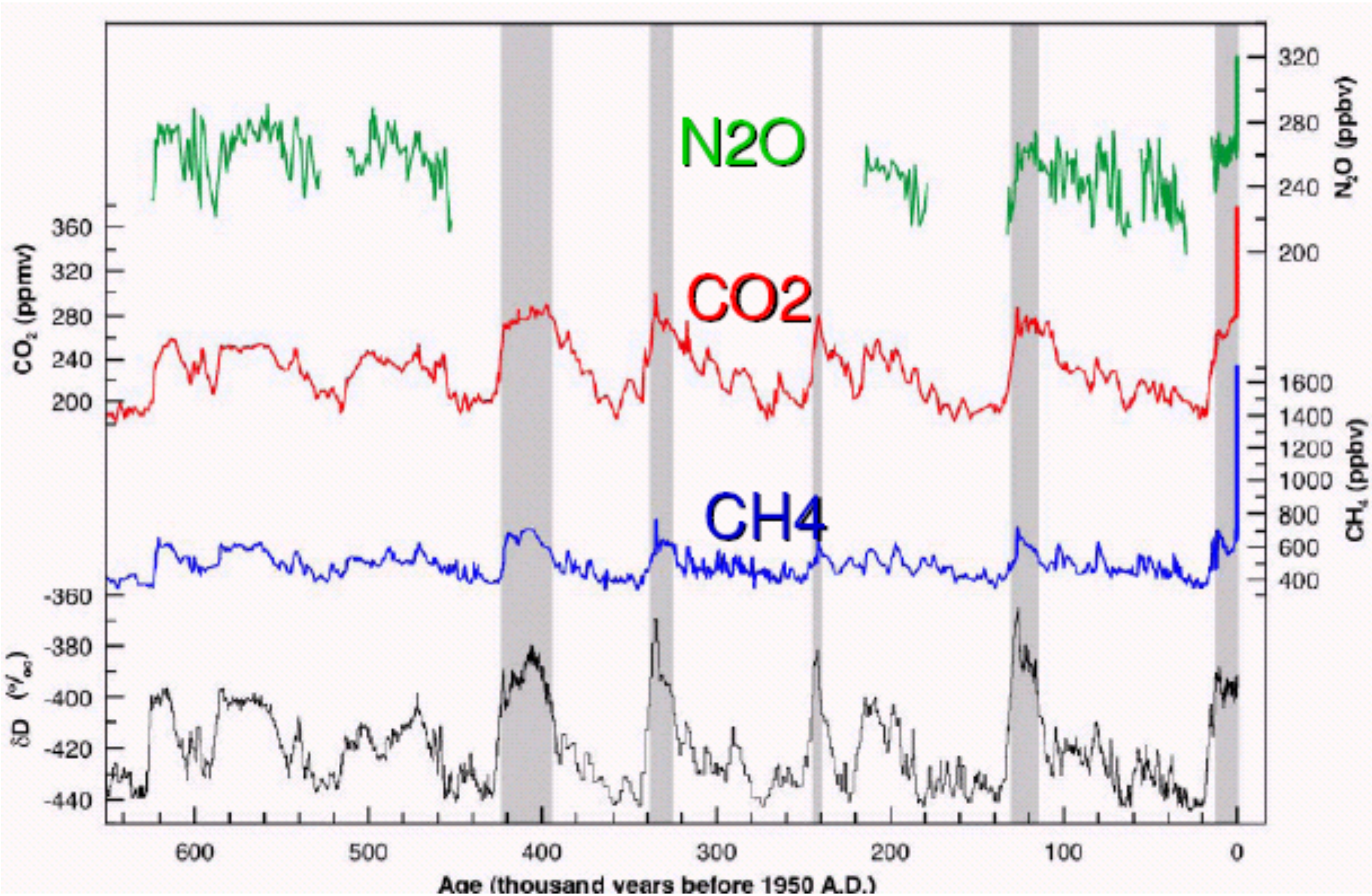


1. Aerosols are liquid or solid bodies suspended in air.
2. They influence the climate in the following way:

   a) Direct effects - scattering and absorption of solar and terrestrial radiation.
   b) Indirect effects - change in the microphysics, radiative properties, and lifespan of the clouds.

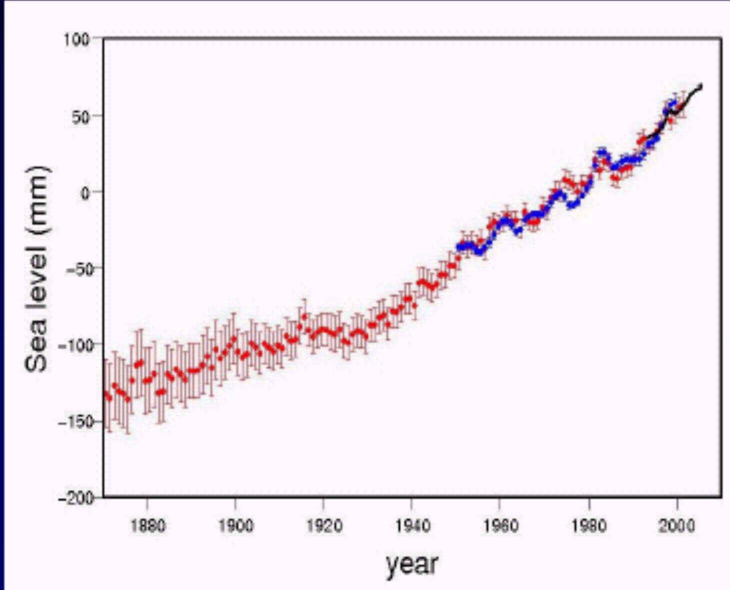
3. They vary widely in space and over time.
4. Information on their distribution is limited.

BASED ON THE 4TH IPCC REPORT



...SEAS

RISING SEA LEVELS



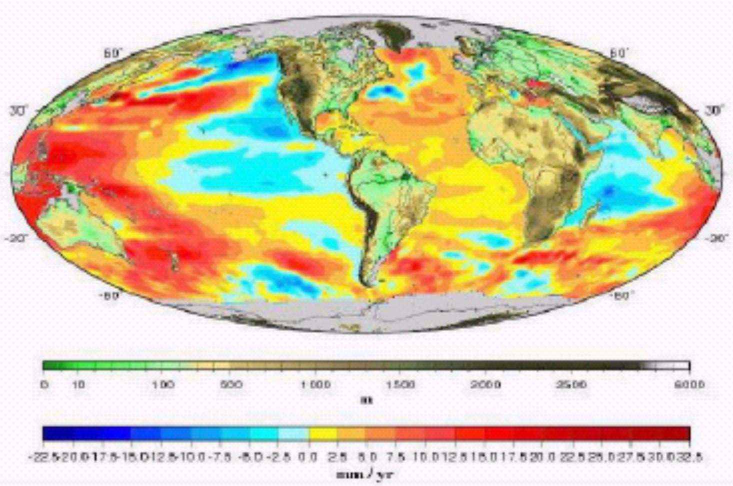


Figure 7. Sea level trends over 1993-2003 from the T/P mission.

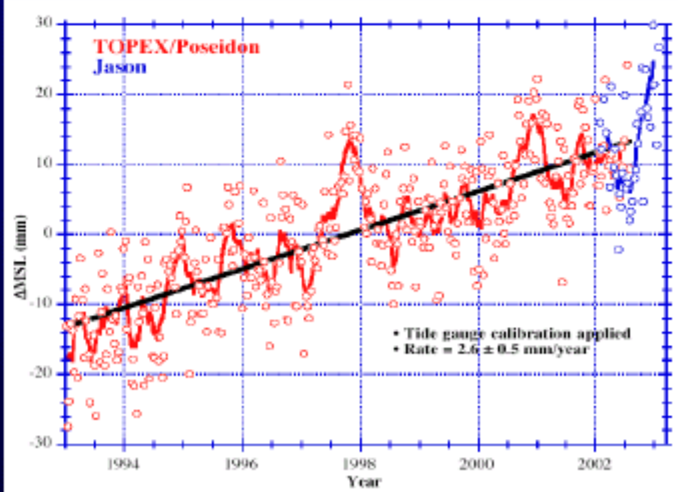
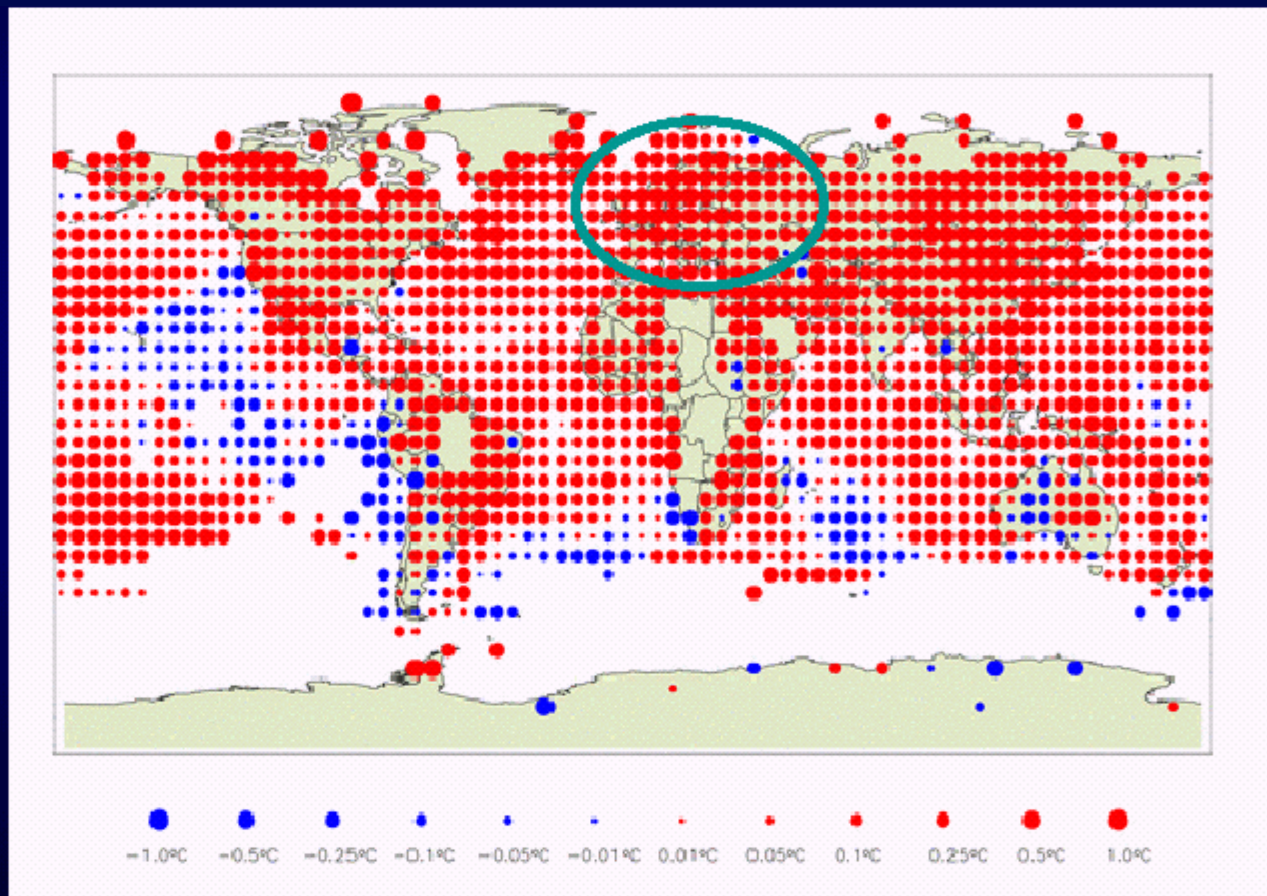
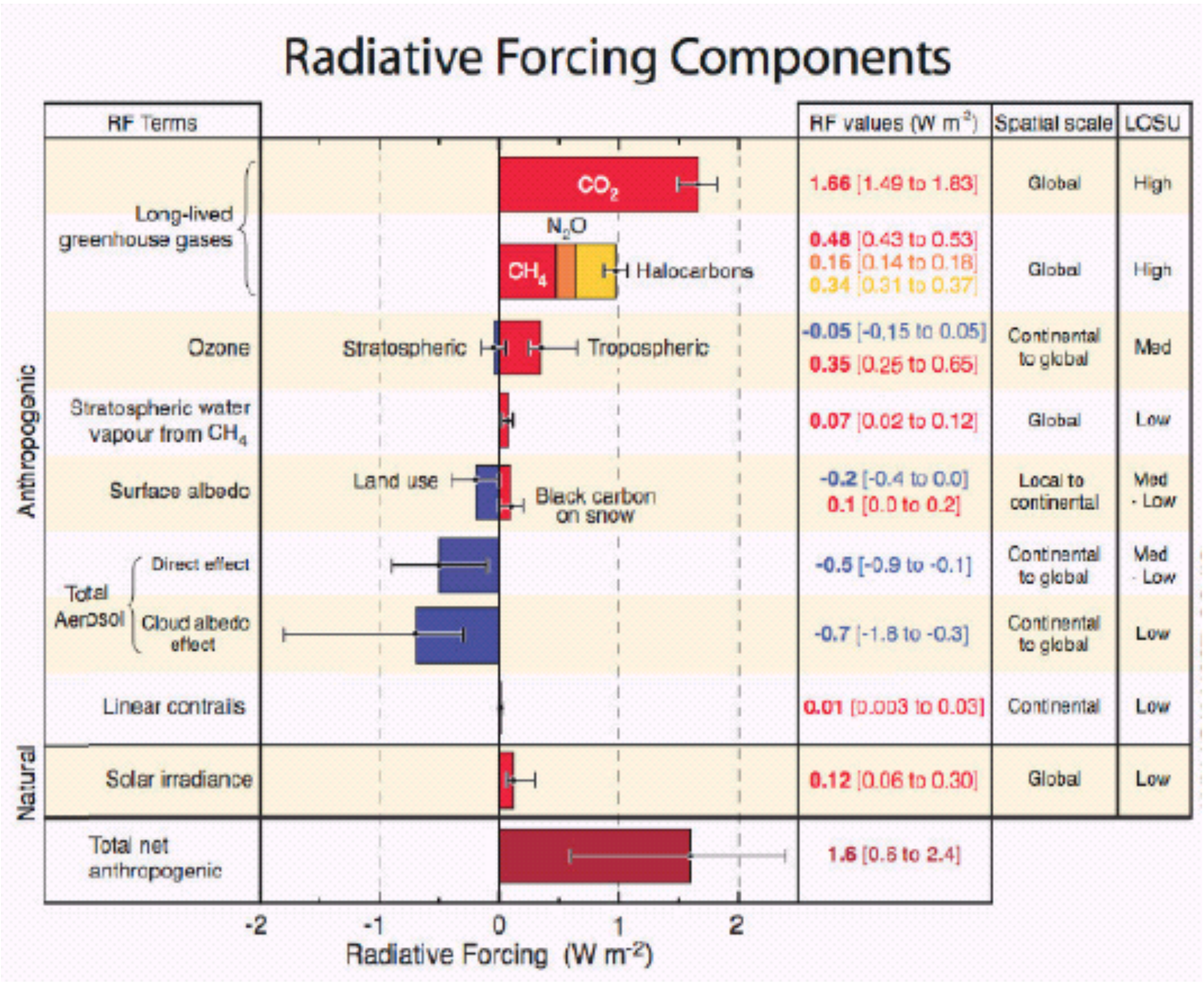


Figure 5. Global mean sea level variations from T/P and Jason.

Regional scale: temperature changes for 1979-2003



FROM THE 4TH IPCC REPORT



All values are expressed with respect to 1750

WE ARE TRYING TO IMPROVE….