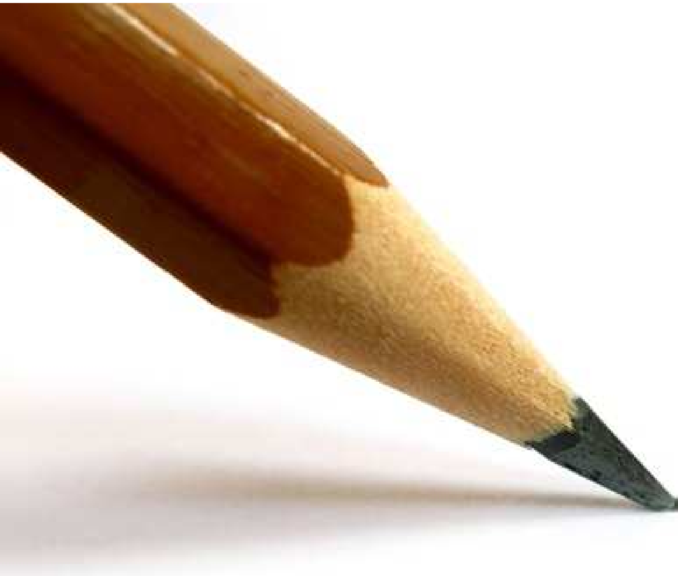
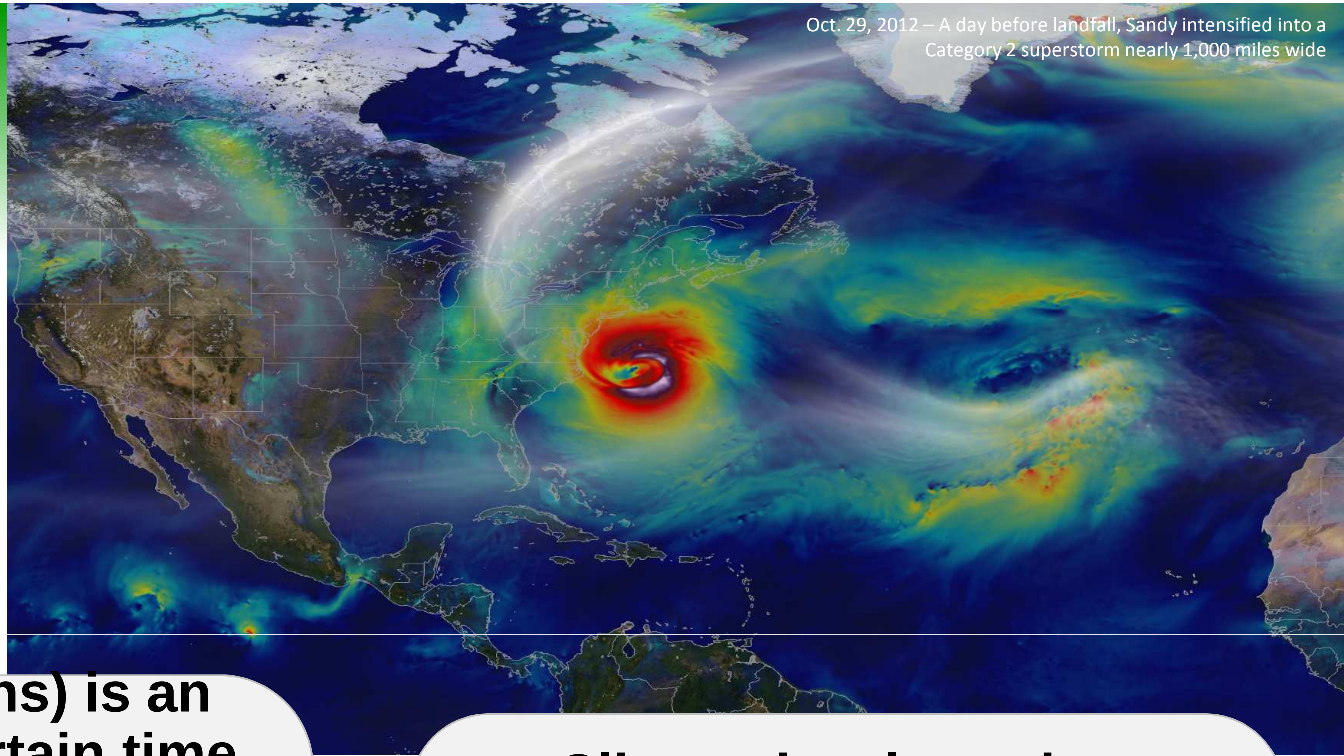


Climate of the Earth and its formation

CLIMATE AND WEATHER CONDITIONS

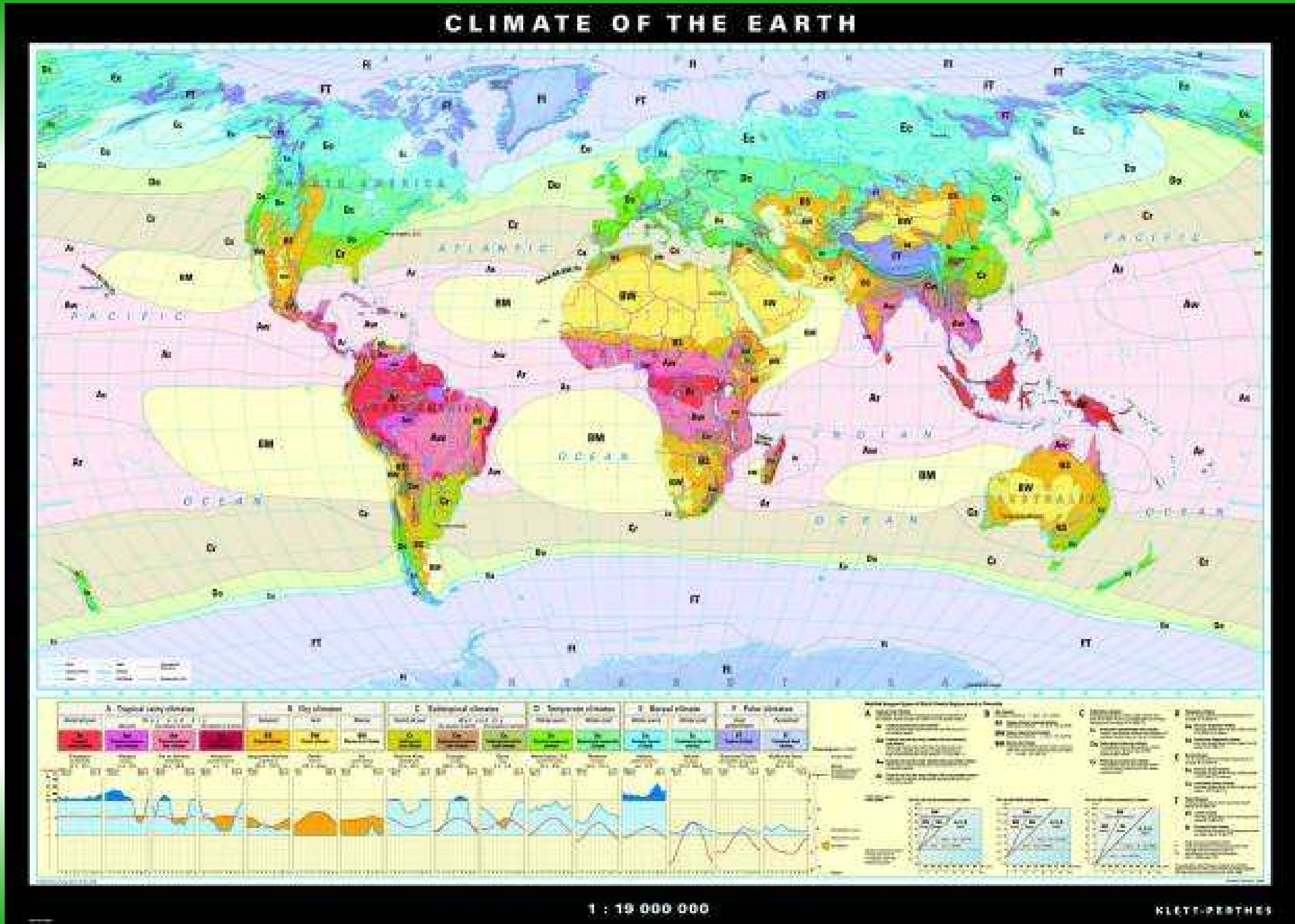


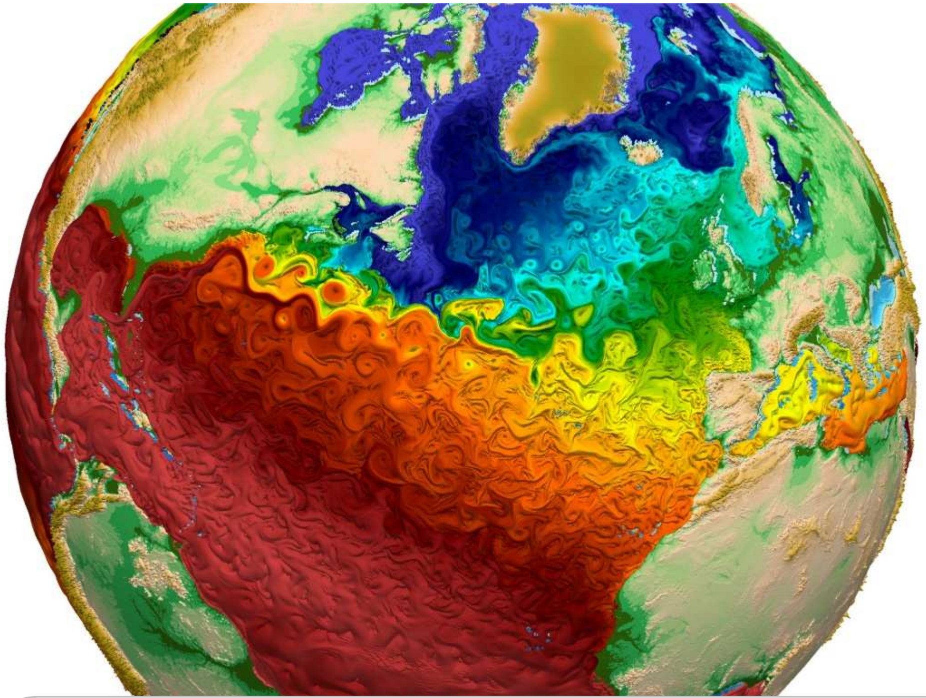
Weather (weather conditions) is an atmospheric situation at certain time period;
and it is characterized by:

- **Atmospheric temperature**
- **Atmospheric pressure**
- **Humidity**
- **Type and amount of precipitation**

Changing of any of these characteristic parameters induces change of weather

Climate is a long-time weather regime, affected by Solar radiation, nature of the Earth's surface and associated atmospheric circulation processes


CLIMATE OF THE EARTH
NORTH AMERICA
ATLANTIC
PACIFIC
OCEAN
INDIAN
OCEAN
AUSTRALIA
OCEAN
1 : 19 000 000
KLETT-PERTHES

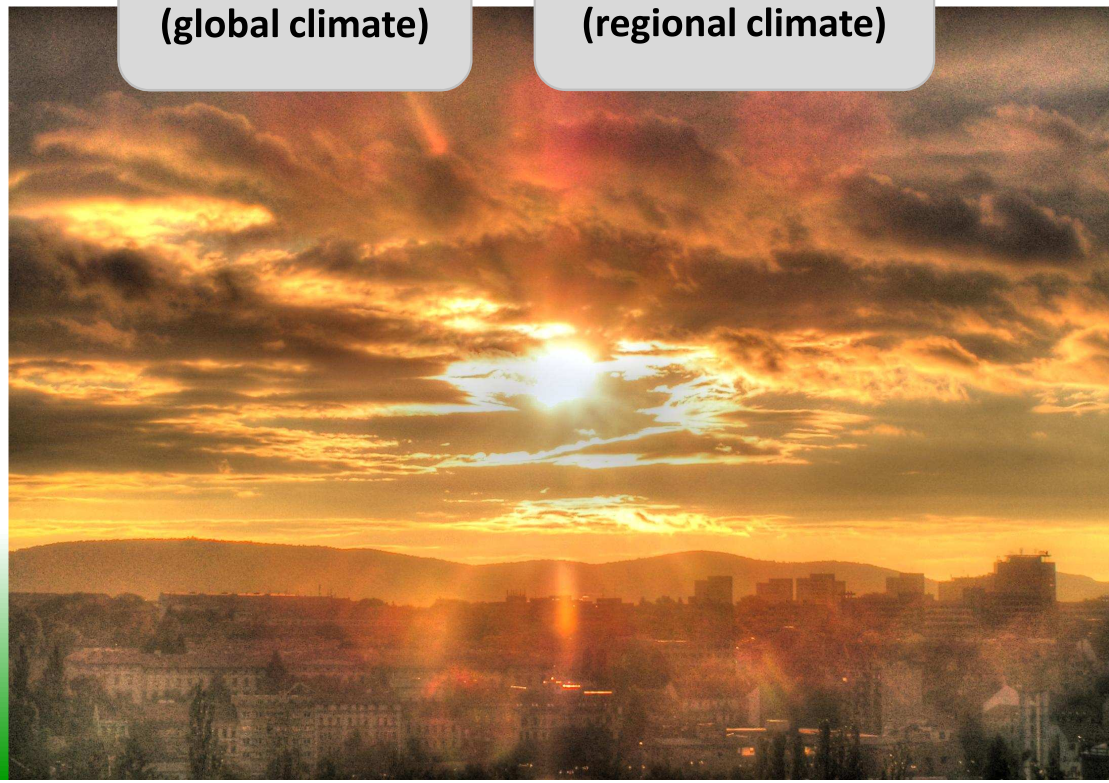


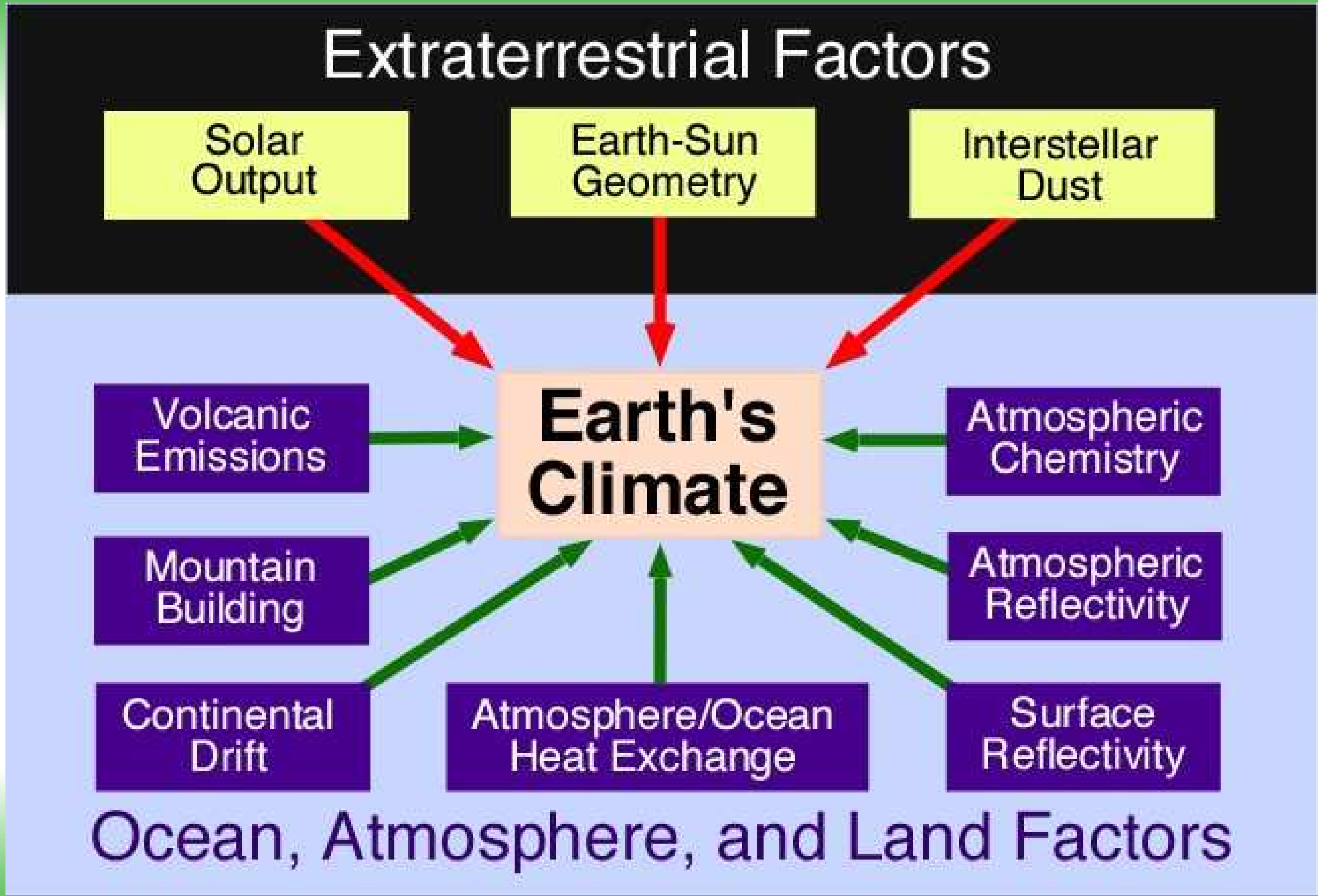
In certain areas **the climate is much more permanent than the weather**, and it is provided by:

- **Amount of solar radiation and its distribution through the year**
- **Atmospheric circulation**
- **Character of Earth's surface**

The climate is characterized by **long-term and averaged atmospheric physical parameters** that are peculiar to:

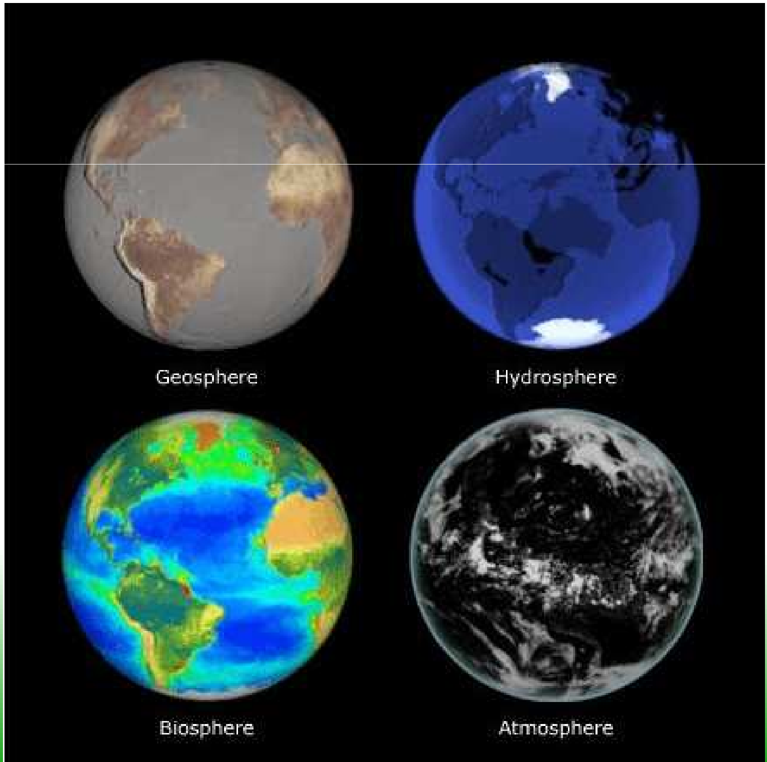
- **The Earth overall (global climate)**
- **The certain area (regional climate)**

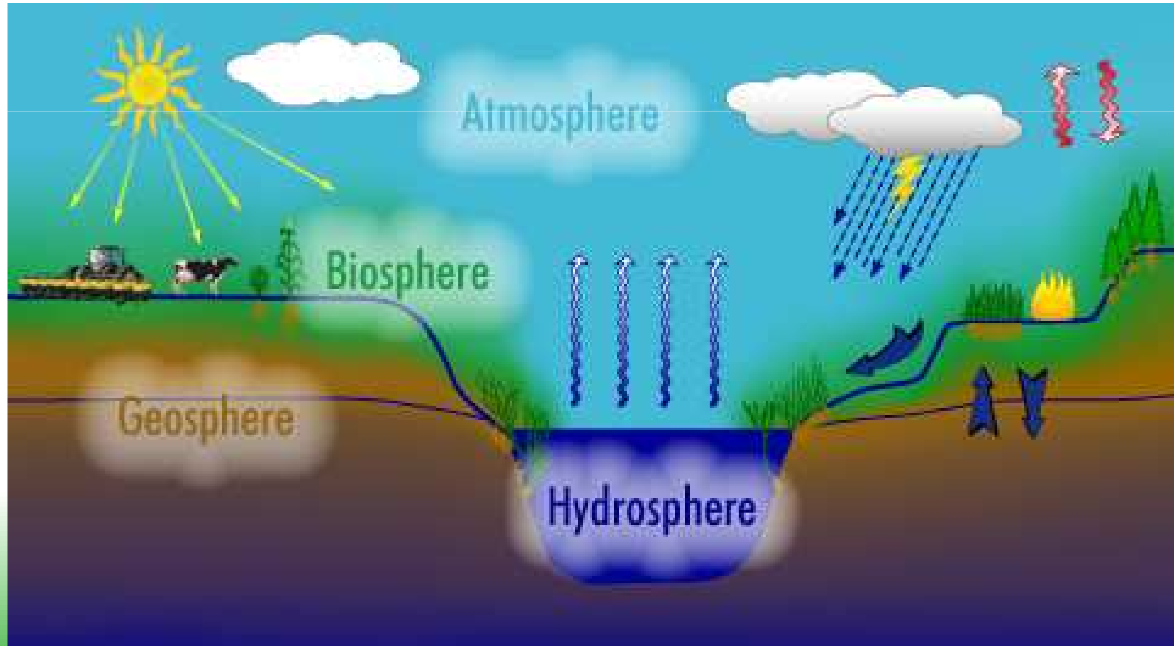



Extraterrestrial Factors
Solar Output
Earth-Sun Geometry
Interstellar Dust
Earth's Climate
Volcanic Emissions
Atmospheric Chemistry
Mountain Building
Atmospheric Reflectivity
Continental Drift
Atmosphere/Ocean Heat Exchange
Surface Reflectivity
Ocean, Atmosphere, and Land Factors

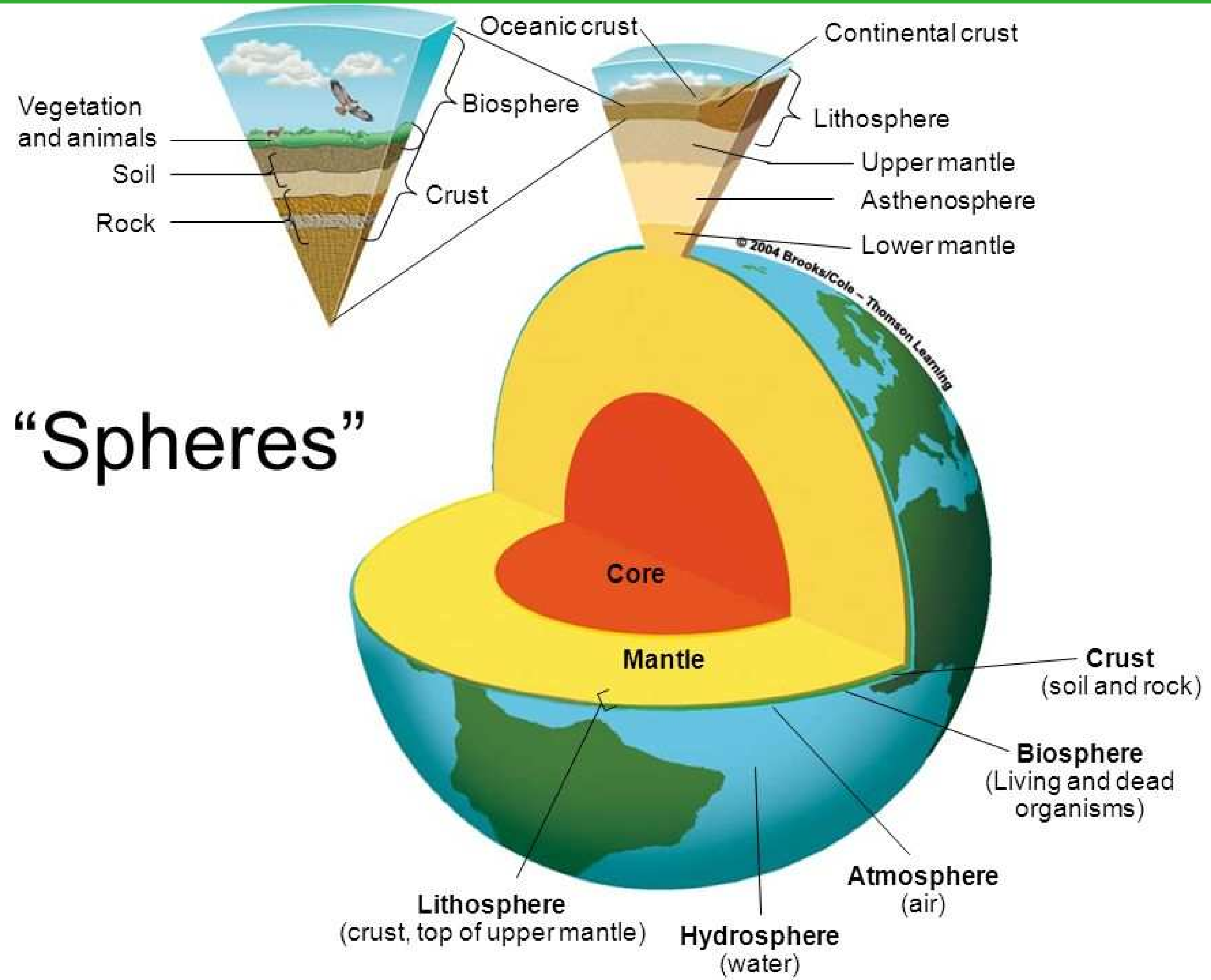
The climate is formed by dispersing of the Solar energy interacting with the Earth; thus the climate system is composed of:

- **Atmosphere**
- **Hydrosphere**
- **Cryosphere**
- **Lithosphere**
- **Biosphere**





"Spheres"

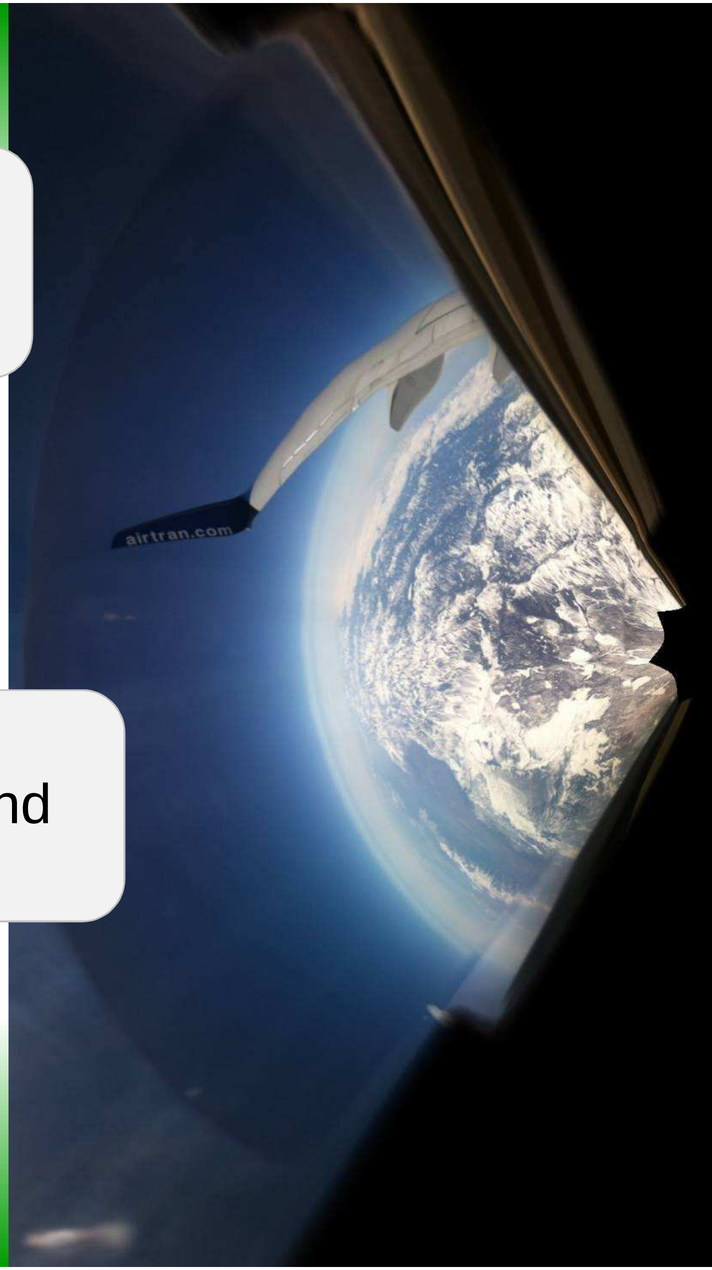

Oceanic crust
Continental crust
Vegetation and animals
Soil
Rock
Biosphere
Crust
Lithosphere
Upper mantle
Asthenosphere
Lower mantle
© 2004 Brooks/Cole – Thomson Learning
Core
Mantle
Crust (soil and rock)
Biosphere (Living and dead organisms)
Atmosphere (air)
Hydrosphere (water)
Lithosphere (crust, top of upper mantle)

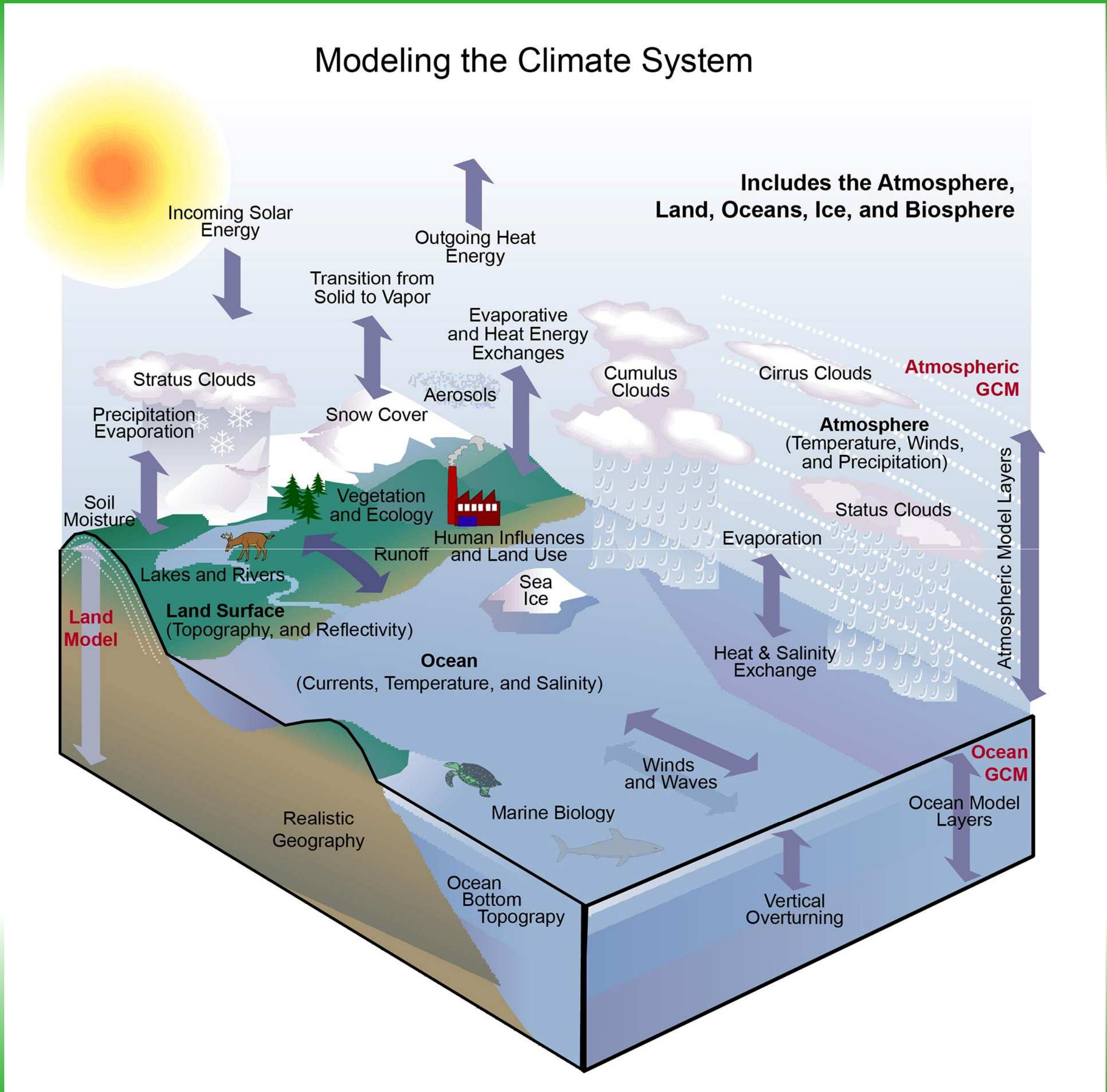
Atmosphere is the most sensitive and rapidly changing part of climate system, made up of gas, water vapour, dust and aerosols

Hydrosphere consists of surface and ground water, sea and ocean waters, which cover around 70% of the Earth’s surface

Cryosphere includes the Arctic, Antarctic and Greenland glaciers, continental glaciers, sea ice and permafrost soil (underground ice)

Biosphere – area of life spreading on the Earth





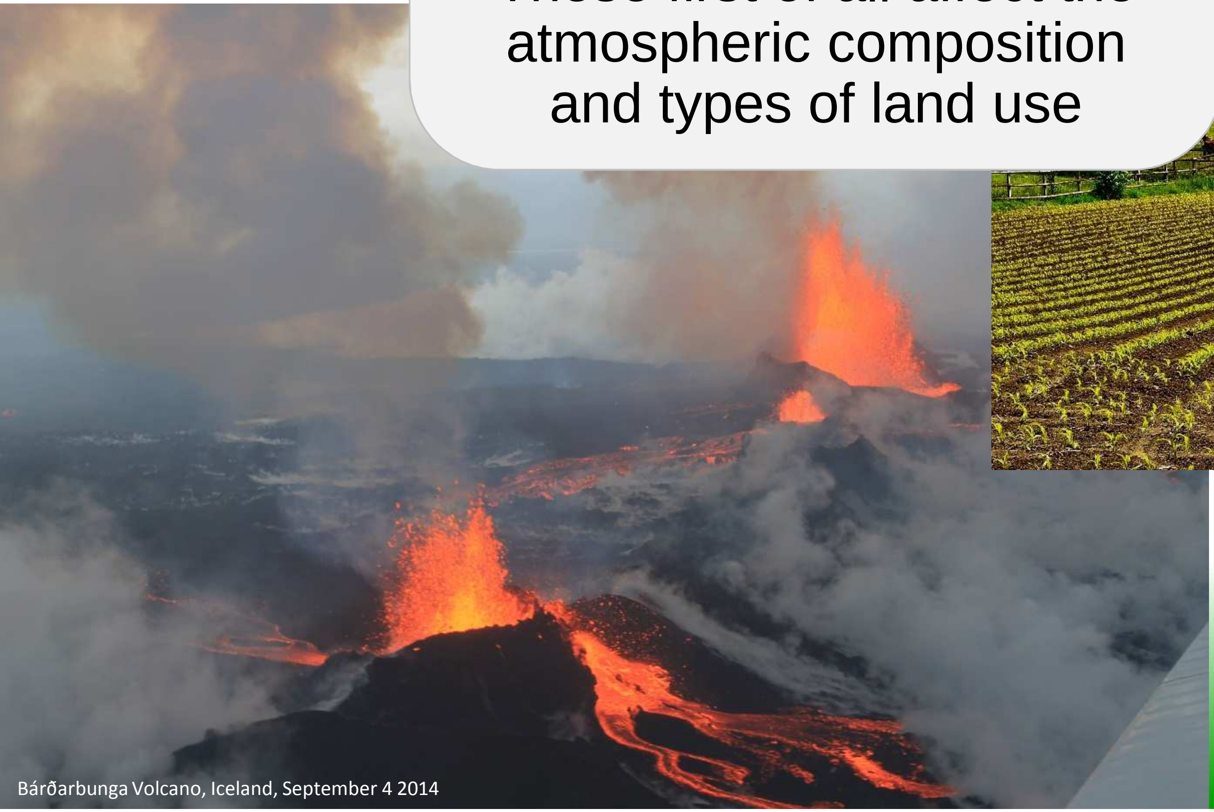
Key elements of the global climate system and processes affecting their variability

Climate change can be caused by:

Natural processes

Human impact

These first of all affect the atmospheric composition and types of land use


Bárðarbunga Volcano, Iceland, September 4 2014

The climate of the Earth can be seriously affected by:

Geological catastrophes (volcanic eruptions, movement of continents)

Cosmic catastrophes (meteorites)

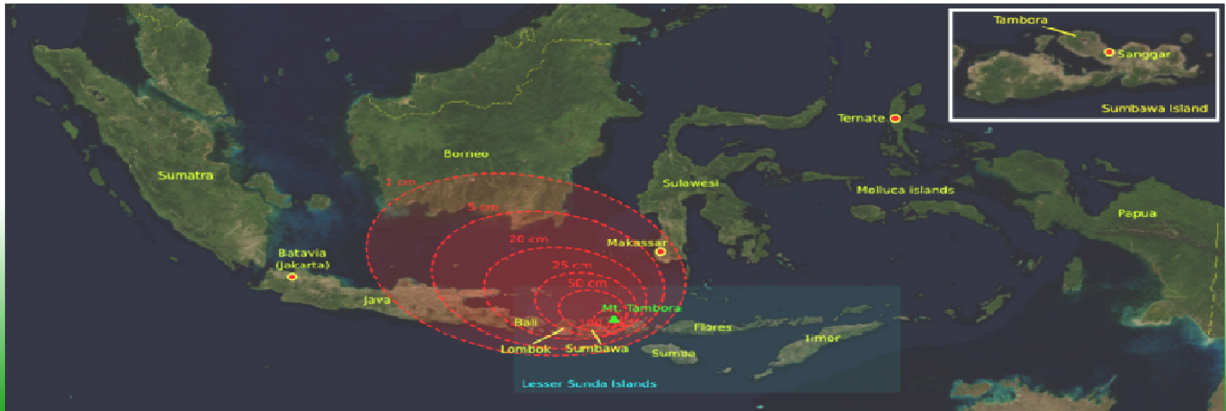
Human activities (use of nuclear weapons, redistribution of river runoff at continental scale)

Cleveland Volcano, Aleutian Islands, Alaska (NASA, International Space Station, 05/23/06)

Meteorite Plaza, Windhoek, Namibia

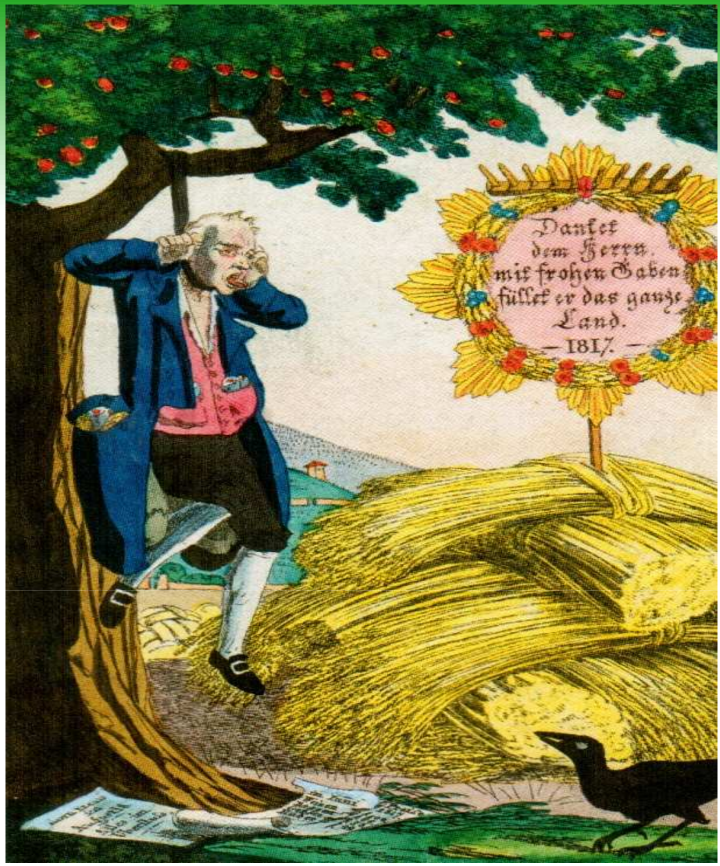
High Explosive from the Last B53 Nuclear Bomb

Mount Tambora, Indonesia

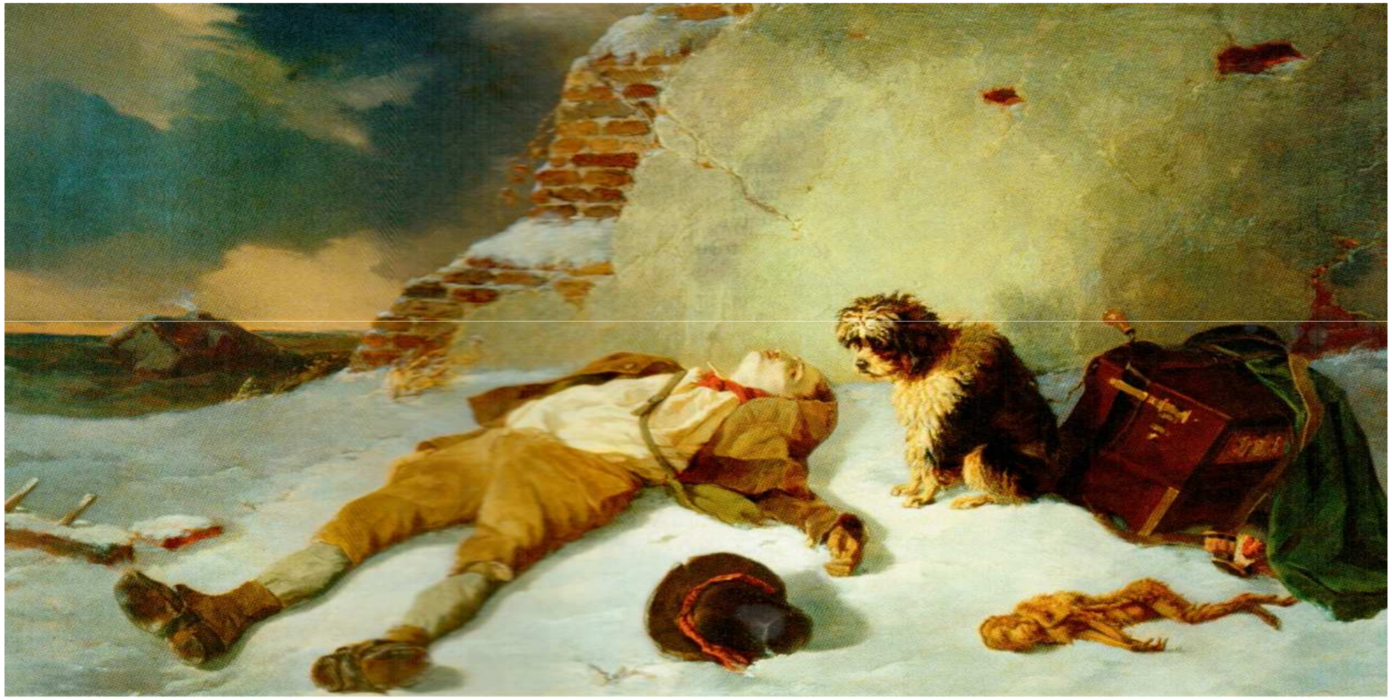


The estimated volcanic ash fall regions during the 1815 eruption. The red areas show thickness of volcanic ash fall.

The outermost region (1 cm thickness) reached Borneo and the Sulawesi islands.



Along with grain prices deteriorated criminal situation and greed.
Here – hanged black marketeer.

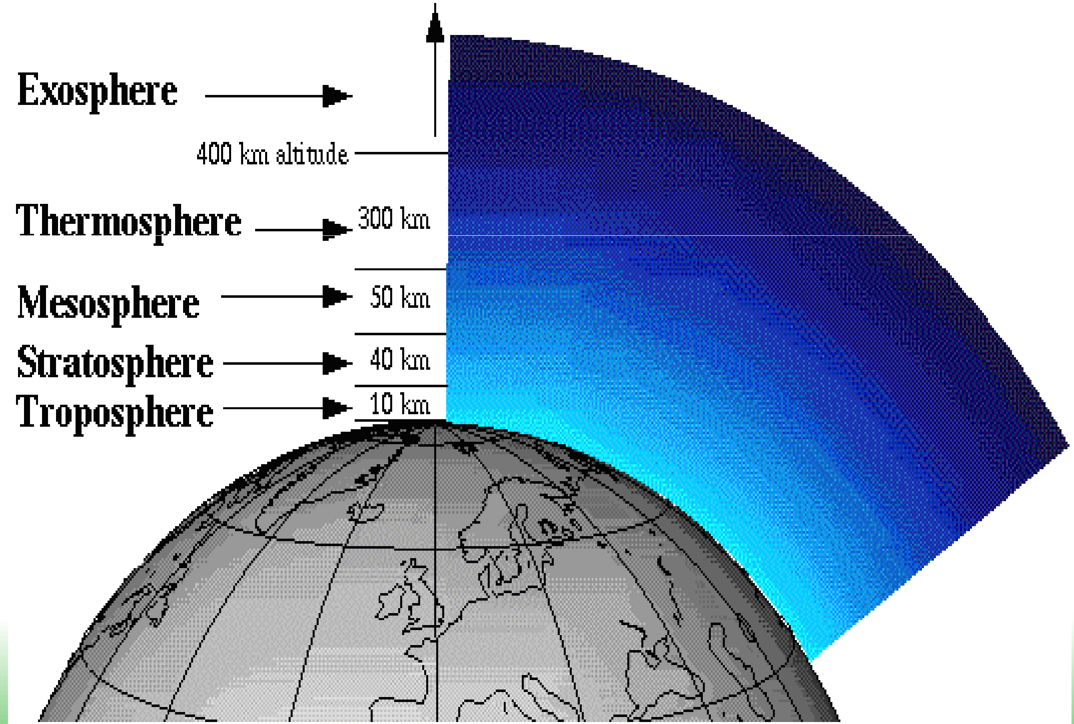


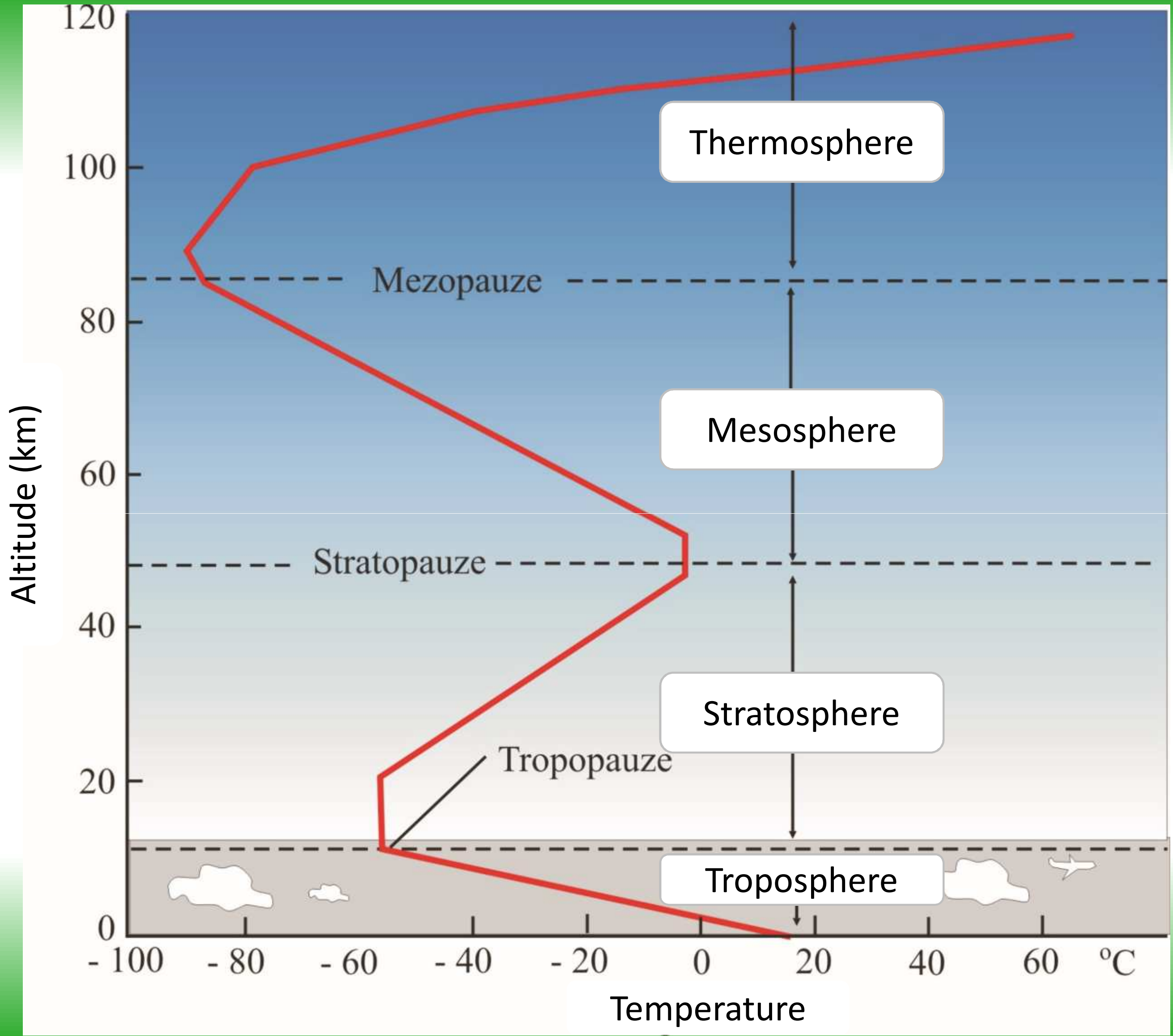
" Death by the wayside " - symbolic picture that reflects the dire reality in many parts of Europe at a time when Tambora volcano ashes blocked the Sun's rays.

EARTH'S ATMOSPHERE AND IMPACT OF ITS STRUCTURE ON THE CLIMATE

The atmosphere is not homogeneous – it is composed of various thickness zones:

- Troposphere
- Stratosphere
- Mesosphere
- Thermosphere
- Exosphere



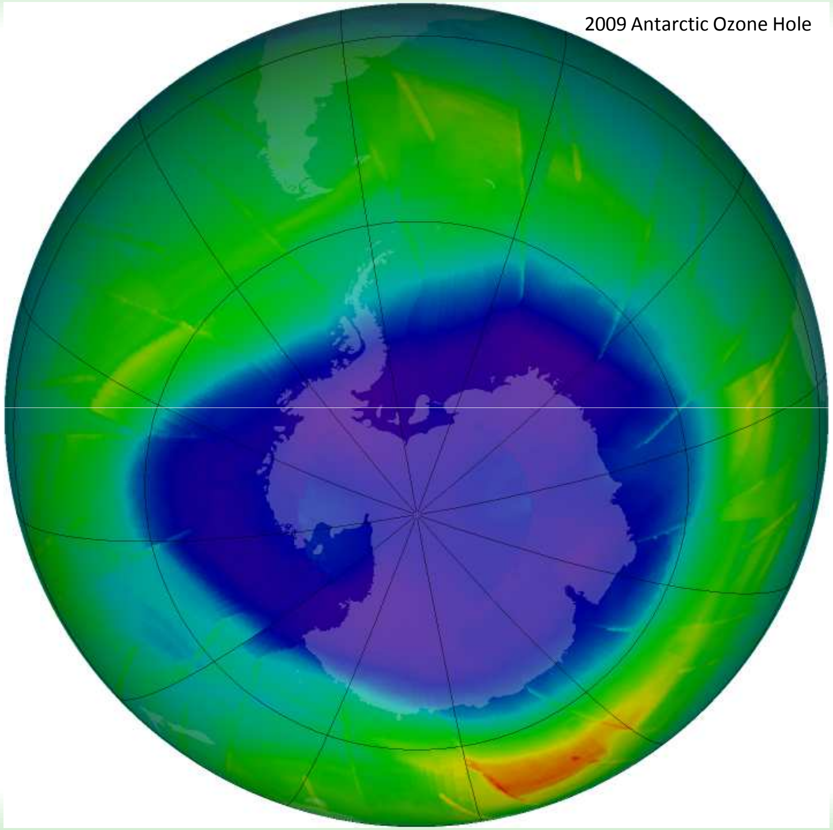


Variability of the Earth's atmosphere and temperature depending on the distance from the Earth's surface

Temperature inversion in the stratosphere is caused by the photochemical reactions (light radiation response, in this case, ultraviolet radiation), which contributes to ozone formation

Maximum ozone concentrations occur in about 25 km altitude, but the maximum temperature – about 50 km altitude

Great part of the energy is absorbed on upper layers of the stratosphere and below the maximum ozone concentration area, but as the air density is low, the heat transfer from the upper stratospheric layers is slow



Atmospheric processes are significantly affected by the interaction of electromagnetic radiation with the atmosphere forming gases

The basic substances of the atmosphere are **nitrogen** (78%) and **oxygen** (21%), but also water vapour and carbon dioxide plays a key role in shaping climate

The main characteristic parameters for atmospheric zones

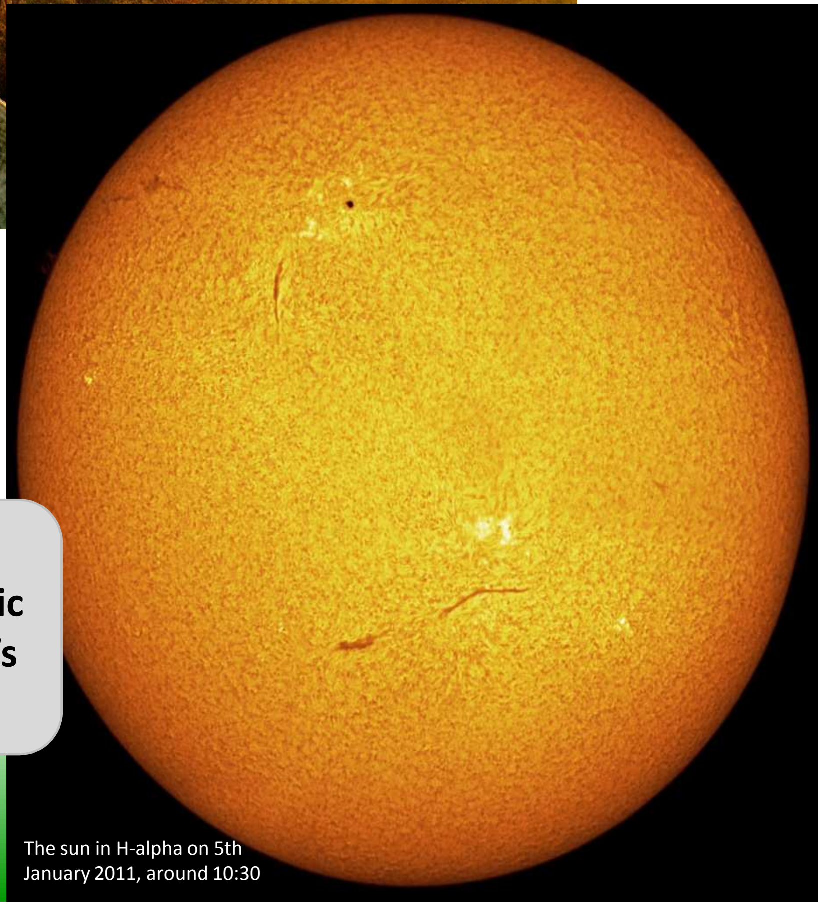
Atmospheric zone	Temperature, °C		Temperature gradient, ºC/km	Lower and upper margin, km	Characteristic substances
	Lower margin	Upper margin			
Troposphere	15	–56	–6,45	from 0–6 to 16	N_2, O_2, CO_2
Stratosphere	–56	–2	+1,38	10–50	O_3
Mesosphere	–2	–92	–2,56	50–85	O_2^+, NO^+
Thermosphere	–92	+120	+3,11	85–500	O^+, NO^+

Characteristics of the layers of the atmosphere

Layer	Range (km)	Characteristics
Thermosphere	Mesopause* to 350-800km	• Temperature increases with height • Very low pressure, low density of molecules • International Space Station orbits here • Aurora borealis (Northern Lights) due to ionization of atmosphere by solar radiation
Mesosphere	Stratopause* to 80-85km	• Very cold • Meteors burn up in this layer
Stratosphere	Tropopause* to ≈51km	• Temperature increases with height • **Ozone layer** is here, protecting Earth from UV radiation • Very low pressure
Troposphere	Surface to 9-17km	• Temperature decreases with height – heated from the ground up • Atmosphere thins with height • Contains 80% of atmosphere (high density particles) • Turbulent and changeable weather (lots of mixing)

Layers of the Atmosphere, from: http://en.wikipedia.org/wiki/Earth%27s_atmosphere

SOLAR RADIATION AND EARTH'S CLIMATE



The sun in H-alpha on 5th January 2011, around 10:30

The main factors that determine the flow of Solar radiation are:

- **The distance of radiation from the source**
- **The angle at which the Solar radiation reaches the Earth**
- **Atmospheric composition and interaction of the Solar and cosmic radiation in space with the Earth's atmosphere forming gases**

The changes of the angle of sunbeam and day length are continuous changes of the Earth's position relative to the long-term fluctuations of the Sun and the Earth's rotation axis inclination

If the Earth's axis of rotation would be perpendicular to the orbital plan, then the sunlight on the Earth would be distributed equally and seasons would remain unchanging

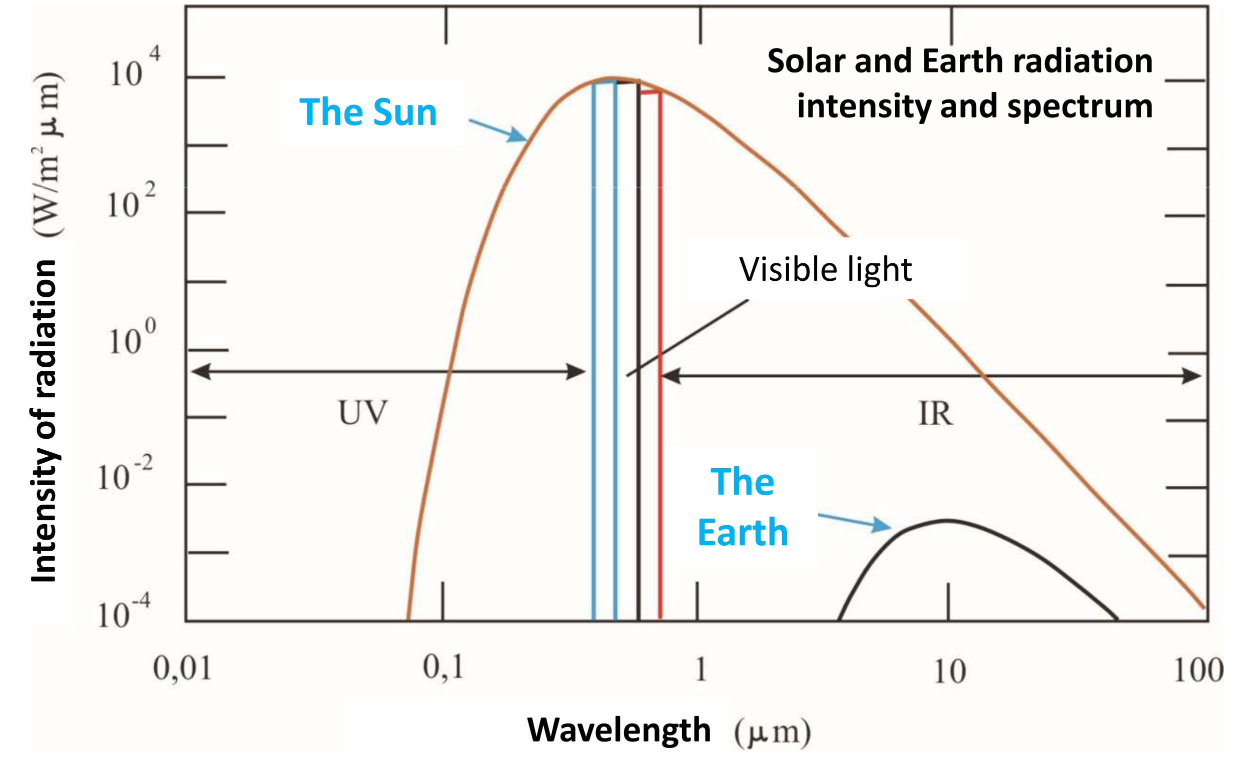
The Earth is reached by:

Full spectrum of electromagnetic radiation of the Sun

Flow of ionized particles (e.g., nuclei of hydrogen or helium)

Cosmic radiation (elementary particles and particles of cosmic space and the radiation flux)

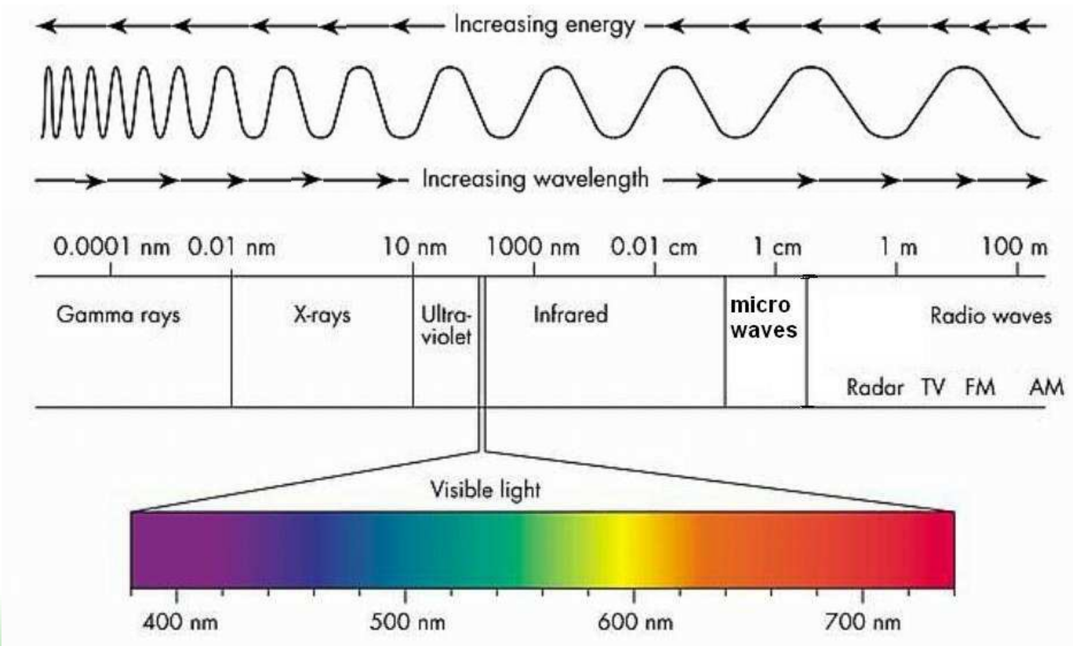
Earth's climate is influenced mainly by the electromagnetic radiation flux –
The outer layers of the Earth's atmosphere are reached by radiation which corresponds to the spectral composition of radiation of the black object at a temperature about 6,000 K



The Earth is reached by full spectrum of solar electromagnetic radiation:

Ultraviolet rays | **X-rays** | **γ (gamma) rays** | **Visible light** | **Infrared rays** | **Radio-waves**

Energy of electromagnetic radiation decreases by increase of wavelength, and most of the radiation that reaches the Earth has a high energy and a relatively short wavelength



Distribution of electromagnetic spectrum by wavelengths; visible light spectrum from 0.40 to 0.71 micrometers (µm)

A significant part of the solar radiation does not reach the Earth’s surface, but is bound at the upper layers of atmosphere or reflected in space

The solar constant is a value that describes the flow of solar energy to the Earth’s atmospheric system

The solar constant is expressed as the amount of solar radiation that falls perpendicularly to the sunbeam angle of incidence when the Earth is at the average distance from the Sun

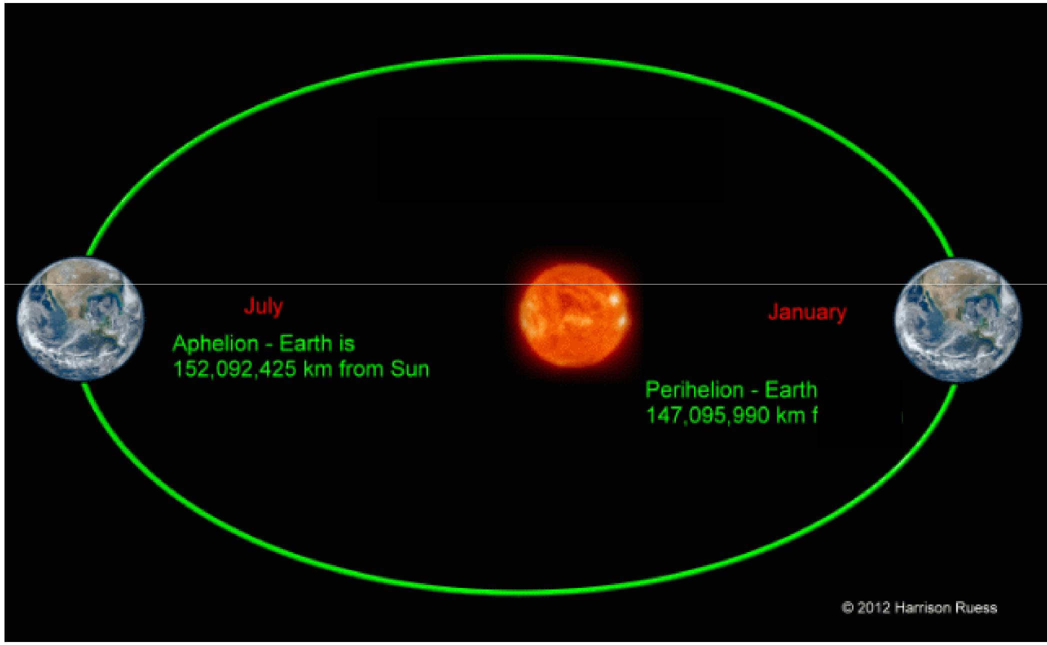
Newfoundland and clouds over the North Atlantic Ocean share a scene with a Soyuz spacecraft; NASA, International Space Station, 01/06/11

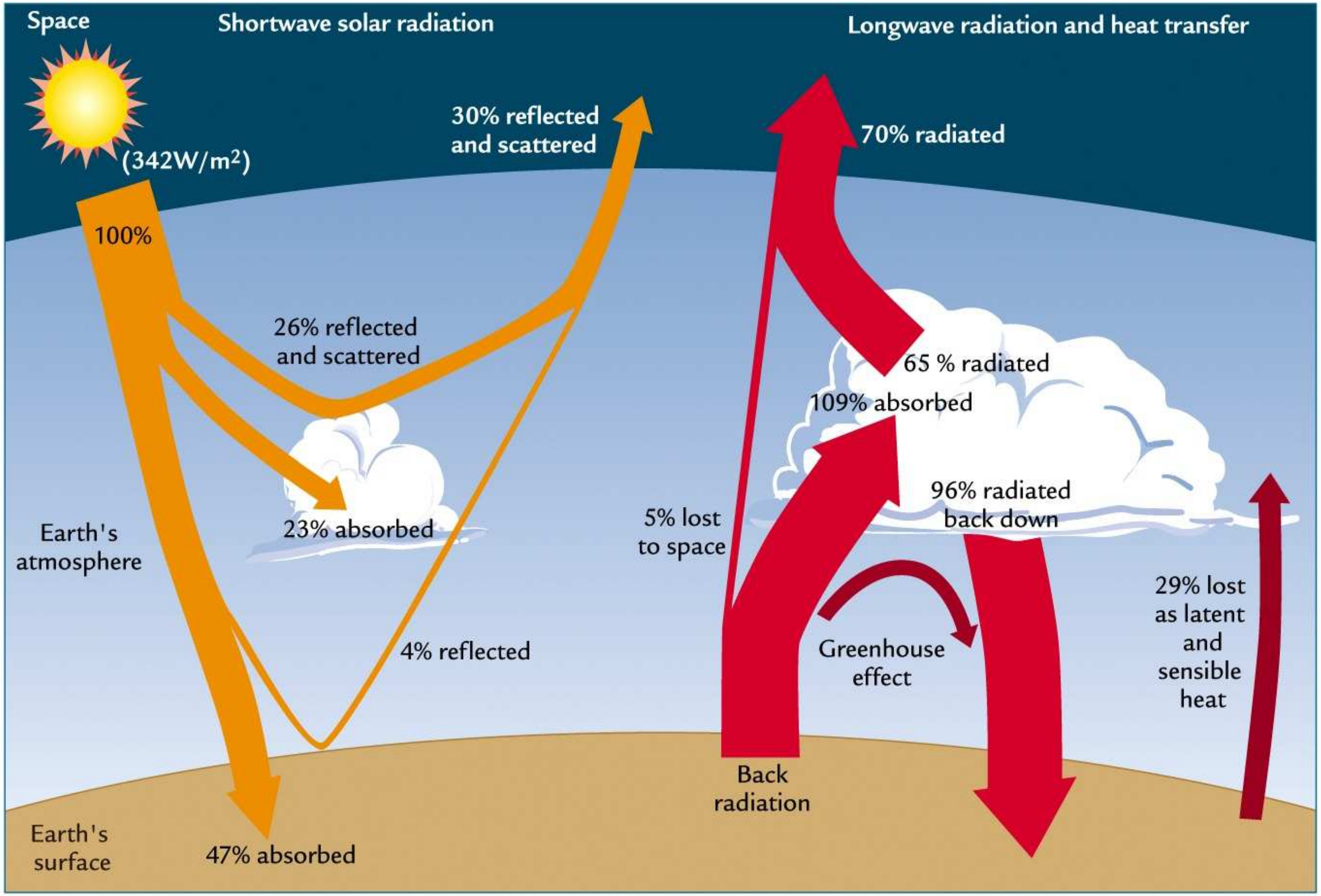
ISS026E015765

During the year, the largest amount of solar energy is reaching the Earth when it is closest to the Sun – **in perihelion**, but the lowest – when the Earth is **in aphelion**

Contrasts of perihelion and aphelion in the distribution of solar radiation, as well as seasonal changes of radiation are able to affect the global climate

Direct radiation is the amount of solar energy reaching the Earth's surface on a unit of area in a certain time, and it is calculated on a horizontal surface or on a surface perpendicular to the angle of incidence of sunlight

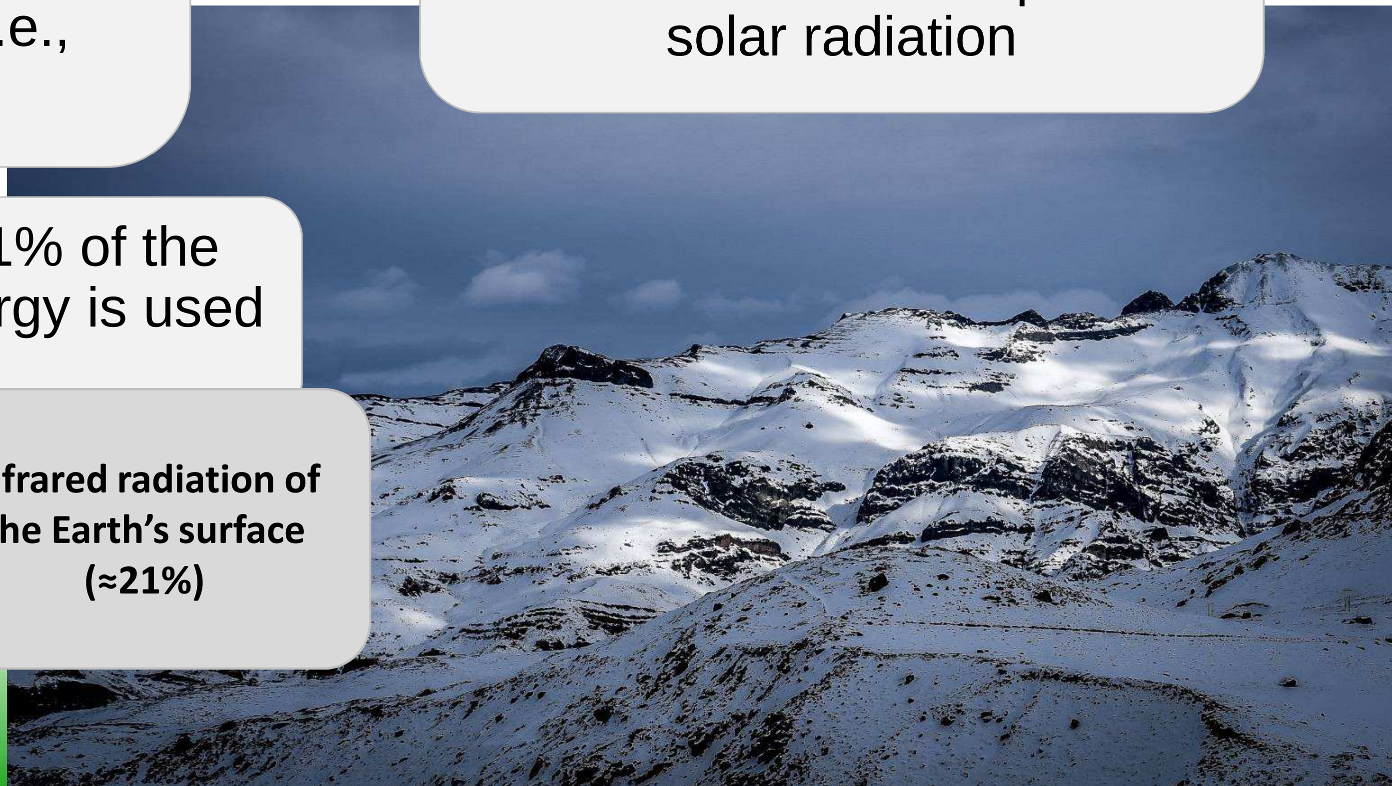




Solar energy is almost in an equal balance with the energy reflected from the Earth’s surface

About 30% of solar radiation is reflected in space – part of this energy is reflected by cloud cover and fine particles in the atmosphere, i.e., aerosols

Lighter areas of the Earth’s surface – snow, ice and deserts – reflect 1/3 part of solar radiation



Earth's surface absorbs 51% of the solar radiation, and this energy is used in:

Evaporation processes (23%)

Convection and advection processes (7%)

Infrared radiation of the Earth’s surface (≈21%)

Major changes in the climate system may be induced by erupted volcanic material - aerosols which rises to great heights - it can lead to decrease of global surface temperature for several months or even years

Also the human-made aerosols may affect the sunlight reflection

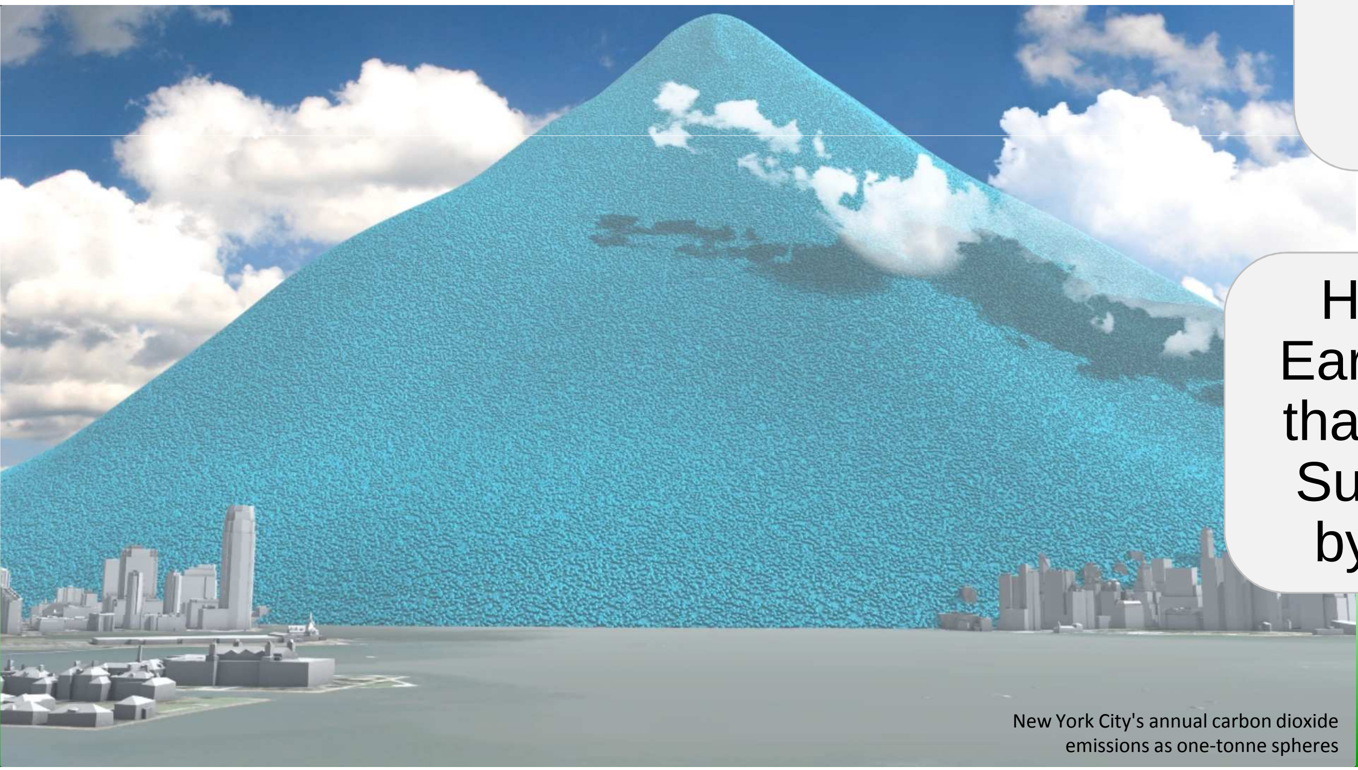
The Earth's climate is affected by **the ability of the Earth's surface to reflect radiation** – part of radiation which is reflected from the Earth's surface, is characterized by **surface albedo**

Different surface albedo values

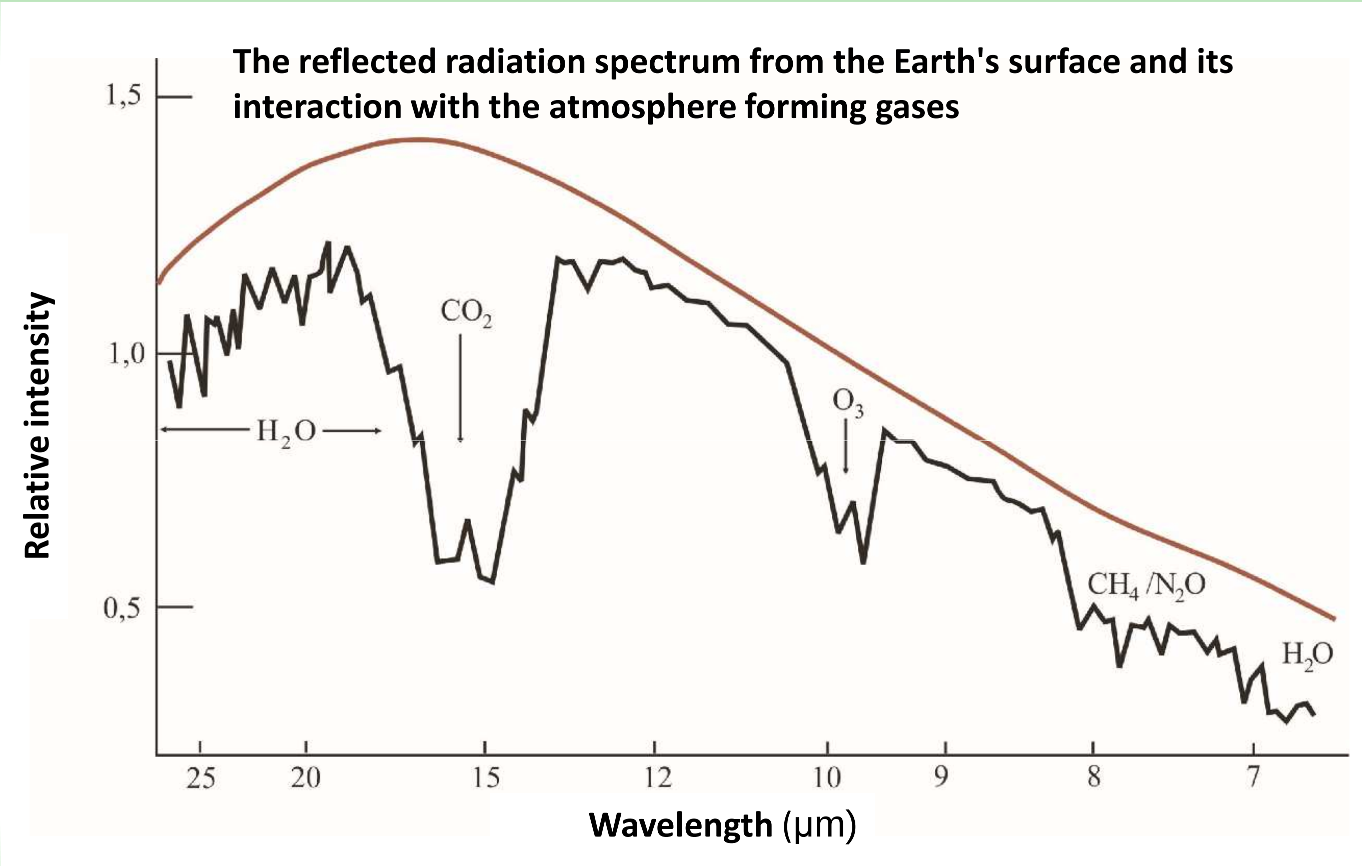
Surface	Albedo, %
Freshly fallen snow	75–95
Tightly clouds	60–90
Ice	30–40
Sand	15–45
Earth and atmosphere – planetary albedo	31
Ocean (daily average)	8
Forest	3–10

GREENHOUSE EFFECT

The Earth's surface is getting warmer from solar radiation, and thus the Earth radiates the heat into space

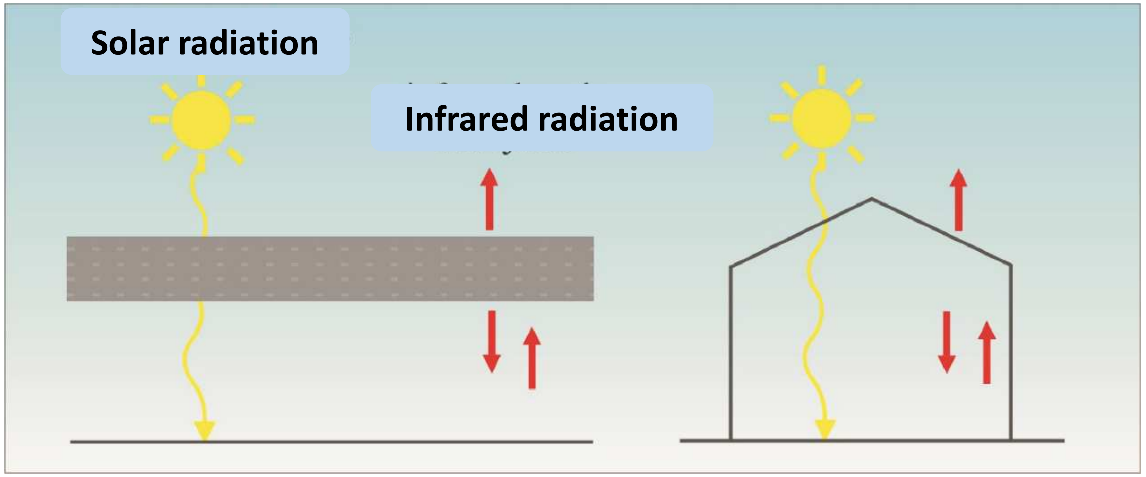


However, the temperature of the Earth's surface is significantly lower than the surface temperature of the Sun, therefore, the energy emitted by the Earth is significantly lower



The Earth's surface mostly emits infrared or thermal radiation - reflected from the Earth's surface infrared radiation also is able to interact with the atmosphere forming gases

Such gases as **carbon dioxide**, **methane** and **water vapour** in the Earth’s atmosphere acts similarly like the glass in a greenhouse



Even small changes in the amount of GHG’s in the atmosphere is accompanied by the temperature changes on the Earth, and thus induces the changes of the glacier area, ocean level, stream regime, distribution of biotopes and global climate

These gases – so called **greenhouse gases (GHG’s)** – are pervious to incoming radiation, but they hold up infrared radiation (heat) reflected by the Earth’s surface

The higher the concentration of GHG’s in the atmosphere, the more infrared radiation (heat) is held up in the Earth’s atmosphere, and therefore the Earth’s surface temperature is increasing

Several atmosphere forming gases –

Carbon dioxide (CO_2)

Methane (CH_4)

Ozone (O_3)

Water vapour

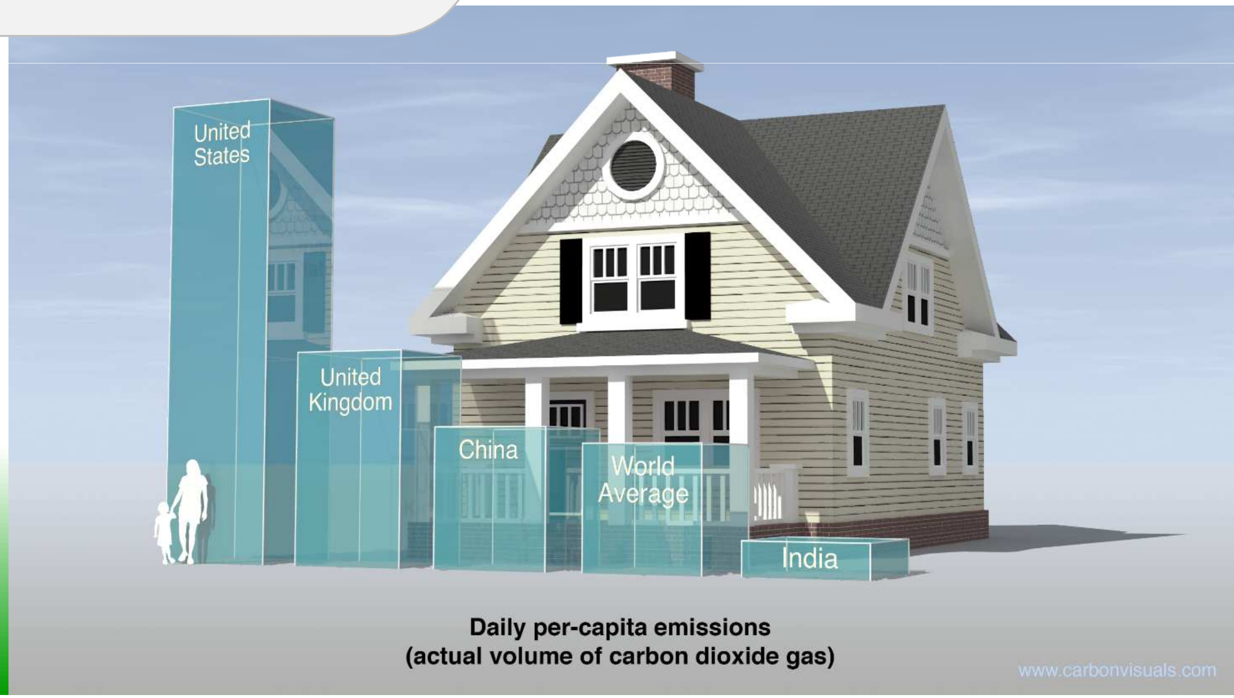
Nitrogen (I) oxide (N_2O)

Chlorofluorocarbons (freons, CFC's)

Sulphur hexafluoride (SF_6)

Including gases released from human activities

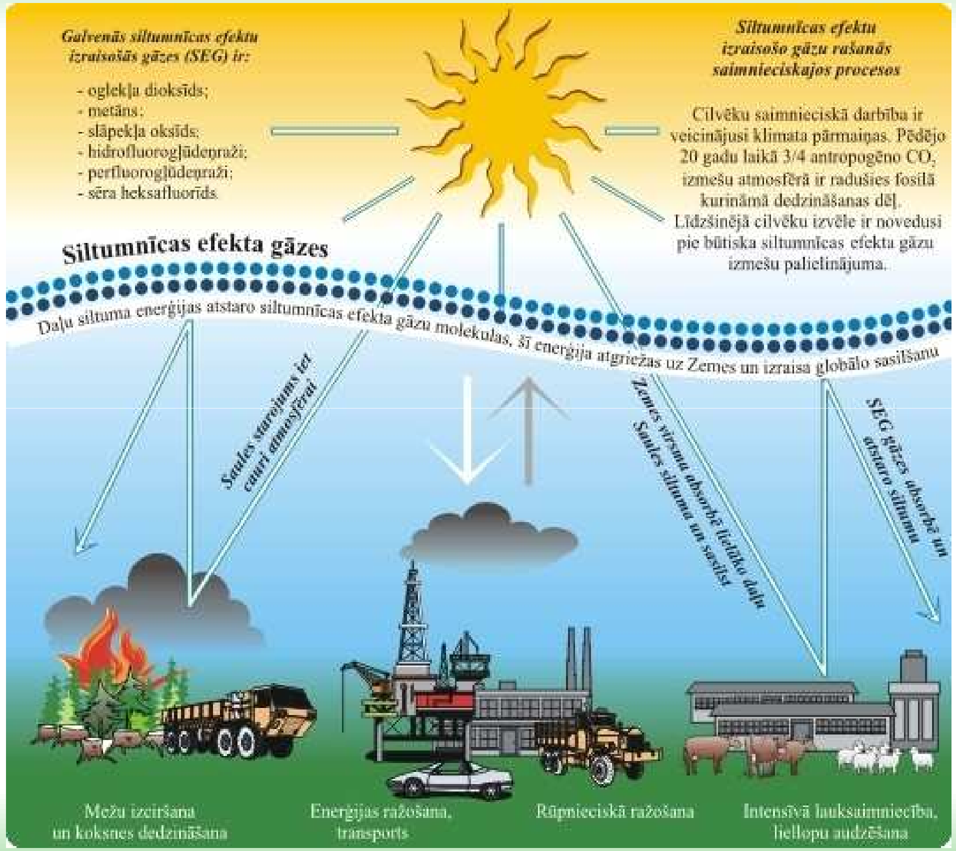
are capable to absorb infrared radiation intensively



Each of GHG’s is characterized by a different ability to bind and return solar radiation to the Earth **– solar radiation or radiation quantity (RQ)** measured in W/m^2

The amount of radiation reveals how the gas affects the amount of energy that reaches the Earth’s surface, and thus reflects the extent to which it is able to influence the mode of climate change

If radiation quantity value is a positive value, the gas contributes to increase of the Earth’s temperature, but if it is a negative value – it contributes to reduction of temperature



Carbon dioxide (CO_2) cycle

On average, the proportion of carbon dioxide in the ambient air is 0.03%, but in places with a greater number of CO_2 emitters (top soil and atmospheric layer adjacent to ground) CO_2 concentration may achieve 0.5-4%

Natural sources of carbon dioxide (CO_2):

- **Decomposition of organic matter (putrefaction, fermentation)**
- **Respiration of living organisms**
- **Fire caused by lightning**
- **Volcanic processes**

The main ingredient of all organic substances is carbon; carbon dioxide originates from splitting of organic molecules in atoms and carbon connecting with oxygen

Significance of carbon dioxide (CO_2) in the environment

Changes of the Arctic glacier over time

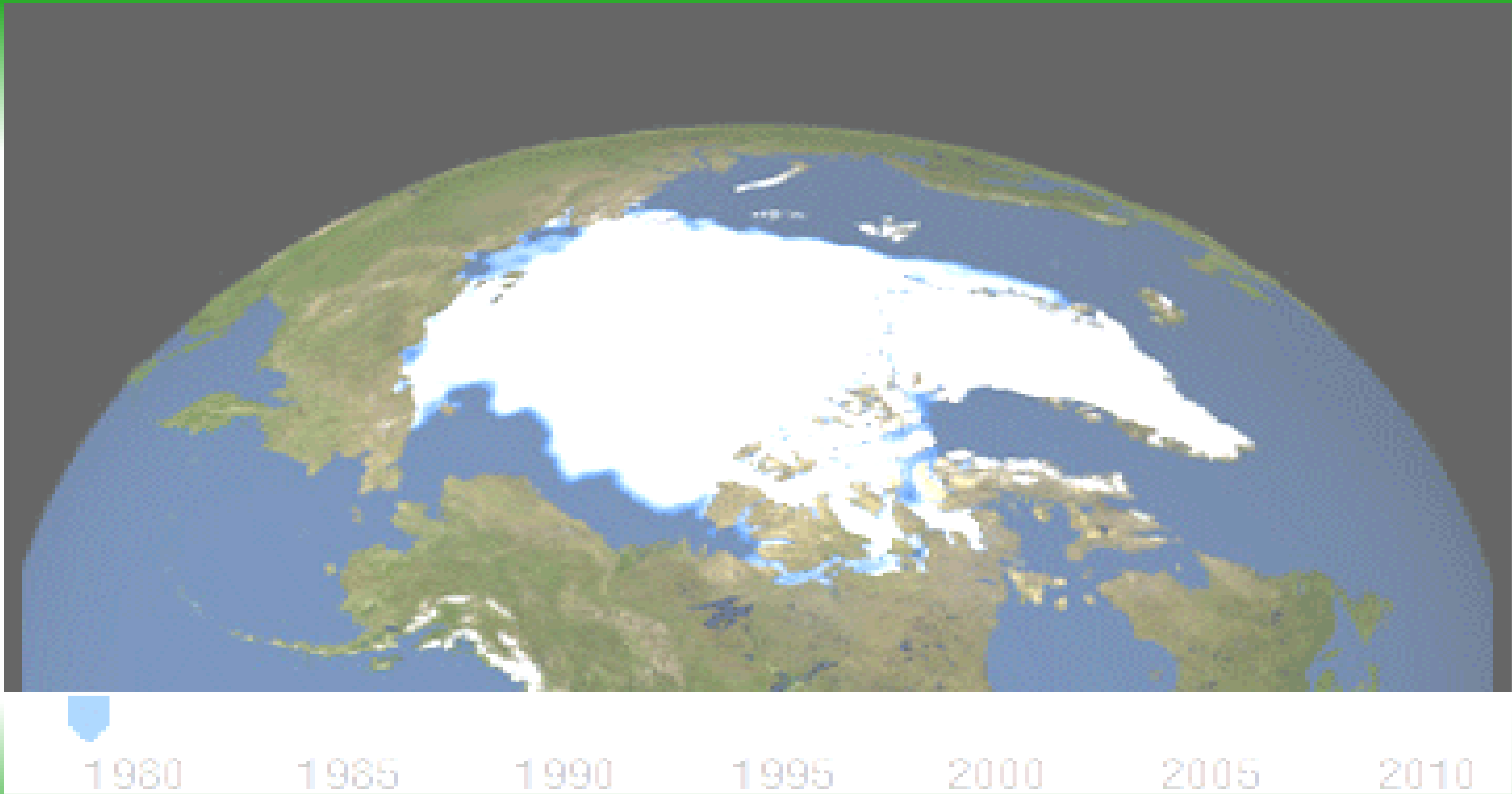
1979 SSMI Composite Data

2003 SSMI Composite Data

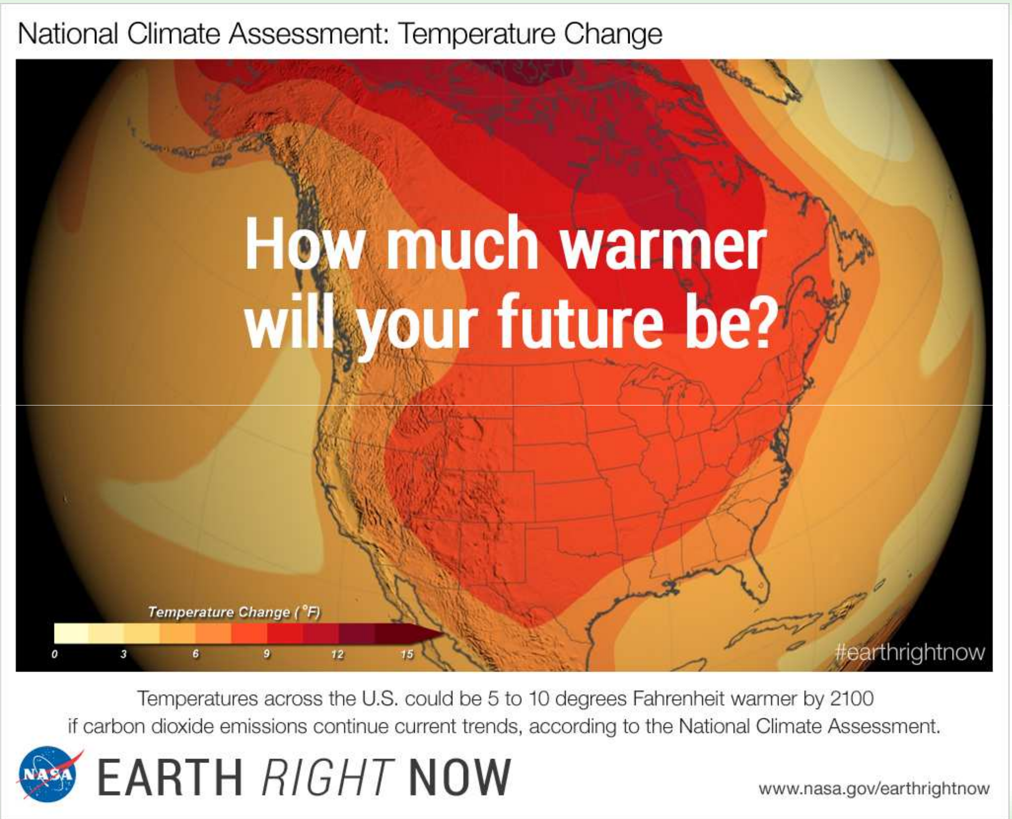
Aerobic organisms are sensitive to elevated content of CO_2 in the air - if the concentration of CO_2 is only 1%, human feeling of comfort significantly deteriorates, but if CO_2 level is above 10%, people die

Increase of CO_2 in the atmosphere does not allow the Earth’s surface to reflect heat received from the Sun, therefore, global warming can be observed

Due to the climate warming, CO_2 content in the atmosphere is tended to increase more rapidly, because permafrost starts to thaw and accumulated retained organic matter and peat bogs in Arctic begin to decline intensively



Arctic sea ice loss



Many of GHG’s are characterized by a high stability which can be measured as the time that it takes for as long as they are bound or discharged from the atmosphere

Existence of natural greenhouse effect ensures that the temperature on the Earth meets the preconditions for the existence of life

The greenhouse effect exists not only on the Earth - it is believed that similar conditions determine the climate on the Venus, and due to the greenhouse effect the temperature on this planet reaches even 450 ℃

Turnover of concentration of GHG's in the atmosphere and their impact on the Earth's energy balance

Greenhouse gas	Concentration of gas in atmosphere, trillionths part		Emissions a year	Life cycle in atmosphere, years	Radiation quantity, W/m²
	2012	1750			
Carbon dioxide CO_2*	385	278	26.4 GT		1.46
Methane CH_4**	1745	700	600 Tg	8.4	0.48
Nitrogen (I) oxide N_2O**	314	270	16.4 Tg N	120	0.15
Perfluorethane C_2F_6**	3	0	≈ 2 Gg	10000	0.001
Sulphur (VI) fluoride SF_6**	4.2	0	≈ 6 Gg	3200	0.002
Freon 11 $CFCl_3$**	268	0	–	45	0.07
Freon 12 CF_2Cl_2**	533	0	–	100	0.17
Freon 23 CHF_3**	14	0	≈ 7 Gg	260	0.002

** Expressed as a millionth part*

*** Expressed as a billionth part*

PERMAFROST

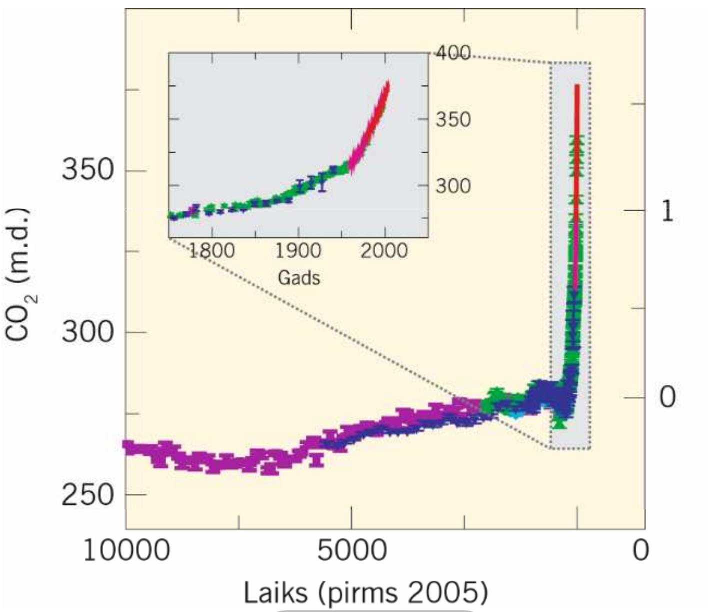
Permafrost or cryotic soil is soil at or below the freezing point of water 0 ℃ for two or more years. Most permafrost is located in high latitudes (in and around the Arctic and Antarctic regions), but alpine permafrost may exist at high altitudes in much lower latitudes.

Permafrost accounts for 0.022 % of total water on earth and exists in 24 % of exposed land in the Northern Hemisphere. It also occurs subsea on the continental shelves of the continents surrounding the Arctic , portions of which were exposed during the last glacial period.

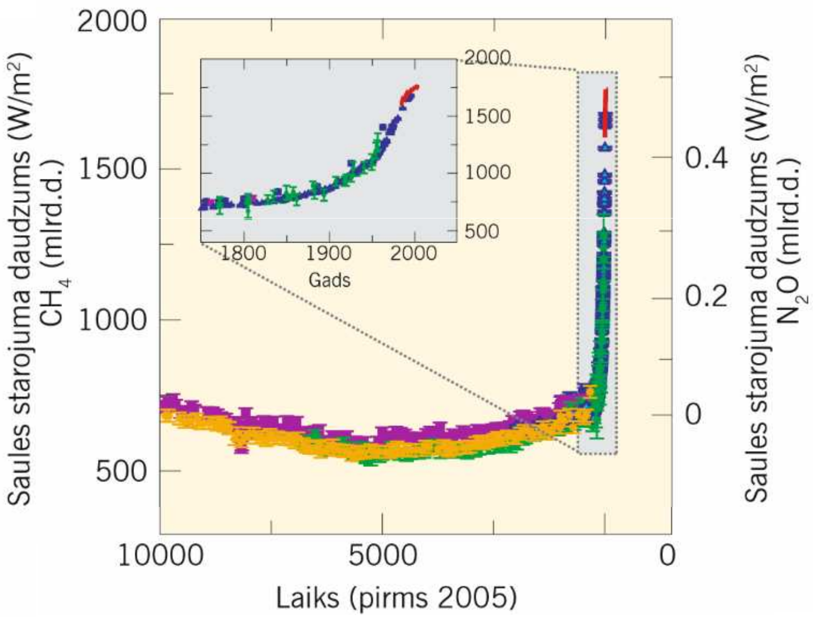
A global temperature rise of 1.5 ℃ above current le vels would be enough to start the thawing of permafrost in Siberia, according to of scientists.

Thickness of the active layer varies by year and location, but is typically 0.6–4 m thick. In areas of continuous permafrost and harsh winters, the depth of the permafrost can be as much as 1,493 m in the northern Lena and Yana river basins in Siberia.

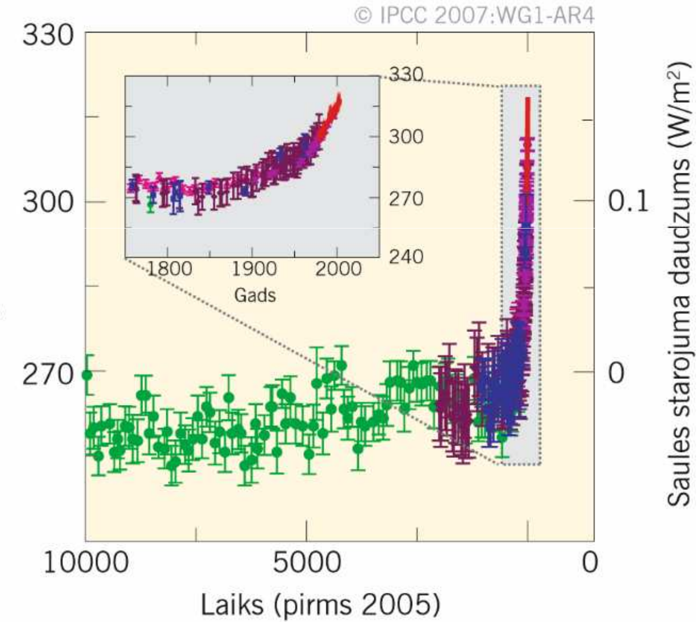
Changes in concentration of GHG’s and their impact on the amount of received solar radiation in the past 10,000 years



Carbon dioxide (CO_2)



Methane (CH_4)



Nitrogen (I) oxide (N_2O)

Various GHG's can differently affect the Earth's climate taking into account their ability to reflect infrared radiation, as well as due to their concentration in the atmosphere:

Potential impact of CO_2 on the Earth's climate is assessed as 1

Relative potential of methane is 11 years

For nitrogen (I) oxide N_2O – 270 years

For freon CF_3Cl – 3400 years

Over the past 10,000 years, but particularly over the last century, concentration of **three major greenhouse gases (CO_2, CH_4, N_2O)** in the Earth's atmosphere has increased significantly, and thereby, the amount of solar radiation which is returned back to the Earth's surface
has increased significantly

Thank you
for the attention!