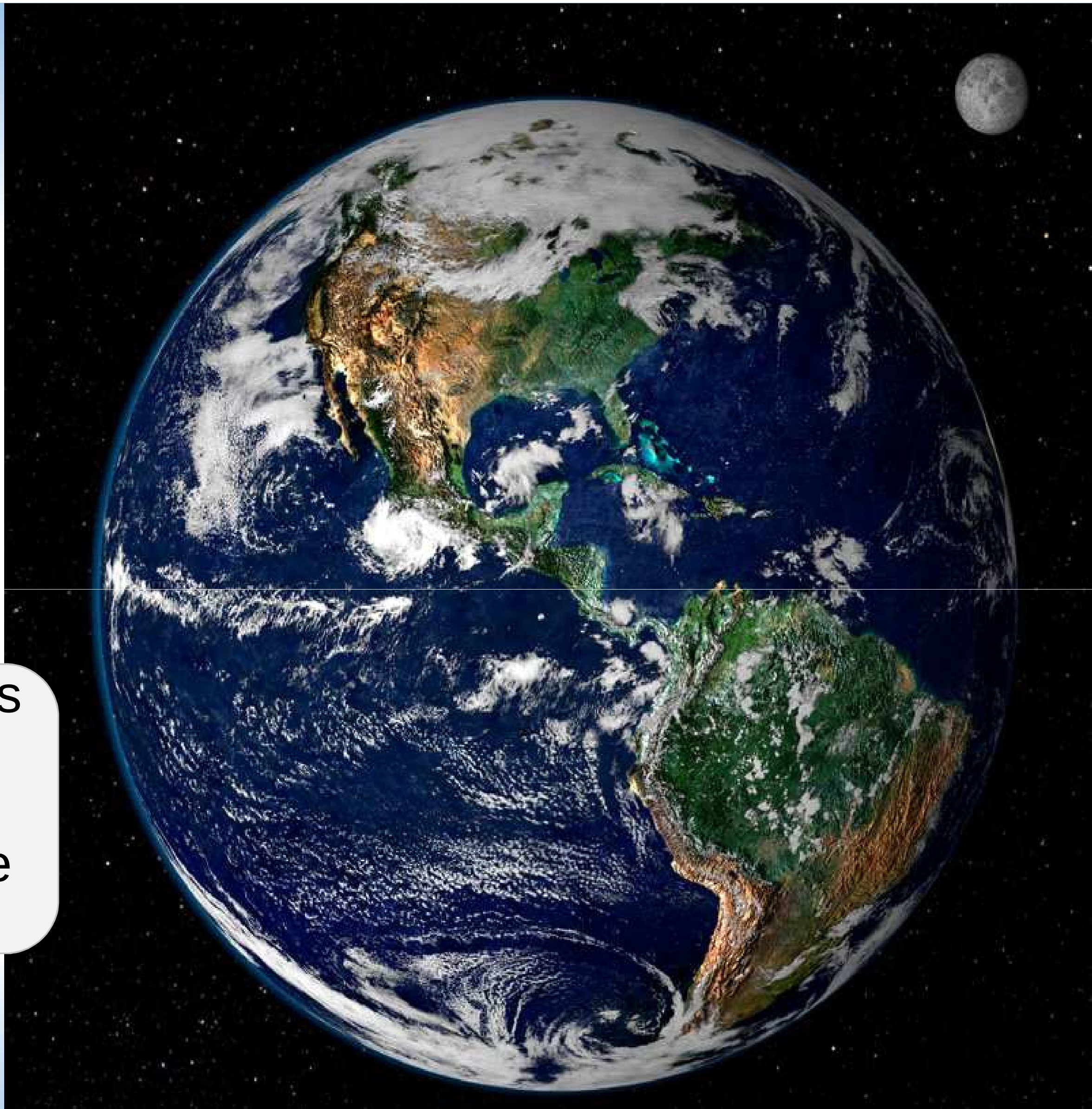
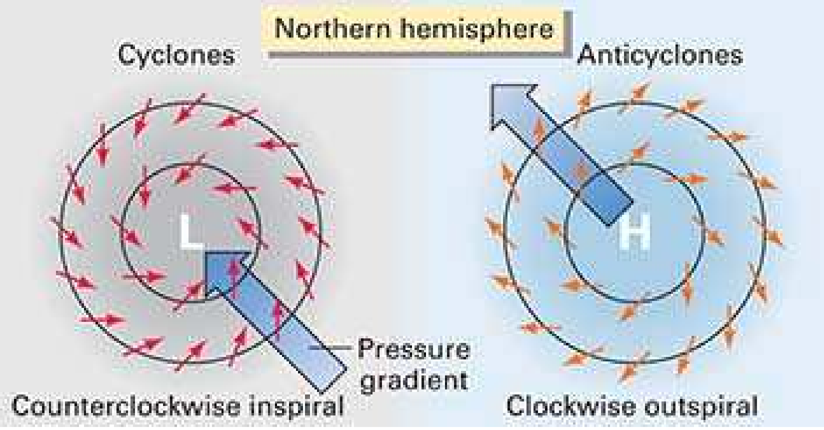
Climate variability and change

FACTORS INFLUENCING FORMATION OF THE EARTH'S CLIMATE

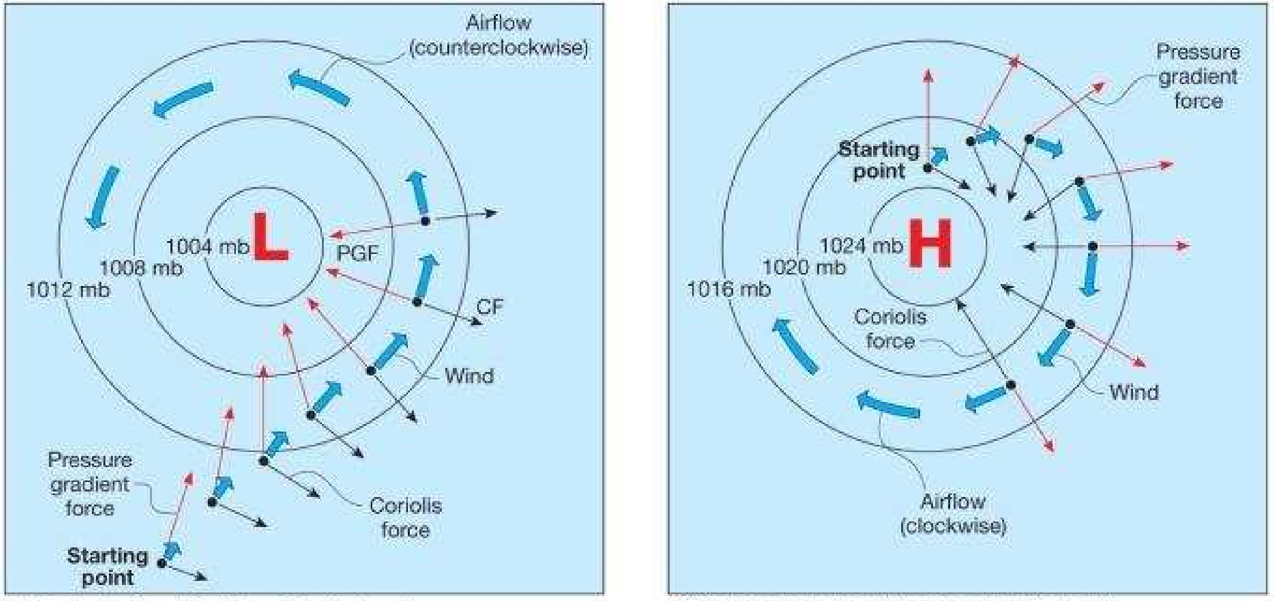
Daily weather, cyclones and anticyclones and the Earth's cloud cover heterogeneity and variability is clearly visible in the satellite photographs of the Earth



True-color image of North and South America as they appear from space 35,000 km above the Earth. October 17, 2000

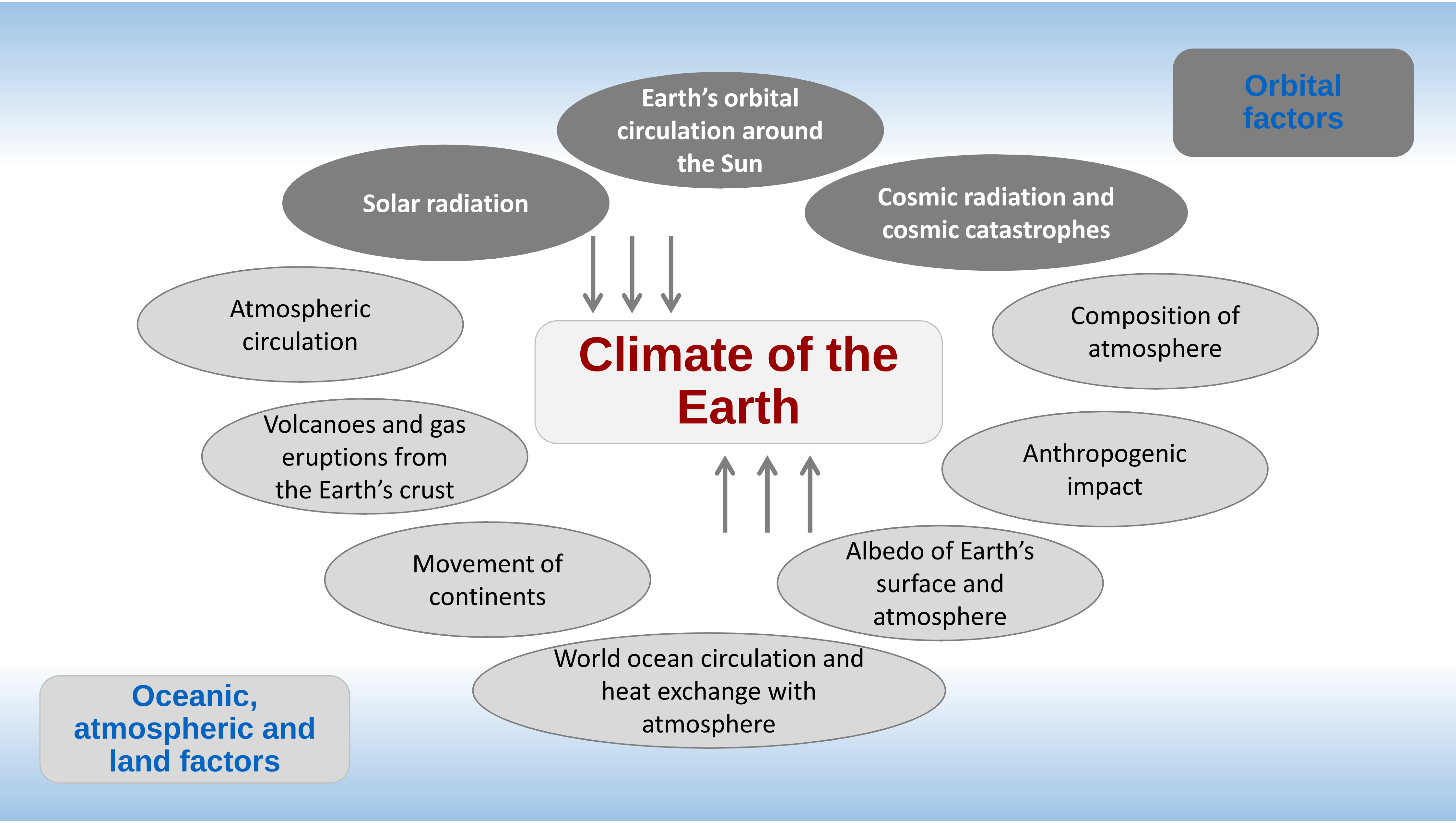


Cyclones and anticyclones in the Northern Hemisphere

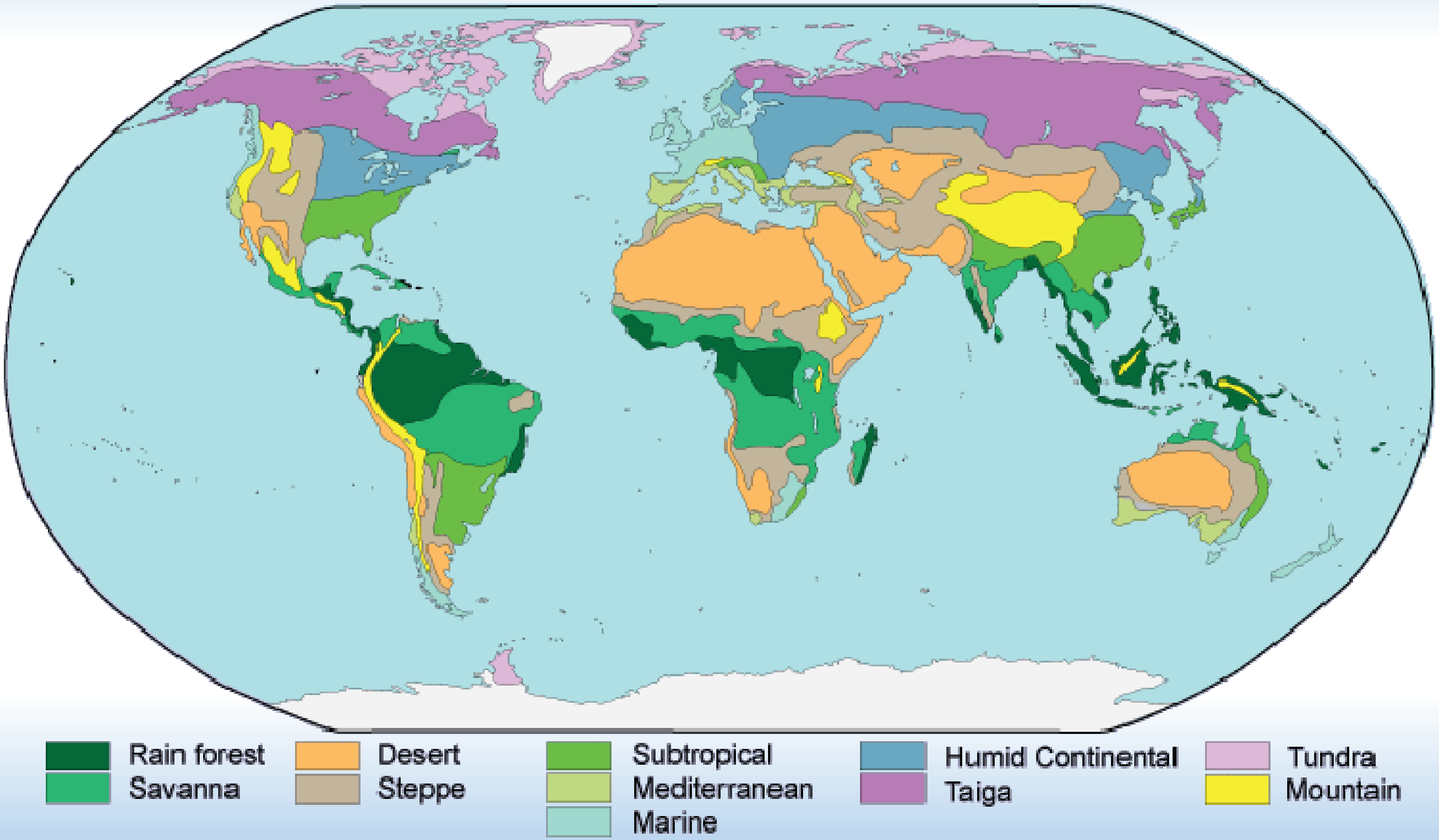


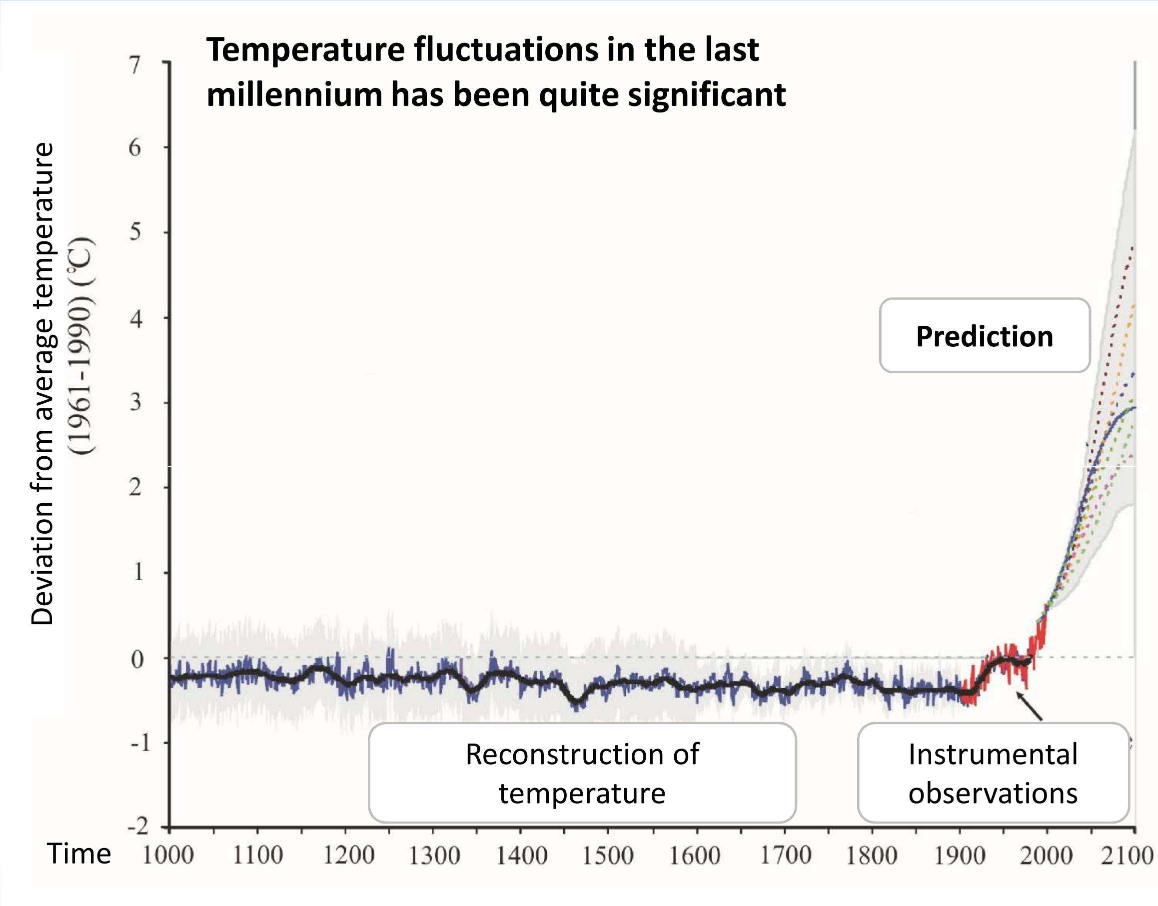
(a) Cyclonic flow (Northern Hemisphere)

(b) Anticyclonic flow (Northern Hemisphere)


Orbital factors
Earth's orbital circulation around the Sun
Solar radiation
Cosmic radiation and cosmic catastrophes
Atmospheric circulation
Climate of the Earth
Composition of atmosphere
Volcanoes and gas eruptions from the Earth's crust
Anthropogenic impact
Movement of continents
Albedo of Earth's surface and atmosphere
World ocean circulation and heat exchange with atmosphere
Oceanic, atmospheric and land factors

World climate map



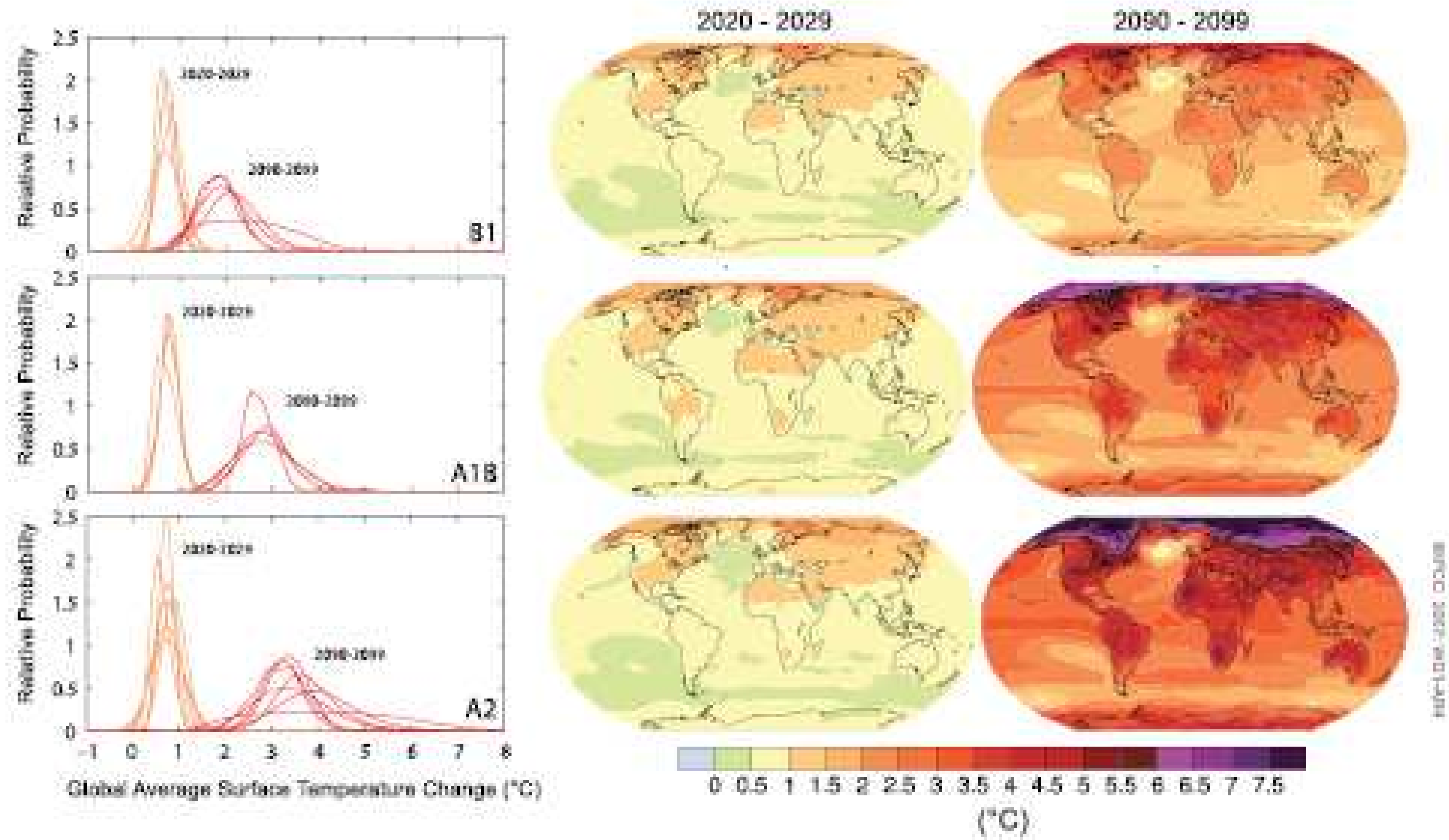


Based on forecasts, the temperature during the centenary may rise even faster

Temperature changes in the environment can be observed by studying:

- **Geological sediments**
- **Annual tree rings**
- **Glacier dynamics**
- **Speed of coral growth**
- **Proportion of stable oxygen isotopes ^{16}O and ^{18}O in glaciers boreholes**

Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999



The Earth's climate elements – **atmosphere, hydrosphere, lithosphere** and **biosphere** – are closely interrelated and interact mutually

Changes in one sphere may lead to a change in another, for example:

Earthquake can lift and expand the coastal zone by changing coastal marine environment

A powerful volcanic eruption can throw away a significant amount of lava and can block rivers by changing their run-off system, as well as generate increase of aerosol concentration in the atmosphere, which in its turn can affect global temperatures even over several years

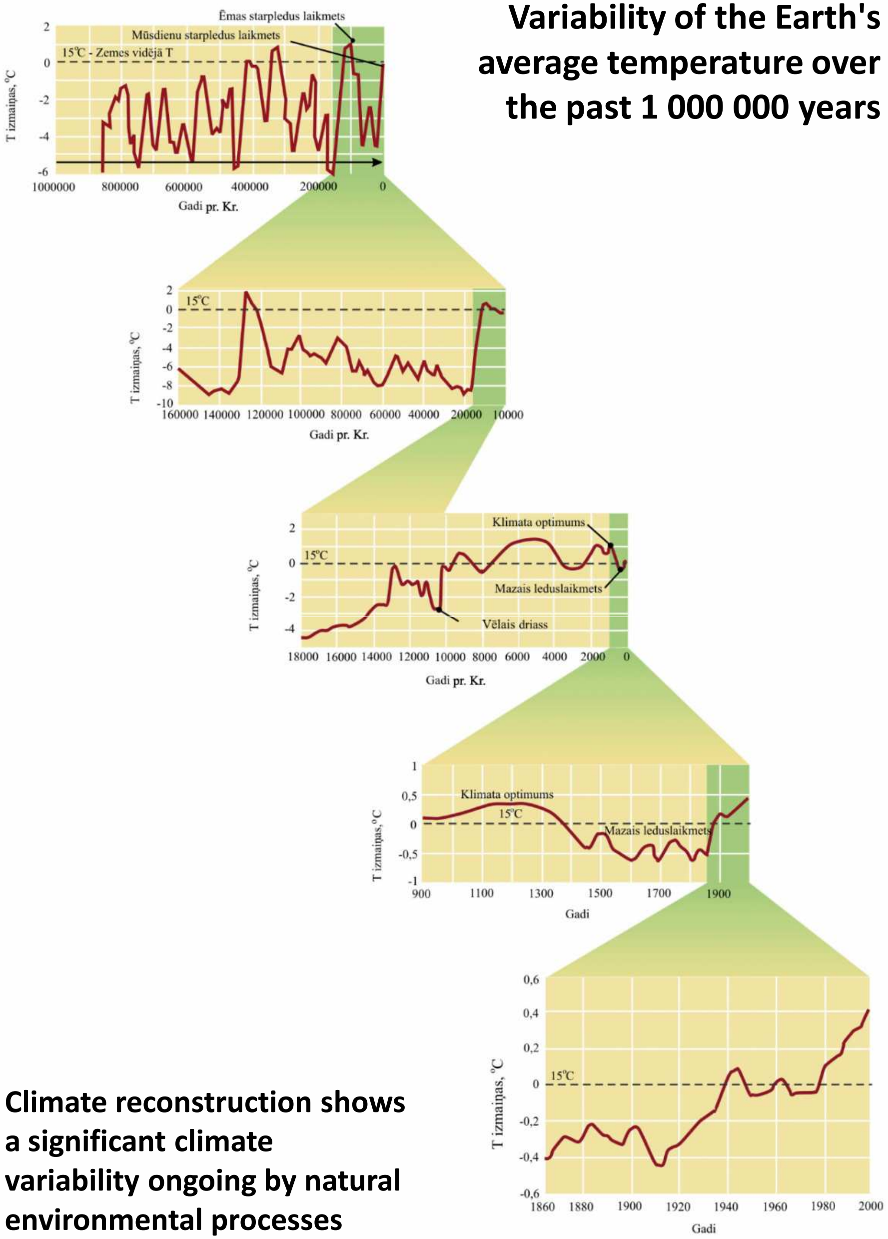
For exploration of climate variability in its nature **direct air temperature measurements and other atmospheric observations** can be used that allows to assess general climate phenomena of the last centuries in Europe

Direct temperature measurements can be compared with hydro-meteorological phenomena observations: beginning of the ice cover in rivers, water freezing time in lakes, floods etc.

Climate is characterized by considerable **natural variability**:

Relatively climate optimum periods (e.g., in North Europe around year 1000) interchange with cooler periods (e.g., so called «Little Ice Age» in North Europe between years 1400-1750)

Variability of the Earth's average temperature over the past 1 000 000 years



Climate reconstruction shows a significant climate variability ongoing by natural environmental processes

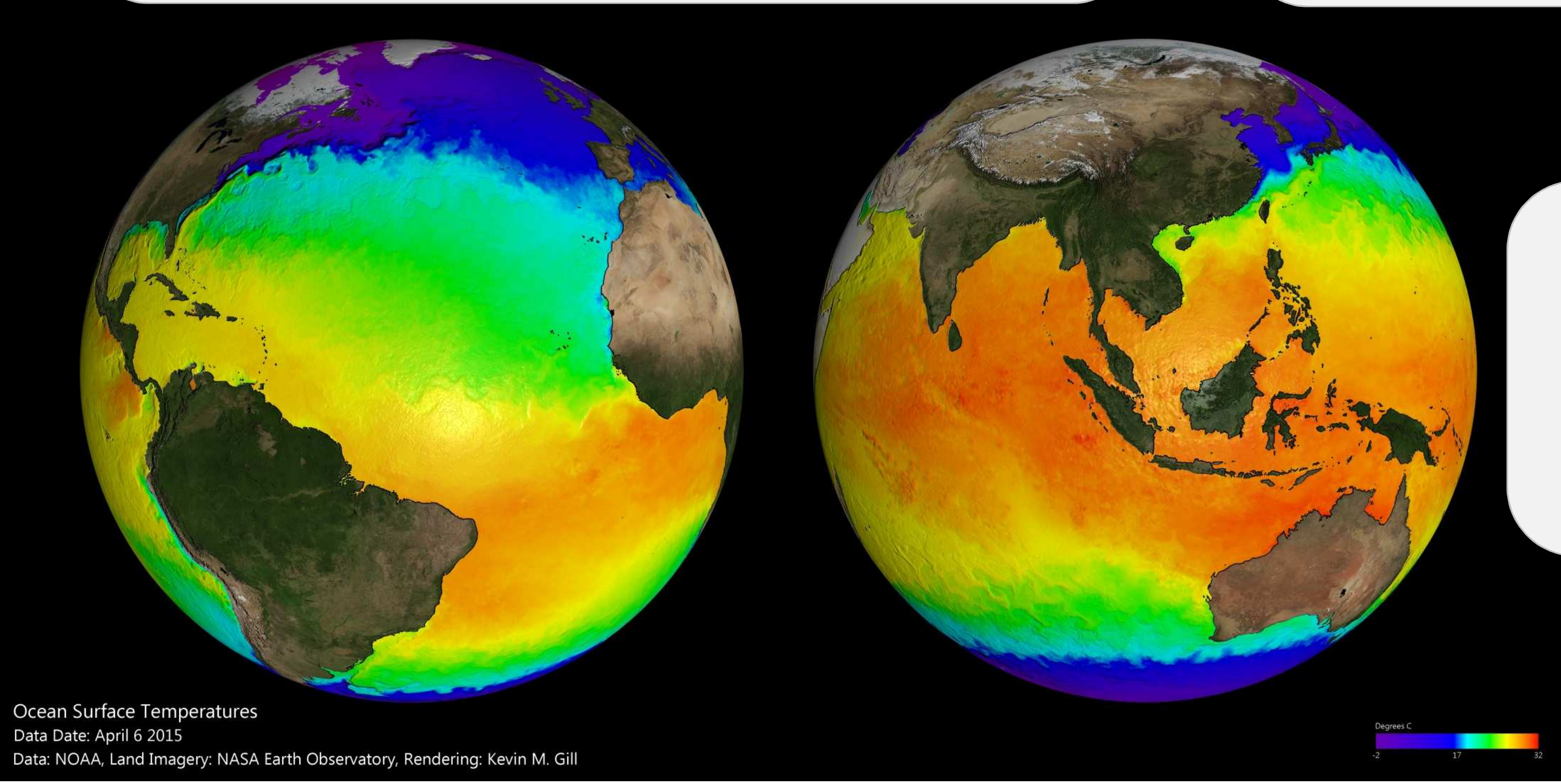
It is possible to analyze climate variability in longer periods through glaciers composition analysis:

Glacier ice (in mountains, Greenland, Antarctica) is formed by icepack mass and its age may reach several hundreds of thousands or even exceed millions of years

By analyzing ice gas composition, it is possible to reconstruct the atmospheric chemical composition and the climatic conditions that existed during the formation of glaciers

Comparing the climatic conditions that have prevalent in most of geologic time, it can be concluded that the average temperature **has been about 10 ºC higher** than in the last 2 million years

Temperature decrease trend began about 40 million years ago and culminated during the Pleistocene ice age



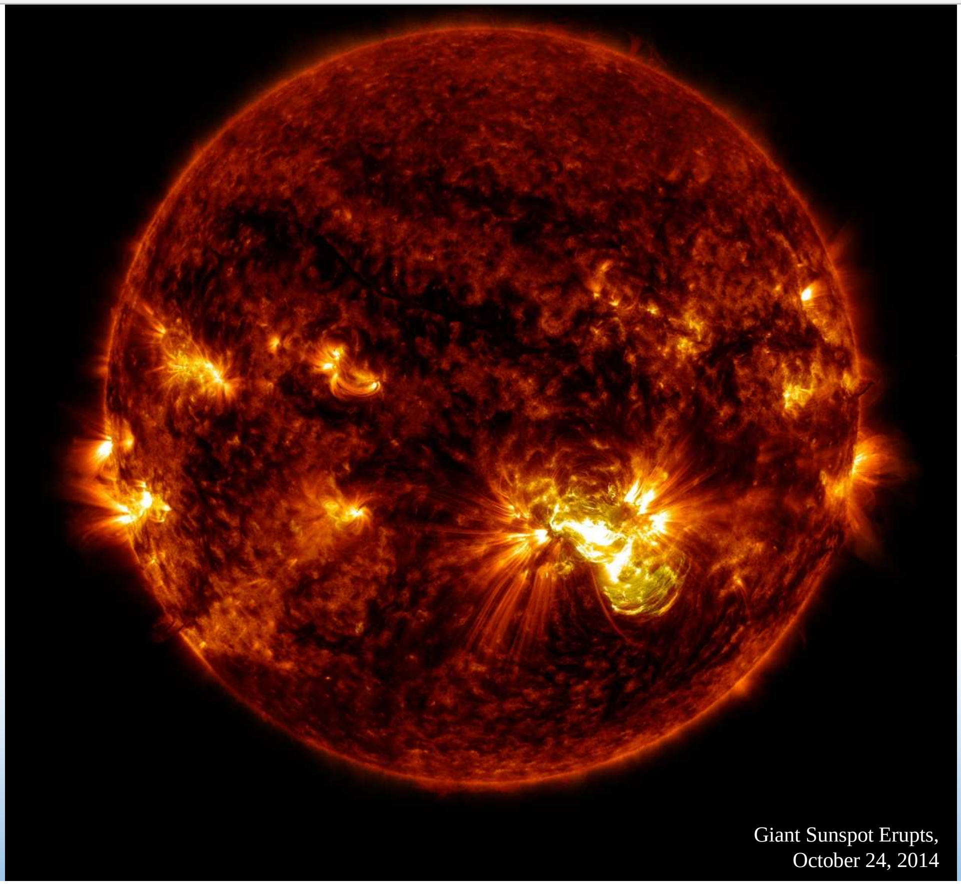
Character of the Earth’s climate variability confirms great impact of naturally ongoing process

IMPACT OF SOLAR RADIATION AND COSMIC RADIATION VARIABILITY ON THE EARTH’S CLIMATE

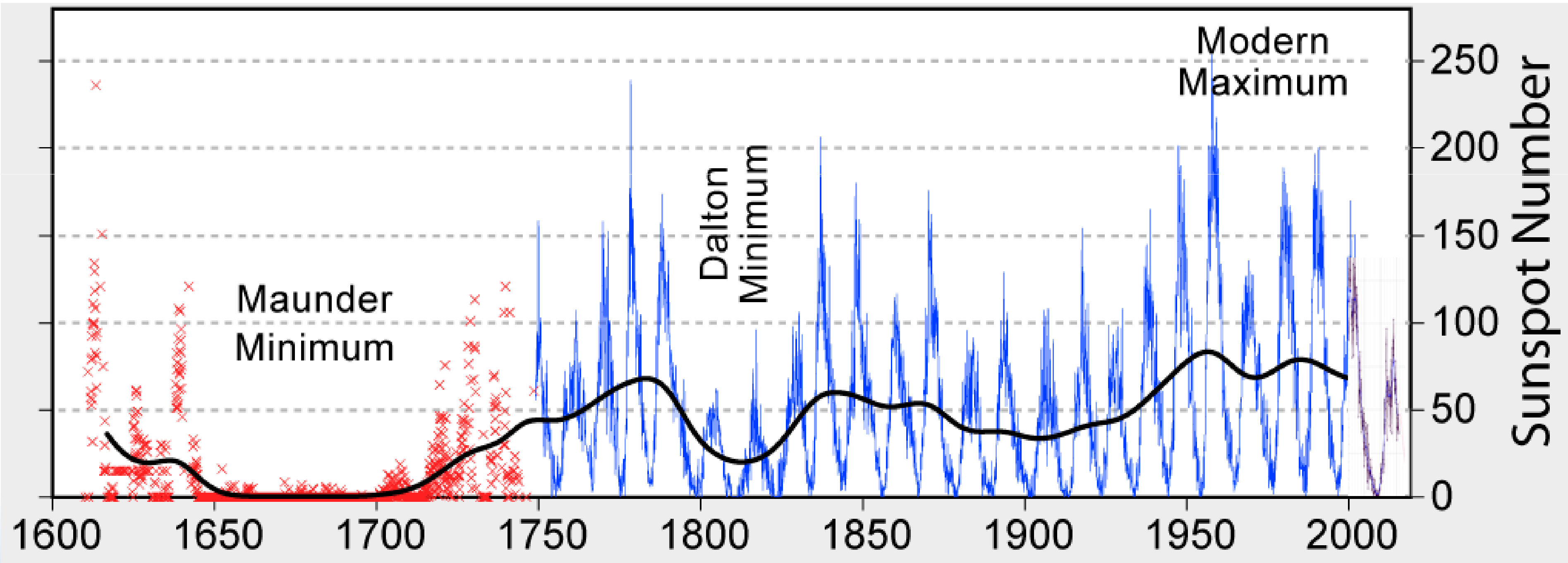
The climate is integral designation of weather characteristic for a certain period of time and therefore depending on the solar activity

The best-known characterizing processes of solar activity are **«solar spots»**:

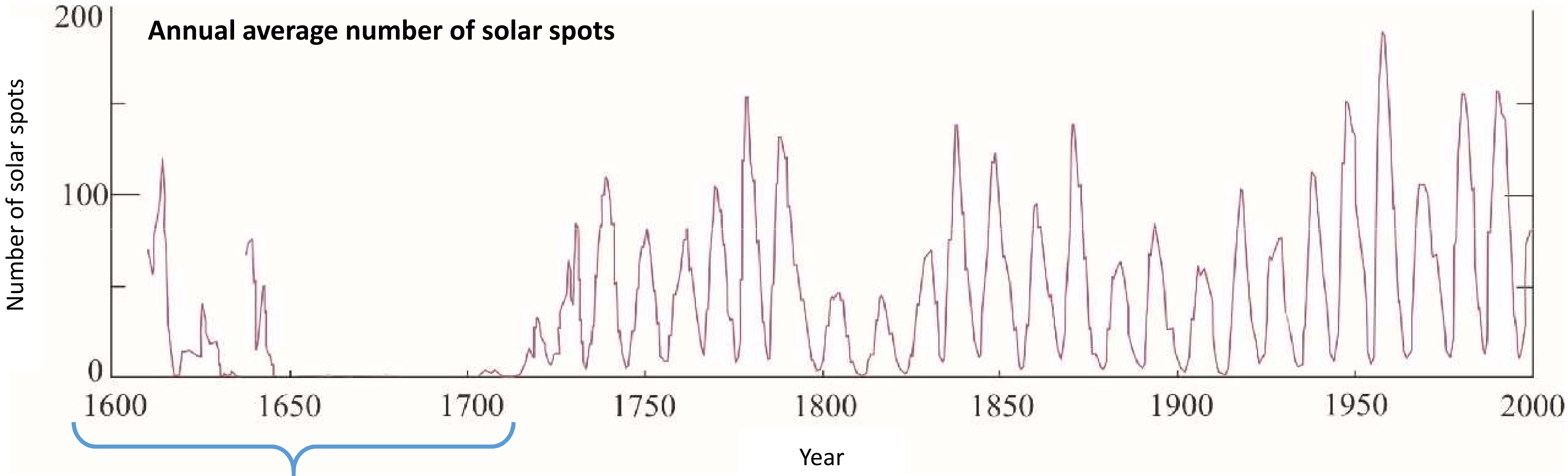
The formation of dark spots on the Sun, which are characterized by 11, 36 and 180 years relapse cycles



400 years of sunspot observations

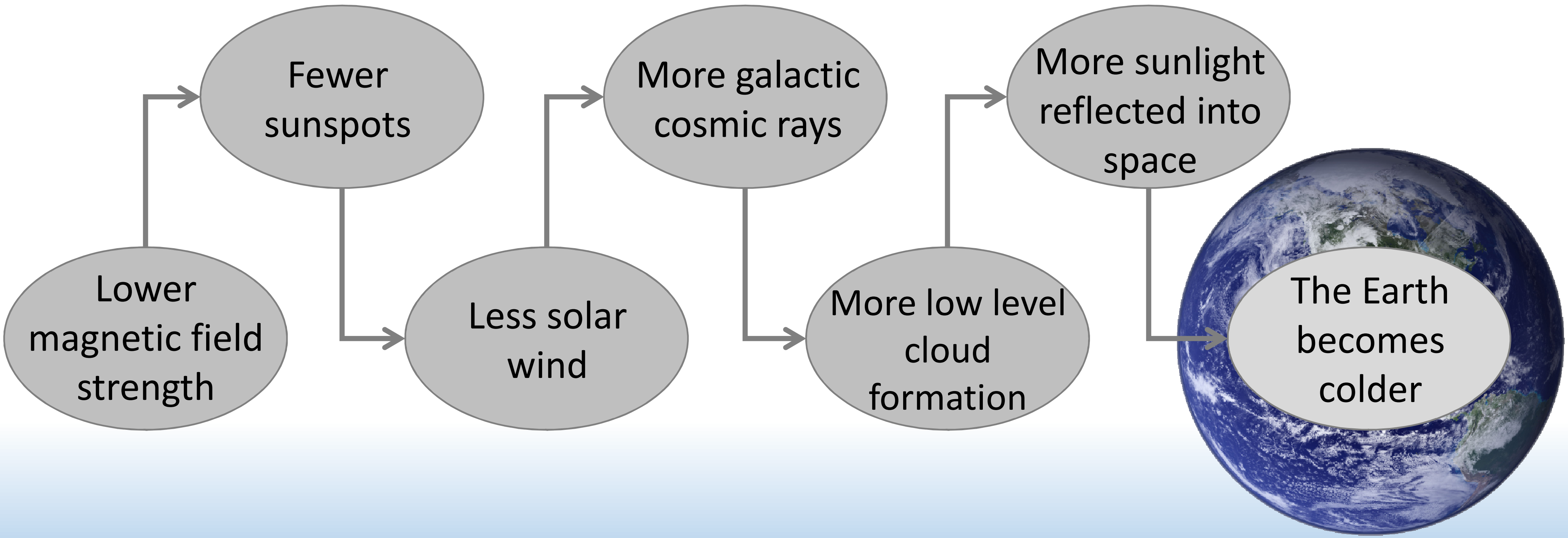


By increasing the number of solar spots, the Earth receives a larger amount of electromagnetic radiation and ionized particles flow



At the time of decreased solar activity (years 1400-1700), on the Earth started so-called Little Ice Age – in the North America, Europe and other parts of the Earth the climate became colder

The solar radiation and the Earth's climate relationship



The climate can be significantly affected by the variability of **cosmic radiation**:

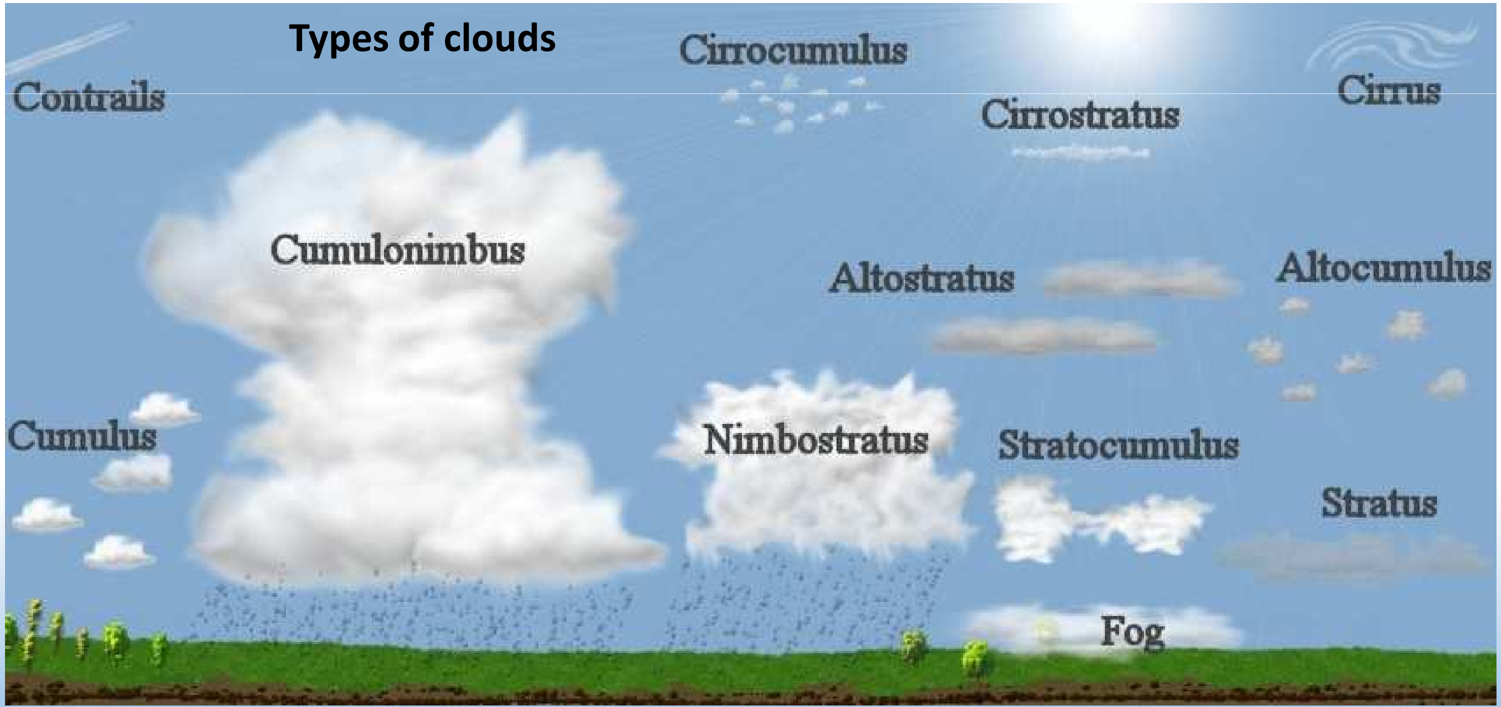
Cosmic radiation have certain impact on formation of aerosols and cloud cover in the upper layers of the atmosphere

It is considered that the cosmic radiation has a large impact on the amount of cloud formation in the atmosphere:

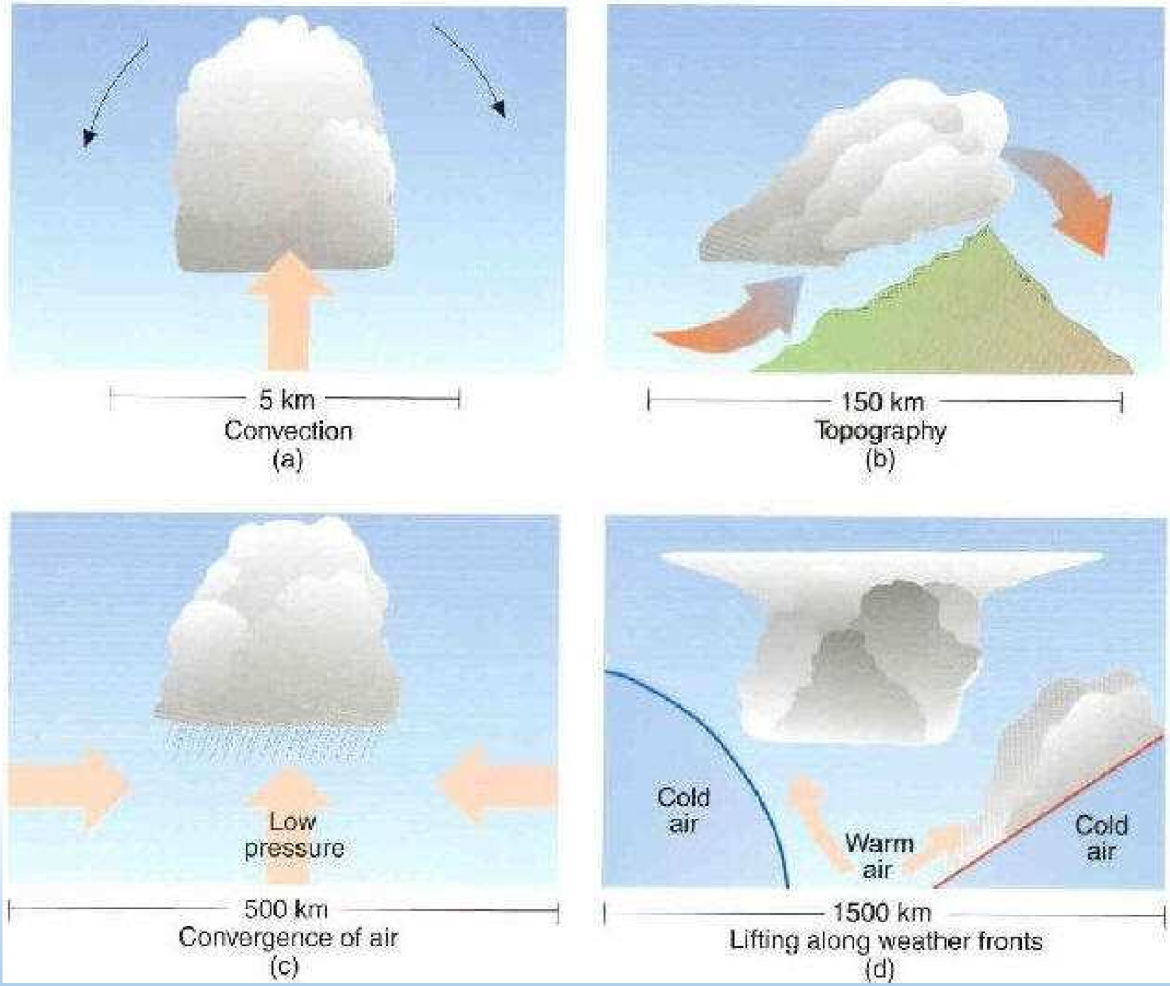
As the cover of clouds reflects a large part of solar radiation, then the amount of clouds largely determines the warmth (air temperature) on the Earth

Clouds are formed by the condensation of water vapour in the atmosphere, and as condensation centers can act ionized particles, which are sourced by both, solar radiation and cosmic radiation

In turn, the Earth's magnetic field intensity affects how large part of the ionised solar particles and cosmic radiation reaches the Earth’s atmosphere



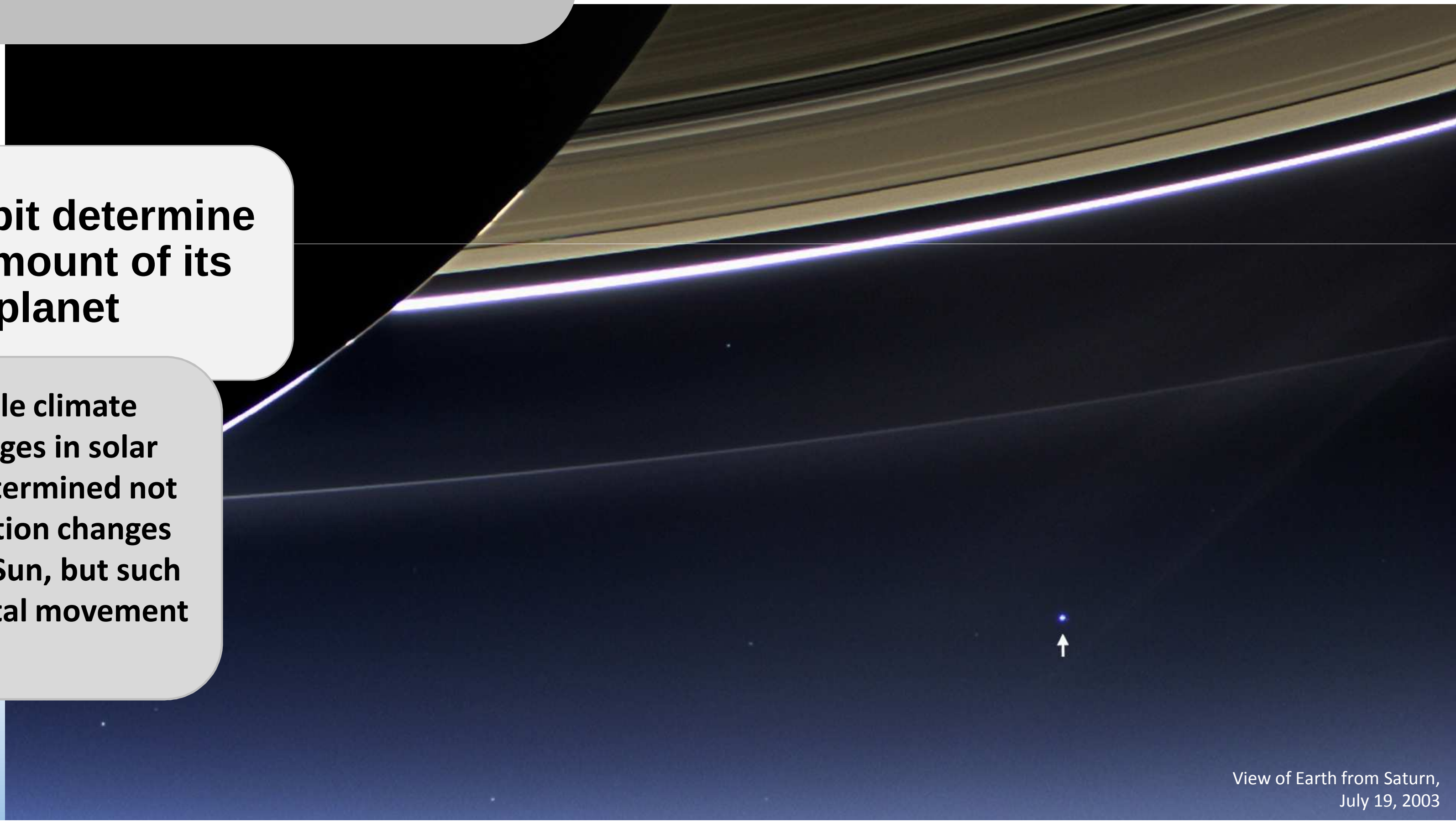
Cloud formation process



THE EARTH'S ORBITAL AND ROTATION MOVEMENT CHANGES

Changes in the Earth's orbit determine solar radiation and the amount of its distribution on the planet

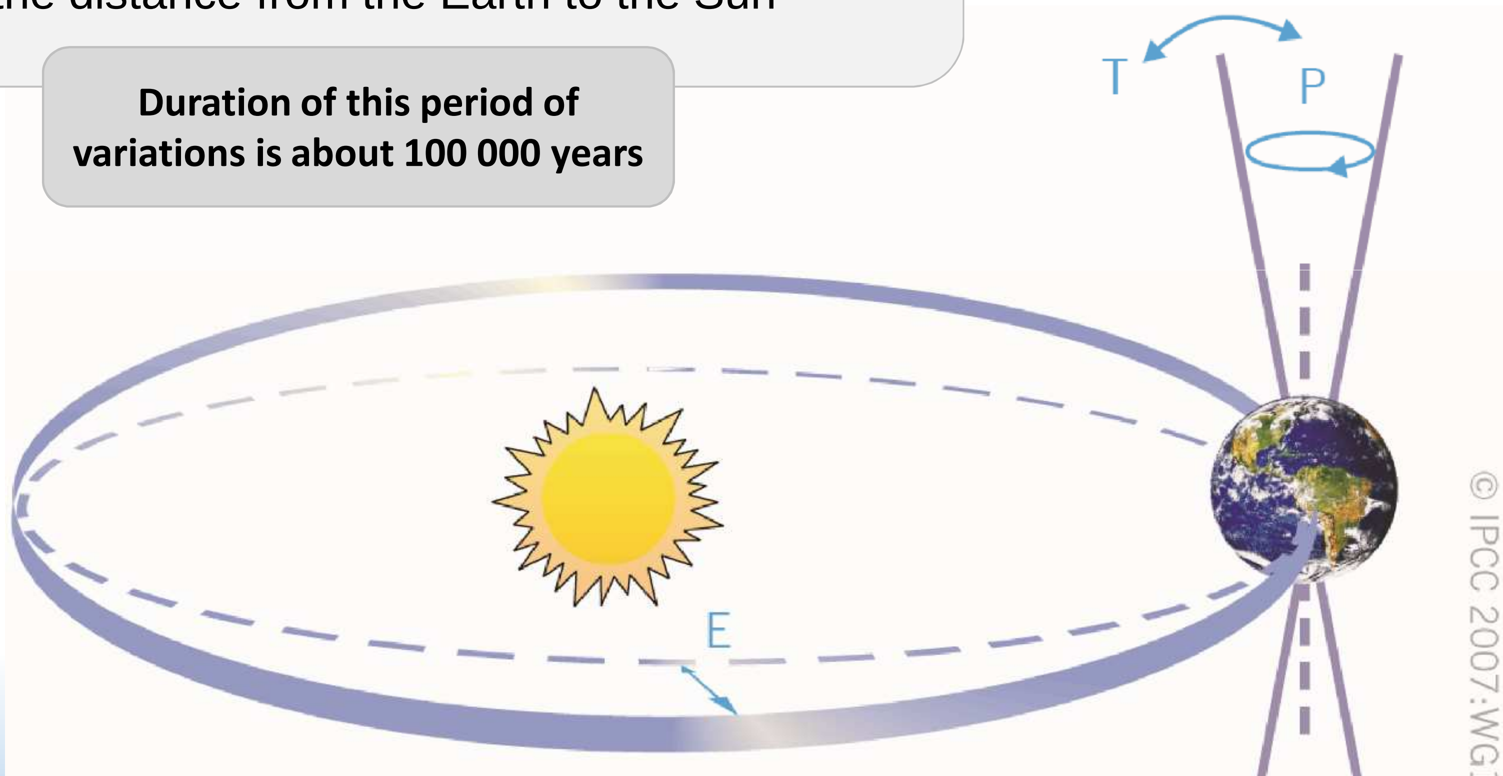
Consequently, periodic multiple climate variability associated with changes in solar radiation intensity, which are determined not so much by the amount of radiation changes that the Earth receives from the Sun, but such as the changes in the Earth's orbital movement around the Sun



View of Earth from Saturn, July 19, 2003

Firstly, the subject of variations is the type of the Earth’s orbital - **ellipse eccentricity**, i.e., the changes in the distance from the Earth to the Sun

Duration of this period of variations is about 100 000 years



Character of the Earth’s orbital movement around the Sun (E), the Earth's rotation around its axis and its position (T, P)

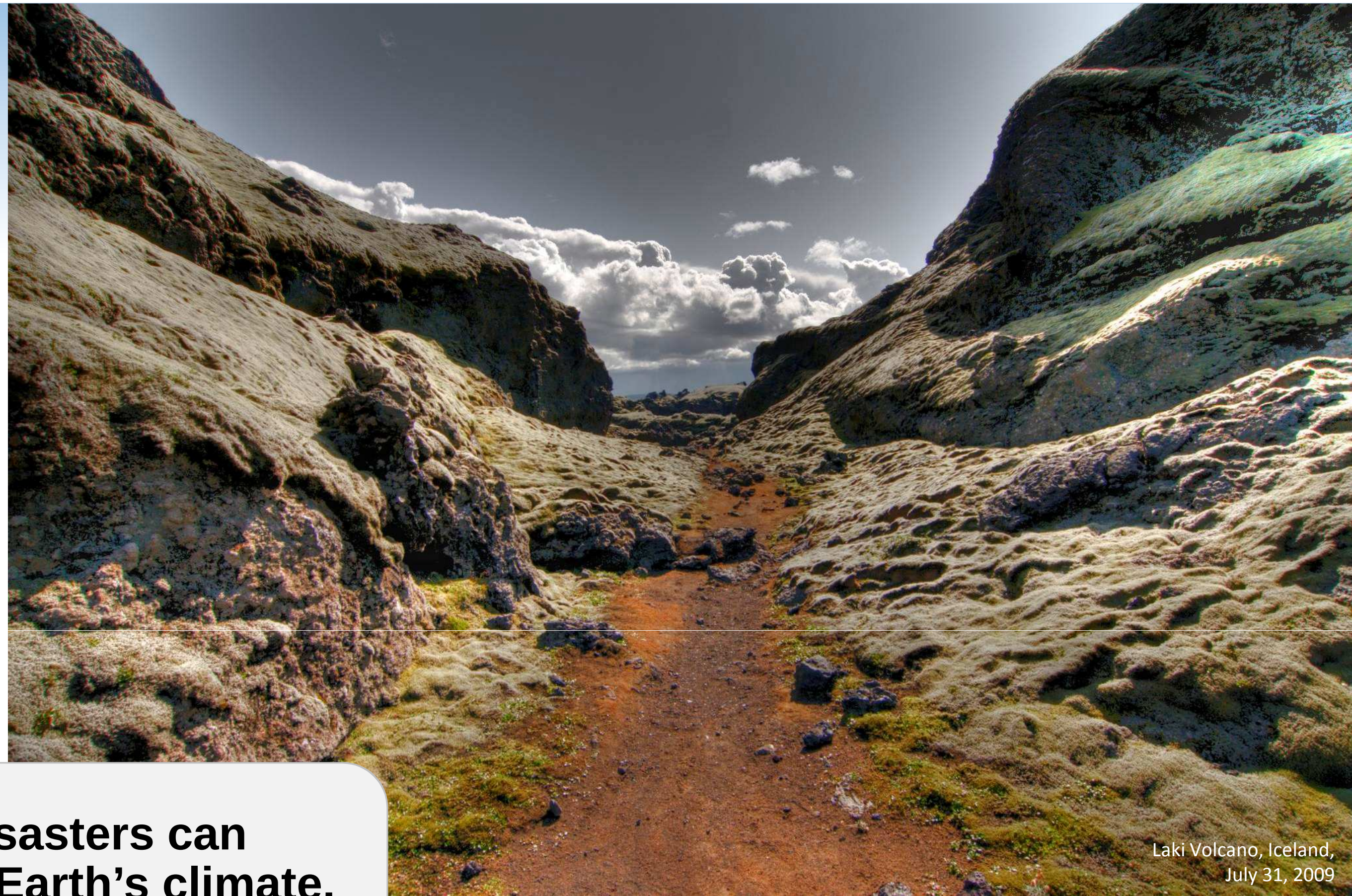
By changing the Earth's rotation around the Sun and its axis position, appear substantial changes in the distribution of solar radiation on the Earth and its changes during the year

These changes particularly affect the Earth's polar regions

Turnover of ice ages correlate with corresponding changes in atmospheric carbon dioxide concentration

According to estimates, an ice age may occur every 50 000 years

GEOLOGICAL AND COSMIC DISASTER



Laki Volcano, Iceland,
July 31, 2009

Various types of disasters can significantly effect the Earth's climate, although it seems that they are rare

Already Benjamin Franklin have noted that volcanic eruptions can influence climate, and he considered that cold winter in Europe in 1783-1784 was provoked by Laki volcanic eruption in Iceland in July of 1783

During the volcanic eruption, dust particles as well as sulfur compounds, mainly sulfur dioxide, are released into the atmosphere and may reach the stratosphere (even at height of 15-50 km)

In the upper layers of atmosphere, dust particles can persist for a long time (up to several years or decades), and they can be dissipated throughout the Earth's atmosphere

Presence of dust and aerosols in the atmosphere determine that a large proportion of solar radiation is reflected into space, and thus the amount of heat reaching the Earth's surface is reduced

Sky with volcanic dust, April 19, 2010

Irruputuncu Volcano, from Collahuasi mine site, North Chile, August 31, 2010

Detailed research have been done on consequences of volcanic eruptions occurring in the last 50 years, for example:

Eruption of the Pinatubo volcano (in Philippines) during 1991, released into the atmosphere 20 million tons of dust and a considerable amount of sulfur compounds

It is estimated that this volcanic eruption reduced the amount of solar energy reaching the Earth by 3-4 W/m^2

It led to decrease of the Earth's temperature, and the consequences of the volcanic eruption affected the Earth's temperature for 2-3 years after the disaster

Tambora crater rim,
Indonesia, June 14, 2008

It is estimated that during the eruption of the Tambora volcano (in Indonesia) in 1815, into the atmosphere were released dozens of times greater amount of dust and aerosols than during the Pinatubo volcanic eruption –

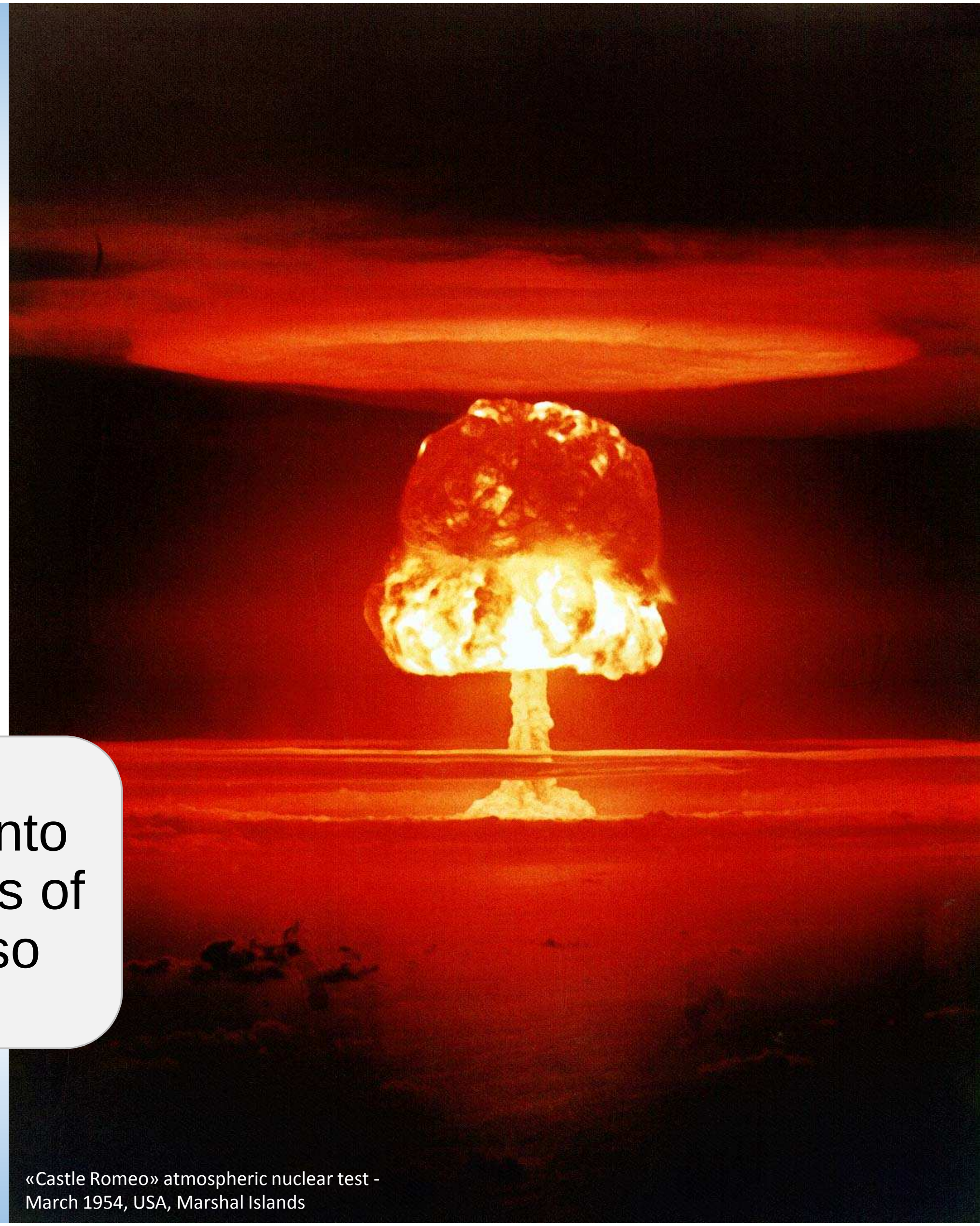
Because of that, year 1816 is described as «the year without summer», when late frost (in June) destroyed the crop yields, but the summer in a large part of Europe was unusually short and cold

It is conceded that much more powerful eruptions (such as those before 73 000 years) could cause the Ice Age

Also cosmic catastrophes can have a major impact on the Earth's climate –

It applies equally to the consequences of falling meteors and comets as well as to the effects of cosmic dust

Nowadays modeling of climate change has proved that even a nuclear war during which into the atmosphere will be released large amounts of radioactive dust, can lead to similar effect – so called, **nuclear winter**



«Castle Romeo» atmospheric nuclear test - March 1954, USA, Marshal Islands

TURNOVER OF OCEAN WATER'S STREAMS

From global ocean surface on average 420 thousands km^3 of water evaporates a year, that corresponds to about 1.25 m thick water layer

Evaluating the buffer impact of the global ocean on the Earth's climate, the amount of heat that is released or bound at change of physical state of water should be taken into account –

water evaporation and ice melting heat (so-called latent heat)

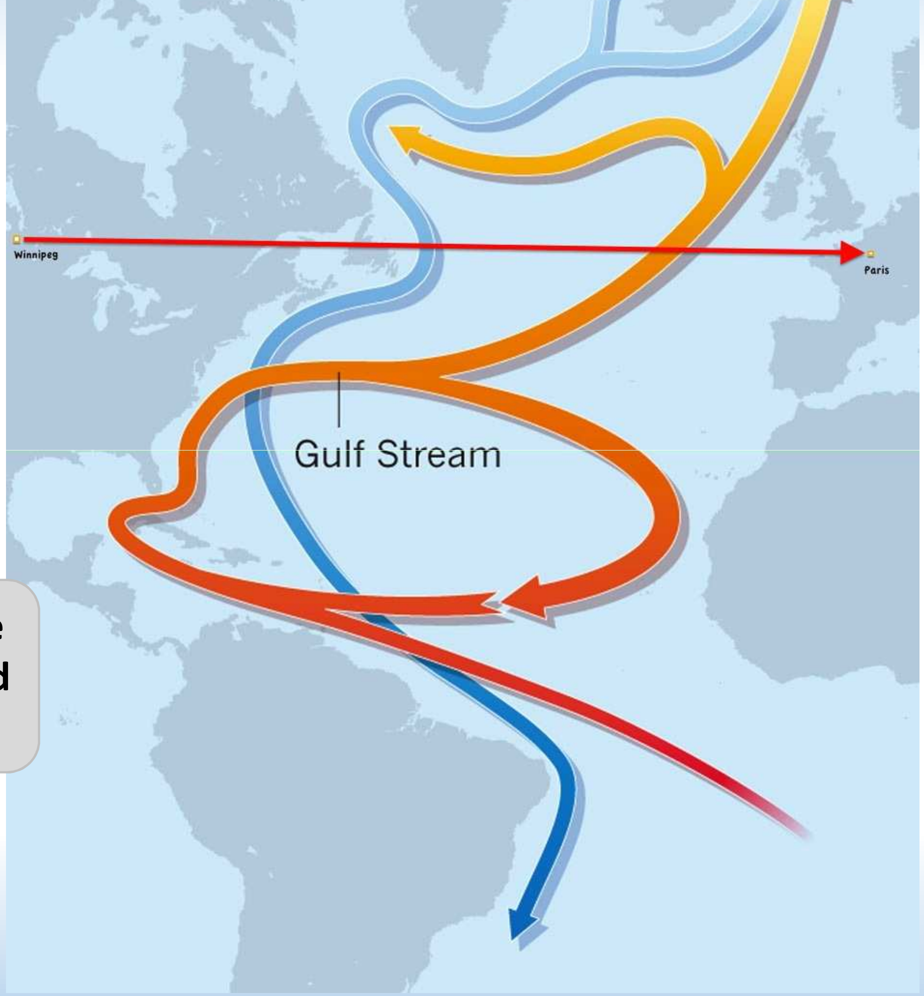
Global ocean makes even not only temporal changes in temperature, but also reduces climate contrasts among different zones and regions

Streams on the top layer of the ocean originate from the interaction of wind and the Earth’s rotation force (the so called Coriolis force) –

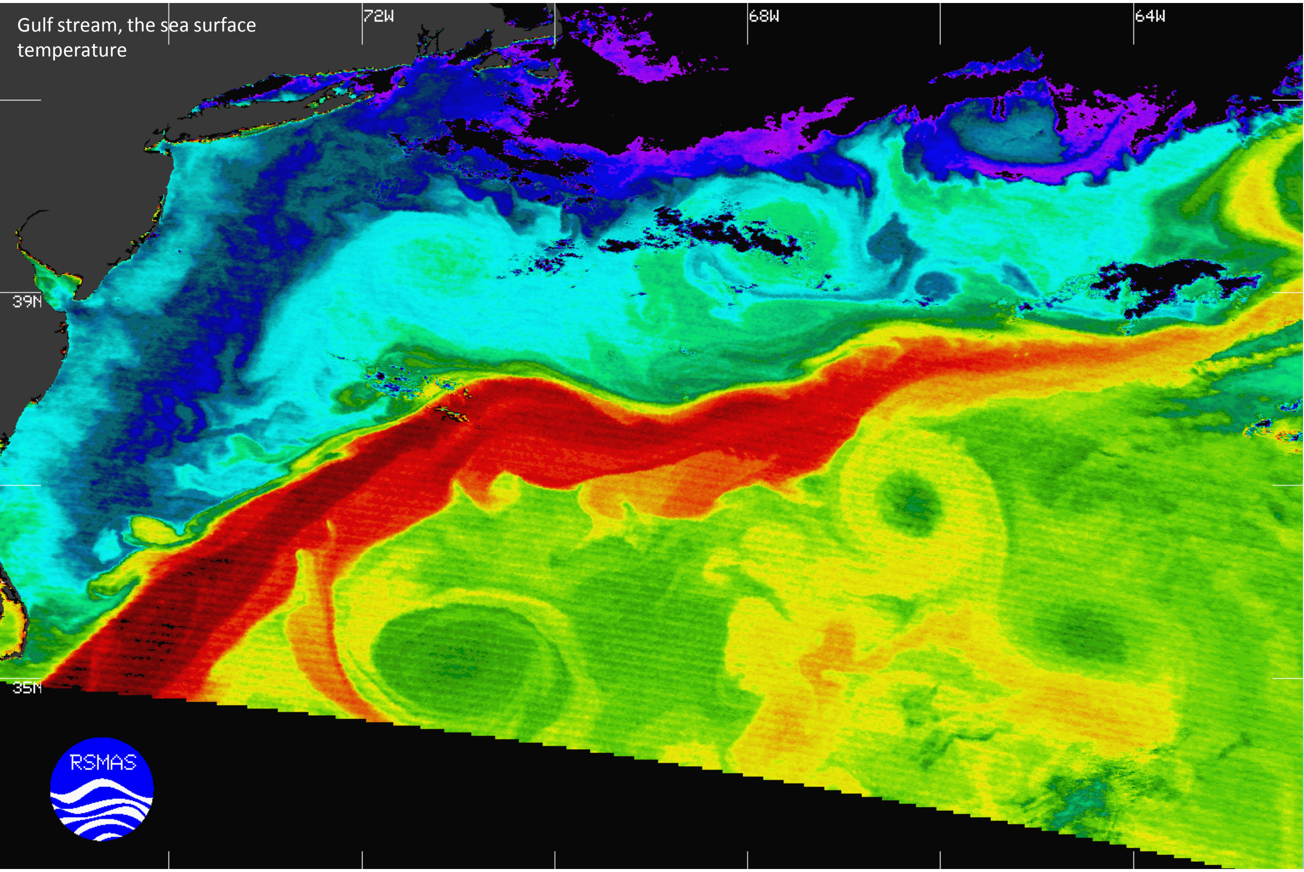
Warm surface streams of the global ocean with water move also huge amount of thermal energy from tropical regions to temperate and cold climatic zones, making much milder climate in vast of the land

By contrast, cold streams makes cooler the tropical areas

Gulf Stream and the North Atlantic circulation



Widely known (and also the most impressive by flow rate) is **the warm Gulf Stream** and its continuation – **the North Atlantic stream** in the Atlantic Ocean and **the Kuroshio stream** in the Pacific Ocean



Gulf stream, the sea surface temperature

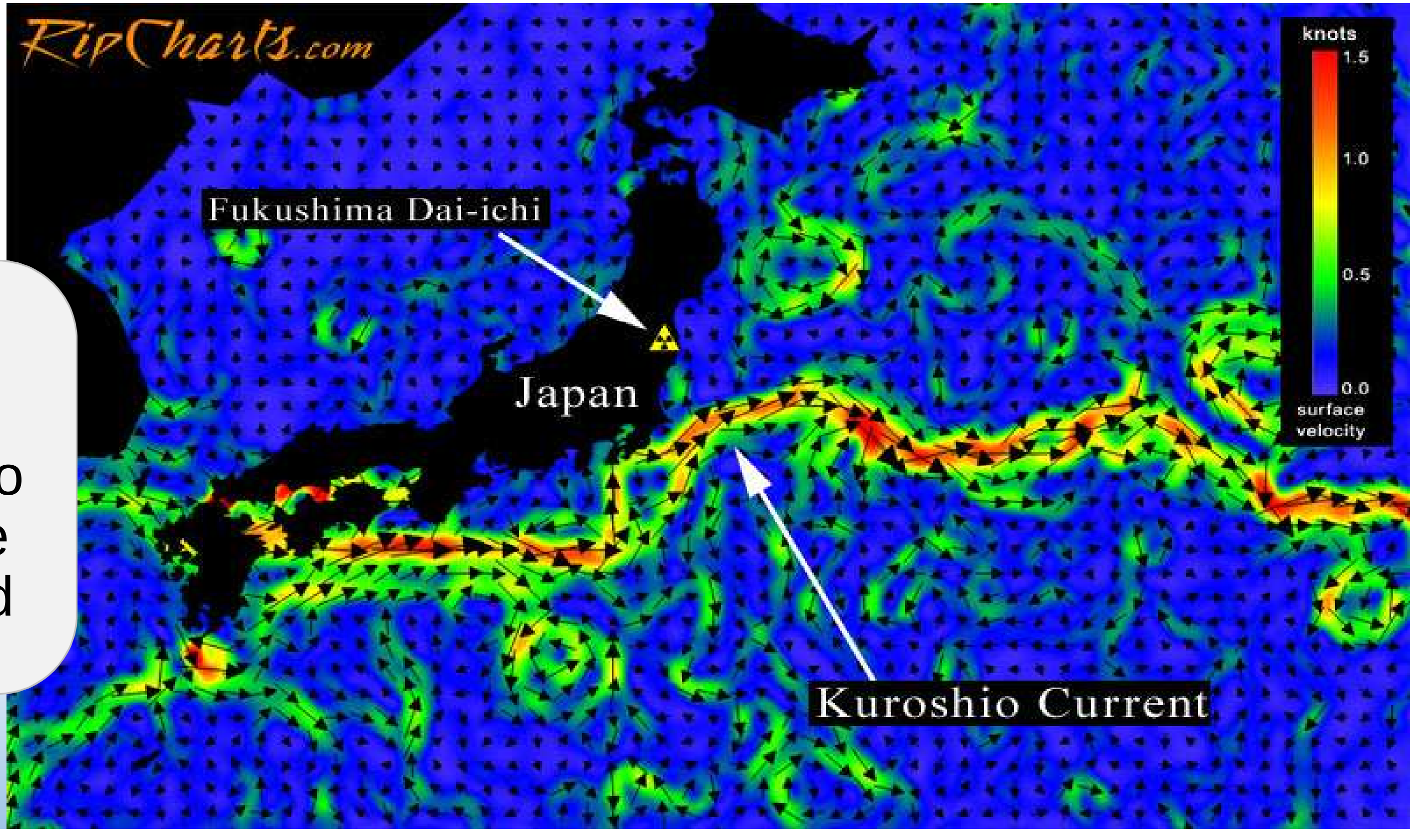
The Gulf stream, which begins to flow in the Gulf of Mexico, usually is 80-150 km wide and 800-1200 m deep; greatest velocity of the stream is on the top layer of the ocean – about 2.5 m/s (9 km/h; ~ 215 km/d)

Gradually releasing its heat to the atmosphere, the Gulf stream flows along the coast of North America, but its continuation – the North Atlantic stream and Norwegian stream – along the coast of North Europe

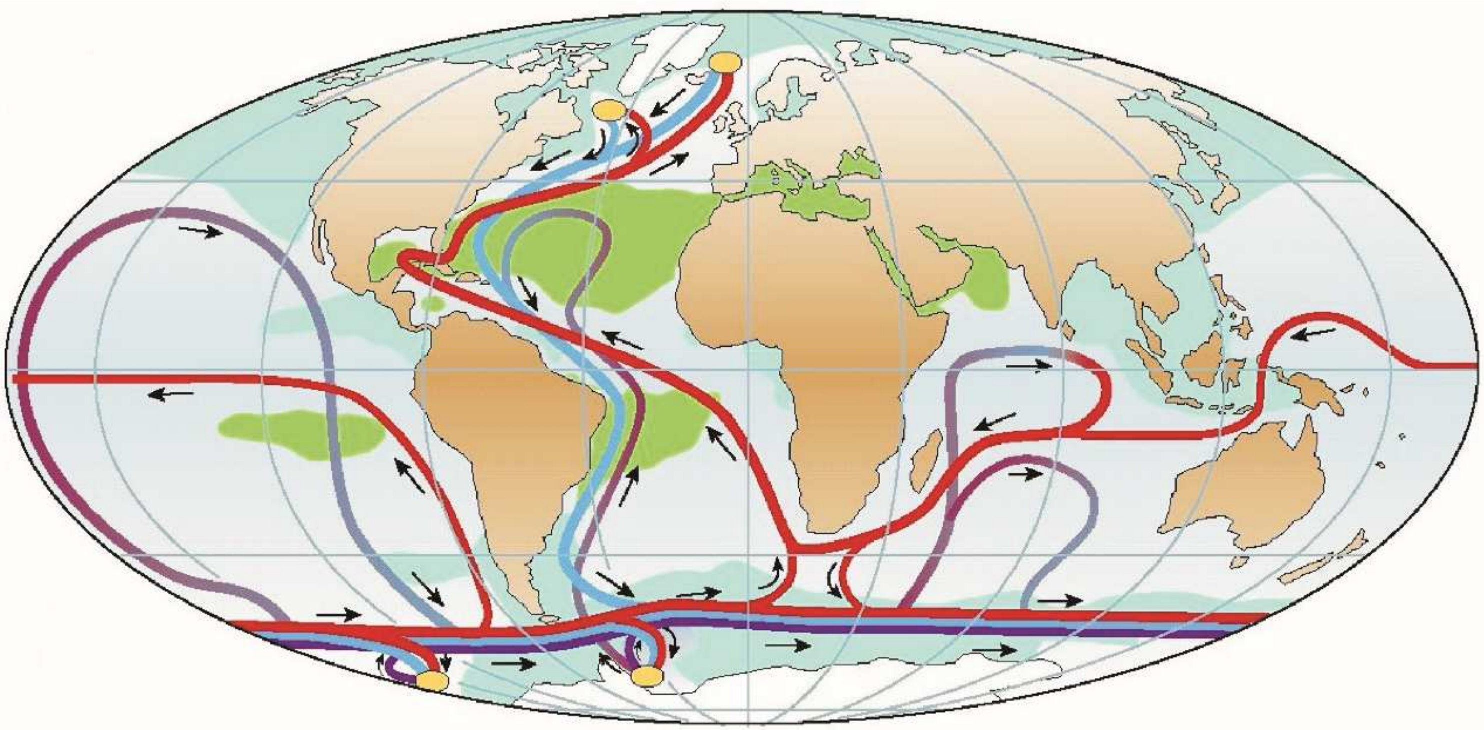
Kuroshio stream begins to flow near Taiwan and flows north-easterly along the eastern edge of the Japanese archipelago

It is considered that due to the Kuroshio stream the climate of the Japanese islands is much milder than it should be according to the geographical location

The Kuroshio stream significantly affects biological productivity of sea providing rich of fish catches, and due to the warm stream's waters the world's most northerly located coral reefs may exist



The water from bottom layers returns to the top layer when it reaches the northern shelf slopes of the Indian and Pacific oceans



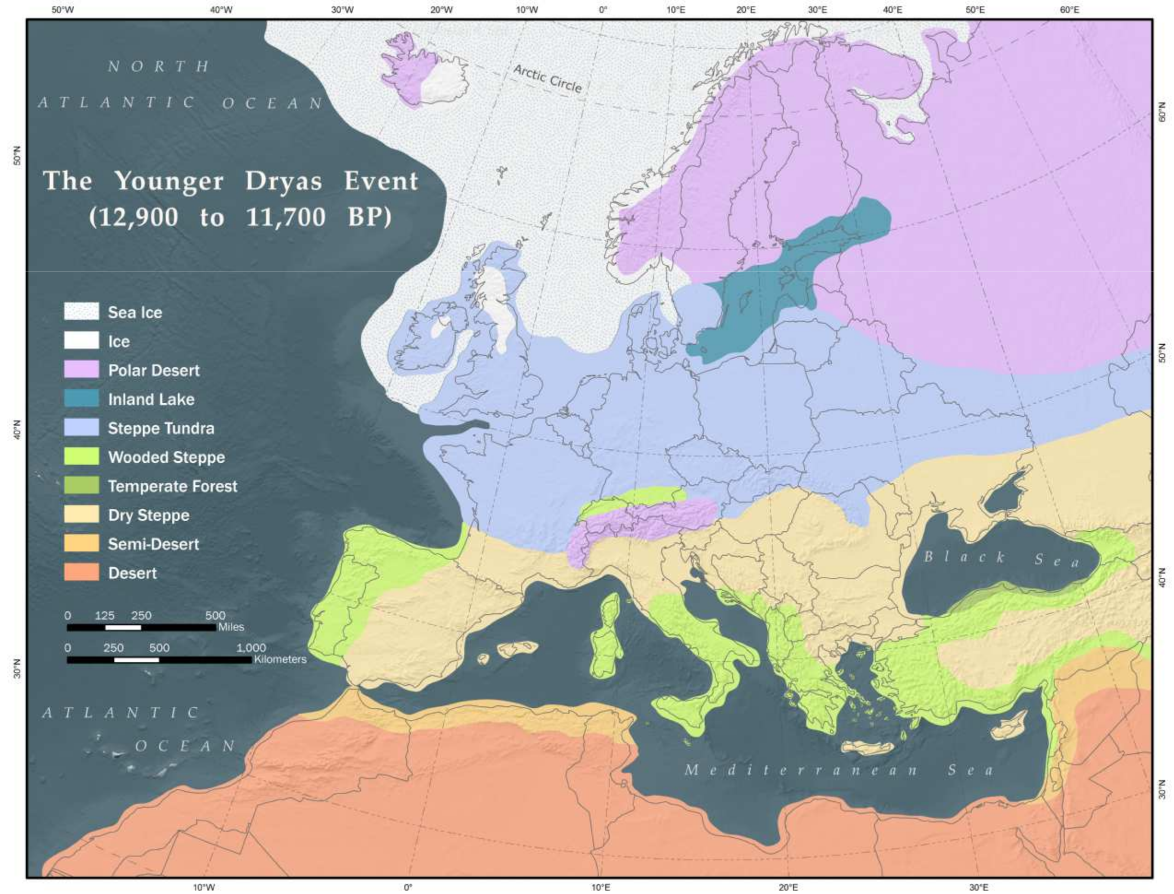
Changes in the ocean water flow character in the Pacific Ocean brings a significant impact on a wide range of regional climate (El Niño un La Niña)

Enormous «ocean conveyor» is moving slowly, its life cycle is 1400-1600 years, but, according to scientists, its role in regulation of the global climate is huge

Character of water flows in the seas and oceans

- Red – warm surface flows
- Dark blue – subsurface flows
- Green – ocean regions with high salinity
- Blue – ocean regions with low salinity
- Yellow circles – regions facing surface water move to bottom layers

Geological studies reveal that during periods when surface water's sinking in north of the Atlantic Ocean was disrupted, but thermohaline circulation weakened or even reversed, the climate in Europe has become significantly severe



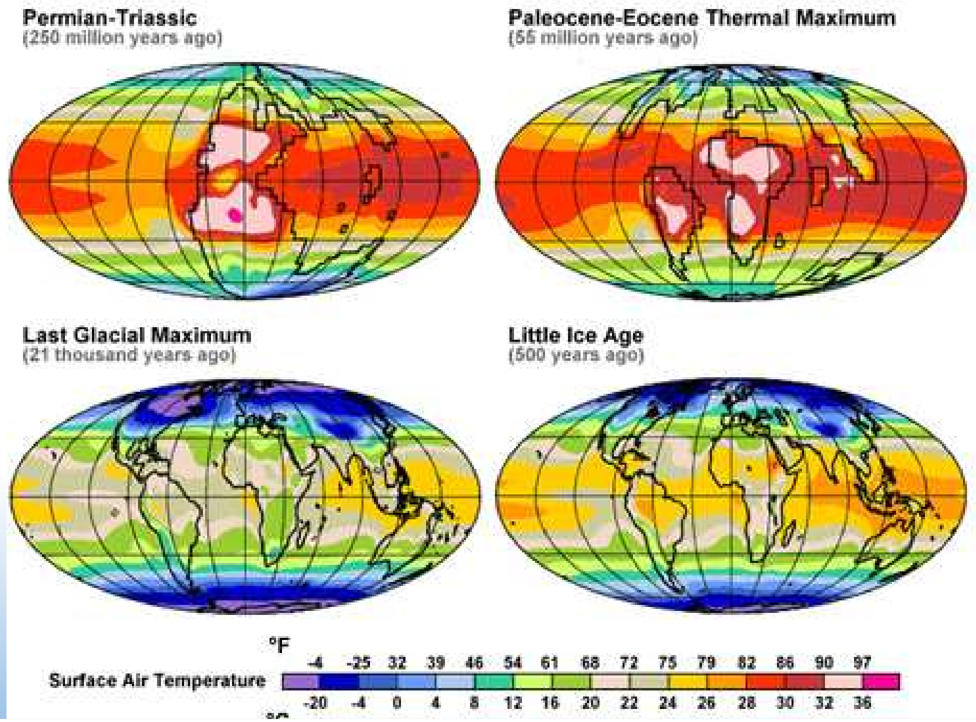
Before around 12,900-11,500 years retreat of glacial ice was interrupted by a temporary cooling period– **the Younger Dryas Event**

In north of Europe taiga forests again were replaced by tundra, but the melting of glaciers in mountain areas was replaced by a new freeze formation

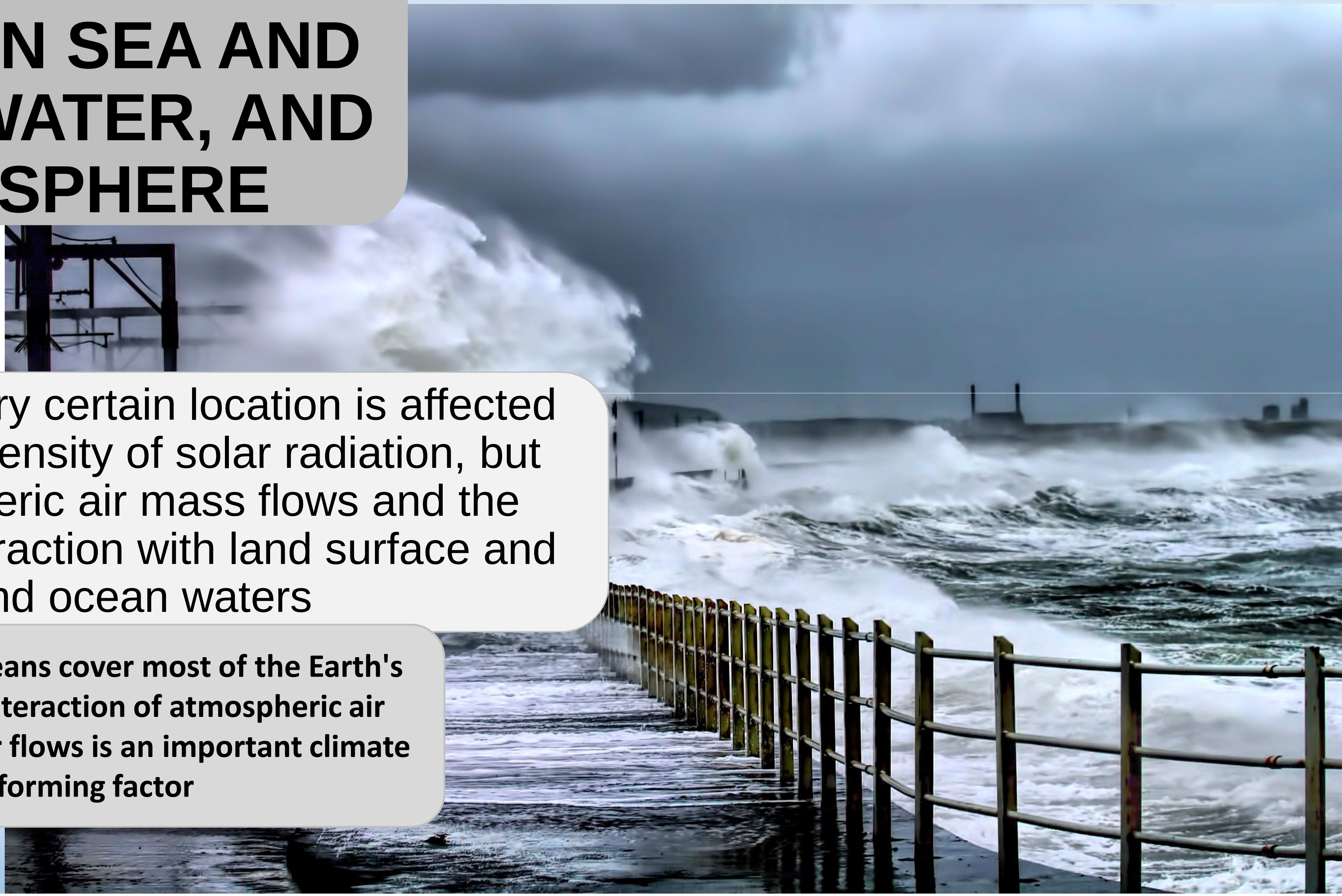
In the context of ongoing global warming it should be mentioned that around 55 million years ago in the Paleocene/Eocene temperature peak time, similarly like today, global warming caused by greenhouse gas concentrations in the atmosphere was observed

Ocean's water warmed up rapidly by about of 7-8 degrees, and during several thousand years, the ocean's thermohaline circulation reversed

It is significant that reversed flow of thermohaline circulation continued at least for 100,000 years



INTERACTION BETWEEN SEA AND OCEAN WATER, AND ATMOSPHERE



The climate in every certain location is affected not only by the intensity of solar radiation, but also by atmospheric air mass flows and the nature of their interaction with land surface and sea and ocean waters

As seas and oceans cover most of the Earth's surface, the interaction of atmospheric air flows and water flows is an important climate forming factor

Air masses differ by:

- Beginning
- Temperature
- Moisture
- Transparency (dust, water vapour and other particles)

Air mass flows affect the weather because their provide:

- Air humidity and temperature
- Stability of air masses

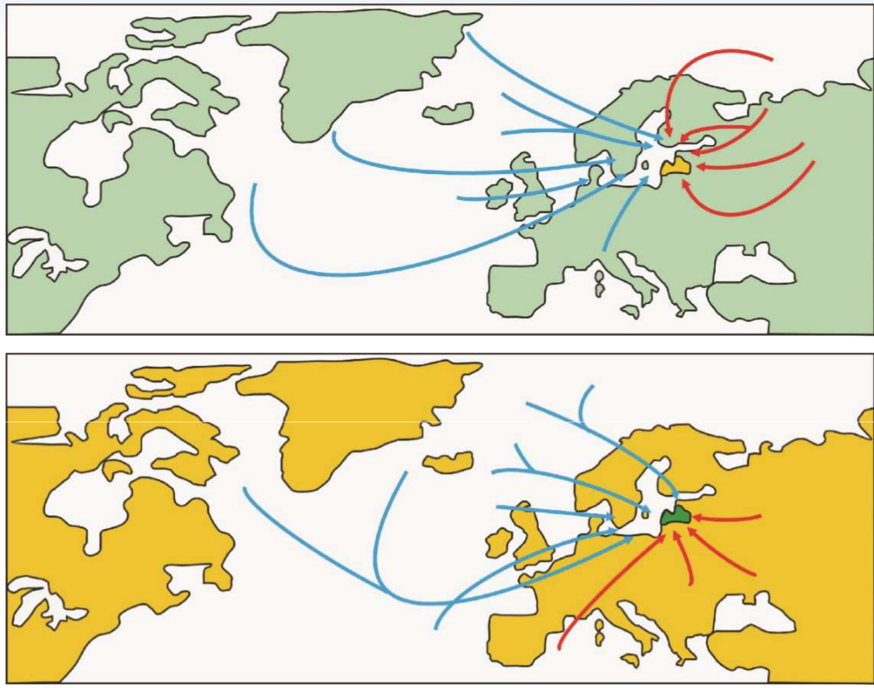
Generally, air masses can be divided into oceanic (maritime) un continental, depending on their humidity or water vapour content in the air

Oceanic air masses are formed over the oceans and they contain a lot of moisture

Provenance (necaurspīdīgums) of continental air masses is land areas, thus, they normally are of lower humidity

In Latvia air masses of various origin are flowing in; those are formed at different latitude over both, the Atlantic Ocean and the continents, and therefore they are very different in temperature, humidity, wind strength and other properties

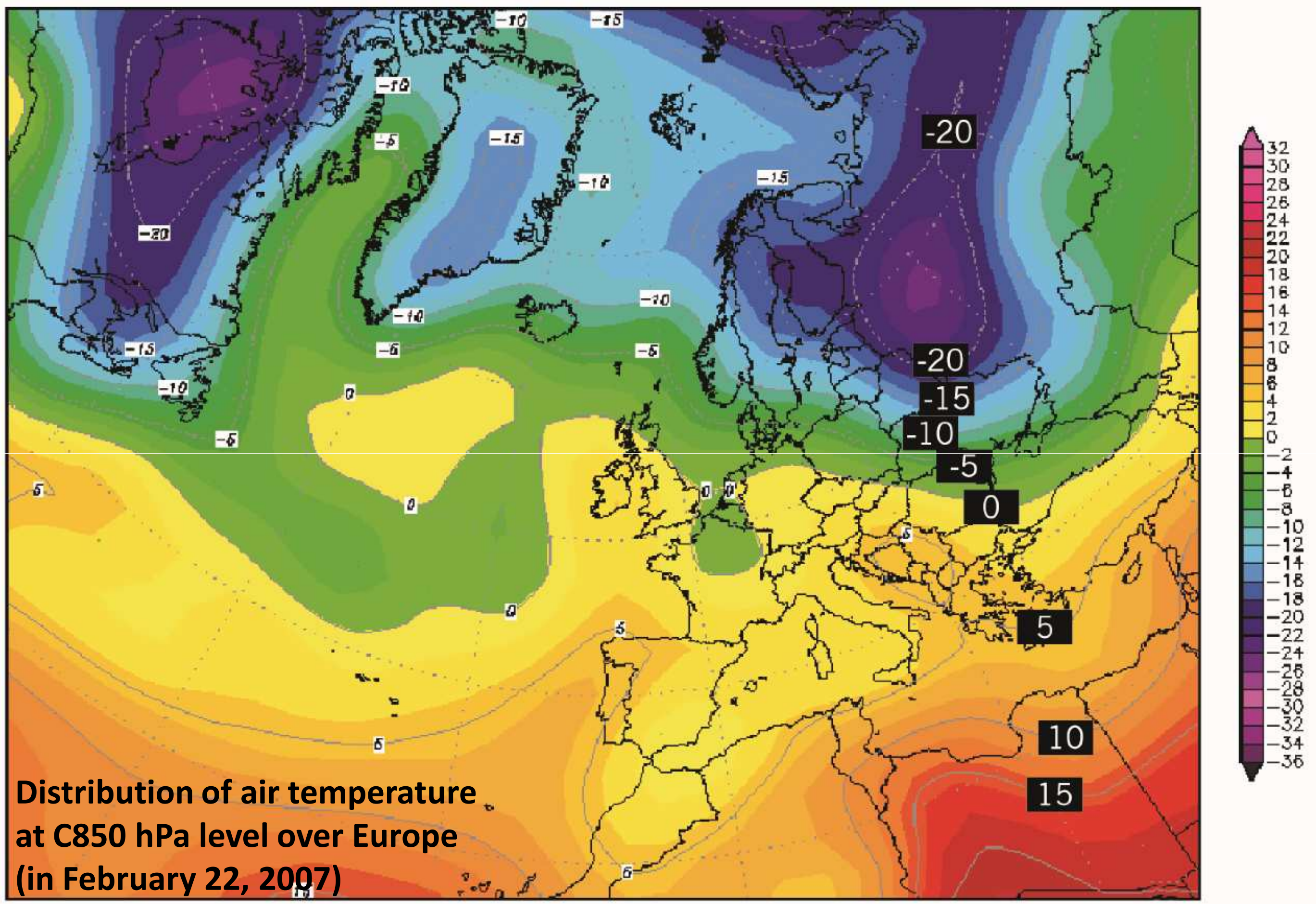
A



B

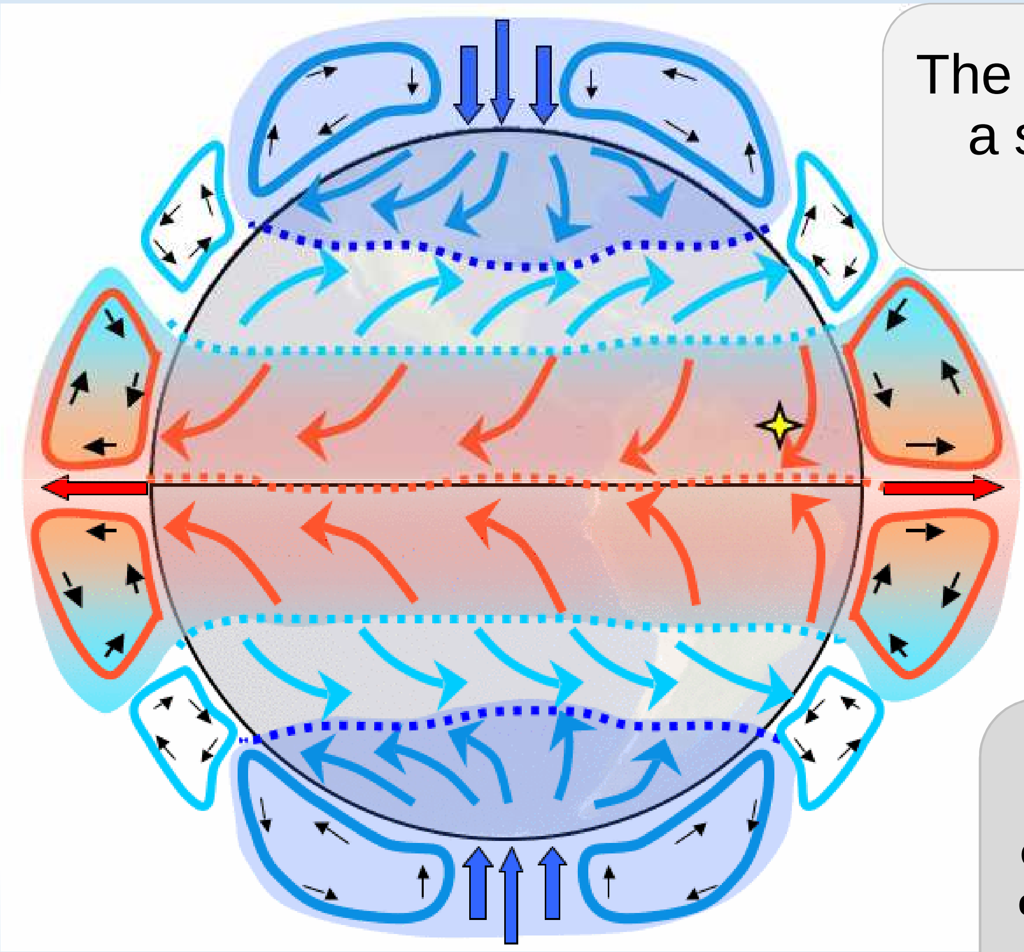
Formation and transformation areas of inflowing air masses in Latvia, and typical trajectories of air masses in winter (A) and summer (B)

- Blue lines - direction of oceanic air mass flows
- Red line - direction of continental air mass flows



Distribution of air temperature at C850 hPa level over Europe (in February 22, 2007)

Location of isotherms reveal inflow of cold air (T850 <-20) in Latvian from northeast, suggesting an inflow of continental arctic air

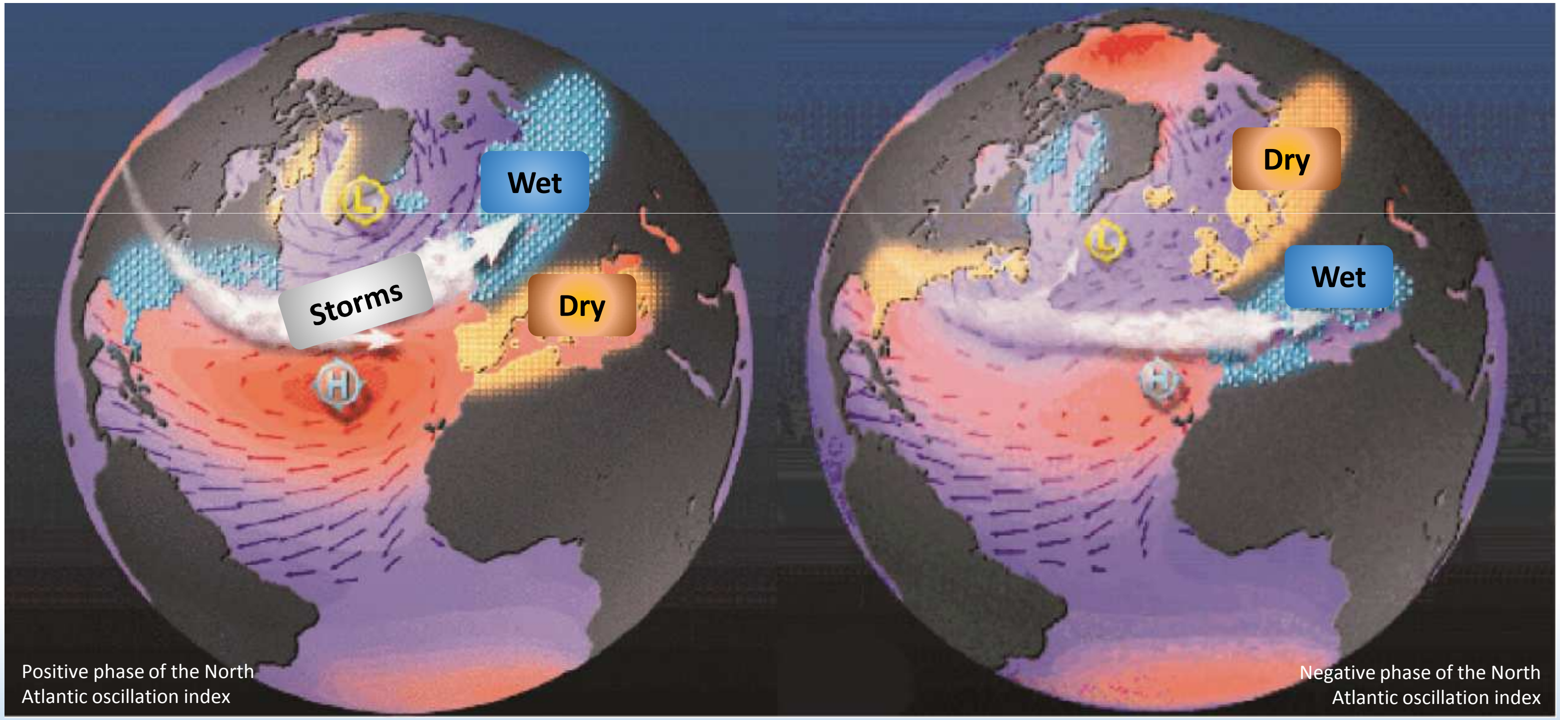


The global atmospheric circulation is a system that in size is similar to continents or oceans

In case of absence of atmospheric circulation, the average winter temperature around the pole areas would be about -100 ºC, not -30 ºC as it is currently

Climate of Latvia is significantly affected by character of water circulation of the Atlantic Ocean and often it is the main determinant of weather, affecting the great variability of weather conditions. Weather in Latvia is dependent on that the large-scale circulation of atmospheric air masses is formed over the north part of the Atlantic Ocean

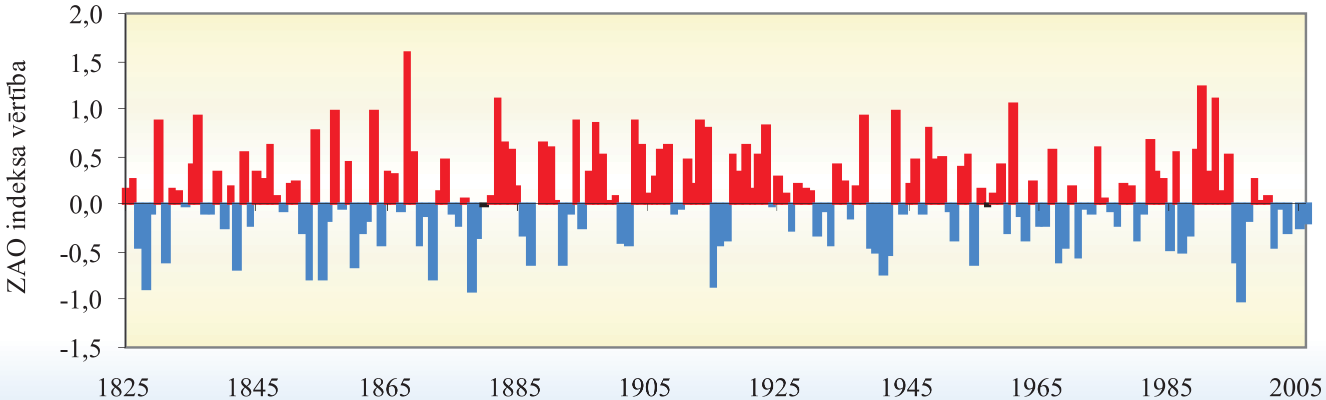
Processes of formation and circulation of large-scale atmospheric air mass are affected by the lowered atmospheric pressure in the north part of the Atlantic Ocean (there is a low pressure system), while near the equator a high-pressure area is formed



Influence of the North Atlantic oscillation phase on weather formation in Europe:
L– low-pressure area, H– high-pressure area

Interaction of water flows in the seas and oceans with atmospheric circulation is considered as an important factor that determines high climate variability

However, changes in the climate system (including global warming) may change the nature of this interaction, contribute to an increase in frequency of extreme events



Variability of the North Atlantic oscillation index from 1825 to 2005

Atmospheric pressure systems of Iceland and the Azores and the pressure difference between them periodically changes and they are described as the North Atlantic oscillation

UNUSUAL WEATHER CONDITIONS IN LATVIA (FROM 900 TO 1860)

Natural and weather conditions in the Baltic Sea region and Latvia described in historical for more than 900 years provide insight into unusual winters, springs, summers and autumns

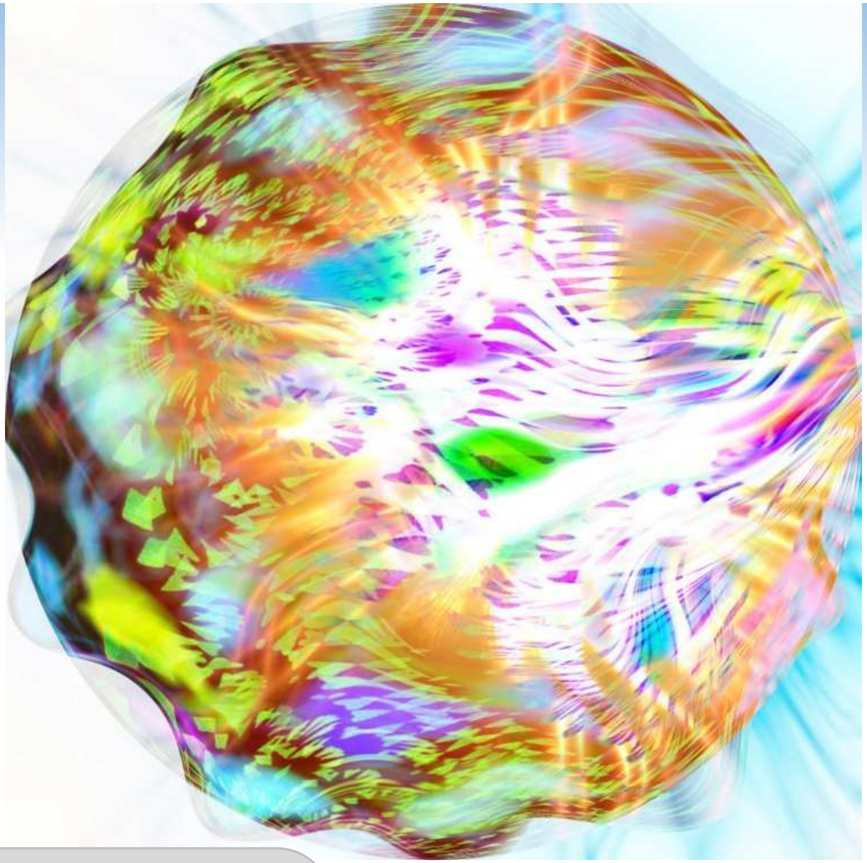
About catastrophic floods in the Daugava River and other rivers

About extreme heat and unimaginable drought when rivers and wells were drying up, forests and swamps were burning or rains continued for months

About winters when snowstorms continue for 1-2 months, and crops were destroyed by frost during spring or early summer around the Midsummer day

About the frozen Baltic Sea, when people from Denmark, Germany and Poland on foot or by horse-drawn sleighs were traveling to Sweden and Finland

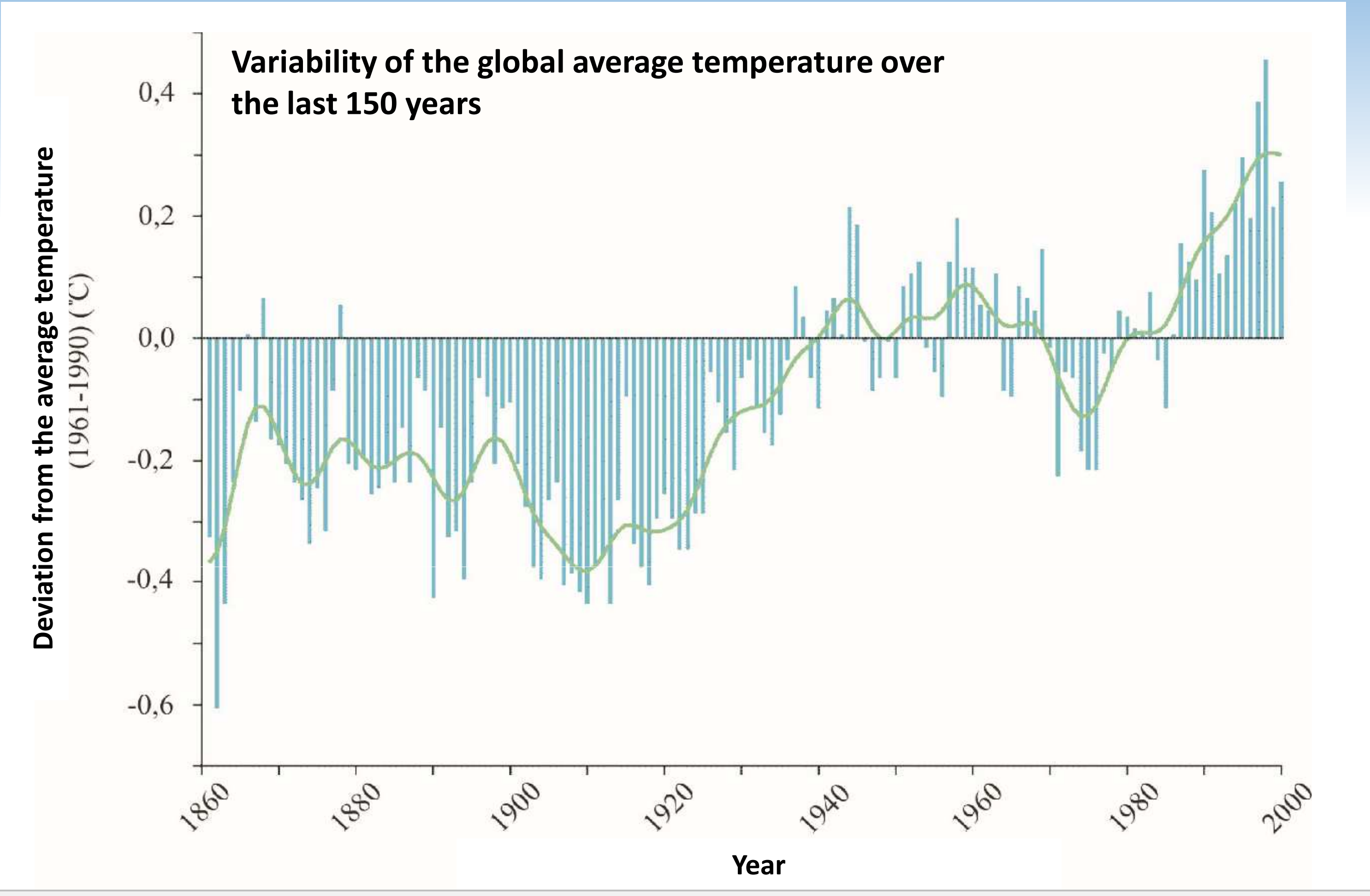
NATURE OF CLIMATE CHANGE AND HUMAN IMPACT ON IT



Climate of the last hundred years is characterized by profound changes that are very rapid if compared to changes in the nature of the last thousand years or longer period of time

Observations confirm that during the last century the daily temperature distribution has changed, as well as the temperature over the surface of seas and oceans have increased

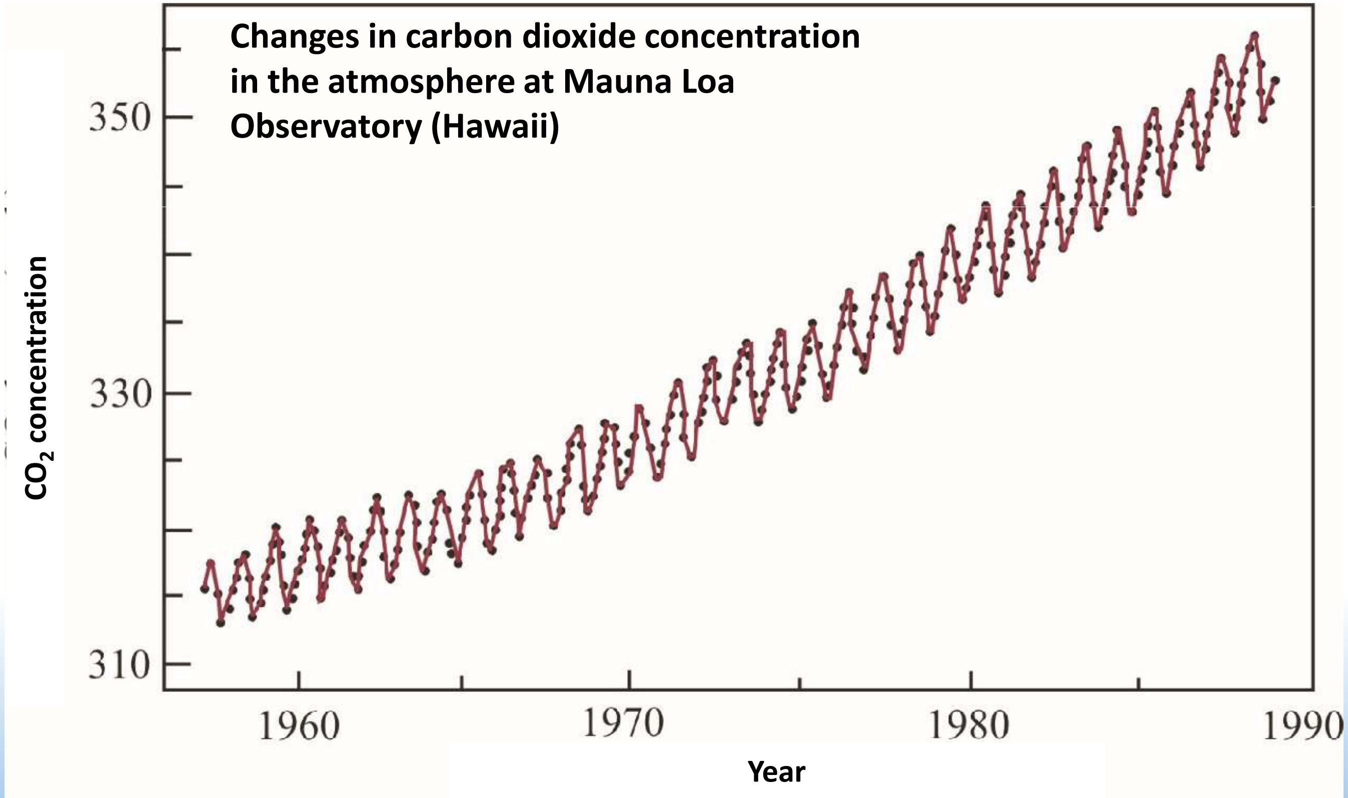
Character of climate change is associated with changes in rainfall, stability of climate as the system, frequency of extreme climatic events and other critical changes in climate changing parameters



It is estimated, that between 1861-2005 the Earth's average temperature has increased by 0.6 ± 0.2 ºC; moreover, the temperature increase has occurred mainly in period 1910-1945 and 1976 until today

It has been proven, that in the last 100 years concentration of the majority of greenhouse gashes has increased significantly

It is demonstrated by trends of CO_2 concentration growth measured in Mauna Loa Observatory in the USA

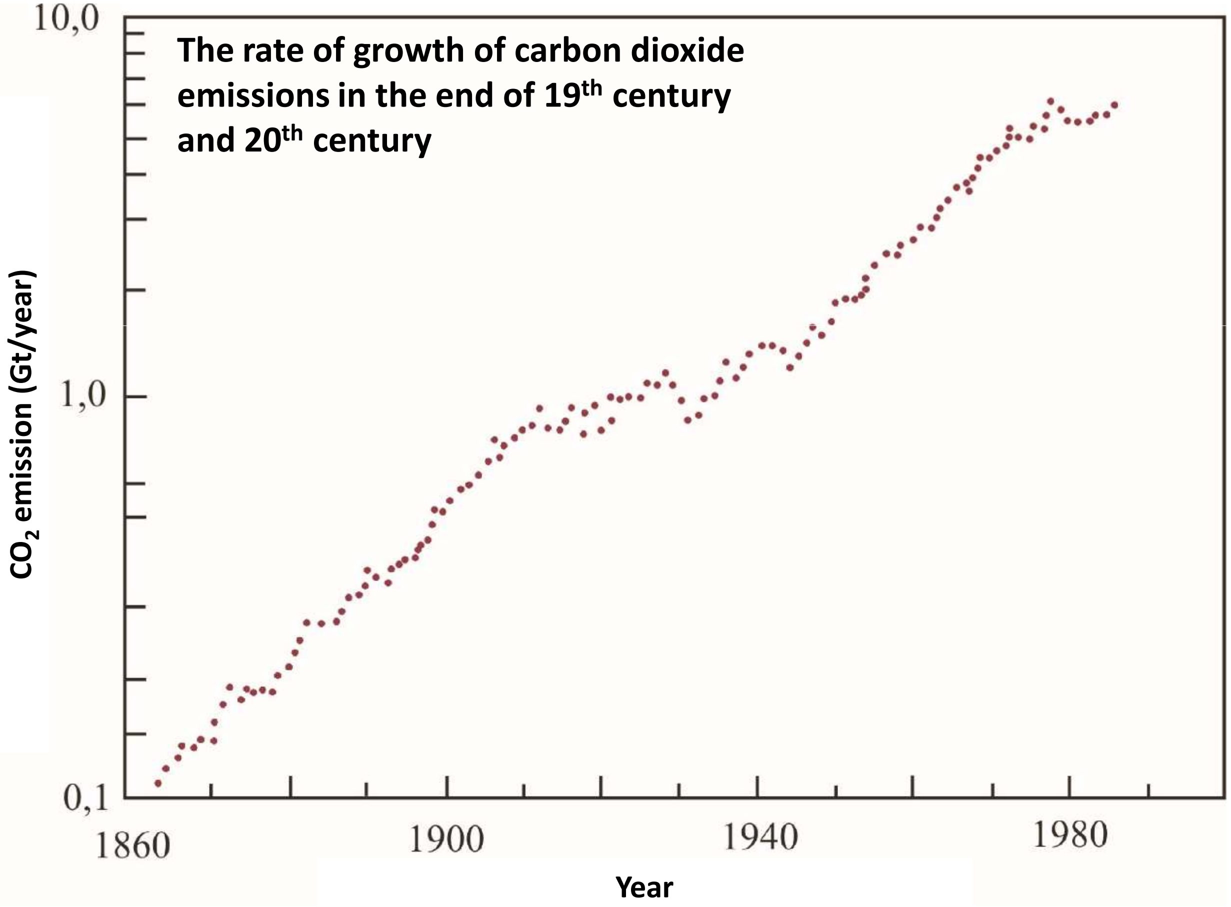


Observations performed in the Mauna Loa Observatory, starting from 1958, revealed that carbon dioxide concentration at the observation point located far from direct sources of pollution, an average increase by 0.46% a year

Carbon dioxide concentration in the air varies greatly depending on the season – it is due to the intensity of photosynthetic process and their seasonal nature

Similar results were also obtained in other research stations in Europe and Asia

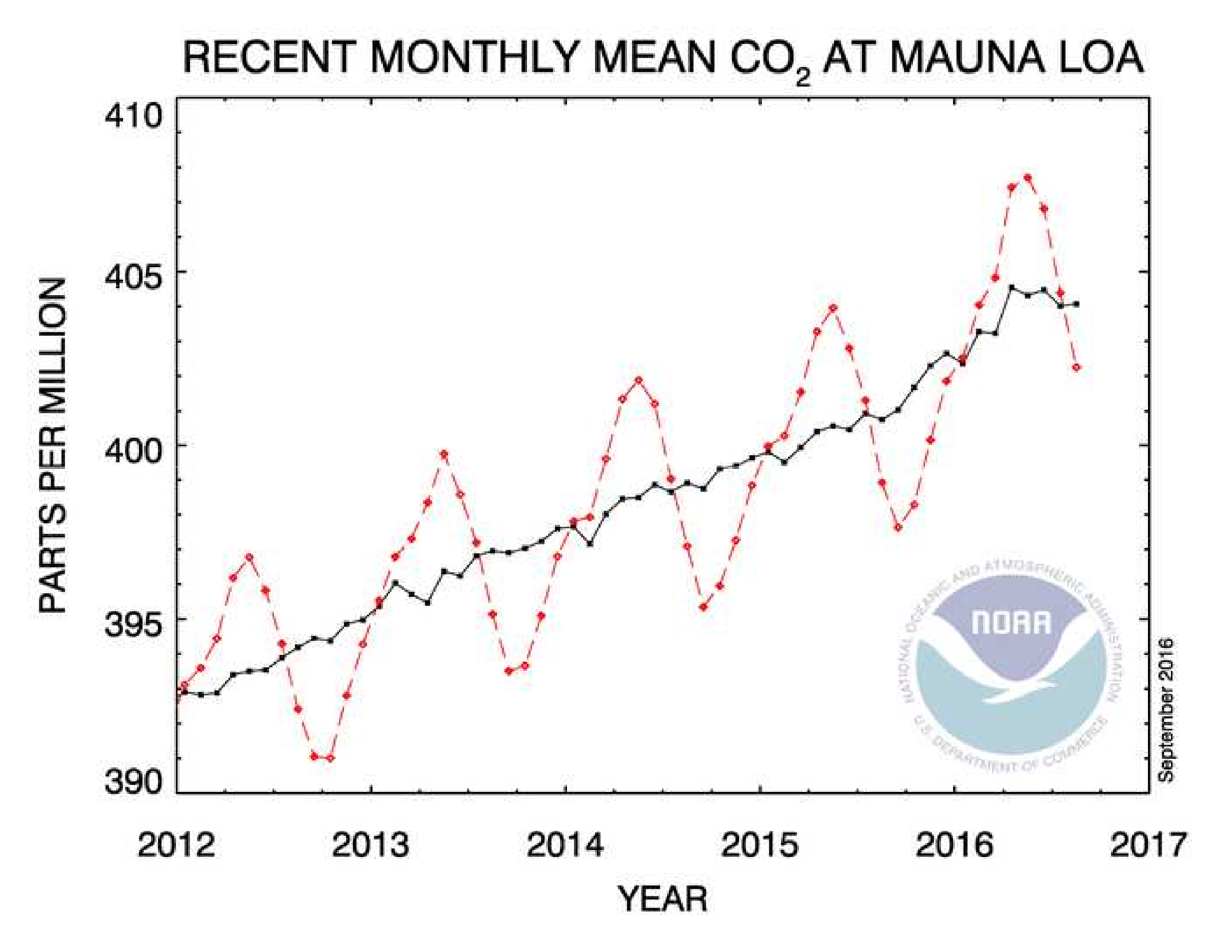
Concentration of carbon dioxide and several other greenhouse gases in the atmosphere correlate directly with the amount of emitted substances by human activities



The rate of growth of carbon dioxide emissions in the end of 19th century and 20th century

Taking into account increase of CO_2 emissions, it is estimated that by the middle of the next century, carbon dioxide concentrations in the atmosphere will be doubled compared to current –

It can cause the Earth's average temperature increase by 1.5-4.5 °C



Recent Monthly Average Mauna Loa CO_2

August 2016:	**402.25 ppm**
August 2015:	**398.93 ppm**

Up-to-date weekly average CO_2 at Mauna Loa

Week beginning on September 25, 2016:	**400.72 ppm**
Weekly value from 1 year ago:	**397.25 ppm**
Weekly value from 10 years ago:	**378.94 ppm**

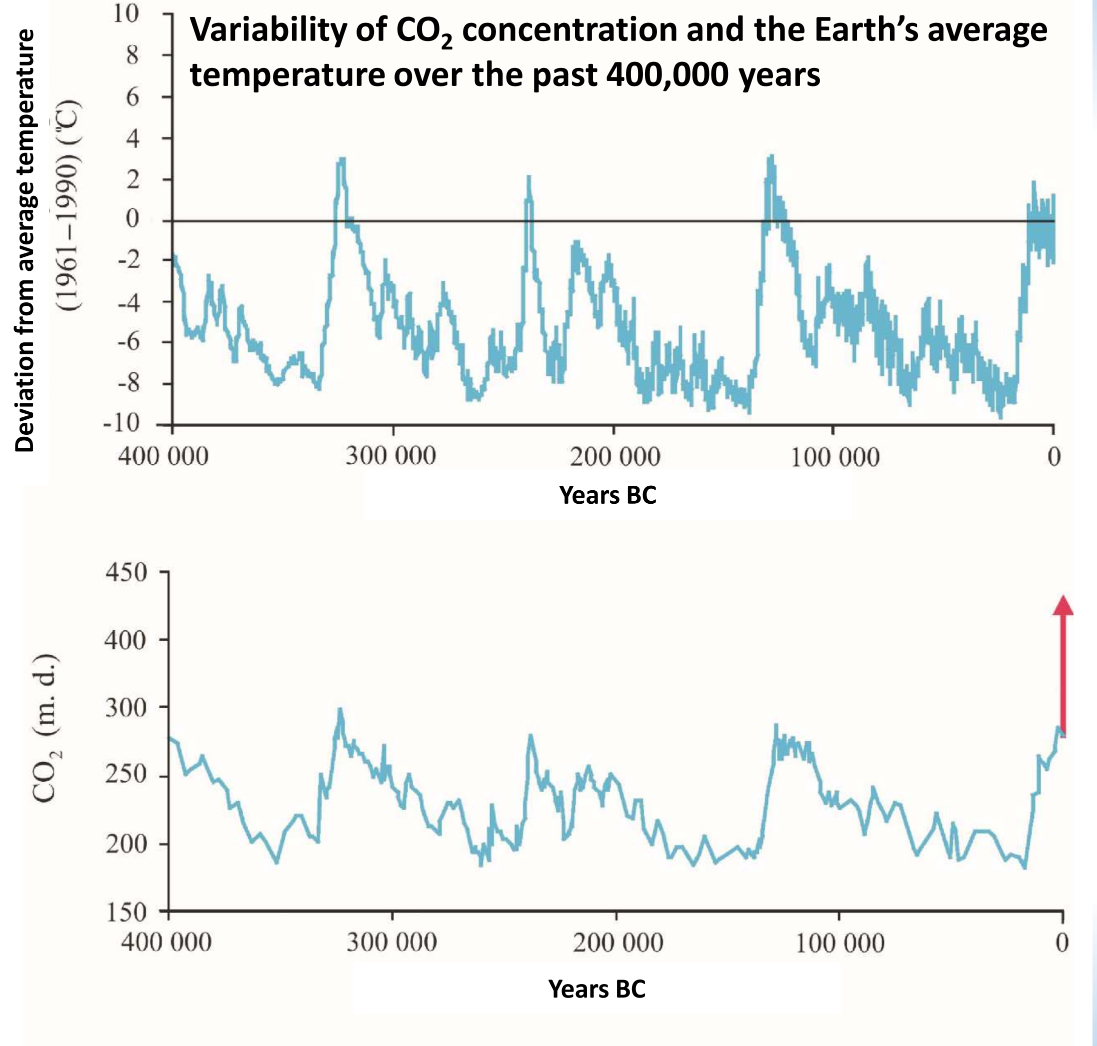
Last updated: October 4, 2016

Analysis of historical data reveals variability of climate influencing parameters, e.g., composition of gases in ice, and reconstructed temperature variability over the last 500 000 years –

It is obvious, that reconstructed temperature values tightly correlate with concentration of greenhouse gases, primarily CO_2

This confirms the assumption that the role of greenhouse gases in formation of the Earth's climate is important and global warming is related to the concentration changes of GHGs

Variability of CO_2 concentration and the Earth's average temperature over the past 400,000 years



CO_2 is one of the most important greenhouse gases, because its concentration in the atmosphere compared to other greenhouse gases is the greatest;
at the same time, carbon dioxide is one of the elements in carbon cycle

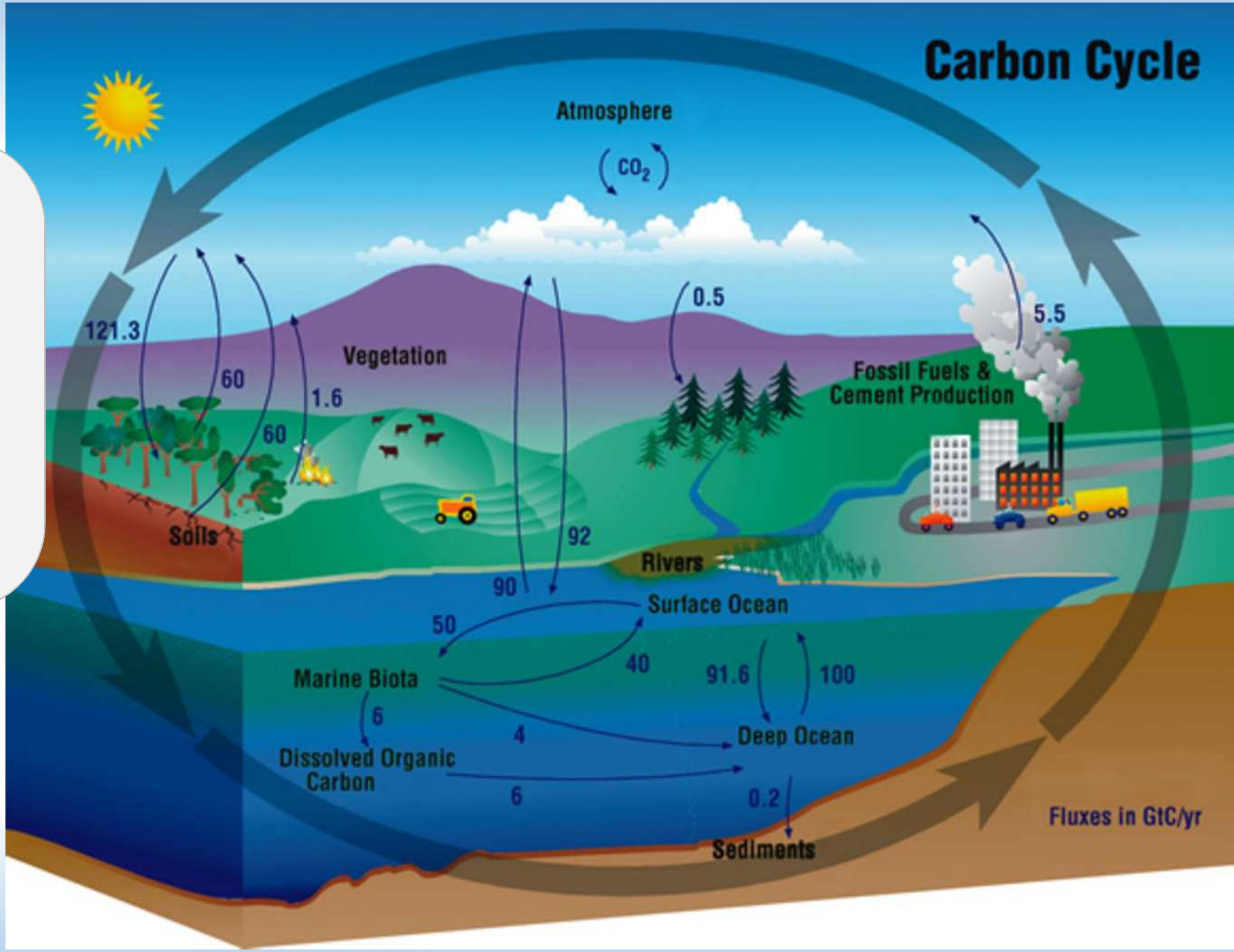
In carbon cycle (**biogeochemical cycle**) one kind of carbon compounds turns into others, and it can happen in the atmosphere, hydrosphere and biosphere

As a chemical element carbon itself is important for all forms of life – carbon is present in the five forms of «reservoirs»:

- **In atmosphere as carbon dioxide**
- **In biosphere in the composition of organic compounds**
- **In soil in the composition of humus**
- **In hydrosphere as dissolved carbon dioxide and carbonate ions, as well as in form of dissolved organic compounds of carbon**
- **As calcium carbonate in limestone and organic sedimentary rocks**

In the carbon cycle, the most important is biosphere and living organisms of seas and oceans that during the photosynthesis continuously are binding CO_2 from the atmosphere and are forming organic compounds

Complete life cycle of CO_2 in the atmosphere is fast and occurs in ≈ 4.5 years



Human economic activities alter all of the carbon reservoirs and promote release of carbon accumulated in lithosphere into the atmosphere

Use of fossil fuels and deforestation contribute to CO_2 transition from the lithosphere and biosphere to the atmosphere at much faster speed than by it happens naturally

At the same time, CO_2 return from the atmosphere naturally takes place more slowly than human economic activity complements it, thus the amount of CO_2 in the atmosphere increases

Methane absorbs infrared radiation more effectively than CO_2, therefore, role of methane in stimulation of greenhouse effect is very important, even though the concentration of methane in the atmosphere is relatively lower

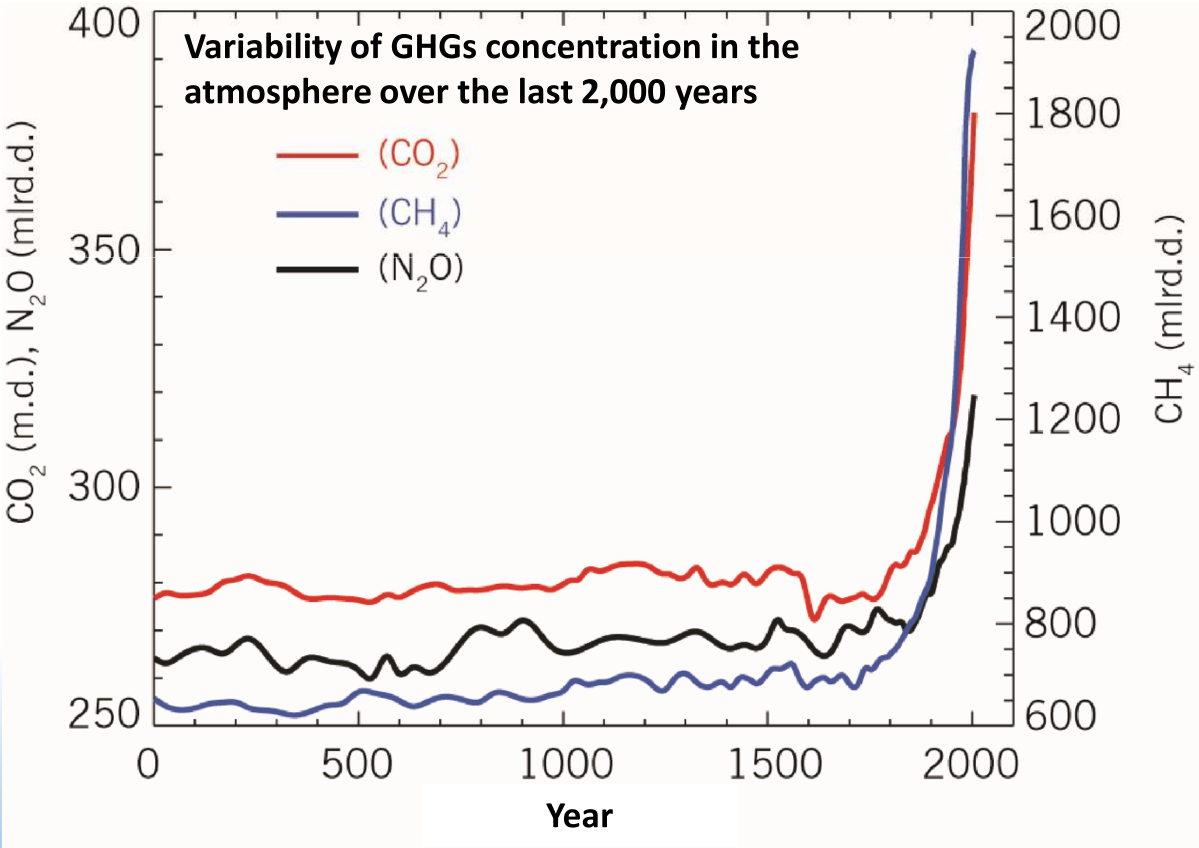
Since 60-ties of the 20th century when were initiated measurements of methane concentration in the atmosphere, the amount of methane in overall increased by around 1% per year

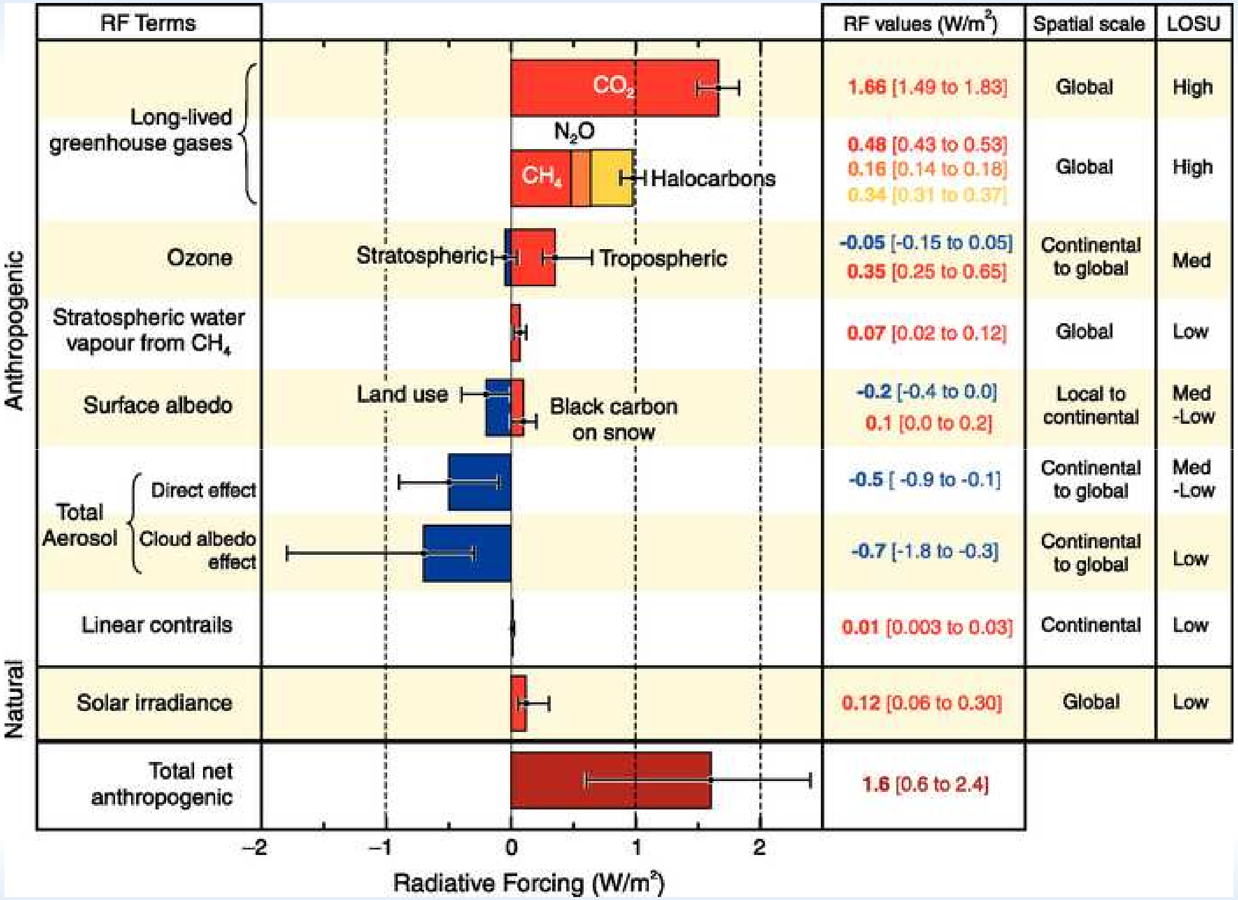
Part of methane is resulting from the rice cultivation as well as from livestock, particularly cattle, breeding

Historically, changes in methane concentration, like changes in CO_2, are associated with climate change during the Ice Age and between ice ages –

However, recent studies reveal that the geological processes can be important source of methane

For example, natural phenomena such as mud volcanoes, can be regarded as the source of almost 10 % of methane released into the atmosphere





The global average radiation quantities for the most important factors influencing the Earth's climate system

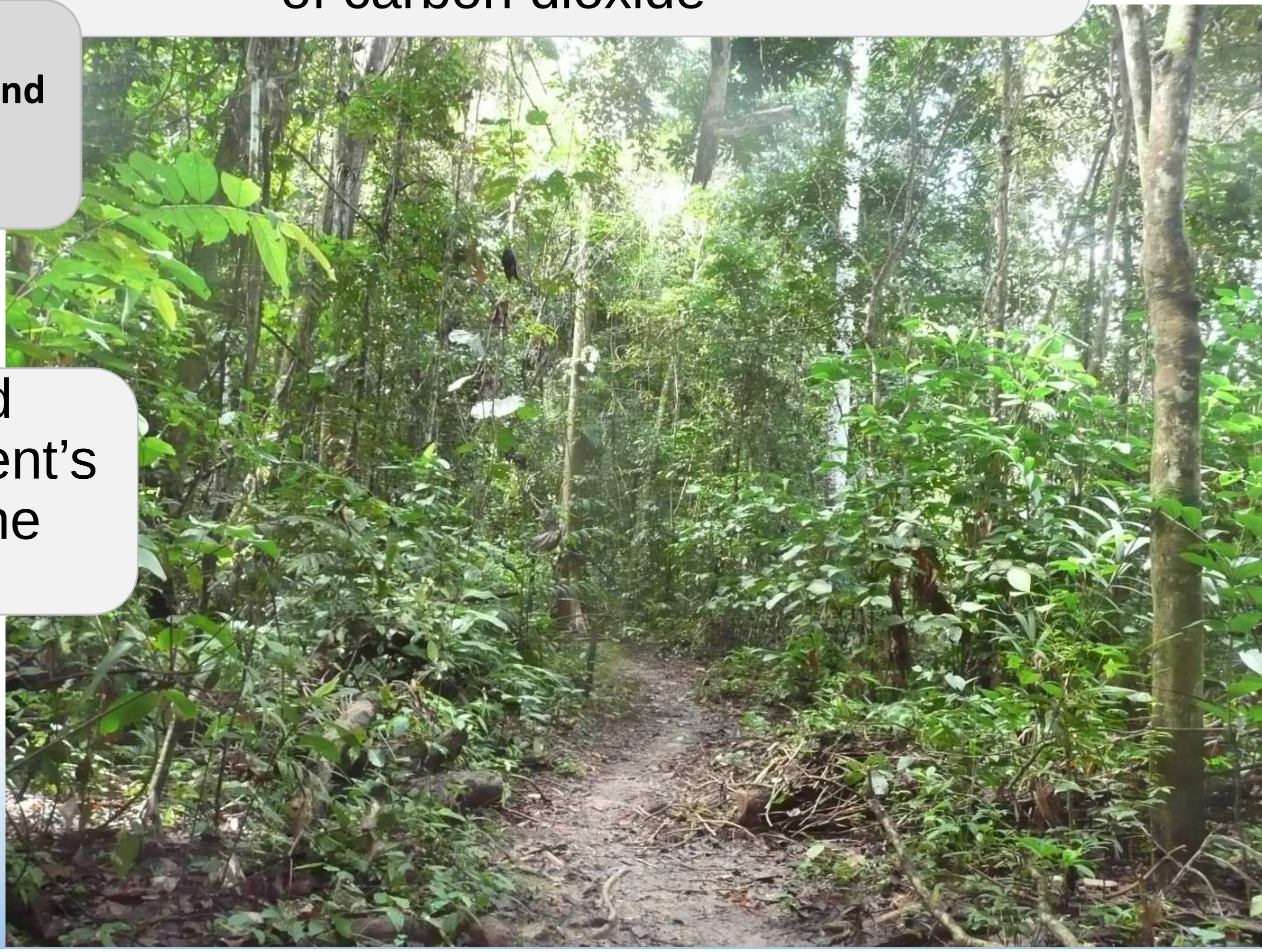
The amount of radiation indicates the changes in emitted energy at the upper margin of the troposphere, which would happen if in the atmosphere would not exist the selected component

Each greenhouse gas in its own way is able to affect the return of infrared radiation to the Earth, and each of them is characterized by its own radiation quantity value

Tropical forests are important elements of carbon life cycle because during the photosynthesis they consume a great amount of carbon dioxide

A part of carbon, assimilated in biomass, accumulates in the form of humic substances, and thereby the concentration of CO_2 in the atmosphere is reduced

Reduction of deforestation could significantly increase the environment's ability to bind carbon dioxide in the future



SOURCES OF GREENHOUSE GASES

Due to the human activities enormous quantities of greenhouse gases are released and their emissions have increased since the beginning of the Industrial Revolution

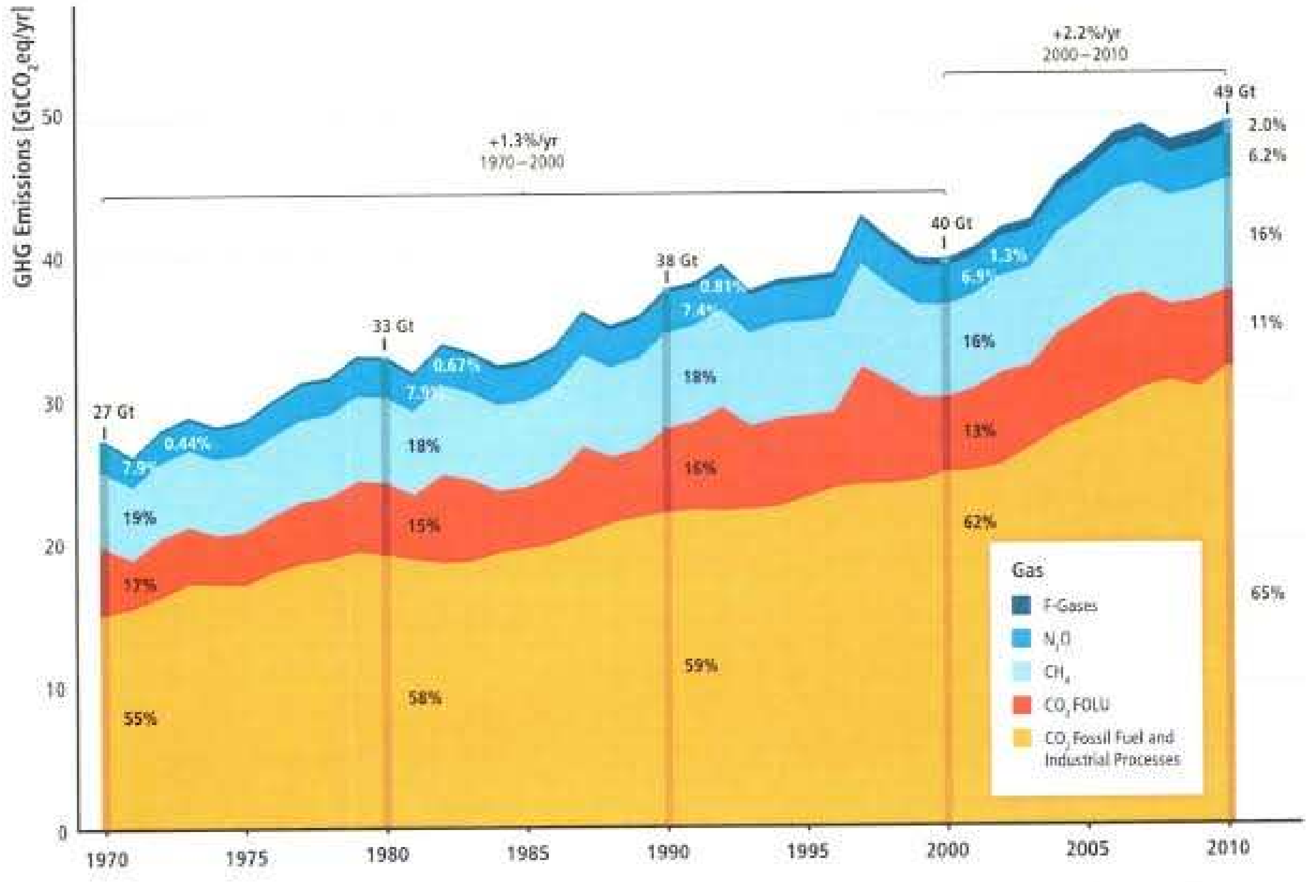
Concentration of GHGs in the atmosphere have reached unprecedented values in comparison with the situation during the last 800 000 years

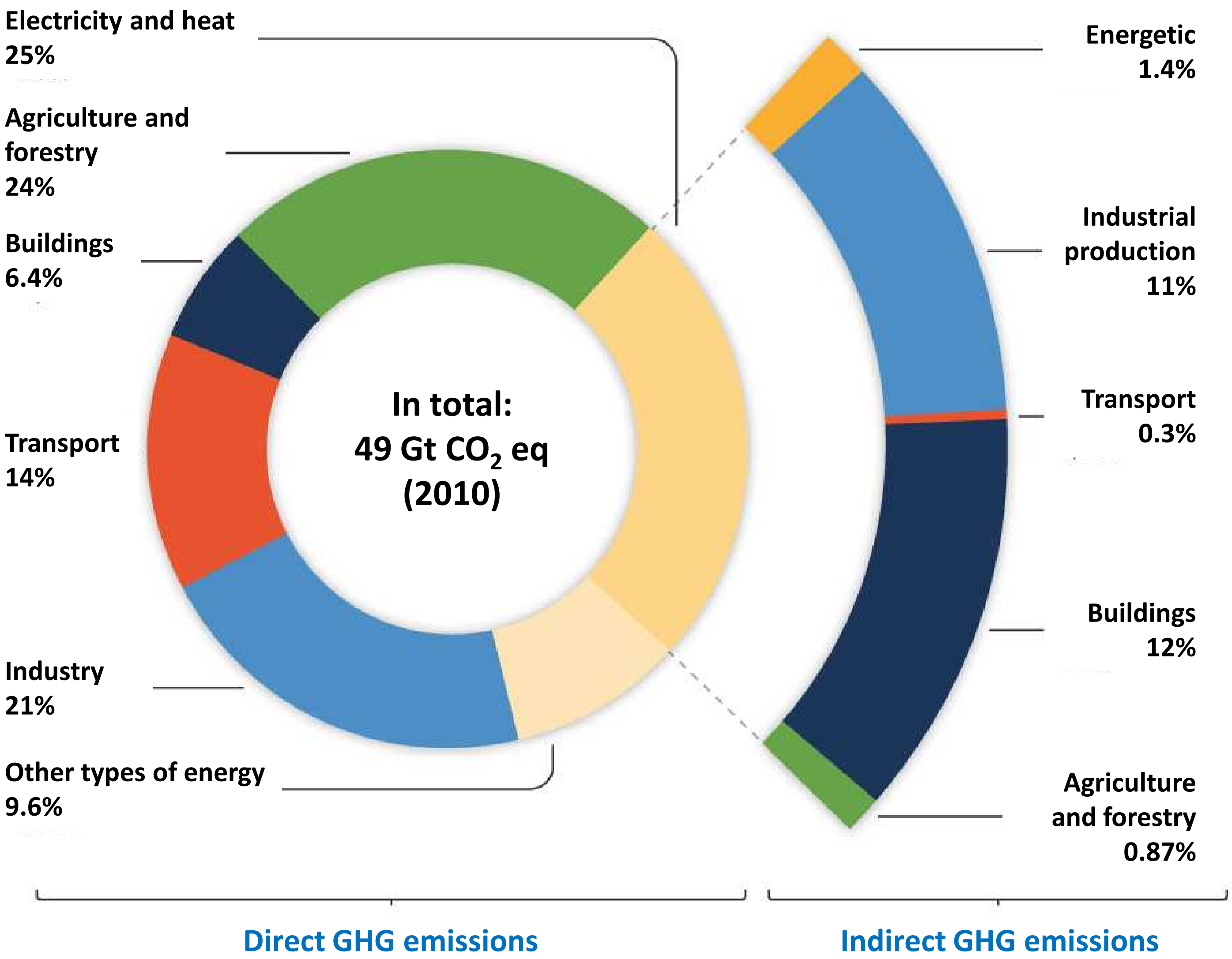
The main factors that determine the amount of GHGs emissions is **economic growth** and **increase in the number of population**

The total amount of human induced GHGs emissions in the period between 1750 and 2011 reached 2040 ± 310 $GtCO_2$

The majority of GHG emissions has formed over the last 40 years

The total anthropogenic GHG emissions for the period 1970-2010 induced by fossil fuel combustion, activities of forestry, land use changes
Amount of methane, N_2O and freon's emissions





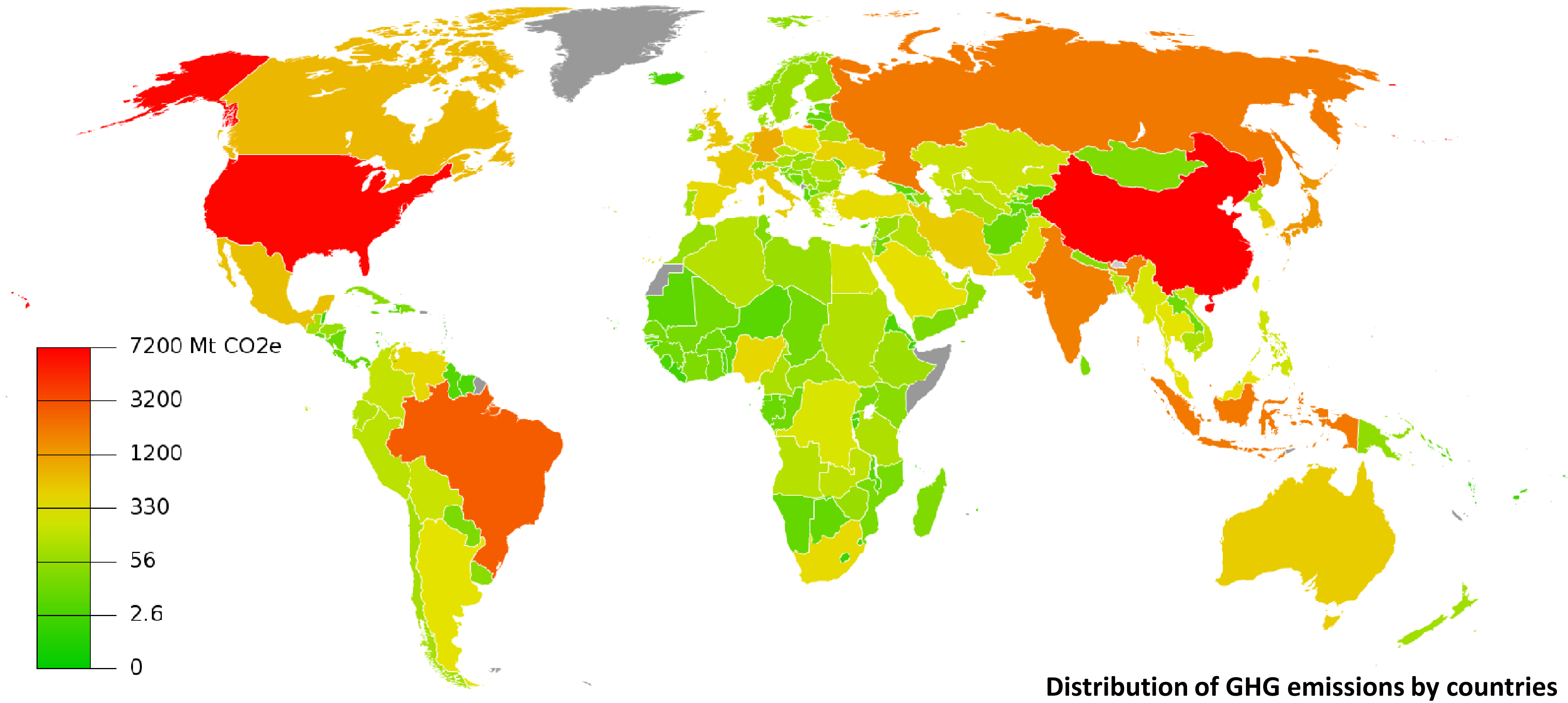
Distribution of CO_2 emissions by economic sectors

Although the developed countries contribute to the development of energy-efficient production and are trying to reduce energy consumption, industrial GHG emissions since 1990 still have reduced only by a few percent

The positive impact on GHG reduction by energy savings and decrease of GHG emissions in industrialized countries is growing up by production in third countries of the world and the development of the BRIC (Brazil, Russia, China, India, South Africa) countries, primarily China and India

However, increase of emissions from industrial production is lower (<1%) than total emissions (> 2%)

Other significant sources of GHG emissions are emissions from residential buildings and transport



Distribution of GHG emissions by countries in 2005, including land use changes

Amount of GHG emissions is significantly different among different countries - national contribution depends on both, the activity of industry and the population

Thank you for the attention!