Global Changes of Climates in Earth’s History

(Summary)

Global and regional climate change has always been of special interest and attracted people’s attention. However, the problem can ~~only~~ be understood only if the long-term regularities of climate fluctuations and the major climate cycles through Earth’s history are known.

Apart from during the early stages of Earth history (the Archean Eon), the Earth’s climate has exhibited cyclic fluctuations with Earth surface temperatures varying by 12° to 25° C or even from 7° to 27° C.

The Earth’s climate system is very complex and dynamic, with chaotic processes characterising the atmosphere, hydrosphere, biosphere, cryosphere (glaciers) and continents. Temperature, precipitation, air and soil humidity, global sea level, the state of polar and continental glaciers and snow cover are all important parameters which have varied through time. In addition, the climate depends on the dynamics of large-scale circulation patterns, the dynamics of oceanic basins, and the frequency and power of extreme meteorological phenomena, e.g. ENSO-effect type, etc.

The Earth’s climate system has been formed and is under the constant influence of several key factors: (1) variations in solar radiation, driven by dynamic processes of the Sun; (2) changes in the orbital parameters of the Earth due to its movement around the Sun; (3) geophysical and geological (tectonic) processes which affect the Earth’s internal structure, the structure and movement of lithosphere plates, the formation of mountain systems, the opening and closing of oceans and the formation of the main features of the geomorphology of the planet. These factors can be divided in two groups: external (astronomical and orbital) and internal (terrestrial – geophysical, geological and geographical).

The reconstruction of palaeoclimate is based on the details of the animal and plant fossil record contained in sedimentary rocks. Paleontological indicators of ancient climates, dendrochronological data and paleotemperatures derived from isotopic data are especially important.

The main factors exerting impact on climate have been triggered even in the very early stages of our planet’s history. The assumption made by some scientists that during the Archean and at the beginning of the Proterozoic solar activity was about 20% lower than at present has not yet been supported by any data. Towards the end of the Proterozoic, the role of greenhouse gases on climate had become noticeable and the greenhouse effect had been incorporated as an important factor in the Earth;s climate system. While astronomical and orbital factors play a central role in long-term climate change, greenhouse gases play a decisive role in shorter-term climate change.

A review of global climate change over the last 1.5 billion years of Earth's history shows continuous cyclic variations in climate, with extensive glaciations in both the Late Proterozoic and in the Phanerozoic. Especially strong climate warming was displayed at the end of the Proterozoic during the Cambrian, the first half of the Ordovician, the Devonian, and the Permian, almost the entire Cretaceous period and a considerable part of the Paleogene (Paleocene and Eocene). In these warm intervals sea level was raised significantly, the highest values being in the Cambrian-Ordovician period (almost 400 m above the contemporary sea level) and in the second half of the Cretaceous period (about 250 m above the present level).

The reconstruction of climate change in the pre-Cambrian eons, especially in the Archean, is hampered by the strongly altered rock record. The occurrence of several extensive and prolonged glaciations (1000–925, 875–800, 680–635 and 610–575 Ma BP) characterises the Proterozoic, providing the grounds for a number of scientists to develop the Snowball Earth hypothesis. According to the protagonists of that hypothesis, glaciations even spread to equatorial areas. From 635 Ma BP a warming climate accelerated biological evolution, stimulated evolutionary diversification within the great tree of life and the rapid development of a previously unseen range of life on the planet. In this way the so-called Cambrian explosion marked the beginning of the Phanerozoic Eon.

Within the context of a dynamic terrestrial climate system, at least in the last 542 million years, i.e. during the Phanerozoic, the average temperature of the Earth's surface has never been 8° C cooler or more than 10° C warmer than present day values. This means that temperature fluctuations during the Phanerozoic only ranged within certain limits, from +12 to +24° C.

During the Phanerozoic (the last 542 Ma) the dynamics of the climate system have been more intense, the cycles of changes have been of relatively shorter duration and the epochs of climate optima have been more frequent. Climate optima in the Cretaceous and around the Paleocene-Eocene boundary have been the most pronounced. Four stages of climate cooling have occurred during the Phanerozoic: in the Ordovician-Silurian, the Late Carboniferous-Permian, to some extent during the Jurassic and a stable period of cooling after the Cretaceous period, in the Cenozoic. These intervals are separated by epochs of warm climates. The transitions between cold-warm-cold climates triggered evolutionary crises, provoking mass extinction of whole systematic groups. New circumstances generated possibilities for extending the distribution of groups capable of rapid adaptation to the altered conditions.

The general regularities of the climate cycles in the Paleozoic period exhibited a number of cyclic fluctuations with endmost states of global warming and global cooling accompanied by significant glaciations.

During the Early Paleozoic climates were isothermal for the whole Earth, while in the Late Paleozoic, especially in the second half of the Carboniferous period and in the Permian, broad temperature zones developed with tropical, subtropical and boreal areas. Early Paleozoic as well as the Devonian climatic fluctuations were therefore related to a significant degree to variations in atmospheric humidity, with both humid and arid phases.

Late Paleozoic climatic belts were oriented sub-equatorially, similarly to contemporary belts. The equator was situated in more northern areas compared to its present position. The relatively cool climate during the Devonian, and partly during the Carboniferous, was similar to present-day climate.

Climates in significant intervals of the Paleozoic era were influenced to a considerable degree by the high content of water vapour and carbon dioxide in the atmosphere. This determined the influence of the greenhouse effect in Paleozoic atmospheres, which was considerably higher compared with the Mesozoic and Cenozoic eras. Correspondingly, surface temperatures during the Paleozoic were also higher. Paleozoic climate was less continental compared to Mesozoic and Cenozoic periods, because the more extensive, warmer oceans enhanced evaporation and amplified atmospheric humidity. This situation lasted until the end of Early Permian when a stable, arid climate was established and dominated the Late Permian and the greater part of the Triassic period.

Paleozoic glaciations occurred mainly in the southern continents which were joined as the Gondwana supercontinent situated in the South Pole area.

Mesozoic climates were warmer and with less contrast compared to those in the Paleozoic. In fact, the warm Mesozoic era was sandwiched between two phases of strong cooling periods – on the one hand, Late Paleozoic glaciations and, on the other hand, the beginning of a new period of global cooling and significant glaciations during the Cenozoic era. Climate between the Middle Triassic and the middle of the Cretaceous was characterized by considerably higher global average temperatures (at least 10–12° C) compared to the present ones.

During the Mesozoic there were no significant temperature differences between lower and higher latitudes, i.e. the temperature distribution at the Earth's surface was more uniform than at present. During the Jurassic and Cretaceous period there were two main types of climate - tropical and boreal. Tropical climate at this time interval had the same characteristics as current analogues, while the boreal climate has no present analogues. Currently, there are no strong data suggesting a moderate climate during the Mesozoic era.

Climate in the Cenozoic era marked the transition from warm to cold oceans. In general, the Cenozoic has very different paleogeographic and paleoclimatic characteristics compared to the Mesozoic era.

The Cenozoic is characterized by significant climatic fluctuations covering different time intervals. These fluctuations were gradually enhanced and became more frequent in the Pliocene and Pleistocene. The Paleogene and the Neogene display two basic climatic cycles which are typical with their internal fluctuations during each single period. Moreover, Paleogene climate made the transition from the warm and practically glacier-free Cretaceous period to a colder Neogene. The continuing drift of the continents changed the configuration of the ocean currents, thus exerting an important impact on climate.

In general, the evolution of Cenozoic paleoclimate is characterized by a gradual decrease of temperature, expressed very clearly at high latitudes. The cooling proceeded non-uniformly and was interrupted by shorter intervals of relative warming.

Cooling at the beginning of the Cenozoic was driven by numerous, complexly intertwined factors of which the most important include the changing position of the continents, the expansion of the Atlantic and Pacific oceans, the emergence at the end of the Mesozoic of big mountain ranges including the Cordilleras, the Rocky

Mountains, the Andes and the Alpo-Himalayan mountain chains, whose growth continued during the Young Alpine tectonic cycle of the Cenozoic.

The beginning of a trend towards climate cooling was outlined in the early Cenozoic, when the average temperature of the Earth's surface decreased over the course of several tens of million years by 10–15° C compared to the Cretaceous period. The global level of the World Ocean also gradually decreased.

After the earliest Paleocene (Danian) cooling, a trend towards gradual global climate warming occurred in the rest of the Paleocene until the middle of the Eocene, including several remarkable temperature maxima. Various terms have been proposed to mark these clearly expressed temperature fluctuations: MPBE – Mid-Paleocene Biotic Event; LPTM – Late Paleocene Thermal Maximum; PETM – Paleocene-Eocene Thermal Maximum; ELMO – Early Eocene Layer of Mysterious Origin ; MECO - Middle Eocene Climatic Optimum; X-event, etc.

The Oligocene marked the beginning of a permanent climate cooling, referred to as the earliest Oligocene Glacial Maximum or Ol 1. This trend continued during the Miocene, interrupted only by several warming episodes.

The most important features of Pliocene climate are the numerous cyclic variations, which were very strong in the interval between 5.2 and 3.3 Ma BP according to isotope data. The Pliocene comprises an interval during which our planet underwent a transition from relatively warm Miocene climate to the global cold climate of the Pleistocene.

The last 5 million years have been characterized by frequent and dynamic glacial and interglacial ages. The most clearly manifested cycles are those with durations of 40 ka and 100 ka, known as Milankovitch cycles. About 10 000 years BP a relatively stable trend towards climate warming was started and today the Earth is within an interglacial stage. Obviously the economic activity of mankind is now included as an important factor in rapid climate change.

The Quaternary was one of the most dramatic periods in the history of our planet, characterised by exceptionally frequent and extreme climatic fluctuations which caused unusual global changes in natural landscapes.

In the Quaternary, over a period of 2.5 million years, several glacial episodes occurred, each of them being characterised by the formation of glaciers and ice caps in the high and middle latitudes of the Northern Hemisphere.

After the last major Late Pleistocene glaciations (13 000 – 10 000 years BP) a trend towards global warming has occurred since the beginning of the Holocene, disturbed by brief episodes of cooling. According to data published by various authors, temperatures in the last 13,000 years were raised by 4 to 5°C and this marked the time when the Earth slipped away from the icy embrace of the Pleistocene. The last big glaciers in the Northern Hemisphere disappeared in the interval of 9000–8000 years BP.

The so-called **Holocene maximum** occurred 8 000 – 4 000 years BP within the Late Boreal – Atlantic – Early Sub-Boreal interval, during which average surface temperatures were about 2° C higher compared to today.

According to some researchers, the so-called MCO (Medieval Climatic Optimum) occurred between 900 and 1300 AD, ending with more moderate conditions in the fifteenth century. This Medieval warm period was followed by a period of considerably colder climate, referred to as the Little Ice Age (LIA) that was most strongly displayed in the period 1450–1850 AD, when the average global temperature was with about 1–1.5°C lower than at present. It is generally assumed that the LIA is the coldest episode during the Holocene. The cold climate of LIA was typical for the greater part of the Earth but it was most distinctly expressed in Europe, the North Atlantic and North America.

High frequency climate fluctuations with marked glacial phases characterise the Quaternary. The strongest and most prolonged glaciation was established during the Pleistocene, from ~110 000 to 10 000 years BP, the glaciation maximum being 20-15 ka BP ago with a peak prior to 18 000 years. This is the Last Glacial Maximum. The Holocene marked a general trend towards warming, at the background of which cooling cycles were also displayed. Well expressed warming was outlined 4000 years BC, with following new cycles: cooling (XIII century BC), warming (X-VI century BC), cooling (III century BC), warming (I century BC), cooling (IV-V century AD), warming (MCO – The Medieval Climatic Optimum, also known as Medieval Warm Period – VIII–XIV century AD), cooling (LIA – Little Ice Age: XV – middle of XIX century AD), global warming (XIX-XXI century).

The reality that we witness today shows us cyclic climate fluctuations with a trend towards global warming. The reasons for these cycles are known – astronomical and orbital forcing phenomena, on which the effect of human economic activity, especially in the last few centuries, has been superimposed.

The lessons of paleoclimatology are clear and should be studied comprehensively. The climate of the Earth has been and always will be dynamic and cyclic, and needs to be included when considering the balance or imbalance of natural systems. Therefore, the climate of Earth should be regarded as the basis for coevolution (joint evolution) of nature and society that has found its synthesis in the theory of sustainable development. When considering the strategy of sustainable development, the **economy-ecology** pair is usually implied, but in most of the cases the basic principles of ecology and the regularities of ecosystem development are not understood. As a result of evolution, man has found a place at the top of the nutritional pyramid and exerts a colossal impact on the balance of ecosystems. Let us hope that we can develop an awareness of the role of man as a natural part of the biosphere, a product of the biological and social evolution.

The dynamics of the climate system over the long history of the Earth have been determined mainly by natural phenomena - astronomical and orbital impacts, geophysical, geological and geographical factors - which also preserve their primary importance at the present time. However, the negative role exerted by man on nature and climate in particular cannot be ignored. This role is huge, comparable to the most powerful factors in the geological history of the planet. For this reason it is important to emphasize ever more strongly the responsibility of man's role in maintaining or regaining a natural and the nature-society equilibrium.

The necessity of readjusting the contemporary global pattern towards sustainable development on the basis of **new civilization principles and new philosophy** becomes even more urgent. This requires the elaboration of a new system of values that will bring man in harmony with the new environmental conditions, in unison with natural laws, with an end to the idea that He is the vicar of God. This requires new education for everybody – from children to politicians.

Today, with the aspiration to reduce by 80 % the emissions of greenhouse gases, and carbon dioxide in particular, trillions of dollars are spent in the world… while just a small part has been allocated to education, *education that will encompass all strata of society, and above all politicians*. At present the knowledge about the Earth, its structure, intensive dynamics and complex and long history of development is at a low level. The climate system represents a part of planet Earth, determined to a great extent by its dynamics, and for this reason we have to acquire knowledge about Earth as an integrated system, the planet as a whole, in order to achieve a deeper understanding of climate dynamics. Without such knowledge the joint efforts for reasonable actions against the trend towards global warming will not achieve substantial progress.

Humanity must endeavour to be integrated into the natural biogeochemical cycles of the biosphere instead of provoking perturbations in the living world, especially those which impact climate system dynamics. Man, regardless of his intellect, cannot suspend geological processes. We should point out that the *real natural catastrophes are not the most terrible part of human existence. What is more, the big geological and cosmic calamities are very rare events*. Furthermore, there are many ways nowadays for avoiding or strongly reducing the consequences of these catastrophes. **Ignorance and/or the illusion that mankind may have the sovereign power over everything may be even more terrible.**

We must all have the awareness that the future of the Earth, on which life emerged and which has become our habitat and home, deserves to be cherished deeply in our hearts and minds, because the destiny of the planet is our destiny too.