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ORIGINAL ARTICLE

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On global forces of nature driving the Earth's climate. Are humans involved?

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Abstract The authors identify and describe the following global forces of nature driving the Earth's climate: (1) solar radiation as a dominant external energy supplier to the Earth, (2) outgassing as a major supplier of gases to the World Ocean and the atmosphere, and, possibly, (3) microbial activities generating and consuming atmospheric gases at the interface of lithosphere and atmosphere. The writers provide quantitative estimates of the scope and extent of their corresponding effects on the Earth's climate. Quantitative comparison of the scope and extent of the forces of nature and anthropogenic influences on the Earth's climate is especially important at the time of broad-scale public debates on current global warming. The writers show that the human-induced climatic changes are negligible.

Keywords Global forces of nature · Climatic changes · Energy fluxes · Earth's outgassing

Introduction

Identification and understanding of global forces of nature driving the Earth's climate is crucial for developing adequate relationship between people and nature, and for developing and implementing a sound course of action aimed at survival and welfare of the human race. The latter is especially important in the light of present-day public debates on causes and ways of mitigation of the current global atmospheric warming.

After the Kyoto Protocol had been announced in 1997 (Kyoto Protocol 1997), many researchers around the world criticized its provisions (that imposed drastic restrictions on anthropogenic carbon dioxide emission in developed countries) as meaningless and catastrophic. Logical and quantitative comparison analyses presented in the publications of Robinson et al. (1998), Soon et al. (2001), Bluemle et al. (2001), Baliunas (2002), Sorokhtin (2001), Sorokhtin and Ushakov (2002), Gerhard (2004), and Khilyuk and Chilingar (2003, 2004) showed that the theory of currently observed global atmospheric warming as a result of increasing anthropogenic carbon dioxide (and the other greenhouse gasses) emission is a myth. This myth proved to be an enduring one.

The Earth's climate is a generic term for a relatively stable long-term state of the Earth's atmosphere. The main parameters that describe the Earth's climate quantitatively are the atmospheric temperature and pressure averaged over certain areas and chosen time intervals. They are determined by the energy and matter flows from inside and outside of the terrestrial body, matter transformation over the Earth's surface (at the interface between lithosphere and atmosphere), and parameters of the Earth's atmosphere and the World Ocean.

Solar radiation supplies the major energy influx to the Earth's atmosphere that determines the Earth's heating and cooling, and the outgassing supplies the major matter influx to the Earth's atmosphere that determines its physical and chemical properties.

The matter transformation at the Earth surface and in the World Ocean is caused by evolutionary physical changes, chemical reactions, and activities of live matter. In addition to these factors, the terrestrial body experiences orbital deviations and spatial mass redistribution that influence the Earth's climate considerably.

The authors identify and describe the global forces of nature driving the Earth's climate and compare their effects with anthropogenic influences on the Earth's climate.

Solar radiation reaching the Earth's body

The total average solar energy flux currently reaching the Earth's surface, $S_0 = 1.75 \times 10^{24}$ erg/s, is determined by the so-called solar constant $s \approx 1.37$ kW/m^2 = 1.37×10^6 erg/cm^2 s (Horrell 2003). The total heat flux through the Earth's surface due to energy generated in the mantle and the crust is estimated at about 4.3×10^{20} erg/s (Sorokhtin and Ushakov 2002), which is approximately 0.0257% of the total Earth's solar irradiation. The world total energy production in the year of 2003 was equal to 1.34×10^{20} erg/s (Key World Energy Statistics 2004), which is about 0.0077% of the total solar irradiation reaching the Earth's body. Comparison of the above figures clearly shows that the solar radiation is the dominating source of energy supply to the Earth's atmosphere and hydrosphere. One can easily estimate that the solar radiation supplies more than 99.95% of total energy driving the world climate. Thus, heating and cooling of the atmosphere is mostly due to variations in insolation of the terrestrial body (Hoyt and Schaten 1997).

The effect of solar irradiation on global atmospheric temperature can be evaluated using the adiabatic model of the heat transfer in the Earth's atmosphere (Sorokhtin and Ushakov 2002; Khilyuk and Chilingar 2003). To analyze temperature changes attributed to variations in energy and matter flux, one can use the following convenient form of this model

$$T(h)/T_0 = (S/S_0)^{1/4}(p(h)/p_0)^{\alpha} \qquad (1)$$

where $T(h)$ is global atmospheric temperature at any given altitude h; T_0 is the present global temperature at sea level; $T_0 = 288$ K; S is the total solar energy flux reaching the Earth's surface; S_0 is the total present average solar energy flux; $S_0 = 1.75 \times 10^{24}$ erg/s; $p(h)$ is global atmospheric pressure at the altitude h; and p_0 is the global average atmospheric pressure at the sea level ($p_0 = 1$ atm).

For a rough estimate of the global atmospheric temperature change at the sea level attributed to the natural variations in insolation S, Eq. 1 can be rewritten in the following form

$$\Delta T = T - T_0 = T_0\left[(S/S_0)^{1/4} - 1\right] = 288\left[(S/S_0)^{1/4} - 1\right] \qquad (2)$$

Data in Table 1 computed using Eq. 2 allow one to translate the variations in the Earth's insolation into corresponding changes in the Earth's global temperature at sea level.

As shown in Table 1, one percent increase in current solar radiation reaching the Earth's body translates directly into approximately 0.86 K increase in the Earth's global temperature. Using Eq. 2, one can also find an upper estimate for the possible atmospheric temperature increase due to anthropogenic activities. Even if the entire world energy generated by humans (1.34×10^{20} erg/s) would be utilized only for heating the Earth's atmosphere, the corresponding atmospheric temperature increase would not exceed 0.01°K at the sea level (based on Eq. 2). If, in addition, one takes into consideration that changes in the global atmospheric temperature are closely correlated with the changes in solar activity (Fig. 1), then one has to conclude that the solar irradiation is the dominant energy supply driving the Earth's climate (see also Hoyt and Schaten 1997; Kondratiev 1992).

Orbital deviations and the Earth's mass redistribution

Parameters of the elliptic Earth's orbit (orbital eccentricity, obliquity, and precession index) are changing over geologic time. The terrestrial mass redistribution also results in changes of the orbital parameters specifically of the precession index (Marov 1986).

Changes in orbital parameters result in corresponding changes in the Earth's insolation. The current yearly difference between aphelion (the farthest departure from the Sun) and perihelion (the closest approach to the Sun) is about 3 million miles, which amounts to about a 6% difference in the Earth's insolation from the month of January to the month of July (http://www.earthobservatory.nasa.gov/Library/Giants/Milankovitch.html). Paleoreconstructions show (Barron 1994) that the variations in the global average Earth's insolation attributed to the planet's orbital deviations can reach up to 10% of the "long-term" average radiation level (Fig. 2). Therefore, maximal orbital deviations result in exactly the same effect on the global temperature as 10% change in solar irradiation. Thus, the resulting effect of orbital deviations on the global temperature can be evaluated using the same adiabatic model of the Earth's atmosphere (Sorokhtin and Ushakov 2002; Khilyuk and Chilingar 2003).

Analyzing Fig. 2 (Barron 1994) and using Eq. 2, one can determine that during the last 500,000 years the global temperature deviated 7.5 K (from the long-term average value) at least 4 times, and more than 20 times this deviation was about 4 K due to changes in the Earth's orbital parameters. This leads one to an important conclusion on considerable variability of the

Table 1 Global temperature changes attributed to variations in the Earth's insolation

S/S_0	0.85	0.90	0.95	0.99	1.00	1.01	1.05	1.10	1.15
ΔT (K)	−11.5	−7.49	−3.77	−0.86	0.00	0.86	3.77	7.49	11.5

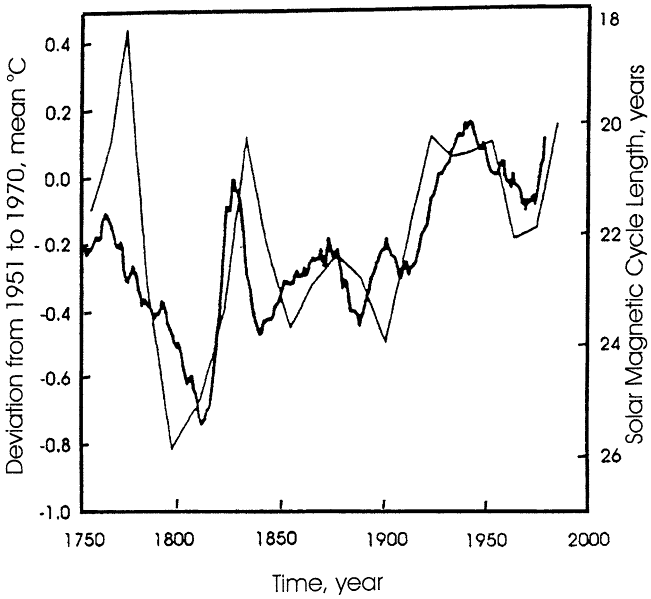

Fig. 1 Moving 11-year average terrestrial temperatures (Northern Hemisphere) shown as deviations in °C from the 1951–1970 mean value (*left vertical axis and thick line*) and the solar magnetic cycle lengths (*right vertical axis and thin line*) (modified after Robinson et al. 1998, Fig. 3)

Earth's climate over geologic time due to natural changes in the Earth's insolation caused by orbital deviations and geologic insignificance of recent global warming period with the global temperature increase of 1°F≈0.56 K during the last century (EPA global warming site 2001).

The Earth's outgassing

Most of atmospheric gases are generated in the inner layers of the Earth (mostly in the mantle) over geologic history and are transferred to the upper systems (atmosphere and hydrosphere) by outgassing. Outgassing is a process of upward migration of various gases generated in the mantle and the Earth's crust and seeping through the Earth's surface into the atmosphere and the World Ocean (Khilyuk et al. 2000). Most of the gasses (methane, carbon dioxide, water vapor, hydrogen, helium, and others) formed in the process of chemical reactions under different physicochemical conditions are continuously migrating upward and forming the atmosphere throughout the geologic history. The Earth's atmosphere and hydrosphere were formed about 4 billion years (BY) ago by outgassing (Vinogradov 1967; Holland 1984; Sorokhtin and Sorokhtin 2002). This process is going on at the present time.

The rate of outgassing is determined by the rate of tectonic activity. As a universal measure of the rate of global tectonic activity one can use the rate of heat flux through the Earth's surface, because its level indicates the magnitude of total energy generated in the mantle. If, for some reason, it is not possible to estimate the value of the heat flux, then the rate of oceanic floor spreading (in the spreading zones) can be substituted for it. The rate of spreading is directly translated into the rate of displacement of the tectonic plates that presently averages 4.5–5 cm/year (Sorokhtin and Ushakov 2002).

Main gasses generated in the mantle and on the ocean floor are: carbon dioxide, methane, and hydrogen. Carbon dioxide (CO_2) dissolves mostly in the oceanic water and transforms to abiogenic methane (CH_4) and carbonate ($2MgCO_3$) (Sorokhtin and Sorokhtin 2002) through the following chemical reactions:

$$4Fe_2SiO_4 + 12Mg_2SiO_4 + 18H_2O + CO_2 \rightarrow 4Mg_6[Si_4O_{10}][OH]_8 \text{ (serpentine)} + 4Fe_2O_3 \text{ (hematite)} + CH_4 + 183.47\,\text{kcal/mol of heat} \quad (3)$$

$$4Mg_2SiO_4 \text{ (olivine)} + 4H_2O + 2CO_2 \rightarrow Mg_6[Si_4O_{10}][OH]_8 \text{ (serpentine)} + 2MgCO_3 + 72.34\,\text{kcal/mol of heat} \quad (4)$$

$$2CaAl_2Si_2O_8 \text{ (anorthite)} + 4H_2O + 2CO_2 \rightarrow Al_4[Si_4O_{10}][OH]_8 \text{ (kaoline)} + 2CaCO_3 + 110\,\text{kcal/mol of heat} \quad (5)$$

These reactions are accompanied by a very large amount of heat release. This heat contributes considerably to the heat flux through the Earth's surface. Thus, the rate of abiogenic CH_4 generation on the ocean floor in the spreading zones can be used as a measure of global tectonic activity. In turn, the rate of the Earth's tectonic activity can be used as a measure of the Earth's outgassing rate.

CH_4 gas enters the atmosphere, contributing to the greenhouse effect and depleting ozone concentration through the following reaction:

$$CH_4 + O_3 + \text{Solar radiation} \rightarrow CO_2 + H_2O + H_2 \quad (6)$$

Due to a high level of current tectonic activity, there is a pronounced increase in the current methane gas gener-

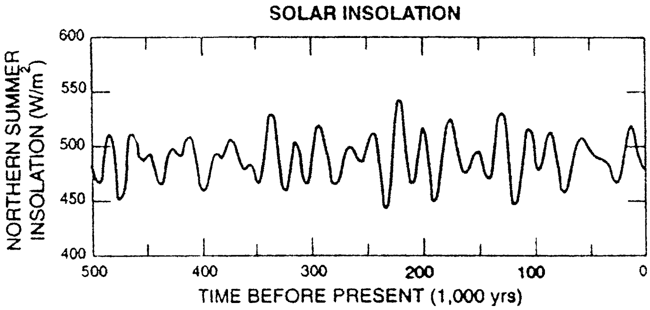

Fig. 2 Variations in insolation (W/m^2) due to deviations of the Earth's orbital parameters (modified after Barron 1994, Fig. 13)

ation at the oceanic floor (Yasamanov 2003). Yasamanov estimates that about 5×10^{15} g/year of CH_4 are currently released to oceanic water at the spreading zones of mid-ocean ridges only. He believes that the increasing concentration of methane leads to significant increase in the atmospheric carbon dioxide content that considerably amplifies the atmospheric greenhouse effect.

Gases accumulating in the atmosphere and the rate of outgassing determine the properties of gaseous atmospheric mixture, in particular, changing the density and thermal capacity of the air. One can assume that: the greater the rate of outgassing, the higher the atmospheric pressure. According to the adiabatic theory of heat transfer in the atmosphere (Khilyuk and Chilingar 2003), the latter leads to increase in the atmospheric global temperature.

Studying the origin and evolution of the Earth's atmosphere, one needs to take into account that the primordial Earth's matter contained only traces of volatile elements (H_2, He) and compounds. All other volatile compounds (H_2O, CO_2, O_2, HCl, HF), except possibly N_2, were mostly degassed out of the Earth mantle throughout geologic history (Sorokhtin and Sorokhtin 2002).

Outgassing could start only after fusion of the upper layers of the Earth's matter and beginning of the Earth's tectonic activity (about 4 billion years ago). Under plausible assumption that the rate of Earth's degassing is proportional to its tectonic activity and realistic estimates of the original amounts of volatile components in gaseous primordial atmosphere and solid matter of the Earth, Sorokhtin and Sorokhtin (2002) modeled degassing of N_2, CO_2, H_2O, and O_2, out of the mantle and their accumulation in atmosphere and hydrosphere. The results of their modeling demonstrated, for example, that the nitrogen of contemporary atmosphere contains 55% of the relic gas and 45% of the gas of magmatic origin. Geologic evolution of the relative content of nitrogen in the atmosphere (under three different hypotheses of the origin of the dominant amount of N_2) is shown in Fig. 3. The most probable "intermediate" evolution of the nitrogen partial pressure in the atmosphere is presented by the curve 2.

Total mass of CO_2 degassed from the mantle throughout geologic history is estimated at 4.63×10^{23} g, and the CO_2 mass remaining in the mantle is estimated at 4.48×10^{23} g (Sorokhtin and Ushakov 2002). Therefore, the total mass of CO_2 in the present Earth's system is about 9.11×10^{23} g (Sorokhtin and Ushakov 2002; Khilyuk and Chilingar 2004). Accumulation of CO_2 in the upper geospheres (atmosphere, hydrosphere, and the Earth's crust) is shown in Fig. 4. Figure 5 illustrates the evolution of the CO_2 partial pressure in the atmosphere.

To estimate the amount of total anthropogenic CO_2 emission, one can use an excellent compendium of data on estimates of anthropogenic carbon dioxide emission from the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, TN, USA (Marland et al. 2002). The estimates in this compendium are expressed in million metric tons of carbon. The data set comprises the annual releases of CO_2 from 1751 to 2002. They can be roughly sorted out into two groups: before the year of 1900 and after the year of 1900. The data of the first group exhibit linear growth of the emission in eighteenth and nineteenth centuries, whereas the data from the second group show exponential growth of the anthropogenic CO_2 emission in twentieth century. This observation allows one to use a piece-wise approximation for the data of compendium: a linear function for the first group and an exponential function for the second group.

Using the endpoints of the domain intervals for evaluation of the coefficients of the approximating

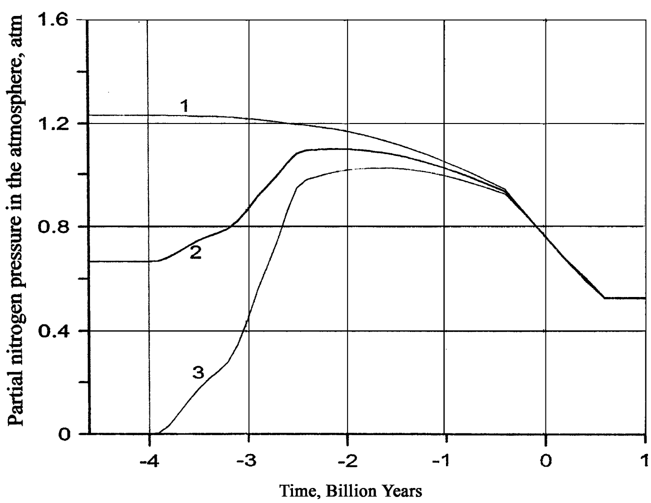

Fig. 3 Evolution of the partial pressure of nitrogen in the atmosphere: *1* under hypothesis that the entire Earth's atmosphere nitrogen mass was of primordeal origin, *2* most probable intermediate scenario, *3* under hypothesis that the entire atmospheric nitrogen mass was degassed from the mantle. On the abscissa 0 (zero) represents present time (modified after Sorokhtin and Ushakov 2002)

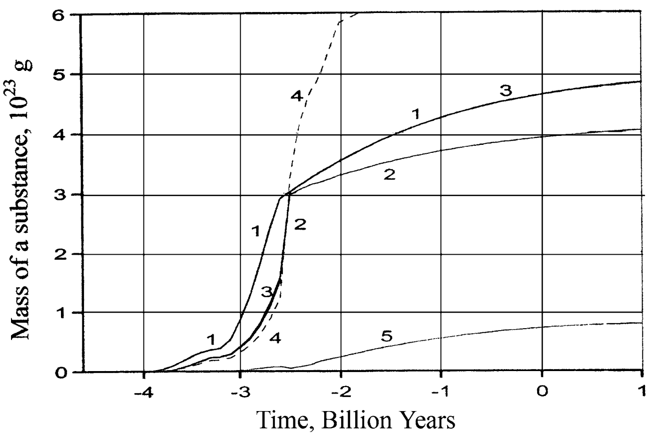

Fig. 4 Mass of carbon dioxide in the Earth's crust: *1* mass of the carbon dioxide degassed from the mantle, *2* mass of the carbon dioxide accumulated in the carbonate rocks of the Earth's crust, *3* total mass of carbon dioxide accumulated in carbonates and biogenic rocks, *4* mass of water accumulated in the Earth's crust, *5* mass of organic carbon present in rocks recalculated as carbon dioxide (modified after Sorokhtin and Sorokhtin 2002)

equations, the writers obtained the following piece-wise function (considering that CO_2 emission prior to the year of 1800 is negligible in comparison with later data):

$$C = 8 + 5.26t \text{ if } t \in [0, 100] \text{ and } t = 0 \text{ is taken for the year of 1800, and} \tag{7}$$
$$C = 534e^{0.025(t-100)} \text{ if } t \in [100, 202]$$

where t is time, in years, and C is the annual carbon dioxide emission rate in 10^6 metric tons of carbon/year.

The writers used this approximating function (Eq. 7) for computing a rough estimate of the total anthropogenic carbon dioxide emission throughout human history.

Integrating the first function over the interval [0, 100], one obtains $27{,}100\times10^6 = 2.71\times10^{10}$ ton. Integration of the second function over the interval [100, 202] results in $253{,}543\times10^6 = 2.53543\times10^{11}$ ton. The latter number indicates that the total anthropogenic CO_2 emission in the twentieth century is about one order of magnitude higher than that in nineteenth century. Adding these two numbers together, the total anthropogenic carbon dioxide emission throughout the human history is estimated at about 2.81×10^{11} metric tons of carbon. Recalculating this amount into the total anthropogenic carbon dioxide emission in grams of CO_2, one obtains the estimate 1.003×10^{18} g, which constitutes less than 0.00022% of the total CO_2 amount naturally degassed from the mantle during geologic history. Comparing these figures, one can conclude that anthropogenic carbon dioxide emission is negligible (indistinguishable) in any energy-matter transformation processes changing the Earth's climate.

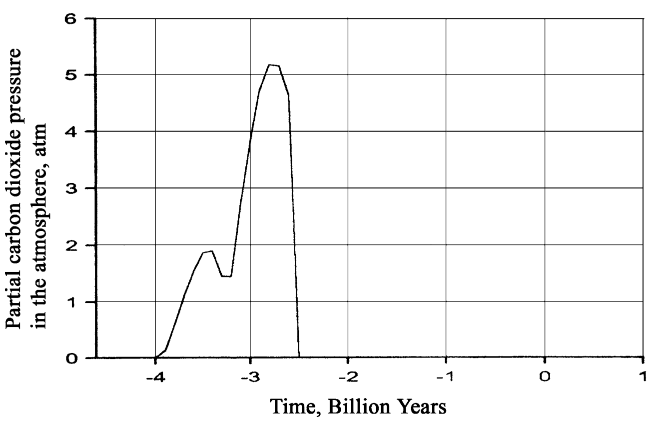

Fig. 5 Evolution of the partial pressure of carbon dioxide in the atmosphere (modified after Sorokhtin and Sorokhtin 2002)

Evaluation of the atmospheric oxygen content evolution throughout the geologic history encounters a great deal of uncertainty because this process was affected considerably by many fuzzy factors, such as photosynthesis ability of ancient microorganisms. Nevertheless, even qualitative reconstructions based only on geochemical data present clear picture of continuously increasing oxygen content in the atmosphere (Sorokhtin and Ushakov 2002). The reconstruction of accumulation of oxygen in sedimentary rocks and in the atmosphere (Sorokhtin and Ushakov 2002) is presented in Fig. 6. Evolution of the atmospheric composition and pressure is shown in Fig. 7.

In the light of debates on global warming (Milloy 2005), one should notice the gradual reduction of atmospheric pressure on the geologic time scale between approximately −0.3 and 0.5 billion years. This means that we live in the cooling geologic time and the global warming observed during past 150 years is just a short episode in geologic history. According to Sorokhtin and Ushakov (2002), the cooling period will continue in the future due to life-activities of the nitrogen-consuming bacteria that transfer the atmospheric nitrogen into soils with subsequent burial in sediments. In approximately 0.6 BY, when endogenic oxygen starts degassing intensively because of formation of the core matter Fe·FeO according to the following reaction:

$$2Fe_3O_4 \rightarrow 3Fe \cdot FeO + 5O, \tag{8}$$

the atmospheric pressure will rapidly increase over 40 atm. This will result in sharp increase in the global temperature to over 80°C (Fig. 8). The impact of this hostile environment on highly organized species will be their extinction.

Inner sources of the Earth's energy

The Earth is a "heat machine". To originate and sustain large-scale matter-energy transfers and transformations

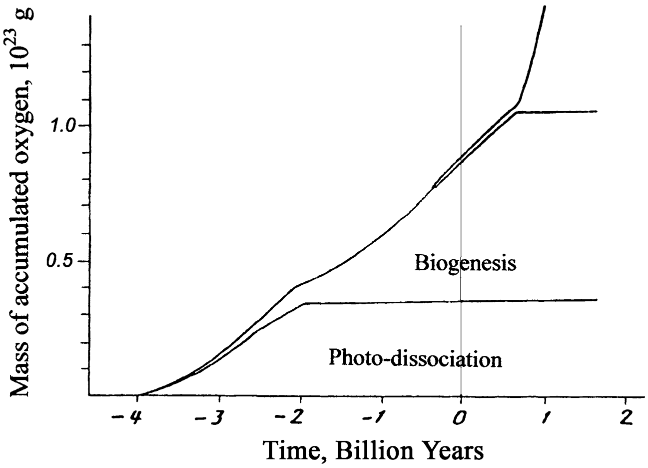

Fig. 6 Accumulation of oxygen in the sedimentary rocks and in the atmosphere, and its origin (modified after Sorokhtin and Ushakov 2002, p. 417)

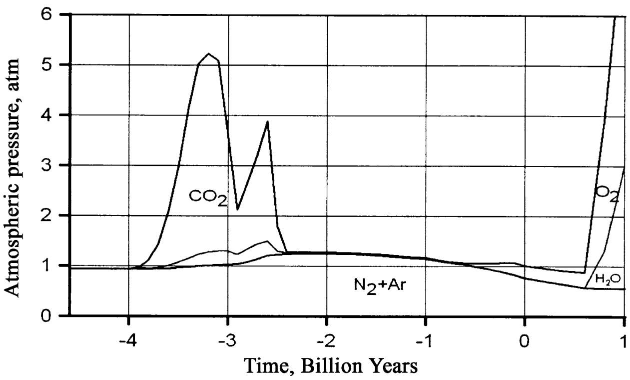

Fig. 7 Evolution of composition and pressure of the Earth's atmosphere (modified after Sorokhtin 2005a, b)

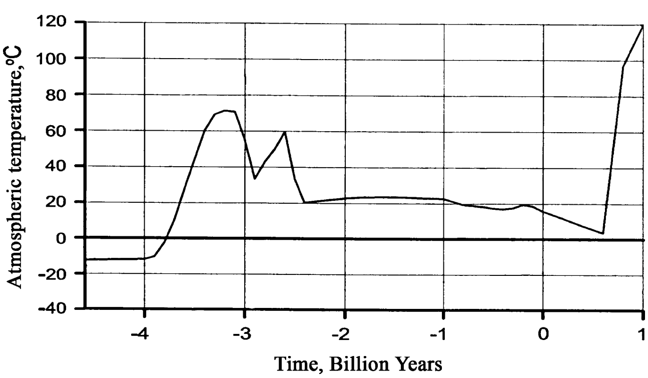

Fig. 8 Temperature evolution of the Earth's atmosphere (average atmospheric temperature at sea level) (modified after Sorokhtin and Ushakov 2002)

in the inner layers, an astronomic amount of heat has to be continuously generated in the mantle and the core of the Earth.

To generate gasses, the upper silicate mantle matter must be in a plastic (semi-molten) state (Sorokhtin and Ushakov 2002). The mass of this plastic matter has to be sufficient to develop vertically-oriented convectional flows in the mantle. The mass of mantle constitutes about 67% of the Earth's total mass of 5.979×10^{27} g (Britannica Student Encyclopedia 2005). To raise a temperature of this huge mass of the mantle matter to the melting point, an enormous amount of heat should be generated. What are the sources of energy that can generate this heat?

Widespread belief that the necessary energy is supplied by the process of radioactive decay of physically unstable elements cannot pass a simple verification test: the estimated total heat flux through the Earth's surface many times surpasses the heat flux that can be generated in the process of radioactive decay of the entire amount of radioactive matter of the Earth. By estimates of Vacquier (1990), the heat from radioactive decay of the entire radioactive matter of the planet can supply at most 25% of the observed total heat flux through the Earth's surface. In addition, the main mass of radioactive matter (about 90% of the total in the Earth) is concentrated in the upper layers of the continental crust (Khain 2003). This means that the heat generated by radioactive decay cannot play a leading role in driving the matter-energy transformations in deep layers of the mantle. For example, it is absolutely insufficient to generate energy for heating a huge mass of the mantle matter (approximately 4.006×10^{27} g) to the temperatures from 100°C (at the top of the mantle layer) to 2,700°C (at the bottom) and to originate and sustain the mantle matter convection. Therefore, one needs to identify a significantly greater source of energy to drive all physical and chemical transformations in the mantle.

This source of energy was first identified and described by Sorokhtin (1972) and Dubrovskiy and Pankov (1972) as the gravitational matter differentiation that results in heat generation in the process of redistribution of the Earth's matter over the terrestrial body throughout geologic history. This redistribution occurs through chemical and physical transformations, driving denser matter toward the center of gravity of the Earth. This process is a manifestation of the universal principle of minimum potential energy for a closed system: in the Earth's body, a denser matter migrates toward the center of gravity to minimize the Earth's body potential energy.

Gravitational matter differentiation supposedly had started in the Archaean time (about 4 BY ago) with zonal melting of an original Earth's matter (Sorokhtin and Ushakov 2002) that was caused by the heat inherited from the proto-planetary "disk" and also accumulated during the accretion period. According to the most likely and popular hypothesis, the Earth's celestial body was formed as a result of homogeneous accretion of a cold matter from the proto-planetary cloud (Safronov 1972). This cold matter was continuously heated by numerous impacts of planetesimals in the process of matter accretion, releasing huge amount of heat. As a result, the temperature in some peripheral zones of the proto-planet coagulum was raised above the melting point of iron oxides, forming iron pools in the "sub-surface areas" of the proto-planetary coagulum.

One can get an idea about an amount of heat generated on these impacts using data from a recent NASA deep impact probe experiment (http://www.spacetoday.org). The NASA copper-clad projectile was relatively small (mass of about 372 kg). It dissipated energy equivalent to the energy of explosion of 5 ton of TNT, on impact with Comet Tempel 1 on July 4, 2005. The impact instantly increased the temperature at the area of collision by several thousand degrees.

The early Earth's matter zonal differentiation during the Archaean time resulted in extreme gravitational instability of the planetary body: a high-density peripheral ring layer consisting of the molten iron was formed due to zonal melting and was positioned above a lighter material of the core. This instability could be resolved in only one way: by squeezing out the core matter through the equatorial belt to the Earth's peripherals and sinking of the heavy molten iron to the center of the planetary body, gradually forming an iron core. This process was accompanied by a huge energy release (about 5.5×10^{37} erg; Sorokhtin and Ushakov 2002). This energy was mostly used for additional heating of the Earth's interior, speeding up the core separation process.

After separation of the Earth's matter into two parts: metallic core and silicate peripherals, the process of squeezing out of the heavy iron oxides from the mostly silicate "mantle" into metallic core accelerated due to baric diffusion differentiation mechanism. This is the most productive mechanism of gravitational matter differentiation. Under high pressures and temperatures at the mantle bottom (about 0.89 Mbar and 2,700 K at a depth of 2,000 km) the atoms of iron and oxygen diffuse through crystalline grid of solid silicate compounds and form the iron oxides, which accumulate in the Earth's core. This process of baric diffusion (or barodiffusion) is accompanied by huge release of heat energy (151.6 cal per 1 g of released Fe_2O at the bottom of lower mantle; Sorokhtin and Ushakov 2002). Therefore, gravitational matter differentiation in the interior of the Earth is a major source of the Earth's inner heat.

In addition to energy of radioactive decay and gravitational matter differentiation, the Earth's interior is also heated by dissipation of tidal energy caused by gravitational influence of the Moon (solar gravitational influence is insignificant and can be neglected). Kinetic tidal energy transforms into tectonic heat of the Earth as a result of inner matter friction in tidal humps, which run around the globe and deform the Earth's body (Khain 2003).

At the present time, the bulk of the tidal energy is released in shallow seas with a considerably smaller part released in deep oceans and the Earth's asthenosphere. Current rate of the tidal energy release is estimated at 2.5×10^{19} erg/s (for comparison, the total heat flux through the Earth's surface is presently 4.3×10^{20} erg/s). Two thirds of this energy is dissipated in the shallow seas due to the friction between the bottom currents and the sea floor (McDonald 1964, 1965). The part of tidal energy dissipated in the mantle does not exceed 6% of the total released tidal energy. This means that the impact of dissipated tidal energy on the Earth's interior heating is insignificant, and that the main sources of the tectonic Earth's heat are gravitational matter differentiation and radioactive decay.

Sorokhtin and Ushakov (2002) estimated that 90% of energy feeding tectonic activity of the Earth is generated by the process of gravitational differentiation of the Earth's material; 9% is generated in the process of radioactive decay; and about 1% is produced in the process of tidal interaction between the Earth and the Moon.

Smoothing role of the World Ocean

The mantle degassing began in the Archaean time (4 billion years ago). One of the main constituents of the degassed mixture was water vapor. After accumulation of sufficient amount of water vapor in the atmosphere (under appropriate atmospheric pressure and temperature conditions), the first aquatic basins were created, which (about 3.6 billion years ago) developed into a unified shallow ocean. As a result, the Earth's global surface temperature began increasing rapidly (Sorokhtin and Sorokhtin 2002).

A huge mass of water in the contemporary World Ocean (approximately 1.37×10^{24} g) slows down all processes of heat and mass transfer between the mantle and the atmosphere and accumulates the excess of solar energy. The top 200 m of the world ocean store 30 times more heat than the atmosphere [http://www.ace.mmu.ac.uk/eae/Climate.html]. Presently, observed global atmospheric heating was also accompanied by the oceanic water warming. During 40 years period from 1969 to 2000, the upper 300 m of the World Ocean warmed on the average by 0.56°F (NOAA News Online 2000).

Global oceanic currents transfer heat from the equatorial warmer regions of the ocean to the cold polar waters and thus mix these waters, reducing oceanic and atmospheric temperature differences between various climatic zones.

Contemporary oceanic water contains 50–60 times more carbon dioxide as the atmosphere (Sorokhtin 2001). When the global temperature rises, the solubility of the carbon dioxide in the ocean water decreases, and part of the carbon dioxide content of the ocean water is transferred into the atmosphere, creating an illusion that the increased concentration of the carbon dioxide heating the atmosphere is a result of anthropogenic activity (Sorokhtin 2001; Khilyuk and Chilingar 2003). All land plants produce food from photosynthesis that utilizes carbon dioxide and water in the presence of solar radiation. Oceanic plankton consumes carbon dioxide for photosynthesis and building the shells. Consumed carbon dioxide is replaced by the gas of magmatic origin and by the atmospheric gas (if the global temperature drops).

Interplay of the energy and matter fluxes between the World Ocean and the atmosphere has a pronounced smoothing effect on the Earth's climate Because of the world ocean one can talk about long-term climatic patterns. Otherwise, all the climatic changes would occur much sharper and faster, and it would be impossible for the forces of nature to originate and sustain long-term trends in changing average global temperature that determine the Earth's climate.

Microbial activity at the interface of lithosphere and atmosphere

From all the live species, only bacteria can directly influence the mass and content of the gaseous mixture of the Earth's atmosphere on a global scale. Considerable changes in concentrations and contents of various gases composing air can alter the Earth's climate. Recent discoveries in microbiology revealed a broad proliferation of methane-generating and methane-consuming bacteria and also (which is even more important) abundance of denitrifying and nitrogen-consuming bacteria. Therefore, the interplay of these ''microbial'' forces should affect the Earth's climate.

Methane gas entering the atmosphere from such natural sources as (1) wetlands, (2) rice paddies, (3) cattle digestion, (4) termite digestion, and (5) marine organisms is actually generated by bacteria. There were only few episodic studies on methane-generating bacteria in spite of the fact that life activity of these bacteria considerably contribute to the total balance of the methane gas in the atmosphere. Among the publicized research works on methane-generating bacteria, one should mention the Cornell University study initiated in 2002 with the support of National Science Foundation (http://www.news.cornell.edu/Chronicle/02/2.14.02/microbial_observatory.html). The purpose of this study was to extract from the wetlands (dominant source of natural methane) and artificially grow the colonies of bacteria and to determine the impact of environmental conditions on the life of colonies.

Recently, the team of researchers (from Penn State University and University of California, Los Angeles, USA) discovered vastly proliferated methane-consuming archaeobacteria (Orphan et al. 2001, 2002). These bacteria are possibly responsible for consuming most of the methane gas at the bottom of the World Ocean.

Microbial activities play an important role in the transit of nitrogen from the atmosphere to the Earth's surface and vice versa. Only bacteria are able to consume and accumulate nitrogen directly from atmosphere. They fix it to organic molecules, making proteins (nitrogen fixation process). All other live species consume and accumulate nitrogen via food chain, from proteins produced by bacterial activity in the process of nitrogen fixation.

Bacteria living on the roots of some plants can fix nitrogen by producing proteins (http://www.starsandseas.com/SAS%20Ecology). Animals can get necessary nitrogen by eating plants. The remains of plants and animals can be buried in oceanic sediments, transferring nitrogen into the solid matter of the Earth. It is not clear yet what is the scope of life activities of such bacteria.

Recently, microbiologists discovered new microbial species consuming nitrogen: spirochetes (corkscrew bacteria) living in termite guts and fresh and sea waters (Lillburn et al. 1999, 2001). Huge population and vast termite proliferation worldwide make spirochetes living in their guts and generating proteins a major supplier of nitrogen for the Earth's live matter.

Some soil bacteria, however, consume NO_3^- (nitrates) and convert them into nitrogen returning the nitrogen gas into the atmosphere. The latter process is called denitrification. Therefore, increase or reduction of the nitrogen content in the atmosphere may be determined by the balance between bacterial activities in the processes of nitrogen fixation and denitrification.

Glacial spells: ice ages

In the geologic history, there were five major ice ages: 2.5 billion years, 600 million years, 440 million years, and 2.5 million years ago (http://www.geosciences.ou.edu/~msoreg/tes/paleoclimate2.html). During the ice ages, large thick shields of ice may cover the entire continents. This had a pronounced impact on the Earth's climate changing the sea level (total oceanic water volume), climatic belts, and distribution of biota.

Traditional explanation of the development of ice ages in the past geologic epochs is based on so-called Milankovitch cycles (http://www.earthobservatory.

nasa.gov/Library/Giants/Milankovitch)—periodic variations in Earth's insolation due to semi-cyclic variations in the Earth's orbital parameters (orbital eccentricity, obliquity, and precession of the Earth's axis). These parameters exhibit semi-cyclic changes with average periods ranging from 20 to 100 thousand years. Corresponding changes in temperature at the Earth poles can reach up to 15 K (Sorokhtin 2005a, b).

These periodic variations in the orbital parameters are well correlated with occurrence of glacial periods (http://www.geosciences.ou.edu/). They contradict, however, the irregular, increasingly more frequent occurrence of main ice ages in the geologic past during the last billion years (Chumakov 2001, 2004). Consequently, one needs alternative (to oscillating insolation) explanations for the pronounced drop in global atmospheric temperature.

According to the adiabatic theory of heat transfer in the atmosphere, atmospheric temperature drop is determined by the decrease in atmospheric pressure. The latter implies that there are some global mechanisms reducing the partial pressures of the Earth's atmospheric constituents.

One of the proposed hypotheses (http://www.geosciences.ou.edu/) on the causes of pronounced atmospheric pressure reduction leading to major ice ages is a persistent drop in atmospheric carbon dioxide content during the Earth's geologic past. Possible mechanisms include long-term weathering of silicates and rapid burying of large amounts of organic matter, preventing contained carbon from oxidation. "This might occur about 300 million years ago when large coastal swamps were buried" that led to considerable reduction of the atmospheric carbon dioxide content and consequent temperature drop (http://www.geosciences.ou.edu/).

One can easily refute this hypothesis by noting that, at that time, the atmospheric CO_2 content was very low (its partial pressure did not exceed 1 matm, and the global atmospheric pressure and temperature were close to their present values) (Sorokhtin and Sorokhtin 2002). Even if the entire content of CO_2 was removed from the atmosphere at that time, this could not have led to considerable temperature drop necessary for the initiation of ice age. Corresponding temperature drop can be conveniently estimated based on the adiabatic model. At the sea level, the temperature change can be computed using the formula (Khilyuk and Chilingar 2003)

$$\Delta T \approx T\alpha\Delta p \tag{9}$$

where Δp is the atmospheric pressure change in atm, T and ΔT are the global temperature and temperature change at the sea level, respectively, and α is the adiabatic exponent.

After substitution of $T = 288$ K, $\alpha = 0.1905$, and $\Delta p = 10^{-3}$ atm into Eq. 9, one obtains $\Delta T \approx 5.49 \times 10^{-2}$ K. This insignificant global atmospheric temperature drop (approximately 0.055 K) obviously could not cause the initiation of ice age.

The main constituent of the Earth's atmosphere during the last 2.5 billion years was (and continues being) nitrogen. The present partial pressure of nitrogen is about 0.755 atm. Three hundred million years ago, the nitrogen content was even higher than the present level. Its partial pressure was approximately 0.95 atm, at the total atmospheric pressure of about 1.1 atm (Sorokhtin 2005a, b). This means that only pronounced persistent drop in the atmospheric nitrogen content can explain a non-periodic ice age occurrence. In other words, certain global mechanisms must exist in the Earth's system transforming gaseous nitrogen of the atmosphere into the solid matter, which is buried in the oceanic sediments.

One of the most plausible explanations is the high nitrogen consumption by the nitrogen-consuming bacteria. In this way, the gaseous nitrogen of the atmosphere can be transferred into the solid matter of the sediments reducing the partial pressure of nitrogen (and thus the total atmospheric pressure) and lowering global temperature of the Earth. Considering this process to be irreversible, Sorokhtin (2005a, b) presented the hypothesis on bacterial nature of the ice ages. Having used simple exponential model of nitrogen degassing and having estimated the total content of nitrogen in the Earth's system, he developed plausible scenarios of evolution of partial atmospheric nitrogen pressure and corresponding global temperature changes throughout the geologic history (Figs. 3, 8). In these scenarios, all the glacial periods that occurred since 900 million years ago were attributed to nitrogen-consuming bacteria.

The bacterial hypothesis gains additional support after discovery of nitrogen fixation by symbiotic and free-living in fresh and salt-water spirochetes (Lillburn et al. 1999, 2001). This process of nitrogen transfer from the atmosphere to the Earth's crust, however, is reversible. For example, some soil bacteria consume nitrates and convert them into gaseous nitrogen (http://www.starsandseas.com/SAS%20Ecology). In this process of denitrification, nitrogen returns back into the atmosphere. To support the Sorokhtin's hypothesis, one needs at least to estimate balance between "nitrogen-consuming" and "nitrogen-generating" bacteria activities and prove that the consumption prevails. This problem, which is very important in the context of evaluation of the causes of global climatic changes, is yet to be studied.

Present developments in the bacterial transport of chemical elements and compounds through the Earth's system are in the embryonic stage. Characterizing the level of knowledge on methane-generating bacteria, for example, Segelkin (2002) noted: "They have been at it for millions of years, but practically nothing is known about wetland bacteria that turn organic matter into the

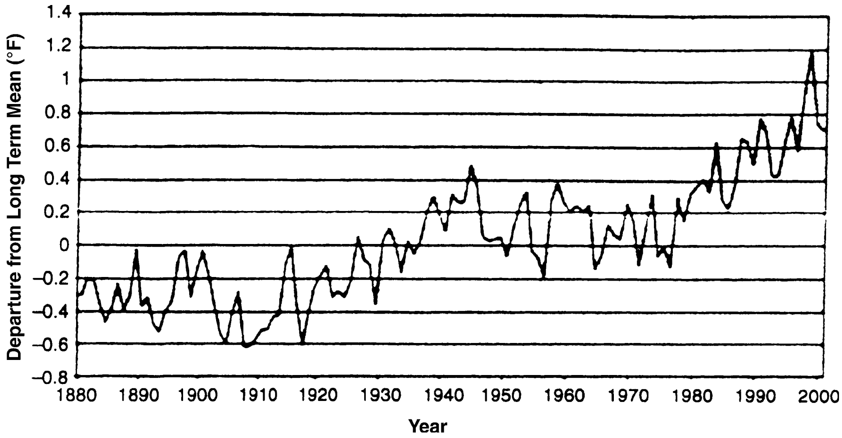

Fig. 9 Global average temperature changes in twentieth century (modified after EPA Global warming site: Climate US National Climatic Data Center 2001)

greenhouse gas, methane''. Microbiologists should yet culture and grow the bacteria, which generate and consume atmospheric gases, and study the impact of various environmental conditions on growth and decay of microbial colonies and their proliferation.

Do we live in the time of global warming or global cooling?

The answer to this question depends on a time span of the observed atmospheric changes. The latest 150 years were (and the near future will probably be) a period of global warming (Fig. 9). The major causes of currently observed global warming are: rising solar irradiation and increasing tectonic activity. On the other hand, if one considers the last three millennia, then one can observe a clear cooling trend in the Earth's climate (Keigwin 1996; Hoyt and Schaten 1997; Sorokhtin and Sorokhtin 2002, Sorokhtin and Ushakov 2002; Gerhard 2004; Khilyuk and Chilingar 2004). During that period, the global temperature deviations were 3 K with a clear trend of decreasing global temperature by about 2 K (Figs. 10, 11).

This trend started at least 7,000 years ago. Friedman (2005) studied the oxygen isotope composition of Gulf of Agaba beachrock (carbonate cement). He showed that the temperature of ambient sea water decreased for approximately half of the Holocene. According to Friedman (2005, p. 849), the average Red Sea water temperature decreased from 33 to 17°C over an interval of approximately 4,500 years—between the ages of 7.07(0.38 and 2.65(0.23 ka. Thus, the general tendency in the Red Sea area (and over the Earth's surface) seems to have been toward global cooling. Combining the Friedman's findings with the results of Keigwin (1996) (see Fig. 10), one may conclude that the latest cooling geologic time comprises most of the Holocene. Inasmuch as the deduced temperature change occurred during the time of relatively stable concentration of carbon dioxide in the atmosphere, the changes in its content were not driving the Earth's global temperature changes (Jenkins 2001, p. 1211).

This cooling tendency will probably last in the future (Fig. 8). The latter means that we live in the cooling geologic period and the global warming observed during the last approximately 150 years is just a short episode in the geologic history. Sorokhtin and Ushakov (2002) predict that the cooling period will be lasting in the future due to life-activities of the nitrogen-consuming bacteria that transfer the atmospheric nitrogen into soils with subsequent burial in the sediments.

In approximately 0.6 BY, when endogenic oxygen starts intensively degassing because of forming of the core matter Fe·FeO by reaction of Eq. 8, the atmospheric pressure will rapidly increase to over 40 atm. This will result in sharp increase of the global temperature to over 80°C (Fig. 8). In such a hostile environment, highly organized species will extinct.

Finally, if we move our horizon 2–3 billion years forward, we should expect the atmospheric overheating

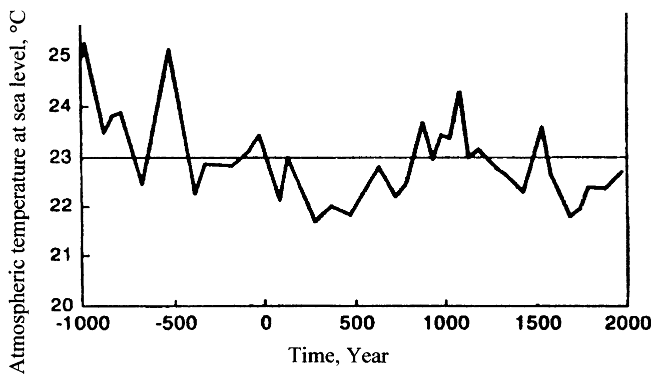

Fig. 10 Surface temperature in the Sargasso Sea (with time resolution of about 50 years) as determined by isotope ratios of remains of marine organisms buried in the sediments at the sea floor. The horizontal line represents the average temperature over 3,000 years period (modified after Keigwin 1996)

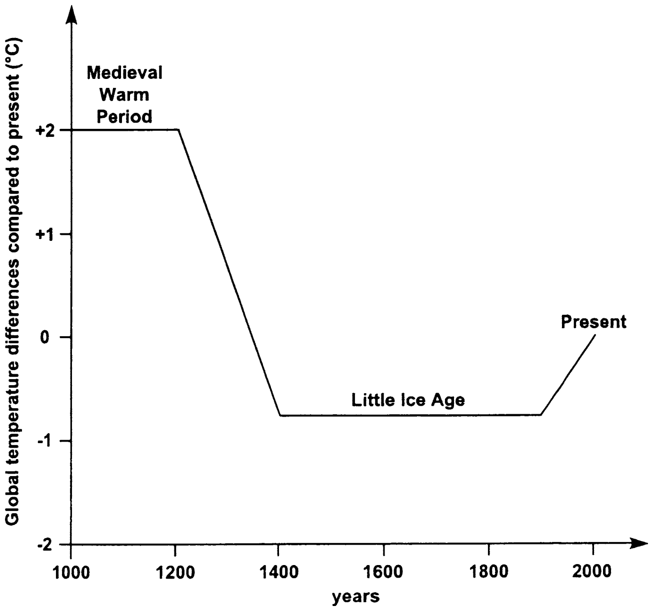

Fig. 11 Simplified diagram of global atmospheric temperature change over the last 1,000 years (modified after Gerhard 2004)

up to 300°C in the remote future due to catastrophic increase of the relative content and the partial pressure of oxygen in the atmosphere. This oxygen will be degassed out of the iron oxides as a result of chemical reactions accompanying gravitational matter differentiation in the Earth's inner layers.

Conclusions

The writers identified and described the global forces of nature driving the Earth's climate: solar irradiation as a dominant energy supplier to the atmosphere (and hydrosphere); outgassing as a dominant gaseous matter supplier to the atmosphere (and hydrosphere); and microbial activities at the interface of the lithosphere and atmosphere. The scope and extent of these processes are 4–5 orders of magnitude greater than the corresponding anthropogenic impacts on the Earth's climate (such as heating and emission of the greenhouse gases).

Inspection of the global atmospheric temperature changes during the last 1,000 years (Fig. 11) shows that the global average temperature dropped about 2°C over the last millennium. This means that we live in the cooling geologic epoch (which comprises most of the Holocene), and the global warming observed during the latest 150 years is just a short episode in the geologic history. The current global warming is most likely a combined effect of increased solar and tectonic activities and cannot be attributed to the increased anthropogenic impact on the atmosphere. Humans may be responsible for less than 0.01°C (of approximately 0.56°C (1°F) total average atmospheric heating during the last century) (Khilyuk and Chilingar 2003, 2004).

The global natural processes drive the Earth's climate: "Climate will change, either warmer or colder, over many scales of time, with or without human interference" (Gerhard 2004). Any attempts to mitigate undesirable climatic changes using restrictive regulations are condemned to failure, because the global natural forces are at least 4–5 orders of magnitude greater than available human controls. In addition, application of these controls will lead to catastrophic economic consequences. Estimates show (http://www.JunkScience.com) that since its inception in February 2005, the Kyoto Protocol has cost about $50 billion (about $10 billion a month) supposedly averting about 0.0005°C of warming by the year 2050. Thus, the Kyoto Protocol is a good example of how to achieve the minimum results with the maximum efforts (and sacrifices). Impact of available human controls will be negligible in comparison with the global forces of nature. Thus, the attempts to alter the occurring global climatic changes (and drastic measures prescribed by the Kyoto Protocol) have to be abandoned as meaningless and harmful. Instead, moral and professional obligation of all responsible scientists and politicians is to minimize potential human misery resulting from oncoming global climatic changes.

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References

Baliunas SL (2002) The Kyoto Protocol and global warming. Imprimis 31(3): 1–7. http://www.hillsdale.edu/

Barron EJ (1994) Climatic variations in Earth history. Understanding global climate change: Earth science and human impact, Global change instruction program #108, USAR, 23 pp

Bluemle JP, Sable J, Karlen W (2001) Rate and magnitude of past global climate changes. In: Gerhard LC, Harrison WE, Hanson BM (eds) Geological perspective of global climate change. AAPG Studies in Geology 47:193–212

Britannica Student Encyclopedia (2005) Britannica Online

Chumakov NM (2001) General tendency of the Earth's climate changes during the past 3 billion years (in Russian). Rep Russ Acad Sci 381(5):652–655

Chumakov NM (2004) Glacial and interglacial climate in Precambrian. In: Climate in the times of global biosphere changes (in Russian). Nauka, Moscow, 299 pp

Dubrovskiy VA, Pankov VA (1972) On structure of the Earth's core (in Russian). Izvestiya AN SSSR. Phys Earth 7:48–54

EPA global warming site (2001) Climate. http://www.epa.gov/globalwarming/climate/index.htm

Friedman GM (2005) Climate significance of Holocene benchrock sites along shorelines of the Red Sea. Am Assoc Petrol Geol Bull 89(7):849–852

Gerhard LC (2004) Climate change: conflict of observational science, theory, and politics. Am Assoc Petrol Geol Bull 88(9):1211–1220

Holland HD (1984) The chemical evolution of the atmosphere and oceans. Princeton University Press, Princeton, 552 pp

Horrell MA (2003) Finding the solar constant and average temperature of a planet. http://www.imsa.edu/edu/geophysics/atmosphere/energy/blackbody2.html

Hoyt DV, Schaten KH (1997) The role of the Sun in climate changes. Oxford University Press, New York, 279 pp

Jenkins DAL (2001) Potential impact and effect of climatic changes. In: Gerhard LC, Harrson WE, Hanson BM (eds) Geological perspective of global climate change. AAPG Studies in Geology 47:337–359

Keigwin LD (1996) The little ice age and medieval warm period in the Sargasso Sea. Science 274:1504–1508

Key World Energy Statistics (2004) Edition (KWES). http://www.iea.org/

Khain BE (2003) Main problems of contemporary geology (in Russian). Nauchniy Mir, Moscow, 346 pp

Khilyuk LF, Chilingar GV (2003) Global warming: are we confusing cause and effect? Energy Sources 25:357–370

Khilyuk LF, Chilingar GV (2004) Global warming and long-term climatic changes: a progress report. Environ Geol 46:970–979

Khilyuk LF, Chilingar GV, Endres B, Robertson J (2000) Gas migration. Gulf Publishing Company, Houston, 389 pp

Kondratiev KYa (1992) Global Climate (in Russian). Nauka, Moscow, 359 pp

Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997) http://www.epa.gov/globalwarming/publications/reference/index.html

Lillburn TG, Schmidt TM, Breznak JA (1999) Philogenetic diversity of termite gut spirochetes. Environ Microbiol 1(4):331–345

Lillburn TG, Kim KS, Ostrom NE, Byzek KR, Leadbetter JR, Breznak JA (2001) Nitrogen fixation by symbiotic and free-living spirochetes. Science 292(5526):2495–2498

MacDonald DJF (1964) Tidal friction. Rev Geophys 2(3):467–541

MacDonald DJF (1965) Geophysical deductions from observations of heat flow. In: Terrestrial heat flow. Academic, Washington, pp 191–210

Marland G, Boden T, Andres RJ (2002) Global CO_2 emission from fossil-fuel burning, cement manufacture, and gas flaring: 1751–2002. Information Analysis Center, Oak Ridge National Laboratory, Tennessee. http://www.cdiac.ornl.gov/ftp/ndp030/global.1751 2002.ems

Marov MYa (1986) Planets of the solar system (in Russian). Nauka, Moscow, 320 pp

Milloy S (2005) Global warming heats up in senate. http://www.foxnews.com/printer_friendly_story/0,3566,159835,00.html

NOAA News Online (2000) Story 399. http://www.noaanews.noaa.gov/stories/htm

Orphan VJ, House CH, Hinrichs KU, MaKeegan KD, DeLong EF (2001) Methane-consuming archaea revealed by directly coupled isotopic and phylogenetic analysis. Science 293:484–487

Orphan VJ, House CH, Hinrichs KU, MaKeegan KD, DeLong EF (2002) Multiple archaeal groups mediate methane oxidation in anoxic cold seep sediments. Proc Natl Acad Sci USA 99(11):7663–7668

Robinson AB, Baliunas SL, Soon W, Robinson ZW (1998) Environmental effects of increased atmospheric carbon dioxide. 8 pp (http://www.info@oism.org; http://www.info@marshall.org)

Safronov VS (1972) Accumulation of the planets. In: Reeves H (ed) On the origin of the Solar system, Centre Nationale de Recherche Scientifique, Paris, pp 89–113

Segelkin R (2002) http://www.news.cornell.edu/Chronicle/02/2.14.02/microbial_observatory.html

Soon W, Baliunas SL, Robinson AB, Robinson ZW (2001) Global warming—a guide to the science: risk controversy series 1. The Fraser Institute, Vancouver, 62 pp

Sorokhtin OG (1972) Differentiation of the Earth's matter and development of tectonic processes (in Russian). Izvestiya AN SSSR. Phys Earth 7:55–66

Sorokhtin OG (2001) Greenhouse effect: myth and reality (in Russian). Vestn Russ Acad Nat Sci 1(1):8–21

Sorokhtin OG (2005a) Generation of abiogenic methane during development of Earth (in Russian). Institute of Oceanology, Russian Academy of Sciences, Moscow, 15 pp

Sorokhtin OG (2005b) Bacterial nature of the Earth's glacial epochs (in Russian). Institute of Oceanology, Russian Academy of Sciences, Moscow, 15 pp

Sorokhtin OG, Sorokhtin NO (2002) Origin and evolution of the Earth's atmosphere (in Russian). Vestn Russ Acad Nat Sci 2(3):6–18

Sorokhtin OG, Ushakov SA (2002) Development of Earth (in Russian). Moscow University, Moscow, 559 pp

Vacquier V (1990) The origin of the terrestrial heat-flow. Geophys J Int 106(1):199–202

Vinogradov AP (1967) Introduction to geochemistry of ocean (in Russian). Nauka, Moscow, 215 pp

Yasamanov NA (2003) Modern global warming: causes and ecological consequences (in Russian). Bull Dubna Int Univ Nat Soc Man 1(8):12–21