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Geophysics

Thermal Balance of the Earth and Global Warming

Merab Dzhibladze*, **Aleksander Mikaberidze***, **Zurab Razmadze***

* *A. Janelidze Institute of Geology, Tbilisi*

(Presented by Academy Member T. Sanadze)

ABSTRACT. By calculation of the thermal balance of the Earth it is shown that about half of the solar energy falling on the terrestrial surface is spent for evaporation of water from surfaces of oceans, seas and land. Part of it is absorbed by green plants, but thermal energy emitted because of human activity is by four orders less than the energy received by the Earth from the Sun. It is also noted that the increase in the concentration of CO_2, which is considered to be the principal cause of the greenhouse effect, has a very poor influence on the average-annual temperature of the Earth and infrared radiation of the terrestrial surface absorbed by molecules of CO_2 cannot evoke the greenhouse effect. *© 2009 Bull. Georg. Natl. Acad. Sci.*

Key words: *thermal balance, solar energy, greenhouse effect.*

Global warming of the Earth, leading to the fatal rise in temperature of the surface of the ground and atmosphere, is considered as one of the most important environmental problems of the twenty-first century. Reduction of emissions of CO_2 into the atmosphere now is considered to be the basic method of struggle against global warming. It is accepted that molecules of CO_2 prevent the ground cooling, because of absorption by them of the infrared photons radiated by the terrestrial surface. Similarity of time dependence curves of growth in concentration of CO_2 and average-annual temperature of the Earth shown in Fig. 1a,b, promotes such conclusion [1-3]. But it is necessary to note that the concentration of CO_2 even in dry air does not exceed 0.035%, which is too small to somehow influence the thermal balance of the Earth. In addition, the presence of aqueous vapour in the air essentially reduces the concentration of CO_2.

Therefore, it is not necessary to expect that accumulation of CO_2 in the atmosphere is the reason leading to global warming. On the basis of a line spectrum of absorption of molecules CO_2 and a possibility of reradiation of photons in other directions, it is possible to conclude that the presence of CO_2 in the atmosphere specifies only the quantity of burned fuel whose emitted energy accumulates in heat. Really, on the absorption spectrum of molecules CO_2 shows three groups of thin lines of absorption in near the infrared area of a spectrum (Fig.2) [2]. The presence of these lines leads to the absorption of some part of infrared radiation of the terrestrial surface. Due to absorption of infrared photons the vibrational-rotational levels of CO_2 are excited, but this occurs at the thermodynamic equilibrium (the number of absorbed photons becomes equal to that of radiated photons). While moving to the upper layers of the atmosphere, where the temperature is considerably lower than at the surface of ground (-40^{0}C and below), the excited levels of CO_2 molecules become empty by transition to the basic level. This process is accompanied by reradiation of those infrared photons which have been absorbed at the surface of the ground by CO_2 molecules. A similar process also occurs for other molecules of air: H_2O, $CH_{4,-}$ etc. Hence, the energy absorbed in the lower layers of the atmosphere is reradiated by molecules of air in the upper layers. Of course, if the temperature of gas at the surface of the Earth is more than that of the surface, radiation of infrared photons by CO_2 molecules heats up the Earth.

Hence, an increase in the concentration of CO_2 does not lead to an increase in the average-annual tempera-

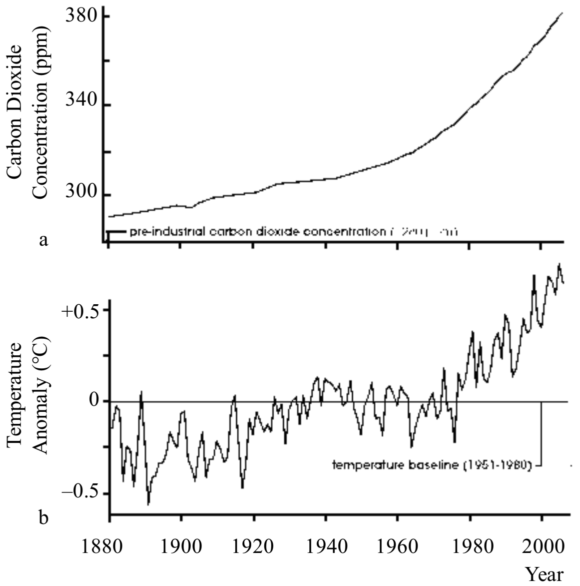

Fig. 1. Change of CO_2 concentration in the atmosphere (a) and dependence of average-annual temperature of the Earth on time.

ture of the ground, but it is a measure of heating of the Earth owing to burned fuel because of human activity and process of oxidation of carbon in the live organisms. During the burning of hydrocarbons, energy which heats up the Earth is liberated, but the process of burning is accompanied by formation of CO_2 molecules. This occurs both in live organisms and during the burning of coal or hydrocarbonic fuel. Thus, CO_2 is a product of burning and indicates only the quantity of energy emitted due to burning of fuel, which heats up the ground (the product of burning of hydrogen is aqueous vapour).

The reason of global warming could be the increase in the population of the Earth and growth of human activity connected with it. The approximately estimated average power of a person is 100 w. This is the power for life-support of human activity followed by energy accumulation on the ground in the form of heat. After multiplication of this value by the density of population of the ground we shall receive the power of 650 GW. This power is provided by food and transforms into heat (upon emission of CO_2 into the atmosphere) both by movement of the person and body temperature. Considering all animals existing on our planet, the power emitted by all live beings will be of the order of 1 TW.

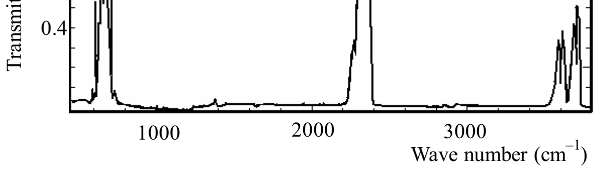

Fig. 2. Spectrum of absorption of CO_2 molecules in the infrared area of a spectrum

An essential cause of temperature increase of the Earth could also be the high temperature in the Earth's centre (about 6000^0C). Heat flow from the bowels is different in different parts of the Earth surface and in average is about 1.6×10^{-6} cal.cm^{-2}sec^{-1}, corresponding to 10^{21}J of energy output per year. Heat can be transferred only from more warmed substance to a less warmed one, hence, temperature of substances in the bowels of the Earth must be higher than on the surface. Actually, in accordance with the measurements in mines and wells, temperature increases by about 20^0 C for each kilometre of depth.

One of the causes of warming could be human activity connected with burning of energy resources of the Earth. This is burning of oil, oil products, coal and natural gas, the use of electric power, etc. Thermal energy produced by burning of energy resources of the Earth can be calculated with the help of the amount of extracted fuels (oil, gas, coal, peat, etc.) Heat emitted owing to volcanic activity of the earth, forest fires, military actions, etc., must be added to this value. It is clear that an increase in the population of the Earth increases the thermal energy of the ground and concentration of CO_2 in the atmosphere is proportional to the quantity of thermal energy received by the Earth owing to burning of fuel.

The balance equation of thermal energy as the basic equation for the kinetics of the process will be:

$$dQ/dt=(1-\alpha)P+\rho N+Q_E/t + k(Q + Q_E)/t -\lambda m_v/t -\sigma Q/t \quad (1)$$

where Q is the accumulated energy on the terrestrial surface and in the atmosphere defining the average annual temperature; α is the average factor of reflection from the terrestrial surface and from the clouds (full albedo); P is the stream of power from the Sun falling on our planet; ρN is increase of heat in unit of time due to human activity; Q_E is the heat emitted from the bowels of the Earth; kQ is the ground cooling due to radiation in the infrared area of the spectrum; λm_v is cooling of the Earth due to evaporation of water (m_v - weight of evaporated water); and σQ is the energy absorbed by green plants on the Earth. The process of evaporation transforms thermal energy into potential energy of water (in clouds) and kinetic energy of winds. Energy absorbed by plants due to photosynthesis produces oxygen from absorbed CO_2.

All these values by themselves are complex functions of time, which rather complicates a more or less exact mathematical description of the whole process.

The solution of the balance equation is possible in a stationary regime when dQ/dt=0. Then from equation (1) we can receive:

$$Q(k+\sigma)=c_i m_i \Delta T(k+s)=(1-\alpha)Pt+\rho Nt+(1-k)Q_E-\lambda m_v \quad (2)$$

where ΔT is the variatioin of temperature per unit of time from absorption of the solar energy and human activity; c_i is the average thermal capacity of the superficial layers of the ground, water and air taking part in thermal processes; and m_i is the total mass of these separate layers (certainly, this member is a set of many similar products); σQ is the energy of the sun absorbed by green plants of the Earth.

Hence, the variation of temperature in unit of time (t =1):

$$\Delta T = \frac{(1-\alpha)Pt + \rho Nt + (1-k)Q_E - \lambda m_v}{c_i m_i (k+\sigma)}. \quad (3)$$

In a stationary regime this growth of temperature is compensated by radiation of the Earth in the infrared area of the spectrum and evaporation of water from oceans and terrestrial surface. As expected, increase in population of the Earth and in the stream of solar radiation could evoke an increase in the average-annual temperature of the planet. Nevertheless, evaporation would lead to reduction of temperature and increase of the full albedo of the Earth, resulting in a decrease of average-annual temperature. It is necessary to note that full albedo (α), power of sunlight (P), and quantity of evaporated water (m_v) are complex functions of time.

It is clear that the first member in the right part of the equation (3) shows an increase in temperature from absorption of solar energy, the second member is the cause of rise in temperature due to human activity, the third member - because of high temperature in the bowels of the Earth, and the fourth member indicates a decrease of temperature due to evaporation of water and increase of full albedo of the Earth.

We can calculate the quantity of thermal energy received by the Earth from the stream of solar radiation. For this purpose we can use the data of Fig.3. According to this figure the density of the power falling on the ground is 1366 w/m^2. If η = 40% of this power reaches terrestrial surface, the power of a light stream shining on the terrestrial surface will be:

$$P = \eta\pi r^2 W = 6.5 \cdot 10^{16} \text{ w},$$

where r is the radius of the Earth. Thus, solar energy received by the Earth for a year will be:

$$E_c = Pt = 2 \cdot 10^{24} \text{ J}.$$

As has been shown, heat received by the Earth's surface from the bowels $Q_F = 10^{21}$J and it is by three orders less than energy received from the Sun.

Now we shall calculate the energy emitted due to burning of fuel for one year.

The world's authentic reserves of minerals, also their world extractions per year and specific heat of combustion are shown in Table 1.

Thermal energy due to combustion of oil per year will be:

$$Q_1 = 3.088 \cdot 10^9 \text{ x } 4.2 \cdot 10^{10} = 1.47 \cdot 10^{20} \text{ J};$$

due to burning of natural gas for a year we receive thermal energy of:

$$Q_2 = 2.223 \cdot 10^{12} \text{ x } 36 \cdot 10^6 = 8 \cdot 10^{18} \text{ J};$$

burning of coal gives thermal energy per year:

$$Q_3 = 3.8335 \cdot 10^9 \text{ x } 2.6 \cdot 10^{10} = 10^{20} \text{ J}.$$

The total thermal energy emitted due to burning of three kinds of fuel will be:

$$Q = (1.47 + 0.08 + 1)\, 10^{20} \text{ J} = 2.55 \cdot 10^{20} \text{ J}.$$

The total energy of all the world nuclear power stations, W_A = 300 Gw [3], can be added to this value. So we have per year:

$$Q_A = W_A t = 3 \cdot 10^{11} \text{ x } 3 \cdot 10^7 = 9 \cdot 10^{18} \text{ J}.$$

Approximately 3 times more heat is emitted upon the maintenance of the ability of all living creatures on the Earth (total power is of the order of 1 TW). It is clear that addition of these energies insignificantly increases the total thermal energy Q emitted due to human activity. So, heat emitted due to human activity is only 0.01% of the energy received from the Sun.

With annual quantity of precipitation of 1020 mm [2] it is possible to calculate the cooling of terrestrial

Table 1

Mineral	World authentic stocks, million tons		World extractions, million tons		Specific heat of combustion MJ.t.
	1990	1997	1990	1997	
Oil	120645	139444	3180	3508.8	42000
Natural gas*	107500	144033	1930	2223.0	36
Coal	565656	509491	3405	3833.5	26000

*Natural gas is in terms of billion.m^3 and MJ/m^3.

surface connected with evaporation of water. The energy required to evaporate water (800 mm from the surface of the World Ocean and 140 mm from land) totals:

$$Q = \lambda m_v = \lambda \rho h S = 4\pi R^2 h \rho \lambda =$$
$$=12.6 \cdot 4.1 \cdot 10^{13} \cdot 2.3 \cdot 10^{9}\ \mathrm{J} = 1.2 \cdot 10^{24}\ \mathrm{J}.$$

As we see, the energy necessary for evaporation of water per year is approximately 2 times less than the solar energy received by the Earth from the Sun, but thermal energy released due to human activity is approximately in four orders less than the energy received from the Sun.

Finally, 0.3 of solar energy falling on the terrestrial surface is absorbed by green plants [5]. Considering that 40% of the solar energy reaches the terrestrial surface, the energy absorbed by plants will be:

$$Q_p = \sigma Q = 0.0012 \cdot 3 \cdot 10^{24}\ \mathrm{J} = 3.6 \cdot 10^{21}\ \mathrm{J}.$$

As we see, far from the entire solar energy is being transferred into heat. More than half of it is spent for evaporation of water, creating clouds and thus, cooling the surface of oceans, seas and land. Part of solar energy is transferred into the kinetic energy of winds (including tornados, hurricanes) and sea waves (including currents in oceans) and another part - into the potential energy of water in the clouds, feeding the rivers and resulting in precipitation on the Earth, and sometimes - into catastrophic flooding and tornadoes, and the energy emitted due to human activity is approximately only 0.01% of the energy received from the Sun.

გეოფიზიკა

დედამიწის სითბური ბალანსი და გლობალური დათბობა

მ. ჯიბლაძე*, ა. მიქაბერიძე*, ზ. რაზმაძე*

* *ა. ჯანელიძის გეოლოგიის ინსტიტუტი, თბილისი*

(წარმოდგენილია აკადემიკოს თ. სანაძის მიერ)

დედამიწის სითბური ბალანსის გამოთვლებით ნაჩვენებია, რომ დედამიწის ზედაპირზე დაცემული მზის ენერგიის თითქმის ნახევარი ოკეანეების, ზღვებისა და ხმელეთის ზედაპირიდან წყლის აორთქლებაზე იხარჯება. ენერგიის ნაწილი შთაინთქმება მცენარეების მიერ, მაგრამ სითბური ენერგია, რომელიც ადამიანის საქმიანობის შედეგად გამოიყოფა, ოთხი რიგით ნაკლებია იმ ენერგიასთან შედარებით, რომელსაც დედამიწა მზისაგან იღებს. აღნიშნულია, რომ ადამიანის საქმიანობასთან დაკავშირებული ნახშირორჟანგის კონცენტრაციის გაზრდა, რაც სათბურის ეფექტის ერთ-ერთ მთავარ მიზეზად ითვლება, დედამიწის საშუალო ტემპერატურაზე მცირე ზეგავლენას ახდენს და CO_2 მოლეკულების მიერ დედამიწის ინფრაწითელი გამოსხივების შთანთქმას არ შეუძლია სათბურის ეფექტის გამოწვევა.

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