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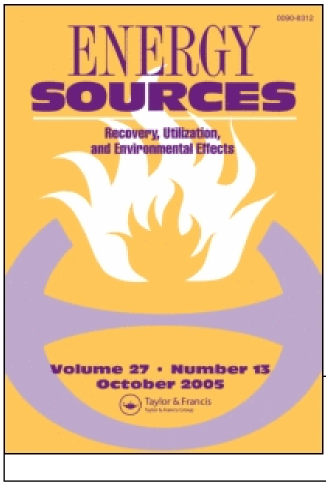

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Cooling of Atmosphere Due to CO_2 Emission

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Abstract *The writers investigated the effect of CO_2 emission on the temperature of atmosphere. Computations based on the adiabatic theory of greenhouse effect show that increasing CO_2 concentration in the atmosphere results in cooling rather than warming of the Earth's atmosphere.*

Keywords adiabatic theory, CO_2 emission, global cooling, global warming

Introduction

Traditional anthropogenic theory of currently observed global warming states that release of carbon dioxide into atmosphere (partially as a result of utilization of fossil fuels) leads to an increase in atmospheric temperature because the molecules of CO_2 (and other greenhouse gases) absorb the infrared radiation from the Earth's surface. This statement is based on the Arrhenius hypothesis, which was never verified (Arrhenius, 1896). The proponents of this theory take into consideration only one component of heat transfer in atmosphere, i.e., radiation. Yet, in the dense Earth's troposphere with the pressure $p_a > 0.2$ atm, the heat from the Earth's surface is mostly transferred by convection (Sorokhtin, 2001a). According to our estimates, convection accounts for 67%, water vapor condensation in troposphere accounts for 25%, and radiation accounts for about 8% of the total heat transfer from the Earth's surface to troposphere. Thus, convection is the dominant process of heat transfer in troposphere, and all the theories of Earth's atmospheric heating (or cooling) first of all must consider this process of heat (energy)–mass redistribution in atmosphere (Sorokhtin, 2001a, 2001b; Khilyuk and Chilingar, 2003, 2004).

When the temperature of a given mass of air increases, it expands, becomes lighter, and rises. In turn, the denser cooler air of upper layers of troposphere descends and replaces the warmer air of lower layers. This physical system (multiple cells of air convection) acts in the Earth's troposphere like a continuous surface cooler. The cooling effect by air convection can surpass considerably the warming effect of radiation.

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The most important conclusion from this observation is that the temperature distribution in the troposphere has to be close to adiabatic because the air mass expands and cools while rising and compresses and heats while dropping. This does not necessarily imply that at any particular instant distribution of temperature has to be adiabatic. One should consider some averaged distribution over the time intervals of an order of months.

Key Points of the Adiabatic Theory of Greenhouse Effect

By definition, the greenhouse effect is the difference ΔT between the average temperature of planet surface T_s and its effective temperature T_e (which is determined by the solar radiation and the Earth's albedo):

$$\Delta T = T_s - T_e \tag{1}$$

The present-day average surface temperature $T_s \approx 288$ K and effective temperature $T_e \approx 255$ K. Therefore, the present-day greenhouse effect is approximately equal to +33°C. The term "greenhouse effect" is confusing from the physical point of view and leads the general public astray. According to the Arrhenius hypothesis, the atmosphere, containing "greenhouse gases," is transparent to the short-wave solar radiation but absorbs the long-wave (infrared) radiation emitted from the heated Earth's surface thus reducing the losses of Earth's heat into space. The latter is considered to be the main cause of atmospheric warming: the greater the concentration of "greenhouse gases" in atmosphere, the higher its global temperature. The term "greenhouse effect" was coined by analogy with the glass greenhouses, because glass is transparent for the visible part of solar spectrum but absorbs the infrared radiation. The main heating effect in the greenhouse, however, is due to the isolation of air volume contained in the greenhouse and preventing it from mixing with outside air. As soon as the greenhouse windows are opened, the convection occurs and the greenhouse effect disappears.

In the Earth's troposphere, the convective component of heat transfer dominates. When the infrared radiation is absorbed by the greenhouse gases, the energy of radiation is transformed into oscillations of gas molecules (i.e., heating of exposed volume of gas mixture). As a result, the heated gas expands, becomes lighter, and rises rapidly to the upper layers of troposphere, where heat is emitted into space by radiation. As the gas cools down, it descends to the Earth's surface, where the previous (or even lower) surface temperatures are restored. Analogous situation is observed with heating of air due to the condensation of water vapor.

The effective radiation temperature is determined by the Stefan-Boltzmann law:

$$T_e = [(1 - A)S/4\sigma]^{1/4} \tag{2}$$

where σ ($= 5.67 \cdot 10^{-5}$ erg/cm^2·s·°C^4) is the Stefan-Boltzmann constant; S is the solar constant at the distance of Earth from the Sun ($S = 1.367 \cdot 10^6$ erg/cm^{2}s); A is the albedo, which is determined mostly by the cloud cover (for the Earth $A \approx 0.3$). According to Eq. (2), the effective temperature T_e is equal to 255 K (or −18°C). Therefore, the present-day greenhouse effect for the Earth should be equal to 33°C.

The water vapor condensation in troposphere begets clouds, which to a considerable degree determine the reflective properties of the planet, i.e., its albedo A. The latter gives rise to a strong negative feedback between the surface temperature T_s and the temperature of "absolutely black body" T_{bb}, which is determined by the solar radiation S reaching the Earth's surface at its distance from the Sun. Indeed, any increase in surface temperature intensifies the water evaporation and increases the Earth's cloudiness, which, in turn, increases the Earth's albedo. As a result, the reflection of solar heat from the clouds into space increases and the heat influx to the Earth's surface decreases and the average surface temperature decreases to the previous level. Strong negative feedback in any system leads to linear dependence of system's output on its input. The latter implies that the surface temperature T_s (as well as the temperature T at any elevation in troposphere) is proportional to the effective radiation temperature T_e, which is determined by the solar radiation at a distance of Earth from Sun.

For adiabatic process, the absolute temperature of gas T is a function of pressure p (Landau and Lifshits, 1979):

$$T = Cp^{\alpha}, \tag{3}$$

where C is a constant, which can be determined using theoretical considerations or using the experimental data. Using previous theoretical considerations, Eq. (3) can be rewritten in the following form:

$$T = b^{\alpha} T_e (p/p_0)^{\alpha}, \tag{4}$$

where p is the atmospheric pressure at a certain elevation; p_0 is the pressure at sea level ($p_0 = 1$ atm); α is the adiabatic exponent, $\alpha = (c_p - c_v)/c_p$, where c_p and c_v are the specific heats of air gaseous mixture at a constant pressure and a constant volume, respectively; and b is a scaling coefficient ($b = [1/(1-A)^{1/4}]^{1/\alpha}$).

Adiabatic exponent α, which is a function of composition and humidity of atmosphere, can be determined using the following equation (Voytkevitch et al., 1990):

$$\alpha = R/\mu(c_p + C_w + C_r) \tag{5}$$

$$C_p = [p(\mathrm{N_2})c_p(\mathrm{N_2}) + p(\mathrm{O_2})c_p(\mathrm{O_2}) + p(\mathrm{CO_2})c_p(\mathrm{CO_2}) + p(\mathrm{Ar})c_p(\mathrm{Ar})]/p, \tag{6}$$

where R (= 1.987 cal/mole·°C) is the universal gas constant; μ is the molecular weight of air mixture (for the Earth, $\mu \approx 29$); $p(\mathrm{N_2}) \approx 0.7551$, $p(\mathrm{O_2}) \approx 0.2315$, $p(\mathrm{CO_2}) \approx 0.00046$, and $p(\mathrm{Ar}) \approx 0.0128$ atm are the partial atmospheric pressures of nitrogen, oxygen, carbon dioxide, and argon, respectively; $p \approx 1$ atm is the total atmospheric pressure; $c_p(\mathrm{N_2}) = 0.248$, $c_p(\mathrm{O_2}) = 0.218$, $c_p(\mathrm{CO_2}) = 0.197$, $c_p(\mathrm{Ar}) = 0.124$ cal/g·°C are the specific heats of nitrogen, oxygen, carbon dioxide, and argon (at a constant pressure), respectively (Bachinskiy et al., 1951); C_w and C_r are corrective coefficients considering the heating effect of water condensation and absorption of infrared radiation by the greenhouse gases, respectively.

From Eq. (5) one obtains:

$$C_w + C_r = R/\mu \cdot \alpha - c_p \tag{7}$$

The best fit of the theoretical temperature distribution (Eq. (4)) to the averaged experimental data in the Earth's troposphere occurs at $\alpha = 0.1905$. For the dry air mixture of Earth's atmosphere, $c_p = 0.2394$ cal/g·°C. On substituting these data into Eq. (7), one obtains $C_w + C_r = 0.1203$ cal/g·°C.

To determine the components C_w and C_r separately, one needs to use the surface (T_s) and effective (T_e) temperatures of the planet (Sorokhtin, 2001a, 2001b):

$$C_r = R(T_s - T_e)/\mu \cdot \alpha \cdot T_s \tag{8}$$

$$C_w = RT_e/\mu \cdot \alpha \cdot T_s - c_p \tag{9}$$

On substituting the parameters of Earth's atmosphere ($\alpha = 0.1905$, $\mu \approx 29$, $c_p = 0.2394$ cal/g·°C, $T_s = 288.2$ K, $T_e = 263.6$ K, and $R = 1.987$ cal/mole·°C) into Eqs. (8) and (9), one obtains $C_r = 0.0307$ cal/g·°C, $C_w = 0.0896$ cal/g·°C, and $C_w + C_r = 0.1203$ cal/g·°C, which is exactly the same as the previously determined value. The obtained estimates for the components of specific heat of air mixture allow one to compare relative effects of various processes of heat transfer in the Earth's atmosphere: convection accounts for about 67%, water vapor condensation accounts for 25%, and radiation accounts for about 8%.

Substitution of T_e determined by Eq. (2) into Eq. (4) results in the following relations:

$$T = b^\alpha[(1 - A)S/4\sigma]^{1/4}(p/p_0)^\alpha \tag{10}$$

It is noteworthy that in Eq. (10) the solar constant S is divided by 4 because the area of Earth's disk insolation is 4 times lower than the total illuminated area of Earth. Equation (10) is valid only if the axis of rotation of planet is strictly perpendicular to the ecliptic plane, i.e., the angle of precession ψ is equal to zero.

The angle of inclination of equatorial plane to the ecliptic plane is not equal to zero and is changing in time. Therefore, each of the Earth's polar regions is insolated during half a year only. In another half a year, it is deprived of the influx of solar energy. When one polar region is insolated, the other is situated in the shadow of Earth's body and does not receive the solar energy. The rest of Earth's surface receives its portion of solar energy on a regular basis and, consequently, Eq. (10) is valid for calculation of temperature of air. Therefore, in computing the average temperature of "inclined" planet at high latitudes (polar regions), one needs to divide the solar constant by 2 (not by 4). In addition, one has to take into consideration the spherical shape of polar region. As a result, the solar constant in Eq. (10) has to be divided by a number N, which lies between 2 and 4. Taking all of the above into consideration and assuming that the precession angle is relatively small, one can derive the following equation for the distribution of average temperature in troposphere:

$$T = b^\alpha \left[\frac{S \cdot (1 - A)}{\sigma \left(\frac{4(\pi/2 - \psi)}{\pi/2} + \frac{4\psi}{\pi/2 \cdot (1 + \cos\psi)} \right]} \right]^{\frac{1}{4}} (p/p_0)^\alpha \tag{11}$$

where ψ is the Earth's precession angle; p is the atmospheric pressure at a given altitude (0.2 atm $< p < p_0$), and $p_0 = 1$ atm.

For the present-day Earth's angle of inclination ($\psi \approx 23.44°$), the average surface temperature at sea level $T_s \approx 288.2$ K and the coefficient b is equal to 1.597. For the nitrogen–oxygen atmosphere $b^{\alpha} = 1.093$. If the albedo is constant, then the coefficient b is constant, whereas the value b^{α} varies with the value of α which, in turn, depends on the composition of atmosphere.

The convective component of heat transfer dominates in the troposphere. When infrared radiation is absorbed by the greenhouse gases, the radiation energy is transformed into the oscillations of gas molecules, i.e., in heating of the exposed volume of gaseous mixture. Then the further heat transfer can occur either due to diffusion or by convective transfer of expanded volumes of gas. Inasmuch as the specific heats of air are very small (about $5.3 \cdot 10^{-5}$ cal/cm·s·°C), the rates of heat transfer by diffusion do not exceed several cm/s, whereas the rates of heat transfer by convection in the troposphere can reach many meters per second. Analogous situation occurs upon heating of air as a result of water vapor condensation: the rates of convective transfer of heated volumes of air in the troposphere are many orders of magnitude higher than the rates of heat transfer by diffusion.

Equation (11) (the adiabatic model of atmospheric temperature) can be applied for computation of atmospheric temperature distribution for any planet possessing a dense atmosphere (with atmospheric pressure higher than 0.2 atm) and also for various geologic periods of Earth's development. To modify the adiabatic model for different conditions, one needs to specify the value of solar constant S, the angle of precession of planet ψ, and the value of adiabatic exponent α.

The adiabatic model of greenhouse effect was verified by comparison of the theoretical temperature distribution in the troposphere of Earth (constructed based on Eq. (11)) with the standard model based on experimental data. For the Earth, the parameters of adiabatic model were chosen as follows: $S = S_0 = 1.367$ erg/cm·s; $\psi = 23.44°$; and $\alpha = 0.1905$. The computations by Sorokhtin (2001a, 2001b) showed that the theoretical temperature distribution based on Eq. (11) was identical to the standard temperature distribution of Earth (Bachinskiy et al., 1951) with the precision of 0.1%. The standard model of Earth's atmospheric temperature gives averaged (over the Earth's surface) values of temperature and pressure as the function of elevation above sea level. This model (with the temperature gradient of 6.5 K/km) is applied worldwide for calibration of aircraft gauges and barometers, which are used for weather observations.

The adiabatic model was further verified by comparison of theoretical temperature distribution in the dense (consisting mostly of carbon dioxide) troposphere of Venus with experimental data. For Venus, $\psi \approx 3°$, $\alpha = 0.179$, $\mu = 43.5$, $c_p = 0.2015$ cal/g·°C; $T_s = 735.3$ K, and $T_e = 228$ K, and, therefore, $C_r = 0.177$ cal/g·°C, $C_w = -0.122$ cal/g·°C, and $C_w + C_r = 0.055$ cal/g·°C. The increased value of parameter C_r, which is a measure of the radiation component of heat transfer, most probably can be explained by the extremely hot condition of the troposphere of Venus. The fact that $C_w < 0$ means that in the troposphere of Venus (especially in its lower and middle layers) the endothermic reactions of dissociation of some compounds dominate (for example, dissociation of sulfuric acid H_2SO_4 into SO_3 and H_2O). Meantime, in the upper layers of troposphere of Venus, at the altitudes of 40 to 50 km and above the altitude of 60 km, the parameter $C_w > 0$. Thus, the exothermic reactions of formation of chemical compounds (sulfuric acid, for example) dominate there. In addition, the water vapor condensation in the clouds of Venus heats its atmosphere.

For the Venus atmosphere, $p_s = 90.9$ atm and $S = 2.62 \cdot 10^6$ erg/cm^2·s (Marov, 1986; Venus, 1989). On substituting all these values into Eq. (11), one can construct the temperature distribution for the atmosphere of Venus. The results of testing the adiabatic model (Eq. (11)) showed a good agreement between the theoretical and experimental data (1% precision for Venus).

Anthropogenic Impact on the Earth's Climate

The adiabatic theory allows one to evaluate quantitatively the influence of anthropogenic emission of carbon dioxide on the Earth's climate. The carbon content in the atmosphere was increasing by approximately 3 billion tons per year at the end of century. The rate of the total human-induced CO_2 emission to the Earth's atmosphere is currently about 5–7 billion tons per year (Schimel, 1995; Robinson et al., 1998), or about 1.4–1.9 billion tons of carbon per year. This amount of carbon dioxide slightly increases the atmospheric pressure.

To evaluate the effect of anthropogenic emission of carbon dioxide on global temperature, one can use the adiabatic model together with the sensitivity analysis (Sorokhtin, 2001; Khilyuk and Chilingar, 2003, 2004). At sea level, if the pressure is measured in atmospheres, then $p = 1$ atm and

$$\Delta T \approx T\alpha\Delta p \tag{12}$$

If, for example, the concentration of carbon dioxide in the atmosphere increases two times (from 0.035% to 0.07%), which is expected by the year of 2100, then the atmospheric pressure will increase by $\Delta p \approx 1.48 \times 10^{-4}$ atm (Sorokhtin, 2001). After substitution of $T = 288$ K, $\alpha = 0.1905$, and $\Delta p = 1.48 \times 10^{-4}$ atm into Eq. (13), one obtains $\Delta T \approx 8.12 \times 10^{-3}$°C. ΔT will be slightly higher at the higher altitudes (Khilyuk and Chilingar, 2003). Thus, the increase in the surface temperature at sea level caused by doubling of the present-day CO_2 concentration in the atmosphere will be less than 0.01°C, which is negligible in comparison with natural temporal fluctuations of global temperature.

From these estimates, one can deduce a very important conclusion that even considerable increase in anthropogenic emission of carbon dioxide does not lead to noticeable temperature increase. Thus, the hypothesis of current global warming as a result of increased emission of carbon dioxide (greenhouse gases) into the atmosphere is not true.

In addition, evaluating the climatic consequences of anthropogenic CO_2 emission, one has to take into consideration the fact that emitted carbon dioxide dissolves in oceanic water (according to the Henry's Law) and then is fixed into carbonates. In this process, together with carbon, a part of atmospheric oxygen is also transferred into the carbonates. Therefore, instead of a slight increase in the atmospheric pressure, one should expect a slight decrease with a corresponding insignificant cooling of climate. In addition, part of carbon dioxide is reduced to methane in the process of hydration of oceanic crust rocks. Because formation of carbonates and generation of methane, about $2.3 \cdot 10^8$ tons/year of CO_2 are removed from the atmosphere; the potential consumption of CO_2 in the process of hydration, however, is considerably higher. Although the period of this geochemical cycle is over 100 years, the effect of CO_2 consumption is additive.

Together with the anthropogenic CO_2, part of O_2 is also removed from the atmosphere (about 2.3 g per 1 g of carbon). If the ocean and plants consume all this additional CO_2, after the year of 2100 this would lead to a reduction in atmospheric pressure by approximately 0.34 mbar and cooling of the climate by -8.2×10^{-2}°C ≈ -0.1°C. Actually, the metabolism of plants should almost completely compensate for the disruption of equilibrium by mankind and restore the climatic balance.

Global Atmospheric Cooling due to Increase in CO_2 Content

Increase in CO_2 content leads to global cooling of atmosphere. This paradoxical, at first sight, conclusion can be inferred from the adiabatic theory of heat transfer. To compare the temperature characteristics of a planet at various compositions of its atmosphere, one can use Eq. (11).

If one assumes that the existing nitrogen–oxygen atmosphere of Earth is replaced entirely by an imaginary carbon dioxide atmosphere with the same pressure of 1 atm and adiabatic exponent $\alpha = 0.1428$, then the value of $b^{\alpha} = 1.597^{0.1428} = 1.069$ and the near-surface temperature would decline to 281.6 K. Thus, the atmospheric temperature would decreases by 6.4°C, instead of increasing according to the traditional theory.

Constructing the distributions of temperature in the carbon dioxide atmosphere, one should take into consideration the fact that for the same pressure the corresponding elevation above sea level is lower than that for the nitrogen–oxygen atmosphere of Earth: $h(CO_2) = h(N_2 + O_2) \times 29/44$, where h is the elevation, and 29 and 44 are the molecular weights of nitrogen–oxygen and carbon dioxide atmospheres, respectively. Such temperature distributions are shown in Figure 1. In this figure, the graph of temperature distribution for the carbon dioxide troposphere lies below the graph of distribution for the nitrogen–oxygen atmosphere. Thus, the near-surface temperature for the carbon dioxide atmosphere is 6.4°C lower than that for the nitrogen–oxygen atmosphere and not considerably higher as some scientists continue to believe. Therefore, the accumulation of carbon dioxide in great amounts in atmosphere should lead only to the cooling of climate, whereas insignificant changes in the partial pressure of CO_2 (few hundreds of ppm) practically would not influence the average temperature of atmosphere at the Earth's surface.

Similarly, if one assumes that the existing carbon dioxide atmosphere of Venus is entirely replaced by the nitrogen–oxygen atmosphere at the same pressure of 90.9 atm, then its surface temperature would increase from 735 to 796 K. Thus, increasing the saturation of atmosphere with carbon dioxide (despite its radiation absorbing capacity), with all other conditions being equal, results in a decrease and not an increase of the greenhouse effect and a decrease in average temperature of planet's atmosphere.

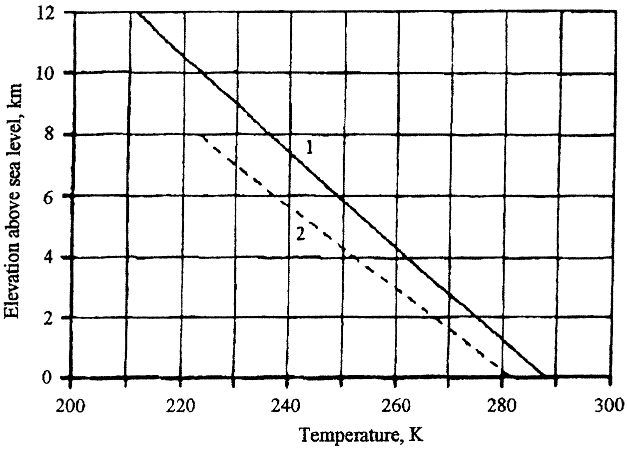

Figure 1. Relationship between the temperature and elevation above sea level for (1) existing nitrogen–oxygen atmosphere on Earth, and (2) hypothetical carbon dioxide atmosphere.

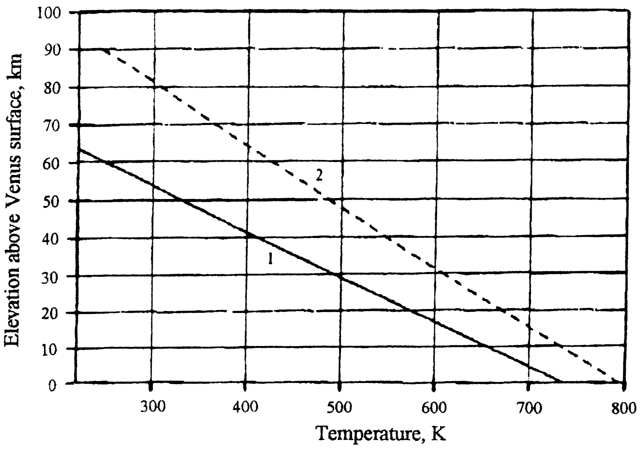

Figure 2. Relationship between temperature and elevation above Venus surface for (1) existing carbon dioxide atmosphere, and (2) hypothetical nitrogen–oxygen atmosphere.

The averaged temperature distributions for the existing carbon dioxide and hypothetical nitrogen–oxygen atmosphere on Venus are shown in Figure 2.

Conclusions

During the latest three millennia, one can observe a clear cooling trend in the Earth's climate (Keigwin, 1996; Sorokhtin and Ushakov, 2002; Gerhard, 2004; Khiyuk and Chilingar, 2006; Sorokhtin et al., 2007). During this period, deviations of the global temperature from this trend reached up to 3°C with a clear trend of decreasing global temperature by about 2°C. Relatively short-term variations in global temperature are mainly caused by the variations in solar activity and are not linked to the changes in carbon dioxide content in atmosphere.

Accumulation of large amounts of carbon dioxide in the atmosphere leads to the cooling, and not to warming of climate, as the proponents of traditional anthropogenic global warming theory believe (Aeschbach-Hertig, 2006). This conclusion has a simple physical explanation: when the infrared radiation is absorbed by the molecules of greenhouse gases, its energy is transformed into thermal expansion of air, which causes convective fluxes of air masses restoring the adiabatic distribution of temperature in the troposphere. Our estimates show that release of small amounts of carbon dioxide (several hundreds ppm), which are typical for the scope of anthropogenic emission, does not influence the global temperature of Earth's atmosphere.

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