

Cosmic Rays, Solar Activity, and Changes in the Earth's Climate

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Abstract—One of the most important problems facing humanity, global climate change, is discussed. The roles of cosmic ray fluxes and solar activity in this process are analyzed. Although several mechanisms explaining global climate change have been proposed, none of them are firmly grounded. At the United Nations summit in Paris at the end of 2015, it was decided that greenhouse gases are responsible for the global warming of our planet. However, the authors of this work believe the question of what causes global changes in the Earth's climate remains open, and will obviously be solved once and for all in the next 10–15 years.

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INTRODUCTION

One of the most important problems facing humanity is finding the physical mechanism responsible for global climate change, particularly global warming on the Earth. Figure 1 presents the data on changes ΔT in the monthly average values of global temperature (averaged over the globe) in the near-surface air layer [1, 2]. The ΔT values, shown as the fine curve, are counted from the average value of the global temperature acquired over the period 1901–2000. It can be seen that the changes in the ΔT values are irregular in character. A more or less smooth increase in temperature has been observed from around 1970 to the present. The thick curve represents calculations based on a spectral analysis of the monthly average data on ΔT for the period 1880–early 2016. The calculations show that the experimental data contain four main periodic components. Their characteristics (amplitude A in relative units; phase Φ and period P in years) are $A_1 = 0.406$, $\Phi_1 = 125.81$, $P_1 = 204.57$; $A_2 = 0.218$, $\Phi_2 = 31.02$, $P_2 = 69.30$; $A_3 = 0.079$, $\Phi_3 = 17.14$, $P_3 = 34.58$; and $A_4 = 0.088$, $\Phi_4 = 10.48$, $P_4 = 22.61$. The amplitudes of other spectral components with periods of less than 22 years are negligible. Summation of these periodicities for the future (after 2015) allows us to forecast the next few decades. The solid heavy line in Fig. 1 shows that cooling (a drop in ΔT values) is expected in the next few decades. The first harmonic A_1 has the highest uncertainty in the considered method, due to the shortness of the series of ΔT values.

BRIEF OVERVIEW OF THE MAIN PHYSICAL MECHANISMS POSSIBLY RESPONSIBLE FOR ΔT CHANGES

In a short work, it is difficult to consider all of the physical mechanisms proposed to explain the global warming process, so we will limit ourselves to a brief consideration of those that are most important from our point of view.

According to the theory of M. Milankovich, global changes in the Earth's climate are explained by

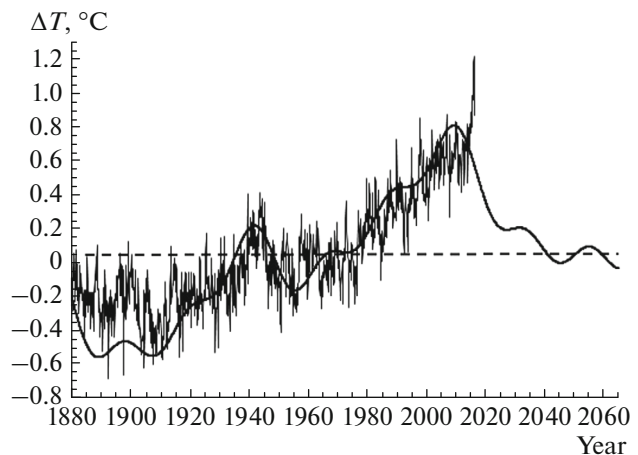


Fig. 1. Changes ΔT in the monthly average values of global (averaged over the Earth) temperature in the near-surface air layer (fine curve). The ΔT values are counted from the average value of the global temperature, acquired for the period 1901–2000. The solid heavy curve represents the calculations performed using spectral data analysis. The forecast is given for changes ΔT in temperature after 2015. The dashed line corresponds to $\Delta T = 0$.

changes in the orbital factors of the Earth in the Solar System. These changes lead to variations in insolation that are dictated by Earth's orbit. Changes in the Earth's eccentricity e over periods of $\sim 400\,000$ and $100\,000$ years influence the total annual insolation arriving at the Earth. Over the above periods, eccentricity e changes from 0.01 to 0.64. The tilt angle of the Earth's rotation axis relative to the ecliptic plane changes from 22.1° to 24.5° over $\sim 41\,000$ years (the main harmonic). This angle is currently 23.44° . Changes in the tilt angle do not affect the total insolation of the planet, but redistribute it over its latitudes: an increase in insolation at high latitudes in both hemispheres is accompanied by a decrease at low latitudes and vice versa. The precession angle changes with periods of 26 000 and 19 000 years (the main periods). Precession leads to changes in seasonal contrasts of insolation. However, the annual change in insolation for any latitude is equal to zero, since an increase in summer insolation is accompanied by a decrease in winter insolation and vice versa. Changes in precession are opposite in different hemispheres and are modulated by changes in eccentricity. All of the above changes happen on a long-term scales and are unlikely to be related to the contemporary process of global warming [3–5].

An important factor that undoubtedly influences the Earth's climate is the Sun. Two aspects should be mentioned here: changes in the Sun's luminosity and changes in solar activity. As for changes in the Sun's luminosity, the experimental data on total solar irradiation (TSI) in the Earth's orbit show that the TSI value changes with the solar activity cycle. The data acquired for the period from 1978 to the present show that the TSI value is highest during periods of maximum solar activity (maximum number of sunspots) and lowest during quiet Sun periods (minimum number of sunspots) [6]. However, this difference in the TSI value for the active and quiet Sun periods is negligible (only 0.07%). Such minor changes in the Sun's luminosity can alter the average global temperature on the Earth by no more than 0.05°C .

Another influence on the Earth's climate is solar activity; the main period of its variations is ~ 11 years. Despite numerous attempts to find a connection between different solar activity indices and temporal variations in ΔT values, no such link has been firmly established [3, 7, 8].

POSSIBLE ROLE OF CHARGED PARTICLE FLUXES IN THE LOWER ATMOSPHERE IN THE PROCESSES OF GLOBAL CLIMATE CHANGE

The question of the substantial role of charged particle fluxes in atmospheric processes has been studied in many works [9–16]. The most important of these are [11–13], where the connection between the cosmic

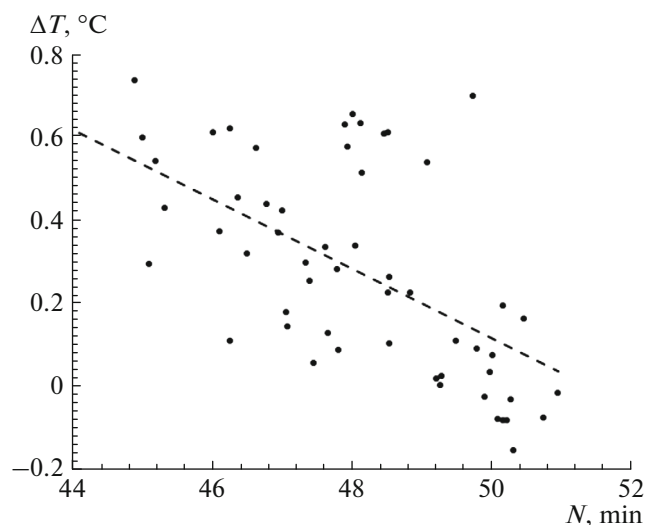


Fig. 2. Connection between changes ΔT in the annual average values of global (averaged over the Earth) temperature in the near-surface air layer and annual average charged particle fluxes N , measured at the middle northern latitudes in the interval of altitudes of 0.3–2.2 km. The dashed line shows the linear relationship between ΔT and N .

ray flux and the area of cloud cover was established. The data from the Huancayo equatorial neutron monitors up to 2000 and from Haleakala after 2000 were used to estimate cosmic ray fluxes and their temporal variations. However, successive studies have cast doubt on the connection between the cosmic ray flux and the cloud cover area [14–16].

In this work, we analyze for the first time the monthly average and annual average data from direct measurements of charged particle fluxes in the lower atmosphere of middle northern latitudes (geomagnetic cutoff rigidity 2.4 GV).

Measurements in the Earth's atmosphere were made using a standard cosmic ray radiosonde [17] from the Earth's surface up to altitudes of 30–35 km. The range in our case included altitudes from ground level to 5 km. Russian-manufactured STS-6 gas-discharge counters served as detectors of charged particles. It should be noted that the charged particle flux registered in the lower atmosphere below ~ 3 km of altitude consisted of secondary cosmic rays (mainly muons and electrons) and products of natural radioactivity.

Figure 2 shows the dependence between the annual average changes ΔT in the global temperature in the near-surface air layer and charged particle flux N in the interval of altitudes from 0.3 to 2.2 km. We can see there is a connection between values ΔT and N : with an increase in cosmic ray flux N , the values of changes of global temperature decrease. This link is expressed by the relation $\Delta T = -0.0838N + 4.307$ (see the dashed line in Fig. 2), where the ΔT values are given in $^\circ\text{C}$, and the N values (in particle/min units) are related to