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ARTICLE

Absence of the Impact of the Flux of Cosmic Rays and the Cloud Cover on the Energy Balance of the Earth

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ABSTRACT

The energy of solar radiation absorbed by the Earth, as well as the thermal radiation of the Earth's surface, which is released to the space through the atmospheric transparency window, depends on variations of the area of the cloud cover. Svensmark et al. suggest that the increase in the area of the cloud cover in the lower atmosphere, presumably caused by an increase in the flux of galactic cosmic rays during the quasi-bicentennial minimum of solar activity, results only in an increase in the fraction of the solar radiation reflected back to the space and weakens the flux of the solar radiation that reached the Earth surface. It is suggested, without any corresponding calculations of the variations of the average annual energy balance of the Earth *E*, that the consequences will include only a deficit of the solar energy absorbed by the Earth and a cooling of the climate up to the onset of the Little Ice Age. These suggestions ignore simultaneous impact of the opposite aspects of the increase in the area of the cloud cover on the climate warming. The latter will result from a decrease in the power of thermal radiation of the Earth's surface released to the space, and also in the power of the solar radiation reflected from the Earth's surface, due to the increase in their absorption and reflection back to the surface. A substantial strengthening in the greenhouse effect and the narrowing of the atmospheric transparency window will also occur. Here, we estimate the impact of all aspects of possible long-term 2% growth of the cloud cover area in the lower atmosphere by *E*. We found that an increase in the cloud cover area in the lower atmosphere will result simultaneously both in the decrease and in the increase in the temperature, which will virtually compensate each other, while the energy balance of the Earth E before and after the increase in the cloud cover area by 2% will stay essentially the same: $E_1 - E_0 \approx 0$.

1. Introduction

Determination of the physical mechanism of the global climate variation is one of the most important problems. The Earth climate is a complex non-linear system subject to the impact of numerous factors, dynamical parameters and cause-and-effect feedback. The climatic system depends on an extremely complicated set of long-term (about 30 years and more) physical processes in the "ocean - ground - atmosphere" system, and these processes, in turn, are susceptible to various, primarily quasi- bicentennial

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variations in the total solar irradiance (TSI). If we take into account only quasi-bicentennial variations in TSI equal to ~0.3% [1,2], the resulting increments in the planetary temperature will be small (~0.2 K). However, these variations are very important as a triggering mechanism for subsequent numerous feedback effects, which result in considerable variations in Bond albedo of the Earth, abundance of greenhouse gases in the atmosphere, and the absorption within atmospheric transparency windows [3-6]. The solar radiation energy absorbed by the Earth, as well as the thermal radiation of the Earth's surface released to the space through the transparency window, depends on variations of the area and optical density of the cloud cover and the parameters of the underlying terrain. The stability of the climate is determined by the long-term equilibrium state of the annual average energy balance of the Earth between the TSI inflow into the outer layers of the atmosphere and the total radiation exhausted from the Earth atmosphere to the space in all directions (Figure 1). However, representative long-term data for deviations of the annual average energy balance of the Earth from the state of equilibrium, regardless of their reasons, are of fundamental importance for determination of the regular patterns of climatic variations and climate forecasts. A vital factor that undoubtedly affects the Earth climate is quasi-bicentennial variations of the TSI. Two aspects should be mentioned here: TSI variations and variations in the solar activity. Experimental data indicate that TSI varies synchronously and correlate both in the phase and in the amplitude with 11-year and quasi-bicentennial cycles of the solar activity [4,5].

2. The Average Annual Energy Balance of the Earth

The energy balance of the Earth E is specified in the outer layers of the atmosphere (Figure 1) as the annual average difference between the power per unit area of TSI inflow and that of escaping thermal radiation and both reflected and scattered fractions of TSI, determined by Bond albedo:

$$E = \frac{\left(S_{\odot} + \Delta S_{\odot}\right)}{4} - \frac{(A_{\mathrm{BE}} + \Delta A_{\mathrm{BE}})\left(S_{\odot} + \Delta S_{\odot}\right)}{4} - \varepsilon\sigma(T_p + \Delta T_p)^4, \quad (1)$$

where $S_{\odot}$ is TSI, $\Delta S_{\odot}$ the TSI increment, A_{BE} the Earth's global albedo (Bond albedo), ΔA_{BE} the increment of the Bond albedo, ε the irradiating capacity of the surface-atmosphere system, σ the Stefan-Boltzmann constant, T_p the planetary thermodynamic temperature, ΔT_p the increment of the planetary thermodynamic temperature, E the power-per-unit-area variations of the heat content of the planet. The planetary thermodynamical temperature is the average temperature over the total surface of the planet (the surface of the Earth and the atmosphere).

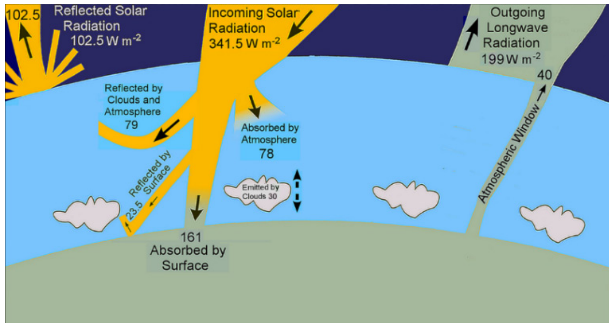

Figure 1. Average annual values of all components in the total energy balance of the Earth as a planet at the outer atmospheric layers in an equilibrium state [3,5,7,8]

Svensmark et al. [9-12] suggest that the increase in the cloud cover area in the lower atmosphere of the Earth presumably caused by the impact of the increasing flux of galactic cosmic rays in the period of the quasi-bicentennial deep minimum of the solar activity results only in an increase in the reflected fraction of the solar radiation inflow and therefore weakens the flux of the solar radiation that reaches the Earth's surface. Presenting no calculations of the variations of the energy balance of the Earth, these authors suggest that this will inevitably result in the deficiency of the solar energy absorbed by the Earth and in the global cooling up to the onset of a Little Ice Age. Along with that, they totally ignore simultaneous impact of opposite aspects of the increase in the area and the optical density of the cloud cover on the climate warming. The above occurs through the following factors: a decrease in the outflowing thermal radiation of the Earth's surface and the solar radiation reflected from the Earth's surface, due to an increase in their absorption and reflection back towards the surface; a significant strengthening of the greenhouse effect and narrowing of the atmospheric transparency window. The authors explain the onset of the global warming by a decrease in the flux of the cosmic rays and decrease in the cloud formation rate, which results in a growth in the absorbed fraction of the solar radiation within the time of the Grand maximum of the solar activity. They also totally ignore simultaneous direct influence of parallel TSI decrease by ~0.3% [1,2] within the framework of quasi-bicentennial cycle on the variation in the energy balance of the Earth and subsequent variations of physical processes in the atmosphere caused by secondary feedback effects. Such a long-term energy imbalance between the Earth and the space, caused by the decrease in TSI by ~0.3% ($\Delta S_{\odot} \approx$ 4 w/m^2), taking into account thermal inertia will inevitably result in the subsequent steady decrease in the temperature (without taking into account other contributions and for at

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immutability of Bond albedo $\Delta A_{BE} = 0$) by

$$\Delta T_e = \frac{\Delta S_{\odot}(1 - A_{\mathrm{BE}} - \Delta A_{\mathrm{BE}}) - \Delta A_{\mathrm{BE}} S_{\odot}}{16\sigma T_e^3} \approx -0.2\ \mathrm{K}. \qquad (2)$$

3. The Spectral Density of Thermal Radiation of the Earth's Surface

Under the current conditions, carbon dioxide and water vapor absorb about 80% of the thermal radiation of the Earth's surface. Out of these, ~68% is absorbed in spectral bands of the basic greenhouse gas - the water vapor, and only ~12% by the carbon dioxide (Figure 2). This ratio is caused by partial overlapping of spectral absorption bands of the carbon dioxide and the water vapor, and also by virtually constant abundance of water vapor in the atmosphere within small variations of the temperature and pressure. If it were not for the overlap of these spectral absorption bands, the water vapor would absorb ~77% of the thermal radiation of the Earth's surface, while the carbon dioxide only ~17%. With their current approximately stable area and optical density, the clouds along with molecules of other minor greenhouse gases absorb another ~10% of the thermal radiation of the Earth's surface, and the remaining ~10% are released to the outer space through the transparency windows of the Earth's atmosphere. Both the fraction of the thermal radiation of the surface released to the outer space, and that absorbed by cloudiness belong to virtually the same broad bands of the spectral wavelengths (Figure 2).

Due to the growth of the cloud cover area, both absorbed and reflected (towards the surface) energy of the thermal radiation of the surface increases within the wavelength range of the transparency windows of the atmosphere. As a result, the energy of non-absorbed thermal radiation of the Earth's surface, released to the outer space within the spectral intervals of the transparency windows, will respectively decrease by virtually the same value. Consequently, the carrying capacity (transparency) of the atmosphere with respect of the release of the thermal radiation of the Earth's surface to the outer space depends in particular of variation of the fraction of the thermal radiation of the Earth's surface absorbed and reflected by the clouds. As a rule, Bond albedo, the width of the transparency windows of the atmosphere, and the carrying capacity of the atmosphere with respect to thermal radiation of the Earth's surface released into the outer space reach their maximum values within long-term periods of deep cooling and decrease to their minimum values at the stage of global warming. Concentration of greenhouse gases in the atmosphere varies inversely.

4. Climatic Effects of Possible Cloud Coverage Variations

The area and optical density of the cloud cover is a basic part of the annual average energy balance of the Earth. Any physical process that may result in their noticeable systematic variations presents big interest. In particular, variations in the area and optical density of the cloud cover affect the fraction power of both the inflowed solar radiation absorbed by the Earth and thermal radiation of the Earth's surface released to the outer space through the transparency windows of the atmosphere. A possible growth of the optical density and area of the cloud cover increases the part of the inflow of the solar radiation reflected back to the space, thereby weakening the flux of solar radiation that reaches the Earth's surface. According to the hypothesis [9-12], this possible growth in the area of the cloudiness will result only in a corresponding deficiency in the inflowed solar energy and a long-term negative annual average energy balance of the Earth. This hypothesis states that the reflecting effect of the increase in cloudiness, additionally weakening the solar radiation, will inevitably result in cooling of the climate up to a Little Ice Age. The same hypothesis also explains the global warming by a decrease in the flux of cosmic rays and lowering of cloud formation rate, which result in an increase in absorbed fraction of the solar radiation within the time of a high maximum of the solar activity. It is extremely important to estimate whether the suggested negative balance of the annual average energy budget of the Earth (due to the increase in the flux of cosmic rays and the cloud cover) will be significant and whether its impact can play a noticeable role in the subsequent cooling and the onset of the Little Ice Age in the time of the forthcoming Grand Minimum of the solar activity [3-6,13]. For the first time, we carried out a combined estimate of oppositely directed previously unknown aspects of an increase in the area and optical density of the cloud cover. They simultaneously increase both the absorption and reflection of thermal radiation of the Earth's surface and the solar radiation reflected from the Earth's surface back to the surface, and also the greenhouse effect. They also result in narrowing of the atmospheric transparency windows through which thermal radiation of the Earth's surface is released to the outer space. They present an important reservoir of accumulation of heat energy, which virtually compensate the cooling caused by the increase in the part of the TSI inflow reflected back to space.

In spite of the current uncertainty in the degree of the impact of the increase in the flux of cosmic rays on the considerable growth of the cloud cover area, on the annual

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balance of the average energy budget of the Earth and on the subsequent cooling of the climate [14-16], for the first time we will attempt to estimate another unexplored and oppositely directed aspect of the influence of the growth in the cloud cover area on the climate. The increase in the area and optical density of the cloud cover simultaneously result also in inevitable increase in the absorption and reflection of thermal radiation of the surface, and also the solar radiation reflected from the surface. Consequently, they lead to direct air heating and to the formation of supplementary energy in the atmosphere, which finally results in an increase in the temperature of the atmosphere due to effective narrowing of the transparency windows of the atmosphere. In addition, the increase in the area and optical density of the cloud cover in the lower atmosphere results in strengthening of the greenhouse effect, which will also add up to the heating of the atmosphere and the planet in total. The resulting supplementary energy is radiated by the heated atmosphere, both to the space and, through the inverse radiation, on the surface, which is heated. Therefore, it is very important to determine the degree and the role of the oppositely directed influence of the growth in the area and optical density of the cloud cover on the annual average energy balance of the Earth and on subsequent heating processes. This determination will make it possible to specify the influence of the growth in the area and optical density of the cloud cover also in the opposite processes of global variation in annual average energy balance of the Earth and the climate. To this end, thorough their research are needed.

Here, we will restrict our consideration with the analysis and estimate of the efficiency of the impact of the possible long-term increase in the area and optical density of the cloud cover during the Grand Minimum of the solar activity simultaneously both on the increase in the reflected part of the inflowing solar radiation back to the outer space and on the growth in absorption and reflection of the thermal radiation of the surface, and also on the solar radiation reflected from the surface. We will also consider their combined oppositely directed impacts on the variation of the balance of the annual average energy budget of the Earth and the subsequent global variation of the climate. Due to the increase in the area and optical density of the cloud cover, the absorbed and reflected (towards the surface) energy of the thermal radiation of the surface increases within a broad wavelength range of spectral bands in the transparency windows of the atmosphere (Figure 2). As a result, the energy of non-absorbed thermal radiation of the Earth's surface, released to the space within the transparency windows of the atmosphere, will decrease virtually by the corresponding value, due to the decrease in the transparency windows of the atmosphere, while the atmosphere itself will gain the absorbed energy. As a result, in the case of long-term increase in the area and optical density of the cloud cover, the atmosphere will effectively display supplementary absorbed energy, which was not released to the space due to the narrowing of the transparency windows of the atmosphere. For the first time, we fully extended and revised estimated the long-term impact of all aspects of possible 2% growth in the cloud cover area in the lower atmosphere on the current annual average energy balance of the Earth E_o. These factors result particularly in the narrowing of the atmosphere transparency window for the release of the radiation of the Earth's surface and also both in the energy deficiency and in the accumulation of supplementary heating energy [17].

Let us try to estimate a possible variation of the current annual average energy balance of the Earth E_o, if the cloud cover area in the lower atmosphere of the Earth will experience a long-term consistent 2% growth, presumably caused by an increase in the flux of galactic cosmic rays. In this case, the fraction of incoming solar radiation reflected from the clouds back to the space (≈79 W/m^2) will also increase roughly by 2%. This will weaken the flux of solar radiation that reaches surface layers and will result in a decrease in E_o by about -0.02 x 79 W/m^2 = -1.58 W/m^2 and in corresponding cooling.

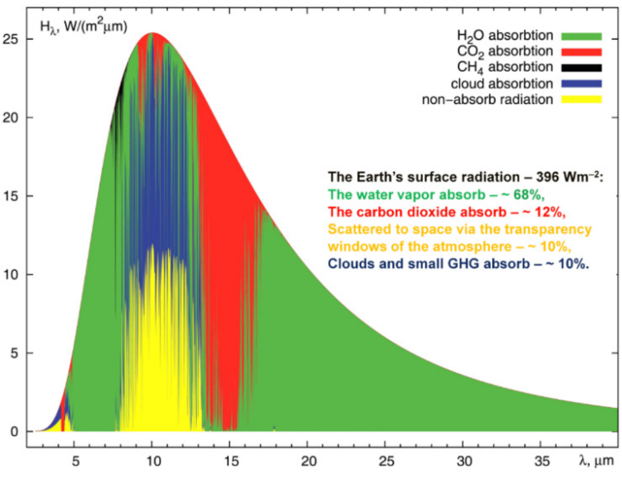

Figure 2. Spectral density of the thermal long-wave radiation flux from the surface of the Earth (as blackbody) [4,5].

However, at the same time, with the increase in the cloud cover area, the energy of thermal radiation of the Earth's surface absorbed by clouds increases by some 2%, while the a energy released to space through the transparency windows of the atmosphere (≈ 40 W/m^2) will respectively decrease. This factor increases the flux of energy in surface under cloud layers and will result in

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some warming and in an increase in E_o by about +0.02 x 40 W/m^2 = +0.8 W/m^2. At the same time, a fraction of the solar radiation reflected from the surface of the Earth and released to space (≈23.5 W/m^2), will also decrease, since its reflection by clouds in the direction of the surface will increase by some 2%. This will result in an increase in E_o roughly by +0.02 x 23.5 W/m^2 = +0.47 W/m^2 and in air heating under the clouds and above the surface. Simultaneously, thermal radiation of the surface of the Earth absorbed and reflected back to the surface by the cloud cover will fare increases roughly by 2%; the same is true for the absorption and reflection of the solar radiation (back to the surface) reflected from the Earth's surface. They will result in some heating of the air between the clouds and the surface and in an increase in *Eo* by +**X.XX W/m^2**. Besides, the increase in the cloud covers in the lower layers of the atmosphere substantially strengthens the greenhouse effect, which also results in a noticeable increase in E_o by +**Y.YY W/m^2** with subsequent heating. The radiation ejected from the clouds (≈30 W/m^2) will increase in 2% both in the direction of the space and in the direction of the Earth's surface. This will lead to a decrease in E_o by approximately -0.02 x 30 W/m^2 = -0.6 W/m^2 and to some cooling. Simultaneously, this will also result in an increase in E_o by roughly +0.02 x 30 W/m^2 = +0.6 W/m^2 and in some warming. The calculations provide a new energy balance of the Earth after an increase in cloud cover area by 2% $E_1 \approx E_o$ - 1.58 W/m^2 + 0.8 W/m^2 + 0.47 W/m^2 - 0.6 W/m^2 + 0.6 W/m^2 + **X.XX W/m^2 + Y.YY W/m^2.** Hence, $\Delta E = E_1 - E_o \approx 0$, i.e. the difference between energy balance of the Earth before and after the increase in the cloud cover area is virtually equal to zero [8,17]. Consequently, the impact of the increase in the cloud cover area, presumably caused by the influence of galactic cosmic rays, on the climate is virtually no-existent. Thereby, a long-term increase in the cloud cover presumably caused by the influence of the increase in the flux of cosmic rays, virtually does not result in variation in the annual average energy balance of the Earth, i.e. essentially does not affect variation of the climate.

5. Conclusions

The increase in the cloud cover area presumably resulted from an increase in the flux of galactic cosmic rays in the time of a deep minimum of the solar activity simultaneously leads to both negative energy balance of the planet, through the increase in reflection of the solar radiation back to space, and in the positive balance, increasing the absorption and reflection of the thermal radiation of the Earth's surface, strengthening the greenhouse effect and narrowing the transparency window of the atmosphere, which compensate the energy losses and cooling. A possible increase in the area and optical density of the cloud cover with the increase of the flux of galactic cosmic rays virtually does not result in violations of the energy balance of the Earth and does not affect the variations of the climate.

Note in addition that according to Clausius-Clapeyron ratio, cooling results in an decrease in vaporization from the World Ocean and the terrain and in the lowering of the abundance of water vapor in the atmosphere. Consequently, the atmosphere will contain less water vapor, which in turn will decrease the formation of clouds and the total area of cloud cover. Global terrestrial climate is determined exceptionally by long-term (for time periods about 30 years and more) variations of the global thermal state (heat content) of the total planet, which is specified by its annual average global energy balance, restricted by excess or deficiency of the difference between the absorbed planet fraction of the inflowing solar energy and the intrinsic thermal energy radiated by the Earth and released to the outer space; this is combined with no less important subsequent numerous impacts of cause-and-effect feedbacks. Influence of oppositely directed aspects of the possible increase in the cloud cover virtually compensate the cooling caused by the growth in the fraction of the inflowing solar radiation reflected back to space.

It is known that very insignificant long-term variations in annual average TSI related to long-term cyclical variations in the shape of the Earth's orbit (the so-called Milankovitch cycles) and combined with subsequent very important (due to long-term variations in the TSI and temperature) non-linear feedback effects, result in Grand Ice Ages (with the period of about 100,000 years) and sequential glacial and interglacial cycles [5,18]. These Grand Ice Ages, with appreciably larger temperature in ~10-12°C drops (practically an order of magnitude more) occur cyclically and independently of any large long-term variations of solar activity, cosmic rays and cloudiness. From the above we can conclude that the increases in the flux of cosmic rays and in cloud cover and the subsequent climate cooling are virtually unrelated and that the hypothesis of the dominating role of the cosmic rays flux in the deep climate cooling up to a Little Ice Age is scientifically unsound. The warming of Mars and virtually of the entire Solar system in the last quarter of the XX century [19,20] also does not confirm the influence of the growth in the cosmic rays flux on variations of the climate compared to the influence of TSI variations observed in the quasi-bi-centennial solar cycle [1,2,4,5,13]. Thereby the climatic sensitivity to the increase in the cosmic rays flux within the Grand minimum of solar activity, supposedly resulting in the increase in area and optical density of the cloud cover, is virtually nonexistent. Therefore, we cannot expect for any real substantial decrease in the temperature of the Earth, leaving alone an onset of a Little Ice Age, caused by a possible effect of the growth in the flux of galactic cosmic rays presumably resulting in an increase in the area and optical density of the cloud cover. Temperature trends of the Earth are dominated by quasi- bicentennial variability of TSI.

As a result, an impact of the long-term growth in the cloud cover area (presumably caused by an influence of an increase in the cosmic rays flux) on variations in the annual average energy budget of the Earth and, consequently, on the climate is virtually nonexistent. The increases in the energy of the radiation emitted by clouds with larger area to the outer space and towards the surface of the Earth are roughly equal, and virtually do not affect the energy balance of the Earth, i.e., the thermal radiation of the clouds does not affect variations in the energy balance of the planet.

Thereby, variations in the cloud cover area caused presumably by the impact of galactic cosmic rays virtually do not result in any climatic effects. The Earth climate does not depend on variations of cosmic rays and the cloud cover and is determined only by long-term variations in energy imbalances between the Earth and the space, as well as subsequent numerous feedback effects.

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