



Grand Minimum of the Total Solar Irradiance Leads to the Little Ice Age

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Abstract

Quasibicentennial variation of the energy solar radiation absorbed by the Earth remains uncompensated by the energy emission to space over the interval of time that is determined by the thermal inertia. That is why the debit and credit parts of the average annual energy budget of the terrestrial globe with its air and water envelope are always in an unbalanced state, which is the basic state of the climatic system. The average annual balance of the thermal budget of the system Earth-atmosphere during long time periods will reliably determine the course and value of both the energy excess accumulated by the Earth or the energy deficit in the thermal budget, which, with account for the data of the forecasted variations of the Total Solar Irradiance (TSI) in the future, can define and predict well in advance the direction and amplitude of the forthcoming climate changes with high accuracy. Since the early 90 has been observed a decrease in both the TSI and the portion of energy absorbed by the Earth. The Earth as a planet will also have a negative balance in the energy budget in the future, because the Sun has entered the decline phase of the quasibicentennial cycle of the TSI variations. This will lead to a drop in the temperature and to the beginning of the epoch of the Little Ice Age approximately since the year 2014. The increase in the Bond (global) albedo and the decrease in the greenhouse gases concentration in the atmosphere will lead to an additional reduction of the absorbed solar energy and reduce the greenhouse effect. The influence of the consecutive chain of feedback effects will lead to additional drop of temperature, which can surpass the influence of the effect of the TSI decrease. The start of Grand Maunder-type Minimum of the TSI of the quasibicentennial cycle is to be anticipated around the year 2043 ± 11 and the beginning of the phase of deep cooling of the 19th Little Ice Age in the past 7,500 years in the year 2060 ± 11 . Long-term cyclic variations of the TSI are the main fundamental cause of the corresponding climate variations.

Keywords: Little ice age; TSI; Energy budget; Albedo; Greenhouse gases; Feedback effects; Climate

Introduction

The climatic system is affected by a quasi-bicentennial cyclic external action connected with corresponding variations of the TSI. Significant cyclic climate changes are a forced response of the climatic system to these external actions. The basic features of climate variations are connected, in particular, with fluctuations of the power and velocity of both the atmospheric circulations and ocean currents, including the thermal current of Gulfstream, which is driven by the heat accumulated by ocean water in the tropics. This is determined by the common action of bicentennial and eleven-year cyclic variations of TSI. The significant climate variations during the past 7.5 millennia indicate that the bicentennial quasi-periodic TSI variation defines a corresponding cyclic mechanism of climatic changes from global warmings to Little Ice Ages and set the timescales of practically all physical processes taking place in the system the Sun-the Earth [1-3]. At the same time, the bicentennial quasi-periodic variation of TSI causes additional temperature decline (with some time-lag), exceeding a direct influence of the TSI variation, due to climatic feedback mechanisms, which are, namely, the gradual non-linear rise of the Earth's surface albedo (an additional decrease in the absorbed TSI fraction) and the natural non-linear decrease in the atmospheric concentration of water vapor, carbon dioxide and other gases (the weakening of the green-house effect influence) in the process of cooling and vice versa.

The observed long-term decline of TSI and forthcoming deep cooling will, first of all, essentially affect climate-dependent natural resources and, hence, influence, in the first place, economic branches closely connected with state of the climate. Nowadays the problem of future global cooling is not only a major and important scientific problem of planetary scale facing the whole mankind but also an economic and political problem whose solution determines further prospects of the human civilization development. A forthcoming global cooling will dictate direction of change of different natural processes on the surface and in the atmosphere as well as conditions for creating

material and financial resources of the society. Deep cooling will directly influence the development of scientific, technical and economical potentials of modern civilization. Early understanding of reality of forthcoming global cooling and physical mechanisms responsible for it directly determines a choice of adequate and reliable measures which will allow the mankind, in particular, population of countries situated far from the equator to adapt to the future global cooling. For practical purposes the most important is to determine the tendencies of expected climate changes for the next 50-100 years that is until the middle or the end of the XXI century.

Interrelated Variations of the Climate and the Orbital Forcing of the Earth

Significant long-term variations of the annual average of the Total Solar Irradiance (TSI) due to changes in the shape of the Earth's orbit, inclination of the Earth's axis relative to its orbital plane and precession (Figure 1), known as the astronomical Milankovitch cycles [4,5] together with secondary subsequent feedback effects lead to the Big Glacial Periods. Considerable changes in the annual average distance between the Sun and the Earth with the period of about 100,000 years, and resulting variations of the TSI, cause essential temperature fluctuations from the warmings to the Big Glacial Periods, as well as variable atmospheric concentration of water vapor, carbon dioxide and other gases. The astronomical Milankovitch cycles lead to a change in the amount absorbed by different regions of the Earth and of the whole planet the average annual energy radiated by the Sun due to

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variations of the orbital forcing. The TSI is defined as $S_0 = L_0 / 4\pi R^2$, where L_0 - the solar luminosity-the total energy of the Sun output (per unit time) in the form of electromagnetic radiation, S_0 - the total solar irradiance at the average annual distance between the Sun and the Earth, R -the average annual distance between the Sun and the Earth. The astronomical Milankovitch cycles induced significant variations in temperature and atmospheric concentration of carbon dioxide. For the 420,000 years on the Earth was the four (with a period of about 100,000 years) Big Glacial Periods and the five high temperature phases, as well as variations of the atmospheric concentration of carbon dioxide at 100 ppmv and of the temperature at about 10°C (Figure 2) [6-8]. The ikaite record qualitatively supports that both the Medieval Warm Period and the Maunder Minimum Little Ice Age extended also to the Antarctic Peninsula, which points to the global nature of these changes [9].

Antarctic ice cores provide clear evidence of a close coupling between variations temperature and the atmospheric concentration of carbon dioxide during the glacial/interglacial cycles of at least the past 800,000 years. Precise information on the relative timing of the temperature and carbon dioxide changes can assist in refining our understanding of the physical processes involved in this coupling. Analysis of ice cores from the ice sheets in Antarctica shows that the concentration of carbon dioxide in the atmosphere follows the rise temperatures very closely and lagged warmings by 800 ± 400 years [6,8,10]. In during of the glacial/interglacial cycles the peaks of carbon dioxide concentration have never preceded the warmings. In the modern era using data series on atmospheric carbon dioxide and global temperatures also was investigated the phase relation (leads/

lags) between these for the period January 1980 to December 2011 [11]. The maximum positive correlation between carbon dioxide and temperature is found for carbon dioxide lagging 11-12 months in relation to global sea surface temperature, 9.5-10 months to global surface air temperature, and about 9 months to global lower troposphere temperature. Thus changes in the amount of atmospheric carbon dioxide in the modern era also always are lagging behind from corresponding changes in temperature. Carbon dioxide released from anthropogenic sources has little influence on the observed changes in atmospheric carbon dioxide, and changes in atmospheric carbon dioxide are not tracking changes in human emissions [11]. Changes in ocean temperatures can explain a substantial part of the observed changes in atmospheric carbon dioxide since January 1980 [11]. This means that global warming causes increases in carbon dioxide, which being their consequences. Thus natural considerable changes of the atmospheric concentration of carbon dioxide were always determined by corresponding temperature fluctuations of the World Ocean which contains carbon dioxide in the amount exceeding that in the water by a factor approximately of 50 (heated water absorbs less carbon dioxide) [12]. Therefore there is no evidence that carbon dioxide is a major factor in the warming the Earth now (see below). Considerable changes of the atmospheric concentration of carbon dioxide are always determined by corresponding temperature fluctuations of the World Ocean.

Thus, significant long-term cyclic variations of the annual average of the total energy of solar radiation entering the upper layers of the Earth's atmosphere caused by the astronomical Milankovitch cycles are the main fundamental cause of corresponding climate variations on the Earth with a period of about 100,000 years (even if the solar luminosity L_0 remains constant).

Interrelated Variations in the Climate and the Solar Activity

The correlation between the sunspot activity and climate was first announced by a well-known English astronomer William Hershel in 1801 after he had discovered of inverse interrelation between the wheat prices and solar activity level before and during a period known as the Dalton Minimum [1]. During high levels of solar activity the wheat production increased resulting in a dropped of prices. When the number of sunspots significantly dropped the prices went up. Hershel assumed that the change in wheat price was due to corresponding climate changes but he was not able to explain the physical nature of the phenomenon. Later, the phase and amplitude correlation was found between the distinct periods of appreciable variations in sunspot formation activity and corresponding deep climate changes over the whole past millennium [2]. During each of the eighteen deep Maunder-type minima of solar activity with the quasi bicentennial cycle established over the past 7,500 years was associated with the period of deep cooling while the periods of high solar activity (maxima) corresponded to warming [3]. At present, it is generally accepted that the quasi bicentennial cycle of the Sun is one of the most intense solar cycles. However, deep coolings and warmings were caused not only by direct influence of the quasi bicentennial variation of TSI but also by its secondary additional influences in the form of subsequent feedback effects. The latest studies [13,14] confirm our earlier results [15,16] indicating the direct joint effect (with some lag) of the 11-year (11 ± 3 yr) and quasi bicentennial (200 ± 70 yr) cyclic variations in the total solar irradiance (TSI) on the changes in surface layer state (tens to hundreds of meters deep) of the tropical Pacific resulting in El Nino and La Nina events associated with appearance of warm or cold water affecting the climate. The changes in the observed parameters of El Niño over the

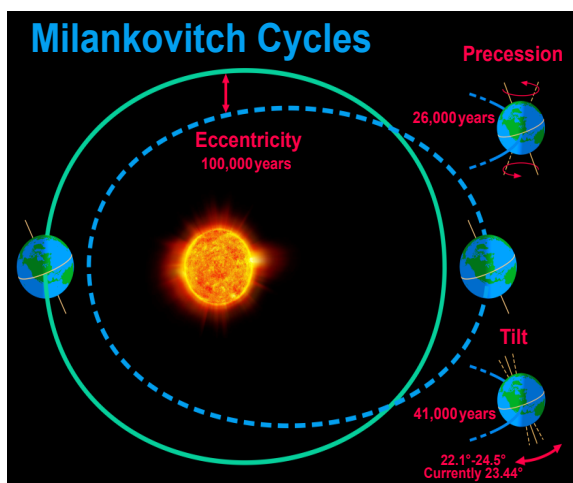


Figure 1: Well-known the astronomical Milankovitch cycles [4,5].

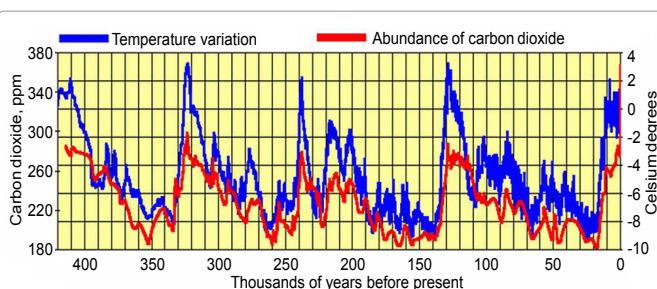


Figure 2: Earth climate and abundance of carbon dioxide variations in the past – for the period of 420,000 years (according to the 3,623 m ice core data drilled near Vostok site, Antarctica) [6,7].

past 31 years did not correspond to the changes predicted by the climate models suggesting the dominant role of greenhouse gases [13,14]. Thus, the oscillations in El Nino parameters were mostly due to the natural causes, namely, the cyclic variations of the TSI.

Variations of the TSI and Feedback Effects

The physical nature of deep climate changes over the past 7,500 years was directly related to the corresponding changes in the TSI S_0 . We have found that the variations of the TSI S_0 are synchronous and correlated (both in phase and amplitude) with the quasibicentennial and 11-year cyclic variations of the sunspot activity index W (Figure 3) [15-20]. We used data PMOD composite [21] since the constructed “mixed” ACRIM-SATIRE composite shows no increase in the TSI from 1986 to 1996 in contrast to the ACRIM composite [22]. This allows extrapolating a relatively short series (since 1978) of precision extratmospheric measurements of the TSI S_0 [21] over longer periods of time using long runs of the W index of solar activity [23-27]. It enables one to study the course of TSI during the past centuries and even millennia to match it to the corresponding climate changes in the past and to study its future variations.

Thus, we can state that all of at least 18 deep coolings and warmings established within the last 7,500 years were caused by the corresponding quasibicentennial cyclic variations of the TSI together with secondary subsequent feedback effects [17,18,20]. However, the quasibicentennial changes in the TSI are relatively small (maximum value approximately 6.6 W m^{-2} , or $\sim 0.5\%$, from the latest reconstructed data [26], where authors attribute the brightening specifically to small-scale magnetic fields produced by turbulent cascades in the network and intranet work) and their direct impact is insufficient to account for the corresponding

cyclic quasibicentennial Earth's temperature changes, from the periods of warming to Little Ice Ages. An additional “amplifier” is needed to enhance the direct impact of the variations in the TSI on the observed global climate changes.

Such amplifiers of the direct impact of variations in the TSI on the climate variations are the feedback effects: natural changes in the global albedo of the Earth as a planet (Bond albedo) and changes in the concentration of greenhouse gases in the atmosphere (water vapor, carbon dioxide, methane, etc.).

The Bond albedo is defined by the global optical properties of the Earth as a whole with its air and water envelopes averaged over the total vertical starting from the surface through the atmosphere. The Bond albedo is a proportion of the solar radiation energy reflected (scattered) back into the Space by the whole Earth – atmosphere system; thus, it is a particularly important physical parameter in the energy budget of the Earth as a planet. The Earth's albedo increases up to the maximum level during a deep cooling and decreases to the minimum in a warming, while the concentration of greenhouse gases in the atmosphere varies inversely since it depends mostly on the temperature of the World Ocean. Variations in the parameters of the Earth's surface and atmosphere, which are due to the quasibicentennial cyclic variations in the TSI, give birth to successive further changes in temperature due to multiple repetitions of such causal cycle of the secondary feedback effects, even if the TSI will subsequently remain unchanged over a certain period of time. As a result, global climate changes can be further enhanced by a value exceeding the impact of the quasibicentennial variation in the TSI. A similar pattern was observed in the late 20th century. Thus, during the past 7.5 millennia, the quasibicentennial cyclic TSI variations together with subsequent secondary feedback mechanism of climate changes from warmings to Little Ice Ages and set time – scales of practically all physical processes taking place in the system Sun – Earth. Unfortunately, the dynamics describing the rate of increase in the total areas of snow and ice covering the Earth's surface, as well as the rate of decrease in the concentration of greenhouse gases in the atmosphere, is a nonlinear function of the temperature drop and almost unpredictable. The natural concentration of carbon dioxide in the atmosphere is known to have been, during the Big Glacial Periods in the Earth's history, approximately twice as low as today [6,7].

Quasi-bicentennial Variation of the TSI Leads to the Unbalanced Energy Budget of the Earth–Atmosphere System

The temporal changes in power emitted into space by the envelope of the Earth-atmosphere system in the form of longwave radiation always lag behind the changes in solar radiation power absorbed by the Earth because the enthalpy of the Earth as a planet changes slowly. The thermodynamic temperature specifying the integral heat balance of the planet lags appreciably behind the changes in power of absorbed solar radiation, which is due to the thermal inertia of the Earth–atmosphere. This is equivalent to the excess or deficit in the budget between the absorbed and radiated powers. Any long-term change in the solar radiation energy absorbed by the Earth, which is due to the quasibicentennial variation in the TSI allowing for slow changes in the enthalpy of the Earth-atmosphere over the time defined by thermal inertia, remains uncompensated by the energy of longwave self-radiation emitted into space. This process is described by an increment in the planetary thermodynamic temperature changing slowly over time. Thus, the annual mean energy balance of the Earth as a planet is

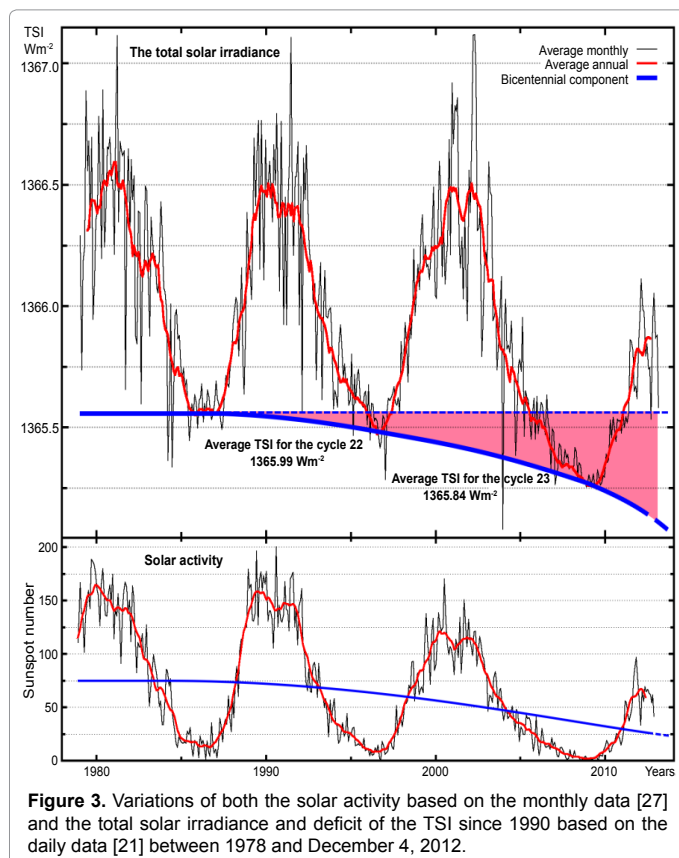


Figure 3. Variations of both the solar activity based on the monthly data [27] and the total solar irradiance and deficit of the TSI since 1990 based on the daily data [21] between 1978 and December 4, 2012.

always in a nonequilibrium state and oscillates around the equilibrium state, with the absorbed and radiated energy being unequal due to the quasibicentennial variation in the TSI. As a result, the planet will warm up or cool down gradually. The annual mean difference between the solar radiation energy coming into the outer layers of the Earth's atmosphere

$$E_{in}=(S_0+\Delta S)/4 \quad (1)$$

and the reflected solar radiation and longwave radiation energy outgoing into space

$$E_{out}=(A+\Delta A)(S_0+\Delta S_0)/4+\varepsilon\sigma(T_p+\Delta T_p)^4 \quad (2)$$

specifies the balance of the energy budget of the Earth-atmosphere. Here S_0 is the TSI, ΔS_0 the increment of the TSI, A is the albedo of the Earth as a planet (Bond albedo), ΔA is the increment of the Bond albedo, ε is the emissivity of the Earth-atmosphere system, σ is the Stefan-Boltzmann constant, T_p is the planetary thermodynamic temperature. The factor 1/4 on the right side of Eq. (1 and 2) reflects the fact that the solar radiation flux is projected onto the cross-sectional area of the terrestrial sphere (circle), while the Earth emits from the entire sphere surface that is four times as large. The specific power ΔE of the enthalpy change of the Earth-atmosphere system (difference between the incoming E_{in} and outgoing E_{out} radiation) is described by the following equation:

$$E=(S_0+\Delta S_0)/4-(A+\Delta A)(S_0+\Delta S_0)/4-\varepsilon\sigma(T_p+\Delta T_p)^4; E=C\frac{dT_p}{dt}, \quad (3)$$

where E is the specific power of the enthalpy change of the active oceanic and atmospheric layer [$W\ m^{-2}$], C is the specific surface heat capacity of the active oceanic and atmospheric layer related to the total area of the planet's surface [$J\ m^{-2}\ K^{-1}$], and t is the time. The specific power of the Earth's enthalpy change E is a particular indicator of the deficit or excess of the thermal energy, which can be considered as the energy balance of the annual mean budget in the debit and credit of the thermal power of the planet.

At the same time, the increment of the Earth's effective temperature involved in the radiation balance follows immediately after the change in the absorbed power, in contrast to the planetary thermodynamic temperature that is involved in the heat balance. The relative impact of variations in the TSI and Bond albedo on the change in the effective Earth's temperature can be determined from the radiation balance of the Earth as a planet:

$$S_0/4=\sigma T_{ef}^4+AS_0/4, \quad (4)$$

where T_{ef} is the Earth's effective temperature.

Let us introduce the increment of the effective temperature $\Delta T_{ef}=T_{ef}-T_{ef0}$, where T_{ef} is the current value of the Earth's effective temperature and T_{ef0} is its initial value. This increment is assumed to be due to the increments of the TSI ΔS_0 and Bond albedo ΔA . In this case, the radiative balance equation (Eq. (4)) takes the form

$$(S_0+\Delta S_0)/4=\sigma(T_{ef}+\Delta T_{ef})^4+(A+\Delta A)(S_0+\Delta S_0)/4. \quad (5)$$

Since the increments of the effective temperature are small, $\Delta T_{ef} \ll T_{ef0}$, the following equality is fulfilled with a high degree of accuracy:

$$S_0/4+\Delta S_0/4=\sigma T_{ef}^4+4\sigma T_{ef}^3\Delta T_{ef}+AS_0/4+A\Delta S_0/4+\Delta A(S_0+\Delta S_0)/4. \quad (6)$$

Subtracting Eq. (4) from Eq. (6) yields

$$\Delta S_0/4=4\sigma T_{ef}^3\Delta T_{ef}+A\Delta S_0/4+\Delta A(S_0+\Delta S_0)/4 \quad (7)$$

or

$$16\sigma T_{ef}^3\Delta T_{ef}=\Delta S_0-A\Delta S_0-\Delta A S_0-\Delta A\Delta S_0. \quad (8)$$

The formula for the increment of the Earth's effective temperature due to the increments of the TSI and Bond albedo can be obtained from (8):

$$\Delta T_{ef}=[\Delta S_0(1-A-\Delta A)-\Delta A S_0]/(16\sigma T_{ef}^3). \quad (9)$$

If the TSI does not change ($\Delta S_0=0$), we obtain from (9) that

$$\Delta T_{ef}=-\Delta A S_0/(16\sigma T_{ef}^3). \quad (10)$$

By assuming the currently known values of the Earth's effective temperature and the TSI to be $T_{ef}=254.8\ K$ and $S_0=1366\ W/m^2$, respectively, we obtain from (10) for $\Delta S_0=0$:

$$\Delta T_{ef}=-91\ \Delta A. \quad (11)$$

With the Bond albedo being constant ($\Delta A=0$), Eq. (9) yields

$$\Delta T_{ef}=\Delta S_0(1-A)/(16\sigma T_{ef}^3). \quad (12)$$

By assuming the known value of the global Earth's albedo, which is equal to $A=0.30$ according to the latest data [28], we obtain from (12) for $\Delta A=0$:

$$\Delta T_{ef}=0.047\ \Delta S_0. \quad (13)$$

Estimation the determination of the ratio of the relative contributions of the increments ΔS_0 and ΔA to the increment ΔT_{ef} can be done by adopting the conditions of their mutual compensation, while maintaining energy balance [29]

$$\Delta S_0(1-A-\Delta A)-\Delta A S_0=0 \quad (14)$$

in formula (9). from (14) one can get the ratio of relative contribution of the increments ΔS_0 and ΔA to the increment ΔT_{ef}

$$\Delta S_0/S_0=\Delta A/(1-A-\Delta A) \quad (15)$$

or

$$\Delta S_0=1366\cdot\Delta A/(0.7-\Delta A). \quad (16)$$

Equation (13) indicates that if the Bond albedo remains unchanged ($\Delta A=0$) and it is only the TSI that decreases by $\Delta S_0=-6.6\ W/m^2$, the global effective temperature of the Earth, including its water and air envelopes, decreases by $\Delta T_{ef}=-0.31\ K$ (for estimates of the difference between the increments of the global surface air (in view of time of its delay) and the effective temperatures is insignificant). It follows from (Eq. (11)) that the decrease in the Earth's effective temperature by $\Delta T_{ef}=-0.31\ K$ causes the increase in the global Earth's albedo by $\Delta A=+0.0034$, or 1.13%. Such increase in the Bond albedo will result in an additional drop in the effective temperature of the Earth as a planet by approximately 0.3 K, which leads to a long succession of these cycles.

However, the effective (radiative) temperature of the Earth-atmosphere system describes the inertia-free process of radiative heat exchange in the equilibrium thermal regime. As consequence, the immediate radiative balance is effectuated with timing advance relative to the total energy (or thermal) balance of the planet (Eq. (3)) allowing for a slow change in the enthalpy of the Earth-atmosphere system. The effective temperature is the radiative temperature of the planet and indicates the trend of the planet's climate changes rather than reflects temporal changes in the planetary temperature. Thus, the change in the Bond albedo affects appreciably the effective (radiative) Earth's temperature and is (along with the TSI) the most important factor specifying the ongoing climate change. The World Ocean is inertial environment with slow changes in the climate system, the atmosphere is more changeable. However, close cooperation of the atmosphere and

the World Ocean leads to a significant delay and atmospheric climate response to external stimuli. Therefore the Earth's thermodynamic temperature does not change immediately due to variations in the TSI and Bond albedo; there is an appreciable lag in time determined using the constant thermal inertia of the planet [30]:

$$t=0.095(1+0.42l) \text{ yr}, \quad (17)$$

where l is the depth of the active layer of the World Ocean. If the depth of the active layer of the World Ocean is 300-700 m, the constant thermal inertia is

$$t=20 \pm 8 \text{ yr}. \quad (18)$$

Because of its large heat capacity, the enthalpy of the World Ocean changes slowly, which is accounted for by a current value of the constant thermal inertia in the total heat balance. Thus, the thermodynamic planetary temperature changes slowly (allowing for the emissive ability, i.e., the degree of blackness). Thus, the debit and credit sides in the annual mean energy budget of the Earth with its air and water envelopes due to the 11-year and quasibicentennial variations in the TSI are always unbalanced ($E \neq 0$) and have either positive or negative balance. Such unbalanced annual mean heat budget is a major state of the Earth-atmosphere climate system. If the TSI decreases over long time scales, the annual mean change in the Earth-atmosphere enthalpy proves to be negative ($E < 0$); if the TSI increases over long time scales, this change is positive ($E > 0$). The variations of the TSI and Bond albedo play the most important role in the change of the Earth-atmosphere energy balance and its thermodynamic temperature. The annual mean balance of the Earth-atmosphere energy budget over a long period of time will reliably define the trend and magnitude of the energy excess accumulated by the Earth or the deficit formed in its heat budget. Thus, the long-term monitoring of the annual mean energy balance of the Earth as a planet with allowance for prognosis of the variation in the TSI can reliably determine and predict in advance (10-20 years beforehand) the trend (warming for $\Delta E > 0$ or cooling for $\Delta E < 0$) and magnitude of the oncoming global climate change with a high degree of validity.

The Decrease of the TSI in the Phase Decline of the Quasibicentennial Cycle Leads to Deficit of the Energy Budget of the Earth and the Little Ice Age

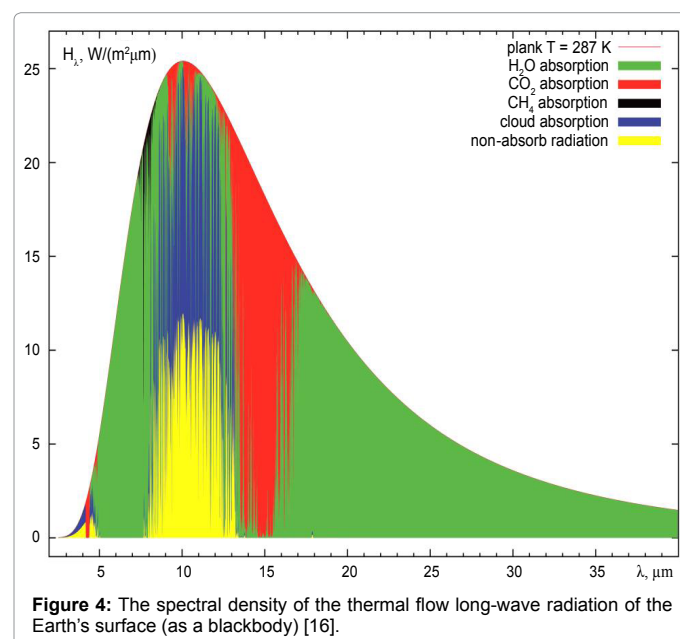
The 11-year and bicentennial components of the TSI have been decreasing since the early 1990s at the presently accelerating rates (Figure 3). Even typical short term variations of 0.1% in incident the total solar irradiance exceed all other energy sources (such as natural radioactivity in Earth's core) combined. Thus, the proportion of energy absorbed by the Earth decreases at the same rates [15,16,18,19,21,29,31]. The lower envelope curve in figure 3 joining together the smoothed minimum values of the TSI level in some successive 11-year cycles (common level relative to which the 11-year cyclic variations of the TSI occur) is a component of quasibicentennial quasiperiodic variation in the TSI [15-19,29].

The mean TSI was lower by 0.15 Wm^{-2} in the 23rd cycle than 22nd cycle. The smoothed value of the TSI at the minimum between cycles 23 and 24 ($1365.27 \pm 0.02 \text{ Wm}^{-2}$) was lower by 0.23 and 0.30 Wm^{-2} than at the minimum between cycles 22 and 23 and between cycles 21 and 22, respectively. However, the deficit of incoming solar energy formed in the early 1990s (see Figure 3) has not been compensated since then by the decrease in the own thermal energy emitted by the Earth into space, which remains almost at the same enhanced level during 20 ± 8 years due to the thermal inertia of the World Ocean. Such energy unbalance of the system ($\Delta E < 0$) will remain for some forthcoming 11

year cycles because the Sun is entering the quasibicentennial stage of low TSI (see [17-19,32-34]). As a result, the Earth as a planet will have a negative balance in the energy budget in future cycles 25-26 too. This recurrent solar cyclic transition indicates that the Earth is on the verge of appreciable long-term climate changes. Such gradual expenditure of the solar energy accumulated by the World Ocean during almost the whole of the 20th century will certainly lead to the drop in the global temperature 20 ± 8 years later, due to the negative balance in the Earth's energy budget. This, in turn, will result in an enhanced albedo of the Earth's surface (due to the increase in snow and ice cover, etc.), reduced concentration of water vapor, which is a dominant factor in the greenhouse effect, as well as carbon dioxide and some other components of the atmosphere [15,16,29,31,35]. Let us note that water vapor absorbs around 68% of the integral power of the intrinsic long-wave emission of the Earth surface, while carbon dioxide – only approximately 12% (Figure 4).

As a result, the proportion of solar radiation energy absorbed by the Earth will further decrease, and so will the impact of the greenhouse effect, due to the secondary feedback effects. The impact of the successive ever-increasing changes feedback effects may lead to a further drop in global temperature, which even may exceeds the direct effect of the decrease of the TSI. Thus, the study of all appreciable variations in the Earth's climate for the past 7,500 years indicates that the bicentennial quasiperiodic variation of the TSI (allowing for its direct impact and secondary one based on the feedback effects) is responsible for the corresponding cyclic mechanism of climate changes, from the periods of warming to Little Ice Ages, and specifies the time scales of almost all physical processes occurring in the Sun–Earth system [2,3,16].

Since the Sun is in the phase of decline of the quasi-bicentennial variation, an average annual decrease rate of the smoothed absolute value of TSI from the 22nd cycle to the 23rd and 24th cycles is increasing: an average annual decrease rate in the 22nd cycle was $0.007 \text{ W/m}^2/\text{yr}$, while in the 23rd cycle it became already $0.02 \text{ Wt/m}^2/\text{yr}$. The mean TSI was lower by 0.15 Wm^{-2} in the 23rd cycle than in the 22nd cycle. The value of TSI at the minimum between 23rd and 24th cycles was lower by 0.23 and 0.30 Wm^{-2} than at the minimum between 22/23 and 21/22 cycles, respectively. The current increasing rate of an average annual



TSI decline (with account for abrupt drop of its 11-year component) is almost $0.1 \text{ W/m}^2/\text{yr}$ (Figure 3) and will continue its increase in the 25th cycle. The observed trend of the increasing rate of an average annual decline in the absolute value of TSI allows to suggest that this decline as a whole will correspond to the analogous TSI decline in the period of Maunder minimum according to its most reliable reconstruction [26] (where authors attribute the brightening specifically to small-scale magnetic fields produced by turbulent cascades in the network and intra-network). Let us note that the level of maximum of the 11-year component of TSI has decreased within four years of the 24th cycle by -0.7 W/m^2 with respect to the maximum level of the 23rd cycle. As a result the most probable onset time of the Solar Grand Minimum of Maunder type is expected around 2043 ± 11 [15-20,29,31-36]. We can predict further decrease in the TSI, based on ever accelerating decrease of its 11-year and quasibicentennial components observed since the early 1990s, similar to the Maunder Minimum; this decrease (with decreasing accuracy) may reach $1363.4 \pm 0.8 \text{ W m}^{-2}$, $1361.0 \pm 1.6 \text{ Wm}^{-2}$, and a deep minimum of $1359.7 \pm 2.4 \text{ Wm}^{-2}$ at the minima between cycles 24/25, 25/26 and 26/27, respectively (Figure 5). The length of the 11-year cycle depends on a phase of the quasibicentennial cycle

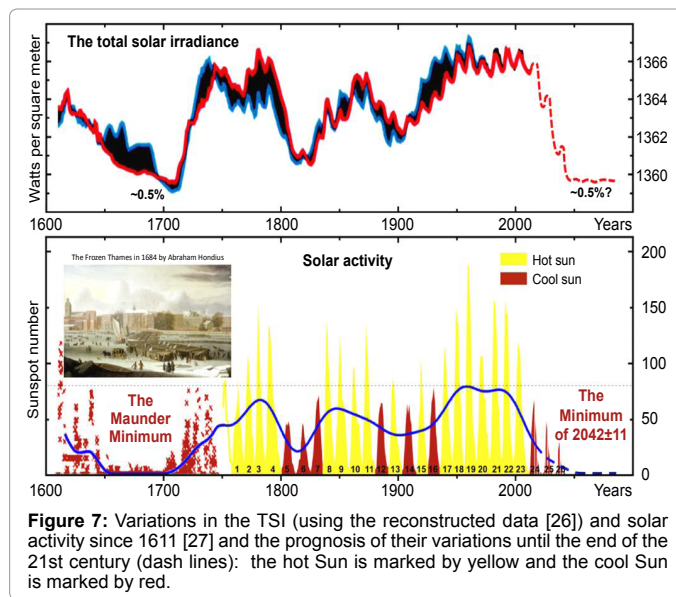


Figure 7: Variations in the TSI (using the reconstructed data [26]) and solar activity since 1611 [27] and the prognosis of their variations until the end of the 21st century (dash lines): the hot Sun is marked by yellow and the cool Sun is marked by red.

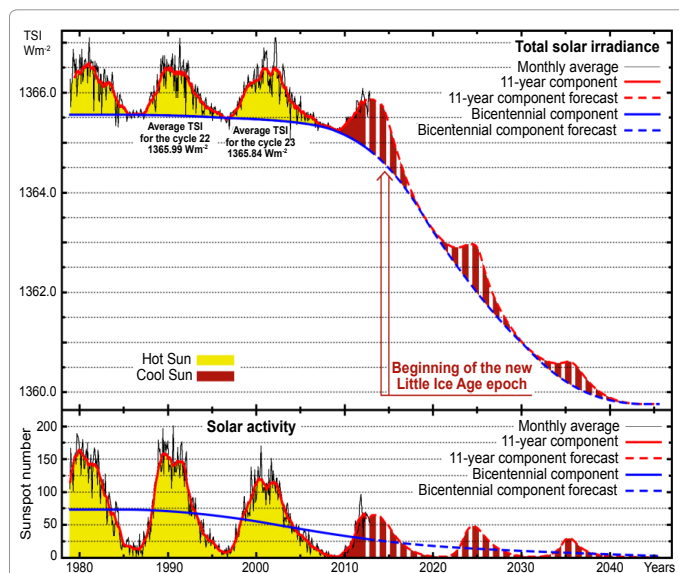


Figure 5: Variations of both the TSI and solar activity in 1978-2012 and prognosis their variations to cycles 24-26 until 2045. The arrow indicates the beginning of the new Little Ice Age epoch.

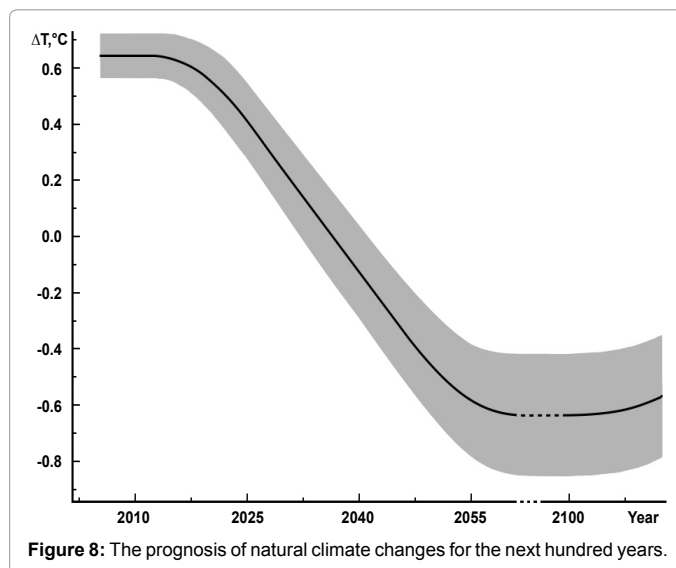


Figure 8: The prognosis of natural climate changes for the next hundred years.

and increases gradually from the growing phase to the maximum and declining phase in the bicentennial cycle (Figure 6) [15,16,37]. Since the lengths of the 11-year cycles are expected to increase in the decline phase of the quasibicentennial cycle, the minima between cycles 24 and 25, 25 and 26, and 26 and 27 are to be expected approximately in 2020.7 ± 0.6 , 2032.2 ± 1.2 , and 2043.7 ± 1.8 , respectively. The maximum level of the sunspots number smoothed over 13 months could reach $65-70$, 45 ± 20 , and 30 ± 20 in cycles 24, 25, and 26, respectively [15,16,19,35].

Thus, we can predict beginning of the Grand Maunder-type minimum of the TSI of the quasibicentennial cycle in the year 2043 ± 11 and the deep 19th Grand Maunder-type minimum of the temperature for the past 7,500 years in the year 2060 ± 11 (Figure 7). Now we witness the transitional period from warming to deep cooling characterized by unstable climate changes when the global temperature will oscillate (approximately until 2014) around the maximum achieved in 1998-2005. The epoch of the new Little Ice Age is expected to begin around the year 2014 after the maximum of solar cycle 24, and begin the phase of deep cooling the Little Ice Age-in around the year 2060 ± 11 (Figure

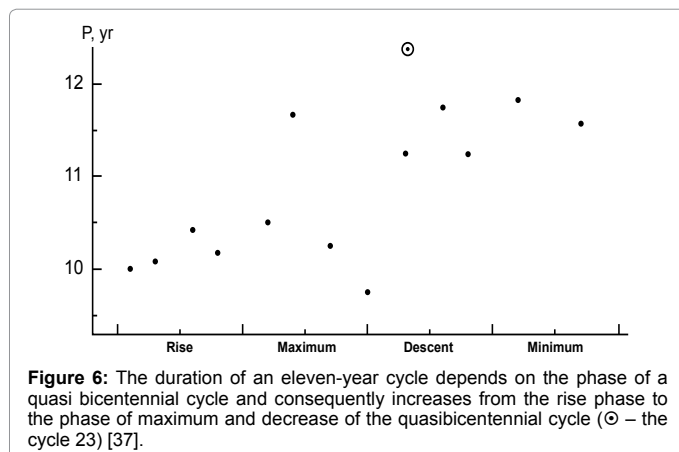


Figure 6: The duration of an eleven-year cycle depends on the phase of a quasi bicentennial cycle and consequently increases from the rise phase to the phase of maximum and decrease of the quasibicentennial cycle (O – the cycle 23) [37].

7). Temperature to the mid-XXI century may be reduced to the level of Maunder minimum, which took place in 1645-1715 years (Figure 8) [35]. Thus, the long-term variations of the TSI (allowing for their direct and secondary impacts, with the latter being due to feedback effects) are the major and essential cause of climate changes because the Earth's climate variation is a function of long-term imbalance between the solar radiation energy incoming into the upper layers of the Earth's atmosphere and Earth's total energy outgoing back to space.

Powerful volcanic eruptions lead to only short-term cooling periods

Relatively powerful eruptions increase the number of solid particles and gases in the lower stratosphere, scattering, screening and partly absorbing the incident solar radiation, thus noticeably decreasing the portion of TSI reaching the Earth surface which can result in short-term climate cooling. Besides, volcanic micro-particles situated in the atmosphere contribute to the clouds formation, which also prevent solar radiation from reaching the surface. They absorb infra-red radiation as well but their anti-greenhouse effect is more pronounced than the green-house effect. However, these changes are not long-term because of the limited life-time of volcanic particles in the atmosphere. The atmosphere is able to self-cleaning and gradual increase of its transparency up to its previous level over a time span from 6 months to a few years, which also help to maintain the temperature at the previous level [16]. That is why the role of volcanic eruptions in climate variations cannot be long-term and defining. It is known that after Pinatubo eruption on the Philippines in 1991, when about 20 million tons of sulfur dioxide entered the atmosphere, global temperature dropped by about 0.5°C from 1991 till 1993. However, later on the atmosphere cleaned itself from these additives and finally reached its initial state.

Sensitivity of climate to carbon dioxide abundance dropped with the increase of water vapour concentration

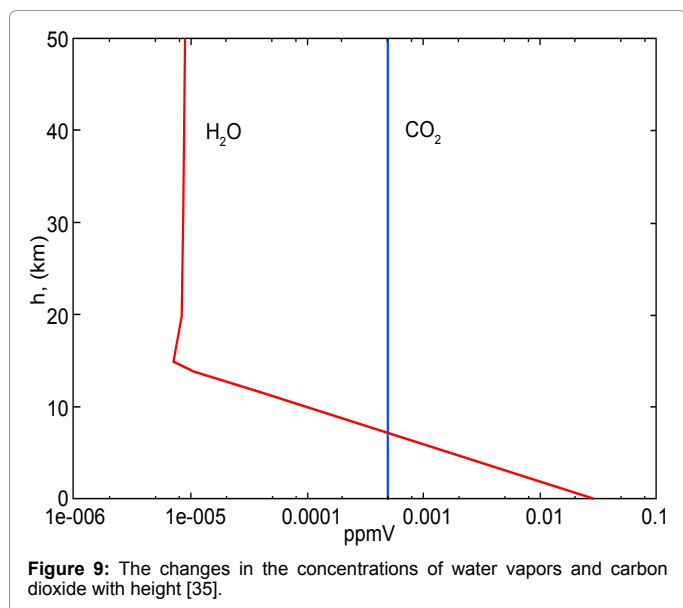
Considering the temperature change caused by green-house gases, it should be mentioned that atmospheric concentration of water vapor rather than that of carbon dioxide is more important. It is water that plays essential role in the green-house effect. The volume concentration of the water vapor in the atmosphere in contrast to that

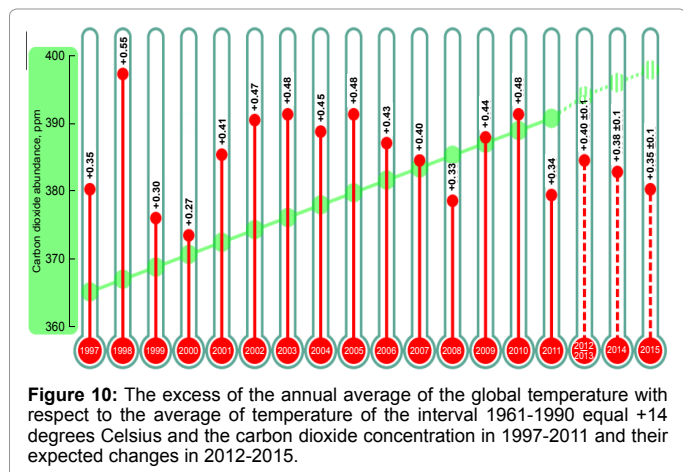
of carbon dioxide strongly depends on the height. Carbon dioxide has a constant mixture proportions until heights of order of 80-100 km (it is homogeneously distributed). The water vapor has its maximum concentration at the surface, abruptly drops with height in the troposphere and remains on some constant level in the stratosphere (Figure 9). Long-term small rise of TSI leads to a lagged temperature increase which according to the Clausius-Clapeyron relation results in increase of water evaporation rate. Even small growth of the water vapor average concentration in the atmosphere together with simultaneous rise in the carbon dioxide concentration can indicate significant increase of water vapor concentration in the surface layers of the air. This leads to substantial changes in the transfer of thermal flow of long-wave radiation of the Earth's surface by the water vapor (in case of high carbon dioxide concentration in the atmosphere: >300 ppmv), due to significant overlapping of the water vapor and carbon dioxide bands predominantly in the three wide regions of the emission spectra (Figure 4) [35]. As a result, the climate sensitivity to increasing concentration of carbon dioxide decreases with significant growth of water vapor concentration in the surface layer [35]. Over the past 40 years concentration of both the water vapor and carbon dioxide has increased due to rise in the temperature of the World Ocean with water vapor tripling effect of the gases. The power of natural cycles and natural flows is tenfold greater than those human-induced [12]. Negligible effect of the human-induced carbon dioxide emission on the atmosphere has insignificant consequences [12].

As early as in 1908 American physicist Robert Wood made two identical boxes (mini-greenhouses) of the black cardboard: one of them was covered with a glass plate, while another-with the plate made of rock salt crystals which are almost transparent in the infrared part of the spectrum. The temperature in both green-houses simultaneously reached 130°F (~54.4°C). However, the plate made of rock salt is transparent at long wavelengths and, according to the commonly adopted theory of the green-house effect; this cover should not produce it at all [38]. Robert Wood has thus established that in the green-house where the heat is blocked from all sides and there is no air exchange with the atmosphere, the radiative component is negligibly small compared to the convective component. Hence, the heat is accumulated in the green-house independent of the transparency of its cover for the infrared radiation, and absorption of infrared radiation by the glass is not the main reason for the heat to be accumulated in the green-house. This contradicts common explanation of the green-house effect. It is necessary to note that the underlying surface of the Earth together with its atmosphere represent the system with an envelope. In the common thermal balance of both the underlying surface and the atmosphere several mechanisms of thermal exchange work together with green-house effect: convection, evaporation and condensation.

Increasing global temperature on the Earth has stopped since 1998

The temperature is known to start decline after it reached its maximum in the glacial/interglacial cycles in spite of the fact that concentration of green-house gases continued rising [6,8,10,39]. Higher or lower levels of carbon dioxide concentration are observed after warming or cooling, respectively. According to Henry law, warm liquid absorbs less gas since the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas above the liquid, and hence more carbon dioxide remains in the atmosphere. A similar picture is observed nowadays. During the past 16 years the carbon dioxide atmospheric concentration has continued to rise at the previous rate, but after 1998 expected influence of its growth on the global





temperature rise is absent (Figure 10). Global warming has stalled and will not raise world temperatures over the next five years, according to a new prediction from the British national weather service [40]. A few years ago the Met Office said that most of the following five years would be record breakers. UK Weather office cuts temperature predictions by 20% in “return to humility”. The fact that UK Met Office had changed its near-term global warming forecast quietly on Christmas Eve 2013 means global warming slowly fading away. It has finally conceded what there is no evidence that “global warming” happening. A study snow variability in the Swiss Alps 1864-2009 also shows a temperature trend reversal has been taking place in the Swiss Alps since 2000 [41]. All of the climate models produced by the global-warming-is-coming have failed in their predictions. An absence of any warming during the past 16 years is a precursor of forthcoming onset of the Little Ice Age. Natural causes play the most important role in climate variations rather than human activity since natural factors are substantially more powerful [12]. As a result, increasing global temperature on the Earth has stopped since 1998, and the concentration of carbon dioxide in the atmosphere reached record highs now (Figure 10). The global temperature standstill seen for the past 16 years will continue in 2013. The directions of their development since 1998 do not comply with each other. In 1998 - 2005 the Earth reached the maximum of the warming [16,29,31,35].

The content of greenhouse gases in the atmosphere largely depends on the World Ocean, and that of dust, on volcanic activity and the rise of aerosols from land. The amounts of natural flows (carbon dioxide, water vapour, and dust) from the ocean and land to the atmosphere (M_{in}) and from the atmosphere (M_{out}) to the ocean and land are exceed many times the anthropogenic discharges of these substances into the atmosphere (M_{ant}) [12]. Average growth in atmospheric carbon dioxide has slowed since early last decade, at a time when reported emissions increased at an unprecedented rate [42]. The overall content of carbon dioxide in the ocean is 50 times higher than in the atmosphere, and even a weak breath of the ocean can change dramatically the carbon dioxide level in the atmosphere [12]. At the same time carbon dioxide is a key component of the life cycle of the biosphere, and the increase of its concentration—a major factor in plant growth and development, increasing agricultural productivity:-

The rise of the World Ocean level due to global warming is the most reliable indicator of the rate of temperature growth (60% of the sea level rise results from increase of the water mass in the Ocean, while 40% are due to thermal expansion of the ocean water as it warms) and one of the most actual problems of our time. More than 40 scientists in 20 groups participating in arctic research combined their efforts in

order to estimate the contribution of ice melting in the Greenland and Antarctica to the global sea level. Since 1992 the polar ice melting has led to global rise in the sea level of the World Ocean by 0.59 ± 0.2 mm/yr on the average [43]. According to this most accurate estimate, polar ice melting has resulted in the growth of the water level in the World Ocean by 11 mm over the past two decades. This means that the current Ocean level does not rise at all which reflects the current state of global warming – it has stopped and the global temperature has not grown during this entire period. Additionally the rate of rise and changes in sea level is also under the direct control of long-term variations in the TSI. Decline in TSI from the early 90s and, correspondingly, less amount of solar energy incoming to the tropical part of the World Ocean can gradually cause a weakening of the atmospheric and oceanic circulation and, first of all, to some decrease of power and velocity of the warm current of Gulfstream since the amount of heat provided by ocean currents from the tropical areas to the Gulf of Mexico will decrease. This will result in gradual climate cooling in the West Europe.

At the same time warming occurring on other planets and satellites in the Solar system: on Mars, Jupiter, Triton (Neptune’s satellite), Pluto. In 2005 data from NASA’s Mars Global Surveyor and Odyssey missions revealed that the carbon dioxide “ice caps” near Mars’s south pole had been diminishing for three summers in a row [44]. Is there anything common for all the planets of the Solar system whose action could result in their simultaneous warming during the same time period? This common factor affecting simultaneously all the bodies of the Solar system is a long-term high TSI level during the whole XX century. That is why simultaneous warming on the Earth, Mars and the whole Solar System has a natural solar origin and confirms the action of “solar summer” throughout the Solar system and alternation of climate conditions in it [45]. Since there are no manmade emissions on Mars, this warming must be due to other things, such as a warming Sun, and these same causes are responsible for warming observed on the Earth throughout the 20th century [15,16,45]. That is evidence that the warming in the end of the twentieth century on Earth is being caused by changes in the Sun. Long – term increase in the solar irradiance is heating both Earth and Mars. At the same time manmade greenhouse warming has made a small contribution to the warming seen on Earth in recent years, but it cannot compete with the increase in solar irradiance [15,16,29,31,35]. Long – term changes in the Sun’s heat output can account for almost all the climate changes we see on planets. In general, by analogy with the seasons on Earth in the Solar System there is also a similar alternation of climatic conditions, dictated by the quasibicentennial cycle variation of the TSI. From this point of view, now all of our Solar System after season of the “solar summer” is moving to the direction season of the “solar autumn” and then will move to the direction season of the “solar winter” of the quasibicentennial solar cycle.

Man-made global warming: even the IPCC admits the jig is up [46]. A leaked draft of the IPCC’s latest report AR5 where admits what: the case for man-made global warming is looking weaker by the day and that the Sun plays a much more significant role in “climate change” than the scientific “consensus” has previously been prepared to concede. The strong evidence the existence of an amplifying mechanism of influence of the Sun forcing changes everything. Now the climate alarmists can’t continue to claim that warming was almost entirely due to human activity over a period when solar warming effects, now acknowledged to be important, were at a maximum.

Conclusion

Thus long-term cyclic variations of the total energy of solar radiation entering the upper layers of the Earth’s atmosphere are the

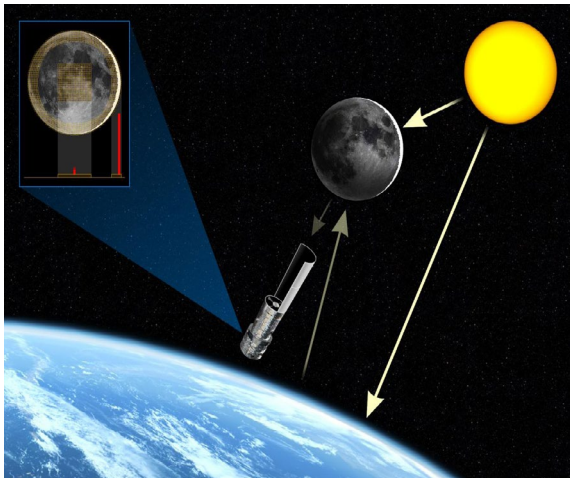


Figure 11: The Selenometria uses the Moon as a mirror to study of the variations in the total solar irradiance reflected and absorbed by the Earth.

main fundamental cause of corresponding climate variations. They also control and totally determine the mechanism of cyclic alternations of climate changes from warming to short - term Little Ice Ages and long - term Big Glacial Periods and set corresponding time - scales for practically all physical processes taking place in the system Sun - Earth. All observed changes in climate on the Earth and the Solar system are common cosmic events. The Sun is the main factor controlling the climatic system and even non-significant long-term TSI variations may have serious consequences for the climate of the Earth and other planets of the Solar system. Quasi-bicentennial solar cycles are a key to understanding cyclic changes in both the nature and the society.

The sign and value of the energy disbalance in the system Earth-atmosphere over a long time span (excess of incoming TSI accumulated by the Ocean or its deficiency) determines a corresponding change of the energy state of the system and, hence, a forthcoming climate variation and its amplitude. That is why the Earth climate will change every 200 ± 70 years and it is the results bicentennial cyclic TSI variation. All observed cyclic variations of climate on the Earth and in the Solar system are ordinary solar events. Long before the beginning of the 24th solar cycle, in 2003-2007 [17-20,36], when the anthropogenic nature of global warming was the most commonly adopted, I predicted onset of the Grand Minimum of both TSI and solar activity in approximately 2040 ± 11 , and of the corresponding decrease of global temperature - the epoch of the 19th (over the past 7500 years) Little Ice Age - around 2012-2015 (after the maximum of the 24th solar cycle). The phase of its deep minimum will begin in 2055-2060 (± 11). These predictions, in the situation of commonly believed anthropogenic nature of global warming raised huge discussions in scientific and other circles, but in the course of years they find more scientific confirmations and supporters, and the main point is that they are confirmed by the Sun itself and course changes of global temperature and the level of the Ocean in the past 16 years. In 2014 - next year - we will begin a about 45-year-long descent into what will be Earth's 19th Little Ice Age. The use of practically full identification of the climate changes with the long-term variations in the incoming solar energy (taking into account their direct and subsequent secondary feedback influences) within a climate model gives a sufficiently precise reconstruction of climatic processes taking place in the past and nearest future. All of the climate models produced by the global-warming-is-coming have failed in their predictions. The mathematical modeling of climate processes on without a fundamental

modernization of the mathematical model and the use more powerful supercomputers and also without the use of the quasibicentennial variations of the TSI will not allow us to obtain significantly more reliable results [46,40]. The most reasonable way to fight against the coming Little Ice Age is to work out a complex of special steps aimed at support of economic growth and energy-saving production in order to adapt mankind to forthcoming period of deep cooling which will last approximately until the beginning of the XXII century.

The most reliable method for accurately predicting the depth and time of the coming Little Ice Age is to study the long-term variations of the effective global parameter: average annual energy balance in the budget of the system Earth - atmosphere in the income and expenditure of thermal power. Therefore, now we are working out a new the space project Selenometria on the Russian segment of the International Space Station to the investigation of long-term variations in the total solar irradiance reflected and absorbed by the Earth and of those in the energy state of the Earth, and of their impact on the Earth's climate (Figure 11). For this the Selenometria uses the Moon as a mirror to study of the variations in the total solar irradiance reflected and absorbed by the Earth.

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