CHAPTER

17

The New Little Ice Age Has Started

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OUTLINE

1. INTRODUCTION

The long-term equilibrium state of the average annual energy balance of the Earth between the total solar irradiance (TSI) coming into outer layers of the atmosphere of the Earth and going out from the Earth into space of the total energy radiation from the top of the atmosphere to the surface determines the stability of the climate so that the Earth's temperature does not change. If in the long term the Earth keeps in more solar energy than it expels, then our planet will warm, and in contrast, if the Earth radiates more energy to space than it receives from the Sun, the Earth will cool. The main reasons for long-term deviations in the average

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annual energy balance of the Earth from the equilibrium state are a quasi-bicentennial cyclical variation in incoming TSI [equal to up to ∼0.5% (Shapiro et al., 2011)] and the portion absorbed by the Earth, and the solar energy absorbed by the Earth remaining uncompensated by the energy of the long-wave radiation emitted by the planet into space over a time interval of 20 ± 8 years, which is controlled by the thermal inertia of the world oceans (Abdussamatov, 2009b, 2012a, 2013a,b, 2015a). As a result, the average annual energy balance of the Earth due to the quasi-bicentennial variations in TSI long term deviates from the equilibrium, which is the basic state of the surface−atmosphere climate system. Long-term deviation in the average annual energy balance of the Earth from the equilibrium state (excess of incoming TSI accumulated by the ocean or its deficiency) dictates a corresponding change in the Earth's energy state and climate (Abdussamatov, 2009b, 2012a, 2013a,b, 2015a). The variations in the TSI quasi-bicentennial cycle, together with important successive influences of a chain of subsequent causal feedback effects can explain all climate changes. Long-term positive (negative) deviation in the average annual energy balance of the Earth from the equilibrium state [excess (deficiency) of incoming TSI accumulated by the ocean] first will gradually warm (cool) the upper layers of water of the oceans in the tropics. The basic features of the Earth's climate variations are connected, in particular, with fluctuations in the power of both the atmospheric circulation and the ocean currents, including the thermal current of the Gulf Stream, which is driven by the heat accumulated by ocean water in the tropics. They are determined by the direct action of the quasi-bicentennial cyclic variation of the TSI and important successive influences of a chain of subsequent causal feedback effects caused by climate changes. Secondary mechanisms have additional influences in the form of subsequent climatic causal feedback effects in the process of cooling, and cause additional significant (depending on the duration of the cooling) temperature decline (with some time lag) due to the gradual, nonlinear rise in the Earth's Bond albedo and the natural decrease in atmospheric concentration primarily of water vapor (according to the Clausius−Clapeyron relation) and other greenhouse gases (according to Henry's law), and the opposite effect in the process of warming. Significant climate variations during the past 7.5 millennia indicate that bicentennial quasi-periodic TSI variations define the corresponding cyclic mechanism of climatic change from warming to a Little Ice Age and set the timescales of practically all physical processes that occur in the Sun−Earth system (Herschel, 1801; Eddy, 1976; Climate Oscillations, 1988; Abdussamatov, 2009b, 2012a, 2013a,b, 2015a; Section 6). The global nature of climate change during the past thousand years confirms an ikaite record: a medieval climatic optimum and a Little Ice Age Maunder minimum also spread to the Antarctic Peninsula (Lu et al., 2012). My definition of the Little Ice Age differs from that in the literature in that a long period of global cooling during the 14th− 19th centuries has been interrupted by several warming periods (Abdussamatov, 2013a, 2014, 2015a). Deep cooling was associated with Wolf (approximately from 1280 to 1340), Spörer (approximately from 1450 to 1550), Maunder (approximately from 1645 to 1715), and Dalton (approximately from 1790 to 1830) grand minima and should not be seen as single little ice ages (Abdussamatov, 2013a, 2014, 2015a). Quasi-bicentennial cyclic climate changes are always the response of the climate system to corresponding cyclic external influences of the Sun.

The observed decline in TSI since 1990 and the upcoming grand minimum in 2043 ± 11 and expected beginning of the deep cooling phase of the Earth in 2060 ± 11 will certainly have a significant impact on the global economy, society, and national security of countries. The upcoming deep global cooling will dictate the direction of variations in different natural processes on the Earth's surface and in the atmosphere as well as the change for worse conditions for creating material and financial resources in society. For practical purposes, the most important task is to determine the tendencies of expected climate change for the next 50−100 years. Nowadays, the problem of future deep global cooling is not only a major and important scientific problem of planetary scale facing humankind, but also a serious economic, social, demographic, and political problem whose solution determines further prospects of human civilization development. A deep cooling will directly influence the development of scientific, technical, and economic potentials of modern civilization. The effects of the recent deep cooling in the period of the Maunder minimum are a warning of the serious threat to the future of energy security for all humanity. Early understanding of the reality of the forthcoming deep global cooling and the physical mechanisms responsible for it will directly determine the choice of adequate and reliable measures that will allow humankind, in particular, the populations of countries situated far from the equator, to adapt to the future conditions, which will be especially strong in the zone of influence of a weakened Gulf Stream on western Europe and the eastern parts of the United States and Canada. After the middle of the current century humankind will meet with the same very difficult conditions of the period of the Maunder minimum.

2. MILANKOVITCH CYCLES AND INTERRELATED VARIATIONS IN CLIMATE AND ABUNDANCE OF CARBON DIOXIDE IN THE ATMOSPHERE

Within the past million years, global cyclical glaciation has occurred with temperature drops of ~10°C, during which the ice cover spread to much lower latitudes than now. What causes these deep changes in the Earth's climate? Any profound climate change is a response to long-term external effects on the Earth's climate system, the world's oceans and land, the cryosphere (snow and ice), and the biosphere. The main factor in profound change of climate has always been a long-term fluctuation of the TSI, taking into account its direct and important subsequent secondary feedback influences. The relative positions of the planets and the Sun influence the distribution and strength of gravitational fields. Indeed, the position and shape of the Earth's orbit and the axis orientation of its rotation in space have experienced over the centuries slow changes that influence the irradiance of the Earth by the Sun. A detailed theoretical description of the mechanisms of the astronomical cycles and their influence on the Earth's climate was proposed by the Serbian astrophysicist Milutin Milankovitch, who developed the astronomical theory of deep climate change with duration of tens of thousands of years. Insignificant, more long-term (more than 10,000 years) variations in the annual average TSI entering the Earth's upper atmosphere because of cyclical changes in the shape of the Earth's orbit, inclination of the Earth's axis relative to its orbital plane, and its precession, known as the astronomical Milankovitch cycles (Fig. 17.1), together with very important (due to long-term variations in TSI and temperature) subsequent nonlinear feedback effects, lead to the big glacial periods (with a period of about 100,000 years) with glacial/interglacial cycles (Fig. 17.2) (Milankovitch, 1941; Astronomical theory). The astronomical Milankovitch cycles lead to long-term changes in the average annual

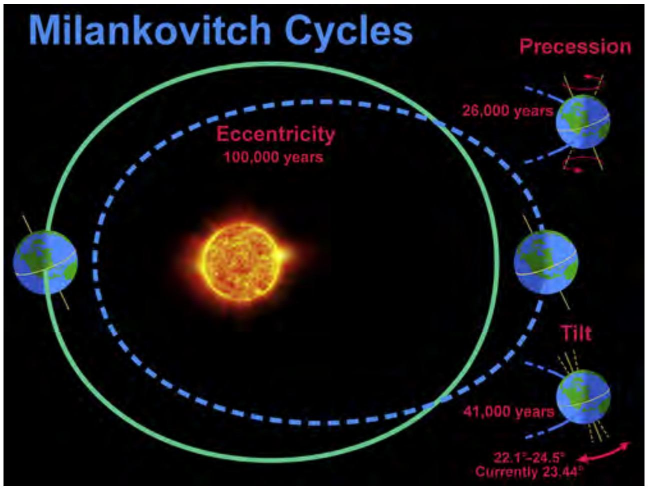

FIGURE 17.1 Astronomical Milankovitch cycles (Milankovitch, 1941; Astronomical theory).

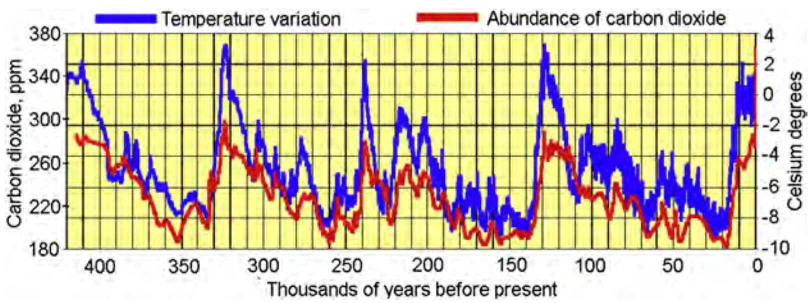

FIGURE 17.2 Variations in the Earth's climate and volumetric concentrations of carbon dioxide for a period of 420,000 years (according to the ice core data near Vostok, Antarctica) (Petit et al., 1999; Climate change, 2000).

energy radiated by the Sun that is absorbed by the whole planet and by different regions of the Earth [taking into account the uneven distribution of land vs ocean in the Northern (approximately 39%) and Southern (approximately 19%) Hemispheres] due to variations in orbital forcing. As a result, considerable changes mostly in the average annual distance between the Sun and the Earth with the period of about 100,000 years lead to more long-term variations in the annual average TSI entering the Earth's upper atmosphere. These variations in the TSI together with many chains of subsequent secondary feedback effects cause significant temperature fluctuations from warming to the Big Glacial Period, as well as in the atmospheric concentrations of water vapor, carbon dioxide, and other greenhouse gases (Fig. 17.2). Significant achievements of modern methods of measurement are determining the climatic characteristics (not only the temperature but also the composition of the atmosphere) in the periods of the last glacial/interglacial cycles. It turns out that the Antarctic ice cores provide clear evidence of a close coupling between variations in temperature and the atmospheric concentration of carbon dioxide during the glacial/interglacial cycles of at least the past 800,000 years.

Precise information on relative temporal changes in the temperature and the atmospheric concentration of carbon dioxide can assist in refining our understanding of the physical processes involved in this coupling. According to the ice core data drilled from a depth of over 3600 m near the Vostok site, Antarctica, during the glacial/interglacial cycles a rise in concentrations of greenhouse gases has begun every time after warming begins and ended after the warming was replaced by cooling (Fig. 17.2). It is worth emphasizing that the temperature starts to decrease, after reaching its highest values in the glacial/interglacial cycles, despite the fact that the concentration of greenhouse gases continues to grow (Petit et al., 1999; Climate change, 2000; Fischer et al., 1999; Pedro et al., 2012). The peaks of the carbon dioxide concentration have never preceded the warming, but on the contrary always took place 800 ± 400 years after it, being its consequence, ie, they have always been a natural consequence of the temperature increase caused by long-term growth of the incoming average annual solar energy (Fig. 17.2) (Petit et al., 1999; Climate change, 2000; Fischer et al., 1999; Pedro et al., 2012). According to Henry's law, warm water absorbs less gas because 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. So, the analysis of ice cores shows that higher or lower levels of carbon dioxide concentration are observed after warming or cooling, respectively, ie, considerable changes in the atmospheric concentration of carbon dioxide are always determined by the corresponding temperature fluctuations of the world oceans.

Thus, long-term cyclic variations in the annual average total energy of the solar radiation entering the upper layers of the Earth's atmosphere caused by the astronomical Milankovitch cycles, taking into account their direct and long-term important subsequent secondary feedback influences, are the main fundamental cause of corresponding significant (glacial) climate variations on the Earth. Long-term Milankovitch cycles cause changes in TSI, which are the causal factor in climate change (Milankovitch, 1941; Astronomical theory). Long-term changes in TSI cause changes in the temperature, which cause long-term subsequent secondary feedback influences and together they are enough to cause climate change in glacial/interglacial cycles. It should be emphasized that the amount of natural flows of carbon dioxide, water vapor, and dust from the world ocean and land to the atmosphere (M_{in}) and from the atmosphere (M_{out}) to the world's oceans and land exceed many times the anthropogenic discharges of these substances into the atmosphere (M_{ant}) (Nigmatulin, 2010). The overall content of carbon dioxide in the world ocean is $\sim$50 times higher than in the atmosphere and as it warms or cools according to the Sun's intensity, it releases or absorbs these gases, respectively. Even a weak "breath" of the ocean can change dramatically the carbon dioxide level in the atmosphere. Changes in atmospheric carbon dioxide are not tracking changes in human emissions (Nigmatulin, 2010). The impact of these gases in driving climate change is secondary and minor compared to the power of the Sun. Natural causes play the most important role in climate variations and in the level of carbon dioxide in the atmosphere rather than human activity because natural factors are substantially more powerful. Therefore, there is no evidence that carbon dioxide is a major factor in the warming of the Earth. Although carbon dioxide has some warming influence, but the Sun plays a far greater role in the whole scheme of things. In the modern era, using data series on the concentrations of atmospheric carbon dioxide and global temperatures, these were also investigated as to the phase relation (leads/lags) between them for the period January 1980 to December 2011 (Humlum et al., 2013). Humlum et al. concluded that the change in atmospheric carbon dioxide from January 1980 is natural, rather than human induced, ie, changes in the amount of atmospheric carbon dioxide in the modern era also are always lagging behind the corresponding changes in temperature. At the same time carbon dioxide is a key component of the life cycle of the biosphere, and the increase in its concentration—a major factor in plant growth and development, increases agricultural productivity.

3. INTERRELATED VARIATIONS IN THE CLIMATE, TOTAL SOLAR IRRADIANCE, AND SOLAR ACTIVITY

The correlation between variations in sunspot activity and climate was first announced by English astronomer William Herschel in 1801 after he had discovered the inverse interrelation between wheat prices and cyclic variations in the solar activity before and during a cool period known as the Dalton minimum (Herschel, 1801). During high levels of the solar activity, wheat production increased, resulting in a drop in prices. When the number of sunspots significantly dropped, the wheat production decreased—and the prices went up. Herschel 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 American astronomer John Eddy discovered the interconnection between periods of significant variations in solar activity during the past millennium and corresponding deep climatic changes of both phase and amplitude (Eddy, 1976). Russian geophysicist Evgeniy Borisenkov discovered that each of the 18, Maunder-type minima of solar activity over the past 7500 years was associated with deep cooling, whereas periods of high solar activity (maxima) corresponded to warming (Climate Oscillations, 1988).

The lower envelope curve in Fig. 17.3, connecting the values of TSI at three successive minima levels between 11-year cycles 21 and 22, 22 and 23, and 23 and 24, is the total level of its quasi-bicentennial variation (Abdussamatov, 2003, 2004, 2005, 2007a,b, 2009a,b, 2012a, 2013a) relative to which its 11-year cyclic variations occur. We used PMOD composite data (Fröhlich, 2013) because ACRIM composite data show an incorrect increase in the TSI from 1986 to 1996 (Krivova et al., 2009). The quasi-bicentennial cycle of the Sun is one of the most intense solar cycles. The 11-year

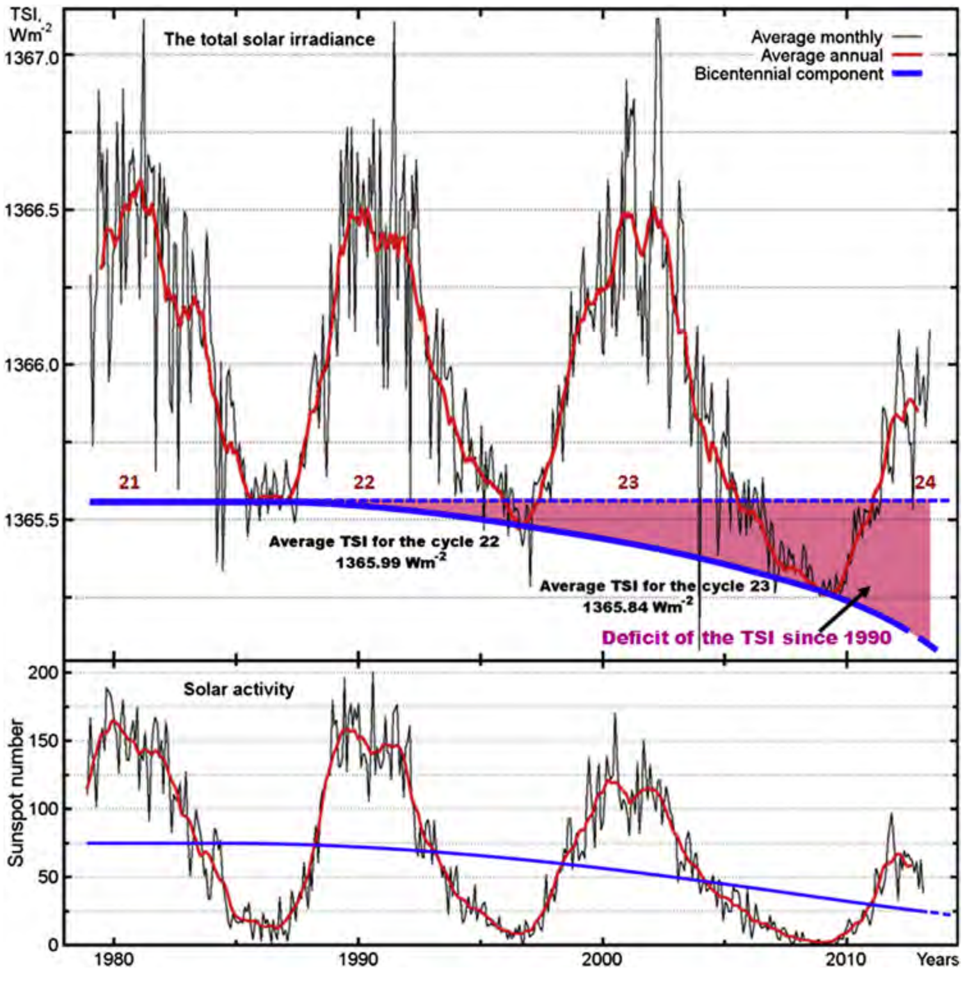

FIGURE 17.3 Variations in the solar activity based on monthly data (SunSpot Data, 2014) and the total solar irradiance (*TSI*) based on daily data (Fröhlich, 2013) between 1978 and 2013 and the deficit in TSI since 1990.

and quasi-bicentennial cyclic variations in solar activity and TSI, being a manifestation of the same processes in the solar interior, are interconnected and synchronized in both phase and amplitude (Fig. 17.3) (Abdussamatov, 2003, 2004, 2005, 2007a,b, 2009a,b, 2012a, 2013a). This allows extrapolating a relatively short series (since 1978) of highly accurate extra-atmospheric measurements of the TSI onto long periods of past time using a long series of solar activity (Avdyushin and Danilov, 2000; Lean, 2000; Solanki and Krivova, 2004; Shapiro et al., 2011; SunSpot Data, 2014). 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 future variations, taking into account their direct and important subsequent secondary feedback influences.

The studies (Bal et al., 2011; McPhaden et al., 2011) confirm our earlier results (Abdussamatov, 2009a,b) indicating the direct joint effect (with some lag) of the 11-year (11 $\pm$ 3 years) and quasi-bicentennial (200 $\pm$ 70 years) cyclic variations in TSI on the changes in the state of the tropical Pacific Ocean surface layer (tens to hundreds of meters deep), resulting in El Niño and La Niña events associated with the appearance respectively of warm or cool water. The changes in the observed parameters of El Niño over the past 31 years did not correspond to the changes predicted by the climate models that are suggesting the dominant role of greenhouse gases (Bal et al., 2011; McPhaden et al., 2011). Thus, the oscillations in El Niño parameters were mostly due to natural causes, namely, cyclical variations in the TSI, taking into account their direct and important subsequent secondary feedback influences. It should be emphasized that cyclical variations in solar activity are the accompanying phenomena of physical processes occurring in the interior of the Sun and do not substantially affect either the TSI and the Earth's climate (Abdussamatov, 2005, 2007a, 2009b, 2013a).

4. QUASI-BICENTENNIAL VARIATIONS IN TOTAL SOLAR IRRADIANCE AND MECHANISMS OF ITS SECONDARY ADDITIONAL INFLUENCES

Quasi-bicentennial variations in TSI are about 0.5% from the latest reconstructed data (Shapiro et al., 2011) and their direct impact alone is insufficient to account for all corresponding quasi-bicentennial cyclic changes in the Earth's temperature, from the periods of warming to the Little Ice Age. An additional "amplifier" is needed to enhance the direct impact of the variations in TSI on the observed global climate changes (Abdussamatov, 2009b, 2012a, 2013a,b). Such amplifiers of the direct impact of variations in TSI on climate variation are the indirect subsequent additional secondary influences of TSI in the form of a successive chain of causal feedback effects: natural changes in the global albedo of the Earth as a planet, the albedo (additional changes in the absorbed part of TSI), and changes in the concentrations of greenhouse gases in the atmosphere (water vapor, carbon dioxide, methane, etc.), additional variations in the influence of the greenhouse effect. The albedo of the Earth is defined as the ratio of the flux of a portion of the solar radiation reflected and scattered by the spherical surface–atmosphere system back into space in all directions to the flow of the total solar radiation coming into the upper atmosphere. The 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 up through the atmosphere. The albedo of the Earth is increased to its maximum level during deep cooling (in particular, because of increasing coverage by snow and ice) and reduced to its minimum level during warming, whereas the concentrations of greenhouse gases in the atmosphere (mostly water vapor at the surface layers of the atmosphere, as well as carbon dioxide and other gases) vary inversely because their variations are mostly defined by the temperature of the ocean and land. The albedo is a particularly important physical parameter of the energy budget of the Earth as a planet. Successive variations in the parameters of the Earth's surface and atmosphere due to variations in the TSI quasi-bicentennial cycle will lead to the generation of numerous nonlinear changes in temperature due to multiple repetitions of such causal cycles of the subsequent secondary feedback effects. The impact of the causal feedback effects in the period of cooling, caused by changes in the parameters of the Earth's surface and atmosphere due to decreasing of the TSI quasi-bicentennial cycle, leads to a gradual nonlinear increase in the value of the albedo and a decrease in the content of greenhouse gases in the atmosphere. It will lead to an additional reduction in the absorbed portion of solar energy and reduce the influence of the greenhouse effect. The multiple repetitions of these changes will lead to a chain of successive drops in the Earth's temperature, which can surpass the influence of the direct effect of the TSI decrease in the bicentennial cycle, even if the TSI will subsequently remain unchanged over a certain period of time. A similar pattern was observed in the late 20th century. Unfortunately, the dynamics describing the rate of increase in the total area 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 difficult to predict. The natural concentration of carbon dioxide in the atmosphere is known to have been, during the glacial periods in the Earth's history, more than two times lower than today (Fig. 17.2) (Petit et al., 1999; Climate change, 2000).

5. THE QUASI-BICENTENNIAL SOLAR CYCLE DETERMINES VARIATIONS IN BOTH THE DURATION AND THE POWER OF THE 11-YEAR SOLAR CYCLE

Long-term successive changes from the impacts of 11-year solar cycles are accompanied by significant changes in climate. The duration and power of the 11-year cycles of TSI and solar activity are the most important characteristics of variations in the physical processes occurring in the deep interior of the Sun (Fig. 17.4). Quasi-bicentennial solar cycles are the primary cycles that govern variations in the 11-year subsidiary cycles in TSI and solar activity (Abdussamatov, 2006, 2009a,b, 2013a). Identification of some common features among the last 14 11-year solar activity cycles is very important. Fig. 17.5 demonstrates variations in the duration of the 11-year solar cycles of activity, *P*, as a function of phases of the quasi-bicentennial cycle. The length of the 11-year cycle depends on the phase of the quasi-bicentennial cycle and increases gradually from the growing phase to the maximum and descending phase of the quasi-bicentennial solar cycle (Fig. 17.5) (Abdussamatov, 2006, 2009b, 2013a). It is obvious that such relationship exists also for the 11-year cyclic variations in the TSI because the cyclic variations in solar activity and the TSI are interconnected and synchronized (Abdussamatov, 2003, 2004, 2005, 2007a,b, 2009a,b, 2012a, 2013a). Eleven-year

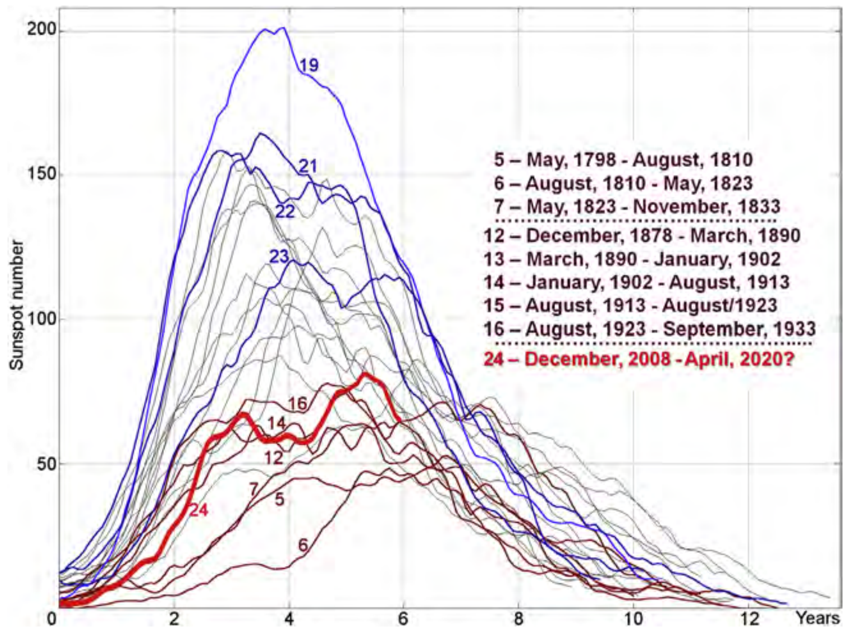

FIGURE 17.4 Variations in the relative sunspot number in solar cycles 1–24. *Data from http://sidc.oma.be/sunspot_data/.*

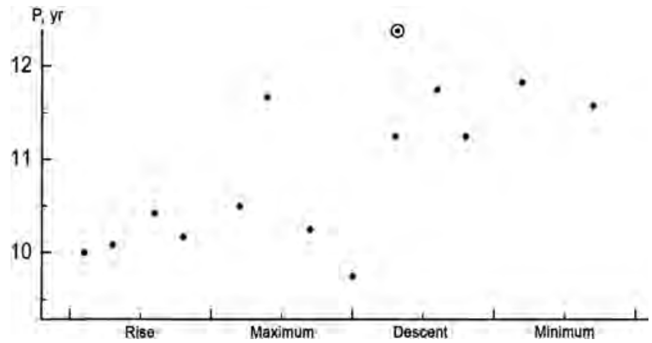

FIGURE 17.5 The duration of an 11-year cycle depends on the phase of the quasi-bicentennial cycle and consequently increases from the rising phase to the maximum and descending phase of the quasi-bicentennial cycle (⊙, cycle 23) (Abdussamatov, 2006, 2009b, 2013a).

cycles of solar activity developing in the descending phase of the quasi-bicentennial cycle have a duration of about $P = 11.7 \pm 0.8$ years, and they are ordinarily longer than in the cycle developing during the rising phase and maximum of the quasi-bicentennial cycle.

These data can be explained by a decrease in the average duration of the last eight cycles of solar activity, from 15 to 22, which developed during the rising phase and maximum of the quasi-bicentennial cycle, down to $P = 10.4$ years, compared to the average duration of $P = 10.9$ years for the last 14 cycles of solar activity. This relationship allows us to predict not only the duration of the current 11-year cycle, but also the durations of the subsequent cycles 25 and 26, which will be formed during the descent of the current quasi-bicentennial cycle. The succeeding cycles 25, 26, and 27 in the phase of the decline of the quasi-bicentennial cycle are expected to begin in approximately 2020.7 ± 0.6, 2032.2 ± 1.2, and 2043.7 ± 1.8, respectively.

It is very important to establish the extent to which such changes in the laws of 11-year cycle duration lead to changes in the power of their average cyclic energy. Only the average weighted level of the TSI and solar activity during the cycle may allow objective and quantitative determination of the average level of the power of the 11-year cycle, as well as prediction of its impact on processes occurring in the Sun−Earth system. The relative power of the 11-year cycle of solar activity is the average weighted level of the index of solar activity throughout the cycle:

$$\overline{W}(\text{cycle}) = \frac{\sum W\Delta t}{\sum \Delta t}$$

Here W is the sunspot number and Δt is the time interval between successive observations throughout the cycle. The absolute average weighted power of the energy of an 11-year cycle is defined as

$$\overline{S}_{\odot}(\text{cycle}) = \frac{\sum S_{\odot}\Delta t}{\sum \Delta t}$$

where $S_{\odot}$ is the TSI (Abdussamatov, 2015a,b).

To establish the relationship between the length of 11-year solar cycles and their relative average cyclical radiative forcing a graph was plotted for all of the 24 cycles of solar activity (Fig. 17.6). The results show the presence of a generally inverse relationship between the length of 11-year cycles and their relative radiative forcing, ie, the lower the relative radiative forcing of a solar cycle, the greater the cycle length, and vice versa. It is obvious that such an interconnection exists also between the absolute average cyclic radiative forcing, the average weighted absolute value of the TSI 11-year cycle, and the solar cycle length. High absolute radiative forcing of 11-year cycles and of their

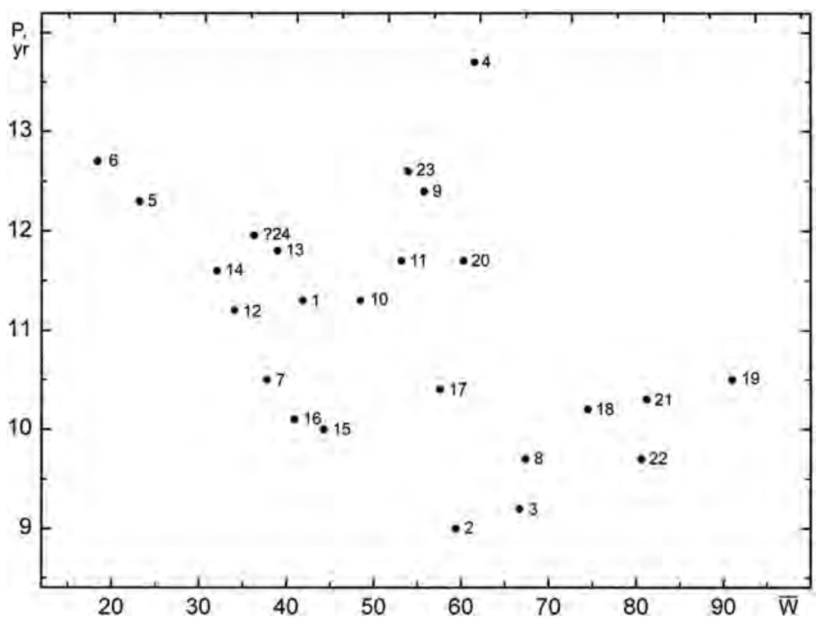

FIGURE 17.6 Dependence of the relative solar activity cycle forcing of all 11-year solar cycles on their length, P. Numerals indicate the cycle numbers (Abdussamatov, 2015a,b).

small length (below average with respect to all 24 cycles) during the growth phase of the quasi-bicentennial cycle and the opposite pattern during its phase decline might serve as an indicator of climate change only during these phases of the bicentennial solar cycle (Abdussamatov, 2015a,b). The inverse relationship between the length of 11-year solar cycles and their radiative forcing is attributed to the influence of the quasi-bicentennial solar cycle, which determines the total pattern of development of 11-year cycles. These facts prove once again that the 11-year cycles are genetically related to the quasi-bicentennial cycle, which determines the regular development of their duration and power as the filial 11-year cycles (Abdussamatov, 2006, 2009a,b, 2013a).

In the growth phase of the Sun's quasi-bicentennial cycle, the length of the solar 11-year cycles typically is shorter relative to the average for all 24 cycles, and the height of their maximum and the absolute power of the average cyclic energy sequentially are increased, which with some delay leads to a temperature rise of the Earth. Therefore, previous studies showed that the length of the 11-year solar cycle might possibly be an indicator of climate change, because a correlation between the solar cycle length and the temperature of the surface layer in the Northern Hemisphere over 130 years was detected (Friis-Christensen and Lassen, 1991). The dependence observed by Friis-Christensen and Lassen (1991) can be easily explained by an established inverse interconnection between the duration of the 11-year solar cycle and its power. However, the observed (Friis-Christensen and Lassen, 1991) dependence can exist only sporadically and only in the phase of rise or decline of the solar quasi-bicentennial cycle. Thus the gradual decline or increase in the duration of the 11-year cycle is generally an indicator of the onset phase of growth or decline of the solar quasi-bicentennial cycle, respectively, and an indicator of the beginning of future climate change, taking into account the thermal inertia of the oceans.

6. THE AVERAGE ANNUAL ENERGY BALANCE OF THE EARTH

When the absorbed average annual energy (TSI) during a long-term period is equal to the average annual energy long-wave radiation emitted into space, the Earth's temperature does not change—the energy budget of the Earth is in balance. To understand climate change, we must determine what drives long-term deviation from the equilibrium state of the average annual energy balance of the Earth. Therefore, we must first identify the components of the average annual energy balance of the Earth and the reasons for their long-term changes. The annual average difference between the energy of the total solar radiation coming into the outer layers of the Earth's atmosphere,

$$E_{\text{in}} = (S_\odot + \Delta S_\odot)/4 \tag{17.1}$$

and the energy portion of the reflected and scattered solar radiation and the energy long-wave radiation of the Earth going out into space,

$$E_{\text{out}} = (A + \Delta A)(S_\odot + \Delta S_\odot)/4 + \varepsilon\sigma(T_{\text{p}} + \Delta T_{\text{p}})^4 \tag{17.2}$$

determine the energy balance of the budget of the surface–atmosphere system, E. The difference between the incoming E_{in} and outgoing E_{out} radiation is described by Eq. (17.3) (Fig. 17.7) (Abdussamatov, 2012a,b, 2013a,b, 2015a),

$$E = (S_\odot + \Delta S_\odot)/4 - (A + \Delta A)(S_\odot + \Delta S_\odot)/4 - \varepsilon\sigma(T_{\text{p}} + \Delta T_{\text{p}})^4 \tag{17.3}$$

or by the difference between the portion of the TSI energy absorbed by the Earth and the long-wave radiation energy emitted into space,

$$E = (S_\odot + \Delta S_\odot)(1 - A - \Delta A)/4 - \varepsilon\sigma(T_{\text{p}} + \Delta T_{\text{p}})^4. \tag{17.4}$$

Here, $S_\odot$ is TSI, $\Delta S_\odot$ is the increment of TSI, A is the global albedo of the Earth (albedo), ΔA is the increment of the albedo, ε is the emissivity of the surface–atmosphere system, σ is the Stefan–Boltzmann constant, T_{p} is the planetary thermodynamic temperature, ΔT_{p} is the increment of the planetary thermodynamic temperature, and E is the specific power of the enthalpy change of the active oceanic and atmospheric layer (Wm^{-2}), which can be considered the energy balance of the annual average budget in the debit and credit of the thermal power of our planet. Planetary thermodynamic temperature is the average temperature over the entire surface of the planet (the Earth's surface and atmosphere). The factor 1/4 on the right side of Eqs. (17.1)–(17.4) reflects the fact that the solar radiation flux is projected onto the cross-sectional area of the terrestrial sphere (circle), whereas the Earth emits from the entire sphere surface, which is four times as large. The specific power of the Earth's enthalpy change E is a particular indicator of

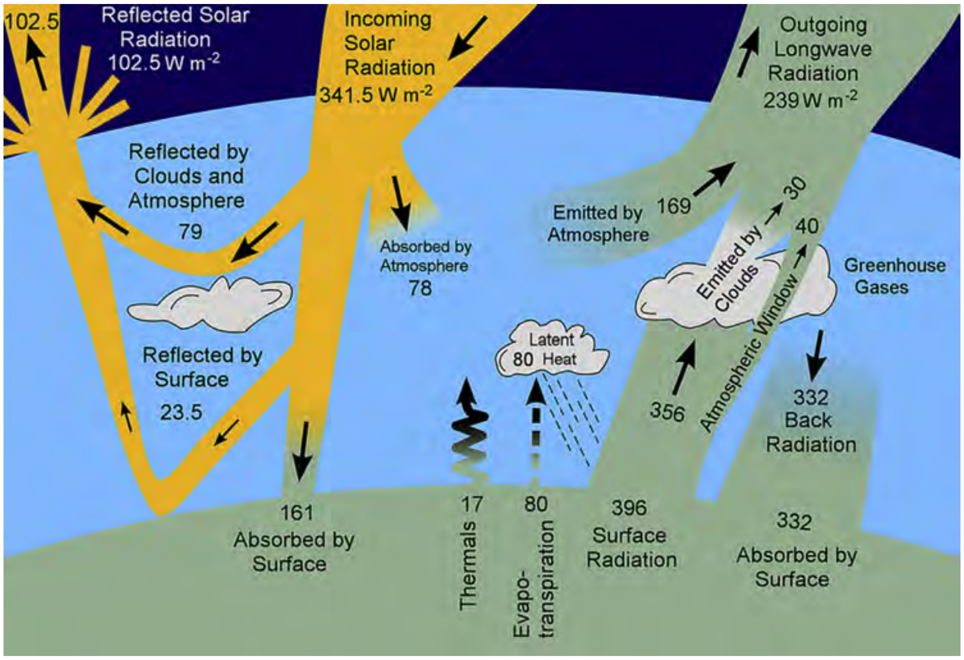

FIGURE 17.7 The average annual values of components of the total energy balance of the Earth as a planet in the equilibrium state (Trenberth et al., 2009; Abdussamatov, 2013a).

the deficit or excess of the thermal energy, which can be considered 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 is involved in the radiation balance immediately after the change in absorbed power, in contrast to the planetary thermodynamic temperature that is involved in the heat balance. The relative impact of variations in TSI and albedo on the change in the effective temperature of the Earth can be determined from the radiation balance of the Earth as a planet:

$$S_\odot/4 = \sigma T^4{}_e + AS_\odot/4, \tag{17.5}$$

where T_e is the Earth's effective temperature. Let us introduce the long-term increment of the effective temperature $\Delta T_e = T_e - T_{eo}$, where T_e is the current value of the Earth's effective temperature and T_{eo} is its initial value. We believe that the increment in the effective temperature is the result of increments in TSI $\Delta S_\odot$ and albedo ΔA. In this case, the radiative balance equation (Eq. (17.5)) takes the form

$$(S_\odot + \Delta S_\odot)/4 = \sigma(T_e + \Delta T_e)^4 + (A + \Delta A)(S_\odot + \Delta S_\odot)/4. \tag{17.6}$$

or

$$(S_\odot + \Delta S_\odot)(1 - A - \Delta A)/4 = \sigma(T_e + \Delta T_e)^4, \tag{17.7}$$

Because the increments in the effective temperature are small, $\Delta T_e \ll T_e$, the following equality is fulfilled with a high degree of accuracy:

$$(S_\odot + \Delta S_\odot)(1 - A - \Delta A)/4 = \sigma T^4{}_e + 4\sigma T^3{}_e \Delta T_e. \tag{17.8}$$

Subtracting Eq. (17.5) from Eq. (17.8) yields

$$\Delta S_\odot(1 - A - \Delta A) - S_\odot \Delta A = 16\sigma T^3{}_e \Delta T_e. \tag{17.9}$$

The formula for the increment of the Earth's effective temperature due to the increment of the TSI and albedo can be obtained from Eq. (17.9):

$$\Delta T_e = [\Delta S_\odot(1 - A - \Delta A) - S_\odot \Delta A]/\left(16\sigma T^3{}_e\right). \tag{17.10}$$

If the TSI does not change ($\Delta S_{\odot} = 0$), we obtain from Eq. (17.10) that

$$\Delta T_e = -S_{\odot}\Delta A/\left(16\sigma T^3{}_e\right). \tag{17.11}$$

Using well-known values of the effective temperature of the Earth and the TSI for the 21st and 22nd solar cycles, which are $T_e = 254.8$K and $S_{\odot} = 1366$ Wm^{-2}, respectively, we obtain from Eq. (17.11) for $\Delta S_{\odot} = 0$:

$$\Delta T_e = -91\ \ \Delta A. \tag{17.12}$$

For the albedo being constant ($\Delta A = 0$) we obtain from Eq. (17.10)

$$\Delta T_e = \Delta S_{\odot}(1 - A)/\left(16\sigma T^3{}_e\right). \tag{17.13}$$

By using the known now value of the Earth's global albedo, which is $A = 0.3$ according to the latest data (Trenberth et al., 2009), we obtain from Eq. (17.13) for $\Delta A = 0$:

$$\Delta T_e = 0.047\ \ \Delta S_{\odot}. \tag{17.14}$$

Estimation of the ratio of the relative contributions of the increments $\Delta S_{\odot}$ and ΔA to the increment ΔT_e can be done by adopting the conditions of their mutual compensation while maintaining the energy balance (Abdussamatov, 2012a, 2013a)

$$\Delta S_{\odot}(1 - A - \Delta A) - S_{\odot}\Delta A = 0 \tag{17.15}$$

in Eq. (17.10). From Eq. (17.15) one can get the ratio of the relative contribution of the increments $\Delta S_{\odot}$ and ΔA to the increment ΔT_e,

$$\Delta S_{\odot}/S = \Delta A/(1 - A - \Delta A) \tag{17.16}$$

or if $S_{\odot} = 1366$ Wm^{-2} and $A = 0.3$, then

$$\Delta S_{\odot} = 1366 \cdot \Delta A/(0.7 - \Delta A). \tag{17.17}$$

Eq. (17.14) indicates that if the albedo of the Earth remains unchanged ($\Delta A = 0$) and only the TSI bicentennial decreases at $\Delta S_{\odot} = -6.4$ Wm^{-2} (Shapiro et al., 2011), the global effective temperature of the Earth decreases at $\Delta T_e = -\ 0.3$K [estimates of the difference between the increment in the temperature of the global surface air (in view of the time of its delay) and the effective temperature are insignificant when their values are small]. Such gradually decline in the Earth's temperature about −0.3K may cause an increase in the Earth's albedo of about 1%, and, according to Henry's law and the Clausius−Clapeyron relation, a substantial reduction in the greenhouse gas concentrations in the atmosphere. Such increase in the albedo will result in an additional drop in the temperature of the Earth as a planet, which in turn will cause a further additional increase in the albedo and substantial reduction in the greenhouse gas concentrations in the atmosphere. A long succession chain of these cycles leads to successive additional chains of cooling and to a Little Ice Age, taking into account direct and important subsequent secondary feedback influences of TSI. The effective temperature of the surface−atmosphere system describes the inertia-free process of radiative heat exchange in the equilibrium thermal regime (Eqs. (17.6) and (17.7)). The increment in the effective temperature of the Earth would be carried out immediately with the change in the power to absorb solar radiation and the albedo of the Earth (Eq. (17.10)), unlike the planetary thermodynamic temperature, which determines the energy balance based on the thermal inertia of the Earth.

The change in albedo appreciably affects the temperature of the Earth and is, along with TSI, the most important factor in determining future climate change. The thermal inertia of the oceans is slowly changing in the climate system. However, the close connection of the atmosphere and the oceans leads to a significant delay of response of the atmospheric climate to external stimuli. Therefore, the Earth's thermodynamic temperature does not change immediately because of variations in the TSI and albedo. There is an appreciable lag in time determined using the constant thermal inertia of the planet (Abdussamatov et al., 2010):

$$t = 0.095(1 + 0.42 \cdot l)\ \ \text{year}, \tag{17.18}$$

where l is the depth of the active layer of the oceans. If the depth of the active layer of the ocean is 300−700 m, the constant thermal inertia is

$$t = 20 \pm 8\ \ \text{year}. \tag{17.19}$$

7. QUASI-BICENTENNIAL VARIATION IN THE TOTAL SOLAR IRRADIANCE LEADS TO AN ENERGY IMBALANCE OF THE SURFACE–ATMOSPHERE SYSTEM

The temporal changes in long-wave radiation emitted to space from the surface–atmosphere system always lag behind changes in short-wave solar radiation absorbed by the Earth because the enthalpy of the world's oceans changes slowly. Variation of temperature lags relative to absorbed solar radiation by 20 ± 8 years owing to the large heat capacity and thermal inertia of the oceans (Abdussamatov, 2009b, 2012a, 2013a, 2015a; Abdussamatov et al., 2010). Any long-term change in average annual short-wave solar radiation absorbed by the Earth due to the quasi-bicentennial variation of the TSI is not compensated by a corresponding change the emission of long-wave radiation from the Earth into space. That is why the debit and credit parts of the average annual energy balance of the Earth (Eqs. (17.3) and (17.4)) always deviate from the equilibrium state of the surface–atmosphere climate system ($E \neq 0$). Therefore, in the growth phase of the quasi-bicentennial solar cycle, the Earth receives more solar energy than is emitted by radiation into space, and its average annual energy balance is positive ($E > 0$), and vice versa in the recession phase of the quasi-bicentennial cycle—it is then negative ($E < 0$). As a result, the average annual energy balance of the Earth oscillates around the quasi-bicentennial equilibrium state. Therefore, long-term monitoring of the deviation of the average annual energy balance of the planet from the equilibrium state will define the trend and magnitude of the energy excess or deficit accumulated by the oceans. In the decay phase of the quasi-bicentennial cycle, the average annual energy balance of the Earth is negative ($E < 0$) and a long-term deficit in incoming solar energy can lead to cooling of the planet. The total quantity of stored solar energy (ΣE) (or its deficit) over a long period of monitoring can determine the corresponding depth of the impending climate variations. Quasi-bicentennial variations in the TSI determine the mechanism of cyclic alternations in climate change and set the timescales for physical processes taking place in the Sun–Earth system. That is why the Earth's climate changes every 200 ± 70 years.

8. CURRENT TOTAL SOLAR IRRADIANCE DECREASE IN THE QUASI-BICENTENNIAL CYCLE HAS LED TO A LONG-TERM DEFICIT IN THE EARTH'S ENERGY BALANCE AND THE BEGINNING OF A NEW LITTLE ICE AGE

Since 1990, TSI has been gradually decreasing. The annual rate of decreasing quasi-bicentennial TSI increased from cycle 22 to cycles 23 and 24 (Figs. 17.3 and 17.8). The smoothed value of TSI in the minimum between cycles 23 and 24 (1365.27 ± 0.02 Wm^{-2}) was lower by approximately 0.23 and 0.30 Wm^{-2} than at the minima between cycles 22 and 23 and cycles 21 and 22, respectively. The average cyclical values of TSI were also lower approximately by 0.15 Wm^{-2} in cycle 23 relative to cycle 22. An average annual decrease rate in the TSI during cycle 22 was approximately 0.007 Wm^{-2} $year^{-1}$, whereas in cycle 23 it became approximately 0.02 Wm^{-2} $year^{-1}$. Note that the level of the maximum 11-year component of TSI has decreased within 6 years of the current cycle 24 by approximately 0.5 Wm^{-2} to the level of cycle 23 (Figs. 17.3 and 17.8). The current increasing decline in TSI (with an abrupt drop in cycle 24) is about 0.1 Wm^{-2} $year^{-1}$ (Fig. 17.3) and its decrease will continue in cycle 25. The proportion of solar energy absorbed by the Earth since 1990 decreases at practically the same rates (Abdussamatov, 2009b, 2012a,b, 2013a,b, 2015a). However, the observed decrease in the average annual TSI portion absorbed by the Earth since 1990 has not been compensated for by a decrease in the average annual energy emitted into space because of the thermal inertia of the oceans (Abdussamatov et al., 2010). Since 1990 the Earth has radiated more energy back into space than the solar energy it has absorbed. Such gradual expenditure of all solar energy accumulated by the oceans during the 20th century led to the beginning of a new Little Ice Age after the maximum phase of cycle 24 (Fig. 17.8).

The Earth will continue to have a negative average annual energy balance ($E < 0$) in cycles 25–28 because the Sun is moving into a grand minimum. The observed trend of the increasing decline in TSI (Figs. 17.3 and 17.8) suggests that this decline will correspond to the analogous TSI decline in the period of the Maunder minimum (Shapiro et al., 2011). This decrease may reach approximately 1363.4 ± 0.8, 1361.0 ± 1.6, and a deep minimum of 1359.6 ± 2.4 Wm^{-2} (with gradual decreasing accuracy) at the minima between cycles 24 and 25, 25 and 26, and 26 and 27, respectively (Figs. 17.8 and 17.9). The maximum number of sunspots smoothed over 13 months could reach 50 ± 15 and 30 ± 20 in cycles 25 and 26, respectively (Abdussamatov, 2003, 2004, 2005, 2007a,b, 2009a,b, 2012a,b, 2013a, 2015a). Based on studies of variations in TSI for three consecutive minima between cycles 21 and 22, 22 and 23, and 23 and 24

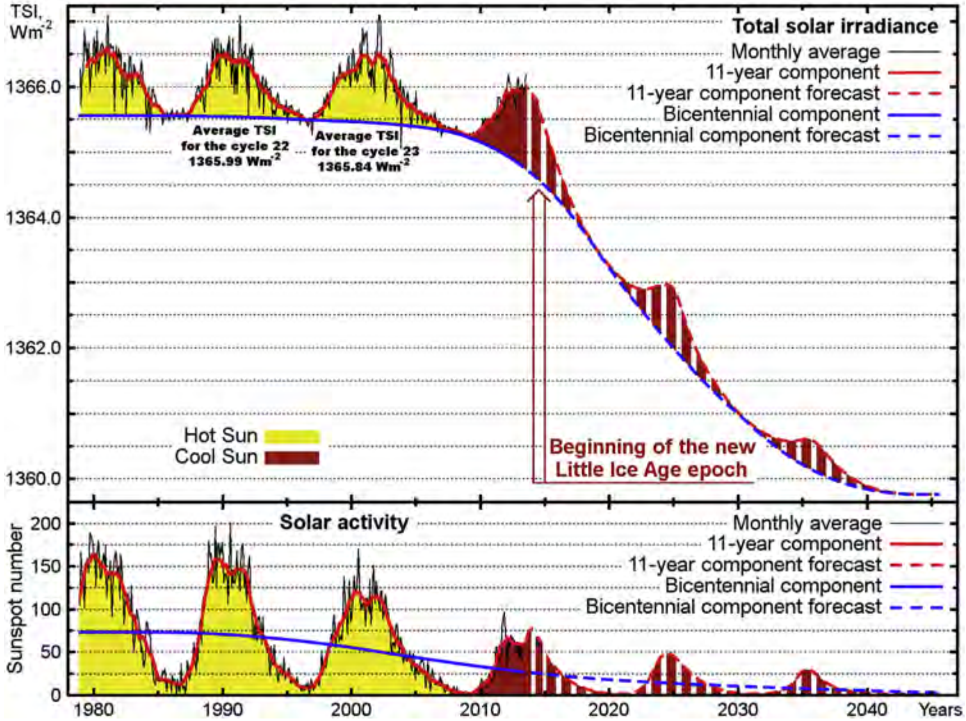

FIGURE 17.8 Cyclic variations in the total solar irradiance (*TSI*) *(data are taken from Fröhlich, C., 2013, Solar Constant. www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant)* and sunspot number *(data are taken from SunSpot Data, 2014. SIDC—Solar Influences Data Analysis Center. http://sidc.oma.be/sunspot-data/)* and a forecast of their variations to cycles 24–26 until 2045 (the hot Sun is marked by *yellow* and the cool Sun is marked by *red*). The *red arrow* indicates the beginning of the new Little Ice Age epoch.

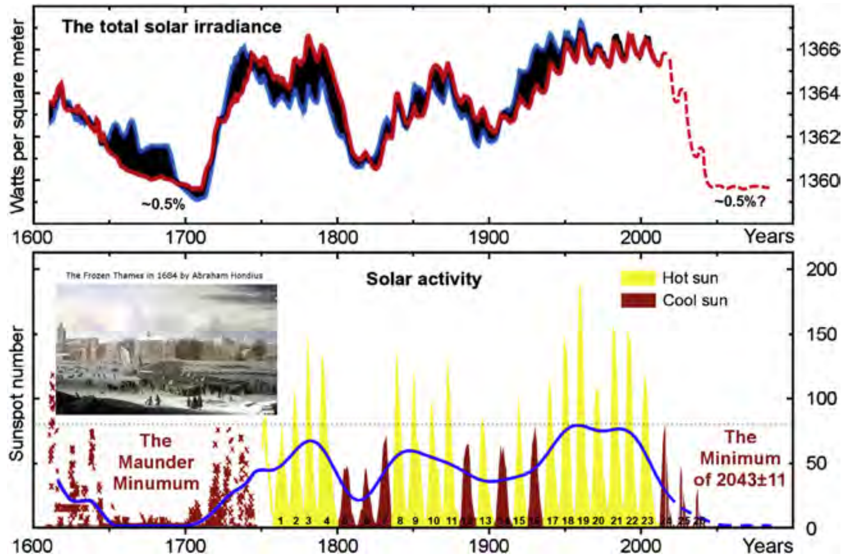

FIGURE 17.9 Total solar irradiance (Fröhlich, 2013) *(using reconstructed data Shapiro, A.I., et al., 2011. A new approach to the long-term reconstruction of the solar irradiance leads to large historical solar forcing. Astronomy & Astrophysics 529, A67.)* and solar activity from 1611 (SunSpot Data, 2014) and the prognosis of their variations until the end of the 21st century (*dashed lines*): the hot Sun is marked by *yellow* and the cool Sun is marked by *red.*

(Figs. 17.3 and 17.8), the projected start of the grand minimum phase of the Maunder-type quasi-bicentennial TSI is in cycle 27 (±1) in 2043 ± 11, with a possible duration of 45–65 years. The start of the deep cooling phase of the new Little Ice Age is expected in 2060 ± 11 (Figs. 17.10 and 17.11). The expected course of lowering temperature is shown in Fig. 17.12. What we are seeing now in solar cycle 24 and bicentennial cycle was predicted by me in 2003–2007,

FIGURE 17.10 The frost fair on the frozen River Thames (WorldGallery.CO.UK).

FIGURE 17.11 Frost fair on the frozen River Thames (Tom de Castella).

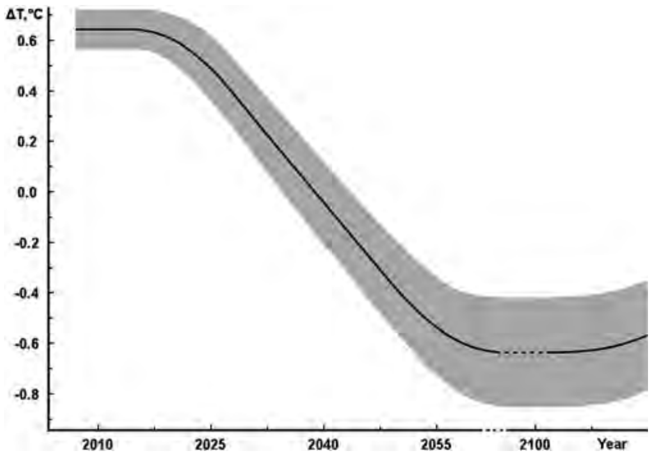

FIGURE 17.12 The prognosis of natural climate changes for the next 100 years.

long before cycle 24 began (Abdussamatov, 2003, 2004, 2005, 2007a,b, In the middle of the XXI century, 2006; Scientist predicts, 2006; The price of sensations, 2006; Russian scientist, 2006; Global cooling, 2006; People, 2007; Russian academic, 2007).

However, it should be borne in mind that the Earth is a large and complex closed system with a large number of simultaneously acting internal structural elements. Therefore, global climate characteristics depend on a combination of many factors, acting both individually and comprehensively. Natural causes of climate change include cloud cover and the surface area of snow and ice cover, ongoing interactions between the atmosphere and the ocean, cryosphere and land surface changes, and shifts in some regional oceanic and atmospheric currents, taking into account, in particular, the uneven distribution of land on the surface of the Northern and Southern Hemispheres, ~39% and ~19%, respectively. Natural internal causes of climate change can lead to short-term fluctuations in the Earth's temperature. However, natural fluctuations in temperature with only internal causes may usually be negligible, only within ±0.1°C. Intrasystem causes of temperature fluctuations are a part of the climate system. However, their long-term cyclical trends are caused by external factors related to bicentennial variations in the TSI in view of the thermal inertia of the oceans.

Long-term changes in the Sun's energy output can account for almost all the climate changes on planets of the Solar system. Even insignificant, long-term TSI variations may have serious consequences for the climate of the Earth and other planets of the Solar system. Warming on Mars (Odyssey, 2005; Ravilious, 2007) and other planets was observed in the last quarter of the 20th century. That was attributed to an action of season "solar summer" and the quasi-bicentennial alternation in climate conditions throughout the Solar system. At the end of 2015, after the maximum phase of solar cycle 24, the season "solar summer" ended and the season "solar autumn" began, and then in 2060 ± 11 will be the coming season "solar winter." "Spring" in the Solar system will come only at the beginning of the 22nd century. Geologists call past warm epochs "climatic optimums," and cold times, dark ages; yet governments across the world are preparing only for warming.

9. SENSITIVITY OF CLIMATE TO WATER VAPOR AND CARBON DIOXIDE

The concentration of water vapor in the atmosphere is the dominant factor in the greenhouse effect (Abdussamatov, 2009b, 2012a,b, 2013a, 2015a). Water vapor absorbs about 68% of long-wave emissions from the Earth's surface, whereas carbon dioxide absorbs only approximately 12% (Fig. 17.13). This proportion is due to the partial overlap of spectral absorption bands of carbon dioxide and water vapor and the constancy of moisture content in the atmosphere at low pressure and temperature variations. Therefore, the absorption by the atmosphere of thermal radiation of the Earth's surface is mainly determined by the concentration of water vapor. Altitude is an important factor in temperature change caused by water vapor in the atmosphere. The concentration of water vapor in

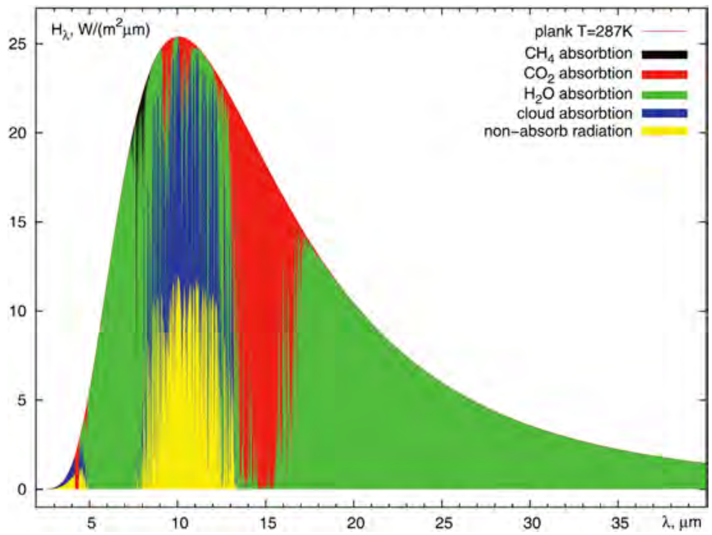

FIGURE 17.13 The spectral density of the thermal flow long-wave radiation of the Earth's surface (as a blackbody).

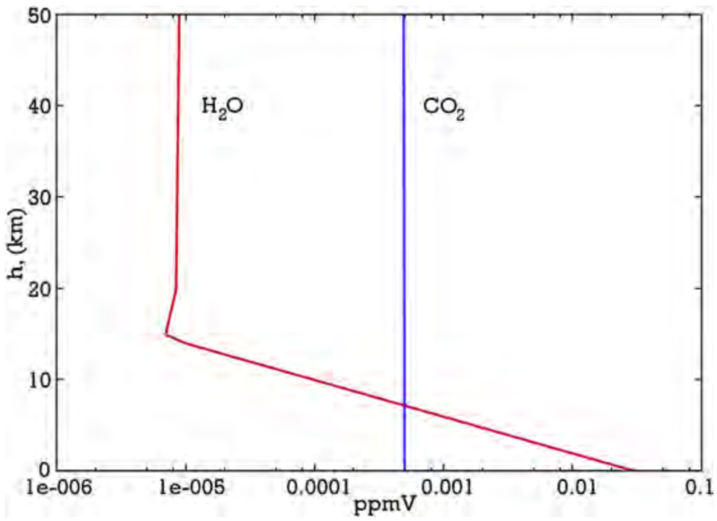

FIGURE 17.14 The changes in the concentrations of water vapor and carbon dioxide with height (Abdussamatov, 2009b, 2010, 2013a, 2014).

the atmosphere depends strongly on altitude (Fig. 17.14). Carbon dioxide is homogeneously distributed to a height of about 80—100 km (it), but water vapor has its maximum concentration at the surface, drops abruptly with height in the troposphere, and remains on some constant level in the stratosphere (Fig. 17.14). Even small growth of the average concentration of water vapor in the atmosphere, together with a simultaneous rise in the average concentration of carbon dioxide caused by warming can lead to a significant increase in water vapor concentration at the very bottom of the surface layers of the air relative to the carbon dioxide concentration. This leads to substantial changes in the transfer of thermal flow of the long-wave radiation of the Earth's surface by the water vapor, because of the significant overlapping bands of the absorption of water vapor and carbon dioxide in the wide regions of the emission spectrum within the windows of atmospheric transparency (Fig. 17.13). A significant increase in the concentration of water vapor in the lowest surface layers of the atmosphere significantly increases the proportion of the absorption by water vapor of the long-wave radiation of the Earth's surface in the overlapping spectral absorption bands of carbon dioxide and water vapor within the windows of the atmospheric transparency. As a result, the climate sensitivity to increasing concentrations of carbon dioxide decreases with significant growth of water vapor concentration in the surface layer caused by warming (Abdussamatov, 2009b, 2010, 2013a, 2014). Therefore, with an increase in the concentration of carbon dioxide in the atmosphere at its current high level, it is impossible to expect a significant increase in the absorption by the carbon dioxide of the radiation of the Earth's surface.

10. CONVECTION, EVAPORATION, AND CONDENSATION IN TRANSFER OF THERMAL FLOW AT THE EARTH'S SURFACE

As early as 1908, the American physicist Robert Wood made two identical boxes (minigreenhouses) of black cardboard: one of them was covered with a glass plate and the other, with a plate made of rock salt crystals, which are almost transparent in the infrared part of the spectrum (Wood, 1909). The temperature in both greenhouses simultaneously reached approximately 130°F (approximately 54.4°C). However, the plate made of rock salt is transparent at long wavelengths and, according to the commonly adopted theory of the greenhouse effect, this cover should not produce it at all. Robert Wood established that in the greenhouse, 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, heat that accumulates in the greenhouse only slightly depends on its cover transparency to infrared radiation, ie, absorption of infrared radiation by the glass is not the main reason for the heat to accumulate in the greenhouse. Thus, convection, evaporation, and condensation, together with the greenhouse effect, participate in the transmission of thermal flow long-wave radiation of the Earth's surface to the atmosphere (for example, see Fig. 17.7).

11. POWERFUL VOLCANIC ERUPTIONS LEAD ONLY TO SHORT-TERM COOLING PERIODS

Relatively powerful volcanic eruptions increase the amounts of solid particles and gases in the lower stratosphere. Their scattering, screening, and partial absorption of solar radiation decrease the portion of the TSI reaching the surface, which can result in short-term cooling, which was observed after the Pinatubo volcano. Volcanic microparticles in the atmosphere contribute to cloud formation, which also prevents solar radiation from reaching the surface. They simultaneously absorb infrared radiation, but their antigreenhouse effect is more pronounced than the greenhouse effect. However, these changes are not long term because of the limited lifetime of volcanic particles in the atmosphere. The impact of volcanic eruptions on climate depends not only on the mass of exhaust gases and microparticles, but also the altitude to which they are ejected, since at an altitude of 15–20 km, they can linger for several years. The atmosphere is self-cleaning and gradually increases its transparency to its previous level over a time span of 6 months to a few years (Abdussamatov, 2009b, 2010, 2013a, 2014). That is why the role of volcanic eruptions in climate variations cannot be long term and cannot be a determining factor. When Mt. Pinatubo erupted in the Philippines in 1991, about 20 million tons of sulfur dioxide was ejected into the atmosphere, and the global temperature dropped by about 0.5°C from 1991 to 1993. However, later the atmosphere cleaned itself of these additives and finally returned to its initial state.

12. FUTURE DEEP COOLING CAN BECOME A MAJOR PROBLEM FOR THE DEVELOPMENT OF PETROLEUM IN THE ARCTIC

The Arctic is a unique territory, primarily because of its incredible oil and gas resources and almost half the world's fish production. The Arctic Ocean, according to geological surveys, is the richest in petroleum of all the oceans. Intense interest in the development of the Arctic has been stimulated by UN experts who have predicted further melting of Arctic ice because of global warming. This could open up new areas of the shelf, making them available for deep-water drilling. However, deep cooling in the new Little Ice Age in the middle of this century would make it almost impossible to exploit offshore fields and pump oil and gas tens to hundreds of kilometers from the coast at depths of hundreds of meters (Abdussamatov, 2009b, 2013a). Because the Arctic Ocean will be covered with thicker floating ice and the ice will move, drilling will be extremely difficult and dangerous. In the future, a fuel and energy complex will not have easy access to oil and gas in the Arctic. Deep cooling can become one of the major risks in the development of hydrocarbon deposits in the Arctic. So long-term forecasts portend for the fuel and energy complex even more complex and difficult working conditions, and not only in the Arctic. In this way, the upcoming new Little Ice Age will have a very serious impact also on energy security. In addition, the possibility of exploitation of the northern sea route in the future seems to the author also impossible.

13. INCREASING GLOBAL TEMPERATURE ON THE EARTH HAS STOPPED SINCE 1997

TSI has gradually decreased since 1990. The Sun has not heated our planet as much as previously since 1990 (Figs. 17.3 and 17.8). However, because of the thermal inertia of the world's oceans, we are basking in warm additional solar energy stored in the oceans during the 20th century. As a result of the TSI fall since 1990, the warming, contrary to predictions by many climatologists, instead of accelerating, has stopped since 1997, and the average temperature on Earth is stabilized, not growing, and there are already signs of deep cooling (Fig. 17.15). At the same time, since 1997, the concentration of carbon dioxide in the atmosphere has continued to grow.

A rise in the world ocean's level is the most reliable indicator of the rate of temperature growth and one of the problems of our time. More than 40 scientists in 20 groups participating in Arctic research combined their efforts to estimate the contribution of ice melting in Greenland and Antarctica to the global sea level. Since 1992 the global rise in the level of the world ocean has been 0.59 ± 0.2 mm/year on average (Shepherd et al., 2012). This means that the current ocean level is not rising, which would reflect a current state of warming—it has stopped, and the global temperature has not grown during this entire period.

The decline in TSI since 1990 and, correspondingly, lower amount of solar energy coming into the tropical part of the world ocean will gradually cause a weakening of the power of the atmospheric and oceanic circulation and, first

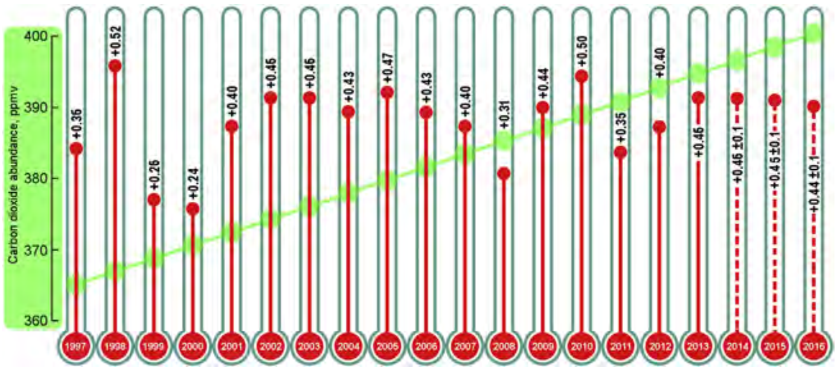

FIGURE 17.15 The trends in both average annual global temperature (with respect to the average temperature for the time interval 1961–90) *(data are taken from the HadCRUT3 (2015))* and carbon dioxide concentration (ppmv).

of all, a decrease in power of the warm current of the Gulf Stream because the amount of heat provided by ocean currents from the tropical areas to the Gulf of Mexico will decrease. This will lead to stronger cooling of the climate in the zone of its action in western Europe and the eastern parts of North America. The temperature in Greenland has shown no increase for decades (Booker, 2015). A study of snow variability in the Swiss Alps in 1864–2009 also shows a reversal of the temperature trend in the Swiss Alps since 2000 (Scherrer et al., 2013). The average temperature around the globe will fall by about at 1.5°C when we enter the deep cooling phase of the Little Ice Age, expected in the year 2060 ± 11. The cooling phase will last for about 45–65 years, for four to six 11-year cycles of the Sun, after which on the Earth, at the beginning of the 22nd century, will begin the new, next quasi-bicentennial cycle of warming–Little Ice Age. Natural causes play the most important role in climate variations, rather than human activity.

14. CONCLUSION

The Sun is the main factor controlling the climatic system and even slight long-term TSI variations may have serious consequences for the climate of the Earth and other planets of the Solar system. The total sign and value of the deviation of the average annual energy balance of the Earth from the equilibrium state over a long time (excess of incoming TSI accumulated by the ocean, or its deficiency) determine a corresponding change in the energy (thermal) state of the surface–atmosphere system and, hence, a forthcoming climate variation and its amplitude. That is, variations in the Earth's climate are a function of long-term deviations in the average annual energy balance of the Earth from the equilibrium state between the total incoming solar radiation energy in the upper layers the Earth's atmosphere and the total outgoing energy from the Earth back into space. Significant climate variations during at least the past 800,000 years indicate that quasi-bicentennial and 100,000-year cyclic variations in the TSI entering the upper layers of the Earth's atmosphere (taking into account the direct and subsequent nonlinear influences of secondary feedback effects) are the main fundamental cause of corresponding alternations in climate from warming to the Little Ice Age and Big Glacial Period. The quasi-bicentennial cyclic variations in the TSI control and practically totally determine the mechanism of quasi-bicentennial cyclic alternations in climate change and set corresponding timescales of practically all physical processes taking place in the Sun–Earth system and also are key to understanding cyclic changes in both nature and society. In 2003–2007, I warned that the world should prepare for imminent global cooling. Long before the beginning of the 24th solar cycle, when the anthropogenic nature of warming was the most commonly adopted, I predicted the onset of the grand minimum of both TSI and solar activity in approximately 2040 ± 11 and the beginning of the corresponding decrease in global temperature—the beginning of the epoch of the 19th (over the past 7500 years) Little Ice Age—the period from 2012 to 2015 (after the maximum phase of the 24th solar cycle) (Abdussamatov, 2003, 2004, 2005, 2007a,b; In the middle of the XXI century, 2006; Scientist predicts, 2006; The price of sensations, 2006; Russian scientist, 2006; global cooling, 2006; People, 2007; Russian academic, 2007; Trimble et al., 2007). And the deep minimum phase of the Little Ice Age will begin in the period from 2055 to 2060 (±11). The most obvious reason for deep global cooling is the upcoming grand minimum of the Sun. These predictions in the course past years are finding more and more practical confirmations, and by the Sun itself (the significant drop in levels of TSI and solar activity at the levels of my predictions) and also by the current lack of warming and of a practical rise the level of the world ocean since 1997, which are under the direct control of the decreasing-phase quasi-bicentennial TSI cycle.

Long-term negative deviation of the Earth's average annual energy balance from the equilibrium state since 1990 has led to corresponding variations in its energy state and thermal mode. On our planet, after the maximum phase of the 24th solar cycle at the end of 2015, we began the descent into the epoch of the quasi-centennial 19th Little Ice Age in the past 7500 years (Abdussamatov, 2016a). Variations in the parameters of the Earth's surface and atmosphere, caused by cooling, will be generating a long chain of causal cycle of the subsequent secondary feedback effects. The increase in the albedo and the decrease in the greenhouse gas concentrations in the atmosphere by the upcoming cooling according Henry's law and the Clausius−Clapeyron relation will lead to an additional reduction in the absorbed solar energy and reduce the greenhouse effect influence. They will lead to an additional drop in temperature, which can surpass the influence of the direct effect of the quasi-bicentennial TSI decrease (Eq. (17.14)). The Earth has experienced such major cooling occurrences five times over the past 1000 years and not less than 18 times in the past 7500 years, and a global freeze will come regardless of whether or not industrialized countries put a cap on their greenhouse gas emissions, because the amounts of natural flows of carbon dioxide from the oceans and land to the atmosphere (M_{in}) and from the atmosphere (M_{out}) to the oceans and land exceed many times the anthropogenic discharges of these substances into the atmosphere (M_{ant}) (Nigmatulin, 2010). The common view that human industrial activity is a deciding factor in warming has emerged from a misinterpretation of cause and effect. Pictures of the frozen Thames (Figs. 17.10 and 17.11) and a historical study of the effects of recent deep cooling in the period of the Maunder minimum are warnings about the serious threat also to the future of energy security for humanity. Humankind by the middle of the current century will meet with the same very difficult times as well as a change for the worse in conditions for creating material and financial resources of the society.

Earlier in the last quarter of the 20th century the simultaneous warming of the Earth, Mars, and other planets and satellites of planets in the Solar system was established. 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 (Odyssey, 2005; Ravilious, 2007). Is there anything in common for all the planets of the Solar system whose action could result in their simultaneous warming during the same time period? Because there are no human-made emissions on Mars, this warming must be due to other things, such as a warming Sun, and these same causes are responsible for the warming observed on Earth throughout practically all the 20th century. This common factor affecting simultaneously all the bodies of the Solar system is a long-term high TSI level during practically the whole 20th century. That is why simultaneous warming on Earth, Mars, and the whole Solar system has a natural solar origin and confirms the action of the solar summer throughout the Solar system and alternation of climatic conditions in it. In general, by analogy with the seasons on Earth there is also a similar alternation of climatic conditions in the Solar system, dictated by the quasi-bicentennial cyclic variation in the TSI (Abdussamatov, 2013a,b, 2015a). From this point of view, now the whole of our Solar system after the solar summer came the season of the solar autumn and then in 2060 $\pm$ 11 we will reach season of the solar winter of the quasi-bicentennial cycle of climate variation. Only in the early 22nd century will come the season "sunny spring" in the entire region of the Solar system. The observed long-term decline in TSI and forthcoming deep cooling will, first of all, essentially affect climate-dependent natural resources and influence, in the first place, economics closely connected with the state of the climate. Temperature to the mid-21st century may be reduced to the level of the Maunder minimum, which took place in the years 1645−1715. Thus climate change is a natural process, beyond human control, and is not practically connected with our activities. The new Little Ice Age could cause long-term and extremely cold winters characterized by the freezing of normally ice-free rivers as well as by snow fields in areas that have for several centuries not witnessed such climate conditions.

Simultaneous gradual weakening of the Gulf Stream leads to a stronger cooling, which will be most felt in western Europe and the eastern parts of United States and Canada. The world must start preparing for the new Little Ice Age right now. Politicians and business leaders must make full economic calculations of the impact of the new Little Ice Age on everything—industry, agriculture, living conditions, development. The most reasonable way to a fight against the new Little Ice Age is a complex of special steps aimed at support of economic growth and energy-saving production to adapt mankind to the forthcoming period of deep cooling, which will last approximately until the beginning of the 22nd century. Early understanding of the reality of the forthcoming global cooling and physical mechanisms responsible for it directly determines the choice of adequate and reliable measures that will allow humankind, in particular populations of countries situated far from the equator, to adapt in advance to the deep global

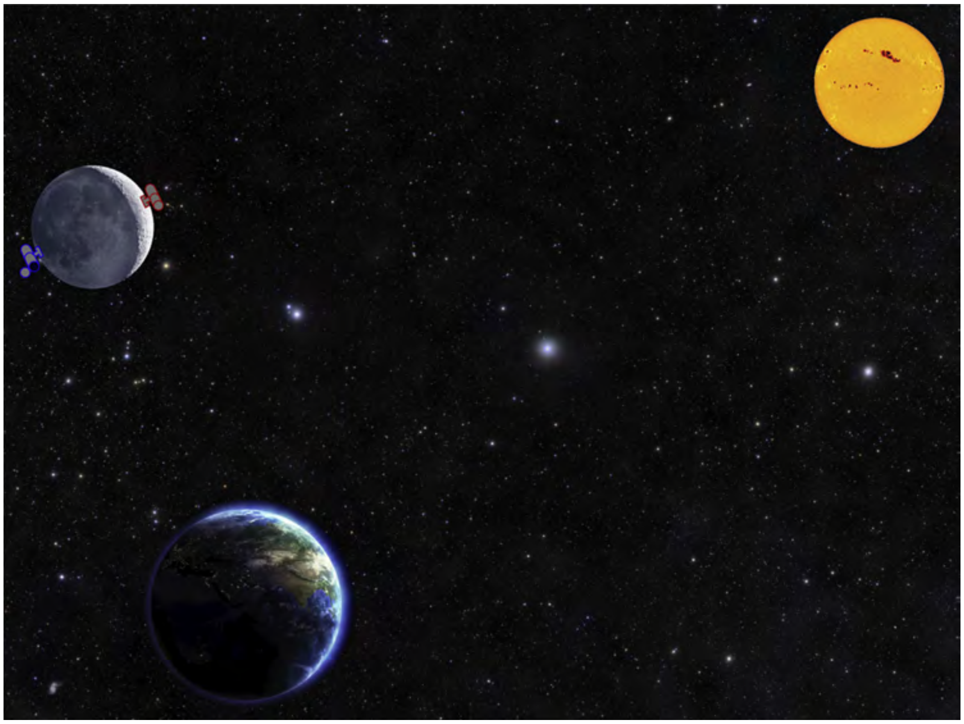

FIGURE 17.16 The Lunar Observatory is a system of two identical optical telescopes.

cooling. The upcoming climate change will be the most important challenge and a priority issue for the world and define the main events in politics, the economy, and the most important areas of the whole of humanity in the coming decades. Monitoring and research of long-term variations in global climate parameters are extremely important tasks in a thorough understanding of the physical mechanisms of global climate change and determining the patterns of its formation, which will allow the development of reliable methods predicting future deep climate changes. The most reliable way to accurately predict the depth and exact time of the beginning phase of a deep minimum of the upcoming Little Ice Age is to study the long-term variations in the most effective global parameter: the deviation of the Earth's average annual energy balance from the equilibrium state. Therefore, we have developed a very important new space project, the Lunar Observatory, for direct monitoring of both the albedo and the long-wave radiation of the Earth going out into space, as well as the state of the surface, clouds, vegetation, cryosphere, concentration aerosols, and ozone around the globe for investigation of the deviation of the average annual energy balance of the Earth from the equilibrium state and the physical reasons for climatic changes, with the Moon's surface having the ideal conditions of the lunar night (Fig. 17.16) (Abdussamatov, 2015c,d, 2016b,c). The Lunar Observatory is a system of two identical optical telescopes working in series to measure the complex of global climatic parameters of the Earth. Comprehensive measurements will be taken of variations in radiation emanating from the Earth, reflected and scattered TSI to space in all directions in the wavelength ranges $\Delta\lambda = 0.2-4$ μm, the thermal radiation of the Earth $\Delta\lambda = 4-100$ μm, and the main atmospheric transparency window $\Delta\lambda = 8-13$ μm, as well as remote sensing of the Earth from the surface of the Moon in 10 narrow intervals of the spectrum range $\Delta\lambda = 0.2-3$ μm. These measurements will be carried out consecutively during ~94% of the lunar day continuously only in the lunar night in places installation of the telescopes. It is a scientific issue of fundamental importance and a unique tool for the best and deeper learning of the physics of solar−terrestrial relations and the establishment of the physical causes of climate change and, therefore, their most reliable forecasting. Establishing physical causes of global climate change and the timely creation of the most reliable methods for predicting the future of deep cooling will prevent and weaken maximally the impact of global deterioration of the natural environment and of climate, social, and economic situations around the world, as well as climate-driven changes in the geopolitical situation.

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