Influence of Space Climate and Space Weather on the Earth.

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Accepted: 27 February 2010

Abstract This paper presents results of our study concerning links between changes of solar activity (sunspot numbers W), rotation rate (ω) and global temperature of Earth (Tgl) to understand their connection on different time scales in the past, present and close future. We apply MGM method of spectral analysis elaborated by us that can quantitatively describe both trends and non-stationary variations to evaluate their input in data. Trend in north hemisphere temperature shows rise since Maunder's minimum with present rate ~0.50C/100yr correlated with trend in W. Variations of high-amplitude 200-yr cycles in W and in Tgl show decrease of the parameters at present. The result also is a proof of the 200-yr solar contribution to temperature rise during the last century. We suggest a possible explanation of observed unexplained rise in temperature for the interval 1905-1940 and its subsequent decrease for 1940-1976 with rate ~0.750C/100yr by variation in ω with period of 72 yr. We present arguments of solar-lunar origin of the power cycle. Based on our results we suggest a possible mechanism for the 22-yr variation in Tgl to be explained. The mechanism successfully reproduces the variations in W, Tgl and ω. We discuss other possible physical mechanisms of solar variability that may influence our climatic changes.

Keywords: Solar variability, Global change, Climate forcing, Spectral analysis

Introduction

Concept of Space Climate includes the long-term change in the Sun, and its effects in the heliosphere and upon the Earth, including climate. Space weather is concept of changing environmental conditions in near-Earth space on relative short time scales. Space weather is greatly influenced by the speed of the solar wind V and the interplanetary magnetic fields (IMF) carried by the solar wind plasma. This brief description concerns those features of the concepts which are important to understand the present paper. More broadened wordings of scientific areas for new researches drawn by these concepts are far away from end in spite of large number of publications devoted to this question. In particular, definitions of space climate, space weather, Sun–Earth connections and space physics have been clearly stated by Rozelot and Lefebvre [1]. However, all present definitions will be changed as we shall improve our understanding physical processes in the Sun-Earth system. If we trace back to the ancient Chinese, who observed a correlation between sunspots and aurora, we can recognize a simple research in the field of the Sun-Earth connections. But science is on the other level of its spiral progression through time. Phenomena in the Sun (or in its heliosphere) correlated with ones in the Earth (or in its spheres) are subjects of investigation in the field of solar-terrestrial physics for now. We should remember nevertheless that main aim of physics is to connect the correlated characteristics to root causes. Physics is often said to be the fundamental science, because each of the other disciplines deals with particular types of material systems that obey the laws of physics. Space physics also known as space plasma physics, which studies plasmas in the universe, is only a part of physics. As to my understanding, appearance of the concepts testifies to beginning of synthesis of narrow scientific disciplines after their specialization as response to changing environmental conditions on the Earth and in near its space (natural and man-made) for long-standing problems in solar-terrestrial physics to be solved.

The observed substantial increase in the Earth's temperature since the beginning of the last century has attracted a great deal of attention to the problem of climate change. This study is also an attempt to find answers to problem of climate change formulated clearly by Akasofu [2] concerning importance of relative contribution of natural sources and sources connected with greenhouse effect of manmade gas CO_2. He attracted attention to the following focal points of the problem: 1) natural components are important and significant, so that they should not be ignored; 2) it is insufficient to study climate change on the basis of data only from the last 100 years; 3) it is difficult to make conclusions about causes of the temperature rise since 1975 until we can understand the rise from 1910 to 1940. Akasofu suggests that the greenhouse effect shown by computer modeling manmade CO_2 greenhouse effect should be carefully re-evaluated, if the present rise (~0.6°C/100 years) contains significant natural components.

IPCC (International Panel on Climate Change) in his recent report confirms that "increasing evidence of anthropogenic influences on climate change has been found"[3]. IPCC also commented point 3) of the problems raised by Akasofu: "In the mid-1970s, several articles about possible global cooling appeared in the popular press, primarily motivated by analyses indicating that Northern Hemisphere (NH) temperatures had decreased during the previous three decades"…. "In the peer-reviewed literature, a paper … reported that increases in carbon dioxide (CO_2) should be associated with a decrease in global temperatures" [3 and references therein]. The fact that IPCC noted popular press as source of information about the global cooling before 1975 points to the IPCC distrust to this cooling. Akasofu makes clear the situation [2]: "the temperature decreased, in spite of the fact that the release of CO_2 increased rapidly". In addition to observational results presented by Akasofu we also show below that temperature decreased in NH and globally during period of ~1940-1975. Moreover, we will present arguments for the temperature variation to be explained by variation of high-amplitude cycle with period of 72 year in rotation of the Earth.

Sun is one of possible natural causes in climate change. IPCC clearly states that the present known solar mechanisms are unable to influence climatic changes. In particular: "The effects of galactic cosmic rays on the atmosphere (via cloud nucleation) and those due to shifts in the solar spectrum towards the ultraviolet (UV) range, at times of high solar activity, are largely unknown."[3]. However, total solar irradiance varies of a factor 2 in EUV, that might have a strong impact on the upper stratosphere [4].

A way of solution of the climate change problem, when a large number of scientists tried (and still try) to prove the only hypothesis of CO_2, can not be satisfactory. It seems IPCC recognizes that the change in CO_2 is not cause of climate change: "It now appears that the initial climatic change preceded the change in CO_2 but was enhanced by it."[3]. But ICCP clearly states yet again: "Scientists have determined that human activities have become a dominant force."[3]. The progress in the problem based on huge number of models run on computers can be compared with an enormous Tower built at the city of Babylon (with all the ensuing analogies from this Biblical story). It is obvious that synthesis of knowledge from different scientific areas is necessary for a real progress in complicated problem of climate change to reach.

Rotation is fundamental characteristics of the Earth, and the other geophysical processes are subordinated to rotation. We study temporal variations from the spectra of solar activity (sunspot numbers W), the Earth's rotation velocity (ω) and the global temperature (Tgl) with the same periods to understand their possible influence on climate change in the past, present and close future. We propose to quantitatively describe long-term variations in solar and temperature data to suggest cause of the trend. Based on our results we discuss long-standing questions concerning influence of space climate on the Earth. The problems are trends, quasi-periodicities and noise in solar and climate processes. Because of the transient character of some signals in solar and climate data they can not be well characterized by the traditional spectral analysis. This study requires the use of non-linear spectral methods. We propose to quantitatively describe both non-stationary variations and trends to evaluate their input in data. Note, traditional spectral analysis gives ambiguous results due to non-stationary processes in data. In particular, a varying phase of non-stationary oscillation with constant period leads to a varying frequency (determined using a traditional analysis); the larger phase change, the larger deviation from true period at that. Traditional analysis does not allow also to describe correctly amplitude of non-stationary oscillation due to its dependence on time. In addition, traditional analysis can not detect time intervals of phase shifts (so called "phase catastrophes") and appearance of high-amplitude oscillation in data. The latter is very important for estimation of its contribution to data during every time interval and understanding causes responsible for the amplitude increasing.

Technique of spectral analysis and data used

We use spectral "method of global minimum" (MGM) that we have developed. Due to lack of space, we only outline here the potential of the method and focus on the specific features that are important for the analysis discussed in this paper. MGM provides a high frequency resolution and offers a number of advantages that make it useful for the proposed applications: self-consistent identification of data trends, non-stationary sinusoids (i.e., sinusoids whose amplitudes and phases depend on time, sometimes referred to as "damping sinusoids"), and of sinusoids with periods longer than the length of the input data sets (providing a mathematical description of long-term trends). A description of MGM can be found in [5]. As non-stationary variations consist of separate wave trains, their amplitude can decrease and increase during analyzed time interval. Correct approach should include evaluation procedure of statistical significance of these oscillations (calculation of probability of a spectral component being signal). The technique of removing a white noise from spectrum is described in [6].

We used annual sunspot numbers W for the period 1700-2005, multi proxy data of anomaly in global temperature Tgl from 17 sites worldwide for the last 1000 yrs [7] and deviation in angular velocity of the Earth υ for the interval 1665-2000 [8]. We used too data of IMF and V measured by various spacecrafts in the solar wind near the plane of the ecliptic at a distance of 1 AU during the period 1964-2005 obtained from the database (http://www.omni.web.gsfc.nasa.gov/)

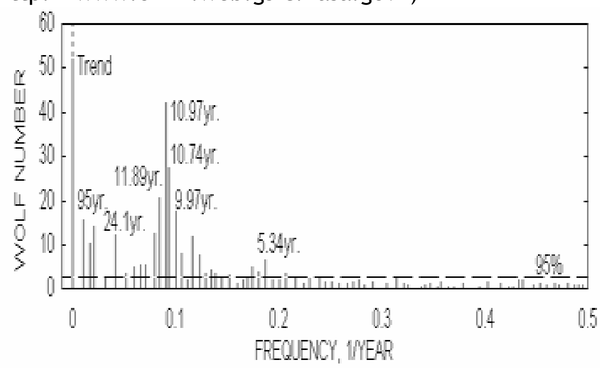

Fig.1. The spectrum of sunspot numbers W for 1700-1998 calculated via the method of global minimum (MGM) [9].

Trends and cycles in sunspot numbers

The spectrum of annual sunspot numbers W for the period 1700-1998 yr. is shown in Fig. 1 [9]. Horizontal dotted line on the plot denotes the 95% confidence level: probability Pj of spectral peak with amplitude Rj being signal. Total analysis of the spectrum is presented in [9]. Here we analyze only those results that concern the topic of present paper. The total number of significant harmonics is equal to 26 (close to the result obtained by Kuklin [10]). Non-stationary harmonics in the spectrum demonstrate non-stationary state of processes in sunspot generation. Spectral component with period T=11.89 yr we connect with influence of Jupiter [9]. Fig.2 demonstrates trend extracted by self-consistent method from the data. The trend is described by a curve close to a cubic parabola, and has a maximum at a point t=1778,4 yr (the maximum time of the 3-rd cycle) and minimum at a point at t=1870,6 yr (the maximum of the 11-th cycle). The coincidence of the extreme points of the trend with maxima of the mentioned cycles, which were the highest before the 18-th cycle, points to outstanding events in sunspots generation. Taking into account that the maxima coincide with the time in sign change of poloidal magnetic field, we assume that the starting conditions for the generation of these components were varying just for these time intervals. We see also way out from Maunder minimum in the Fig.2.

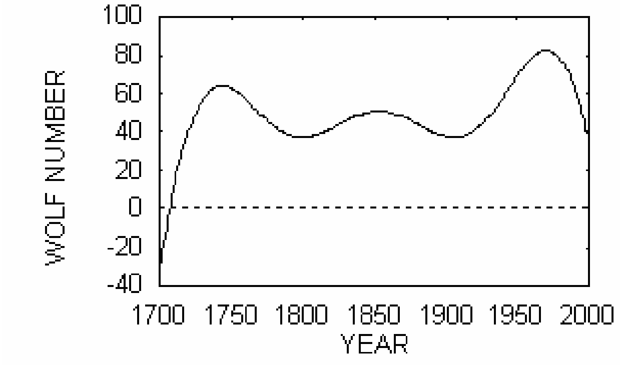

Fig.2. Trend in data of W for period 1700–1998 [9].

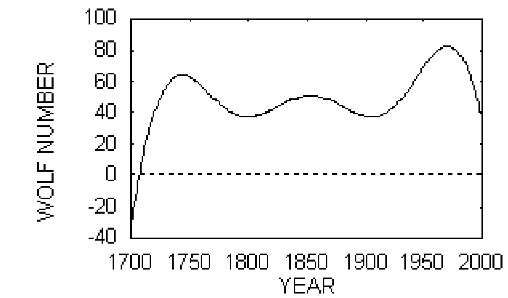

Fig.3. Plot of non-stationary sinusoid at period T=225 year from the spectrum of W for the 1700-1999 [11].

We calculated spectra of W for different time intervals of input data sets. Fig. 3 shows one the most low-frequency harmonics from our spectra of the W numbers for interval 1700-1999 [11]. The plot demonstrates non-stationary triplet with average period of 225 yrs; spectral band of the periods occupies 82 years (202 -284 yrs). We see from comparison of fig. 2, 3 that addition only one annual meaning to the W input set changes the most low-frequency harmonic in the spectra from cubic trend (fig.2, spectrum for 1700-1998) to the non-stationary triplet (fig.3, spectrum for 1700-1999). The result points to the fact that the length of the input data sets is too short for the low-frequency part of the spectrum to calculate reliably. Every spectral method including MGM has limitation on number of long-periodic harmonics that can be extracted from input data set [5]. In this case we attract long data sets of geophysical data. A harmonic at period of 228.4±0.6 years with statistically significant amplitude is present at our spectrum of C14 [12,13]. Presence of 225-yr cycle in the W spectrum is evidence of solar origin the 228-yr cycle in C14. We should remember that source of the terrestrial radiocarbon C14 is the cosmic ray flux, which is controlled by solar activity and by variations of the geomagnetic field. According to [14] Houtermann first reported ~2300 and 208 yr periods in the C14 record. Solar activity was modeled by Damon and Jirikowic as a low-frequency harmonic oscillator in examining the atmospheric production of C14 found in the tree rings [15]. They found a recurrence period of 2115±15 yr and identified two powerful harmonics considered as fundamentals at 211.5 yr and 88.1 yr called respectively the Suess and Gleisberg cycles. Damon and Jirikowic noticed that the cycles with these periods seem to modulate the Schwabe 11 yr cycle and produced intervals of maxima and minima of solar external activity. In vicinity of these periods we extracted from data of C14 for the last 10,000 yrs non-stationary sinusoids with periods T=2230, T=228, T=210 and T=203, T=100 and T=87.7 yrs [16,12,13], which we shall discuss later. In addition, based on our analysis we regard solar activity as a low-frequency polyharmonic oscillator with non-linear effects [9].

The long-term trend extracted from the IMF data measured at AU by our self-consistent method is described by a stationary sinusoid at period of ~198±5 yr [17].

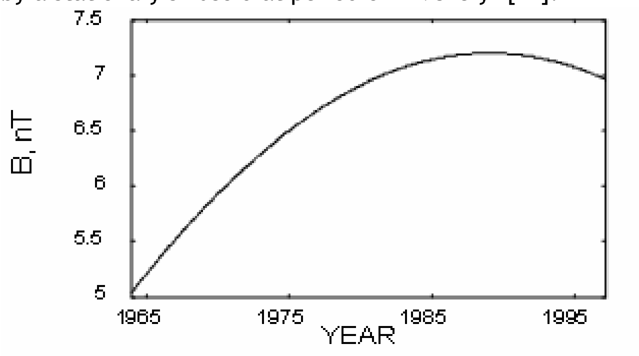

Fig.4 Plot of sine wave with T=198 yr from spectrum of the IMF value for the period of 1964-1997 [17].

Fig. 4 shows the IMF strength maximum at t=1990±5 yr and the IMF value increase by ~45% for the studied interval. As is mentioned above, reality of variations with T~200 yr beyond the studied time interval was shown by our spectral analysis of long data sets of C14 [12,11,16] and results by the others [15, 18]. This allows us to extrapolate variations of the stationary sine wave with T=198 yr from its maximum at ~1990 yr to its minimum at ~1890 yr that also suggests a doubled IMF strength during the last 100 years [17]. Moreover, we compared the time changes of the 198-year cycle with the W long-term trend in the Fig. 3. The 225-year non-stationary sinusoid in Fig. 3 shows rise from ~1900 to ~1985, decrease after 1985 and a doubled W during the last 100 years. Thus, the trends in the fig. 3, 4 are in good agreement.

Trend in north hemisphere temperature

Spectral peaks in the spectrum of the North Hemisphere temperature (Tnh) have confidence statistical level higher than 98% [19,13]. Fig. 5 shows time variations of the most power and long-periodic non-stationary sinusoid at mean T~1270 yr from this spectrum.

Temporal changes of amplitude and phase of the cycle demonstrate typical features of non-linear oscillations that points to a non-linear physical mechanism responsible for their generations (which are not shown here). Values of Tnh at Fig. 5 are higher since 1900 than values for Medieval Warming Period (~1000 yr). The Maunder minimum at t~1700 is the first deep minimum after regime change of the cycle at t~1250 yr. Change of oscillation regime (from damping to building up) is characterized by sharp shift of phase (so called “phase catastrophe”) and amplitude minimum. The time interval at t~1250 yr. is particular time of the Earth’s orbital motion: the planet passed perihelion of its orbit during winter solstice (previous such coincidence was in ~20,000 yr. BC) that points to astronomical forcing of the regime change of the cycle. Physical basis is presented in [12]. Time interval in vicinity of ~1250 yr is characterized by unexplained (in terms of traditional geophysical or astronomical theory) deceleration of the Moon motion derived by Newton [20] and discussed by us in [12]. Temporal change of the 1270-yr cycle shows rise of Tnh from t~1700 to present with rate ~0.5^{0}C/100 yr. This result is in agreement with suggestion of Akasofu [2] that "the recovery rate from the Little Ice Age may be as much as 0.5°C/100 years". The temperature rise described by the trend will continue up to ~2300 yr (extrapolation to future), if the oscillation regime of the 1270-yr cycle is not changed.

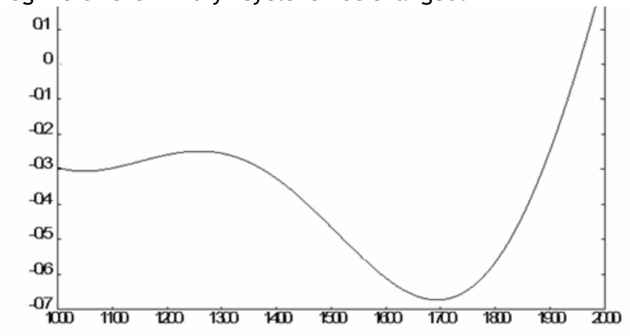

Fig. 5. Plot of nonstationary sinusoid at period T~1270 yr from the spectrum of north hemisphere temperature (^{0}C) for 1000-1998 [19]

72-year cycle in north hemisphere temperature

Non-stationary harmonic at T=72.6 yr has the highest amplitude in range of multi-decadal periods in spectrum of Tnh for the 1000-1998. We showed that rise of amplitude of the cycle began from ~1550 yr, far away from time interval of rapid increase of CO_2 [19]. In addition, sinusoid with period of ~72 yr has the highest amplitude in the spectrum of angular velocity of the Earth ω that we will discuss below. Both 72-yr cycles (in Tnh and ω) vary in phase during discussed time interval and for present. Our analysis shows: temperature rise with rate ~0.75^{0}C/100yr during ~1904-1940 with maximal Tnh in vicinity of 1940 and temperature decrease with the same rate during ~1940-1976 can be explained by temporal change of the 72-yr cycle in the Earth's rotation. Based on our analysis we predict rise of Tnh with rate not less than ~1.15^0 C/100 for ~1976 - 2012. We connect variation in rotation with period of 72 yr with cause of temperature variation with the same period. Additional argument to our conclusion was presented by Akasofu [2]: "the temperature decreased, in spite of the fact that the release of CO_2 increased rapidly". The argument shows failure of the CO_2 hypothesis to explain this temperature decrease. But the rapid temperature change described by power ~72-yr cycle can be explained by variation in rotation with the same period, i.e. natural cause. Details of our analysis of the 72-year cycles can be read in [19].

Spectrum of the Earth's rotation

Figure 6 shows spectrum of the Earth's rotation; υ is expressed in relative units $\upsilon=[(\omega-\Omega)/\Omega]10^8$, where ω and Ω are angular velocities [rad/sec] corresponding to the Earth's length of day and standard day (determined by atomic clock) accordingly [19]. Spectral component with period T=72 yr has the highest amplitude in the spectrum. A harmonic with T~70 yr has the largest power too in spectrum of υ calculated by the other method [8]. We also showed that the most power component from the V spectrum (calculated on basis of measurements of at 1 AU) with T=54 yr is solar-lunar cycle which includes whole number of the Moon's draconitic years, tropical solar years and also whole number of 10.8-yr solar cycles. This period of three Saros cycles (nearly 54 yrs) is known as a Triple Saros or exeligmos; the Saros cycle is eclipse cycle with period of nearly 18 years. Interpretation components of the spectra of V and the IMF by periods of lunar and solar origin can be found in our paper [21]. The fact that period of 72 yr is equaled to four Saros allows to assume its solar-lunar origin. The period of 72 yr is close to six periods of the 11.89-yr solar cycle (i.e. Jupiter cycle in our interpretation) shown in fig. 1.

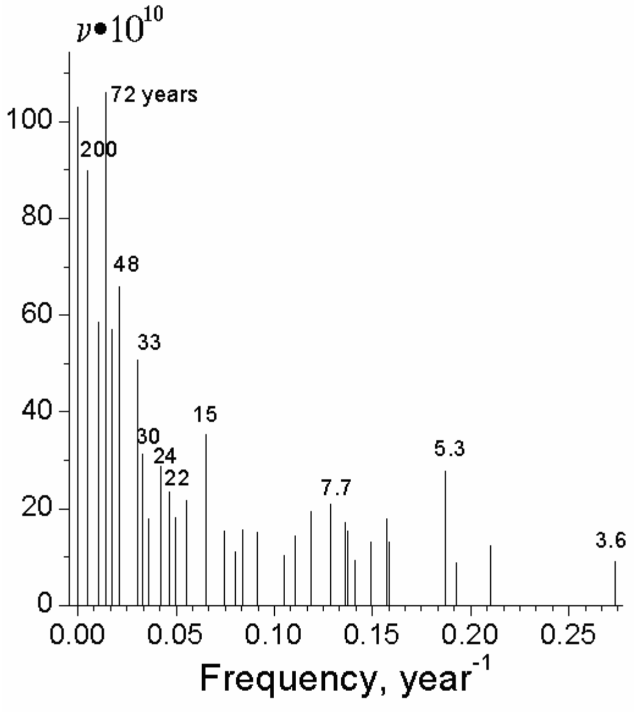

Fig. 6. Spectrum of deviation in angular velocity of Earth for 1656-2000. Amplitude is expressed in relative units □=(□-□)/□, where □ □ - angular velocities [rad/sec] corresponding to the length of day and standard day determined by atomic clock. Numbers near spectral lines point periods in years [25]

Fig. 7 shows plot of stationary sinusoid at period T=72 yr from the spectrum of the Earth's rotation. It is seen from the figure that the Earth slowed down and up during the studied time interval: we see extreme points at t=1940 yr and t=1976. The 72-yr sinusoid in υ demonstrates two minima (1904 and 1976) and two maxima (1940 and 2012). Thus, the Earth was accelerated from 1904 to 1940 and decelerated from 1940 to 1976. The Earth will accelerate its rotation to ~2012. Fig. 7 allows to conclude that the discussed temperature rise for the interval 1904-1940 with maximal value in vicinity of 1940 year was connected with maximal acceleration, and the unexplained temperature decrease for 1940-1976 is caused by deceleration of the Earth. As it has been mentioned above, the 72-yr cycles in Tnh and υ vary in phase during discussed time interval and for present. It is known that periods of acceleration of the

Earth's rotation (decrease of length-of-day) coincides with special epochs of atmospheric circulation. These epochs are characterized by weakening of zonal circulation (impulse moment of atmosphere is decreasing) and by rise of the north hemisphere temperature. Thus, the discussed temperature rise of Tnh and υ for the period 1904-1940 is in agreement with the known observational results [8]. Moreover, the Earth accelerates its rotation (maximum at ~2012 is extrapolation), consequently, the north hemisphere temperature is approaching to the next maximum of the 72-yr cycle. Coming of the maximum follows from correlation of Tnh and υ and does not mean its arrival exactly at ~2012, if one takes into account that 72-yr cycle in Tnh is non-stationary sinusoid with constantly increasing amplitude since ~1550 [19].

It has to be noted that amplitude of the 72-year sinusoid is higher than amplitude of well-known 200-year cycle in υ extracted from different long sets of geophysical data. Detail description of the 200-yr cycle in different proxies and prediction its development for future can be found in [22]. The fact that we extracted the 200-year cycle from the IMF magnitude at near-Earth orbit (fig. 4) proves its solar origin in the data. The stationary component with T=200 yr in fig. 6 has the longest period in the rotation spectrum (except trend). Plot of the 200-yr sinusoid is shown in. fig. 8 together with plot of 206-yr non-stationary sinusoid from the spectrum of Tgl. Cycles varied in phase for the interval ~1950-1970 and in opposite phase after. In addition, Maunder minimum in Tgl was observed during interval of the υ maximum of the 200-yr cycle near 1670 in fig. 8 (but it does not mean that the cycle is cause of Maunder minimum). Moreover, temporal change of 203-yr cycle in C14 also shows cooling for now (the C14 rise). However, the cycle in Tgl has mean period 206.5 yr, which is average period of cycles with T=203 and T=210 yrs from our C14 spectrum. The 206 yr cycle in Tgl displays maximum at ~1770 yr and minimum at ~1870 yr, which can be compared with corresponding maximum at ~1778 yr and minimum at ~1870 yr in trend of W shown in fig. 2. The latter is a clear argument to the 200-yr solar cycle influence on the 200-yr global temperature variation. Fig. 2 shows that these manifestations of the Tgl 206-yr cycle in solar trend is not full history about long-term trend in W. Fig. 3, which shows temporal changes of spectral band with T~228 yr, confirms our conclusion: in spite of the 228-yr solar signal decrease, solar trend is increasing for present (Fig.2). We conclude that long-term trend in W possibly includes 200-yr cycle and a high-amplitude cycle with longer period.

Trends in sunspots and global temperature

We discuss at this section trend in W, which began appear in our calculated mathematical models used data of W including annual values after 2000 year [23]. Our spectrum calculated on basis of W for the interval 1700-2005 also includes the 2000-yr trend. Trend in W described by long-periodic harmonic with T~2000 yr from the spectrum is presented in fig. 9 [23] Comparison of trends in temperature Tnh (fig. 5) and in sunspots W (fig. 9) shows correlated rise since ~1700. We see the long-term solar activity decline beginning from ~2000 in the fig. 9. However, the length of W is too short to do a final conclusion concerning long-term trend in sunspot activity. Presence of extreme point at t~2000 allowed us to extract the sine wave with such long period from the W data for the interval of 305 years.

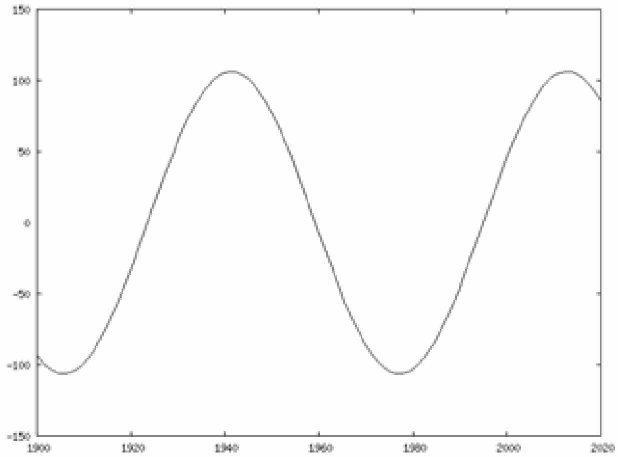

Fig.7. Plot of sinusoid at T=72 yr from the spectrum of deviation in angular velocity of the Earth [19].

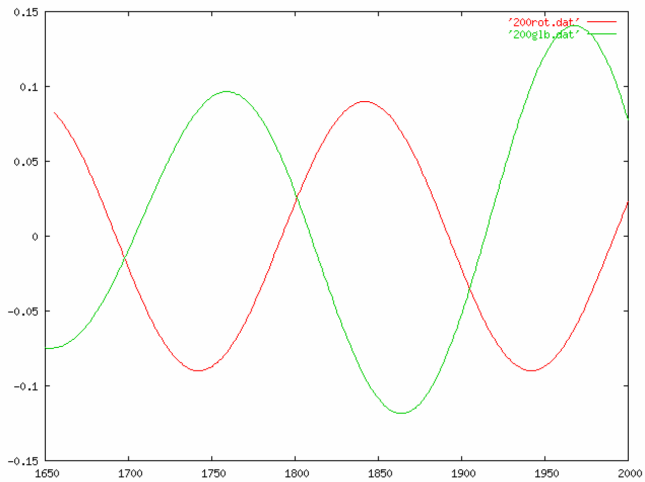

Fig. 8. Plot of the 200-yr cycle from the spectrum of global temperature (left axis, ^{0}C) and plot of sinusoid from the spectrum of deviation in angular velocity of the Earth υ [24,25].

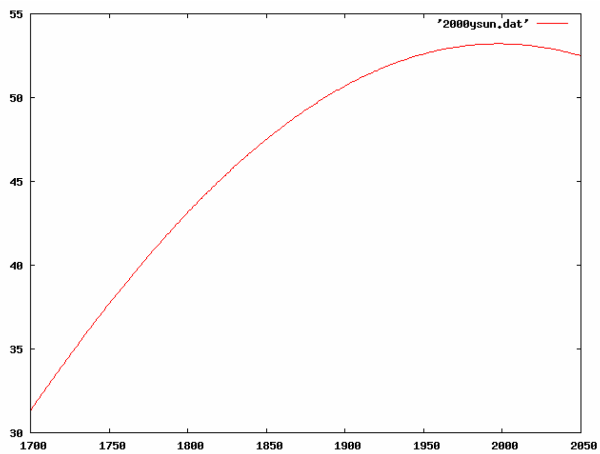

Fig.9 Plot of long-periodic cycle at T~2000 yr from the spectrum of sunspot numbers W for 1700-2005 [23].

The cycle with period of ~2000 yr in W (fig. 9) is presented by it's 2-nd harmonic with T~1000 yr in Tgl (fig. 10) [24,25].

The trend variation from the spectrum of Tgl described by non-stationary harmonic at T~1000 yr (fig. 10) is similar to the trend variation in Tnh in fig. 5 (with T~1270 yr). Temporal change of the 1000 yr cycle in C14 from our spectrum shows also decrease C14 since Maunder minimum [12,13].

Our previous analysis of radiocarbon series of C14 for the last 10,000 years showed a presence of the 2230-yr climate cycle described by non-stationary sinusoid; extrapolation of its temporal change to future points to the C14 decrease up to ~2600 (if oscillation regime is not changed) [12]. A cycle with T~2400 yr extracted by many authors from proxy C14 record in tree rings [14] can be caused by inertial motion of the Sun (i.e. the motion of the Sun around the center of the solar system) caused by Jupiter in [26]. The 2400-yr period appears to be stationary [14]. Based on the arguments presented above we come to conclusion that the most power 2230-yr climate cycle in C14 described by us in [12] can be caused by two cycles of solar origin with periods of ~2000 (fig. 9) and ~2400 years [24-26]. This effect of the cycle confluence (when we can not resolve periods of the component harmonics) is similar to the effect on smaller scale: non-stationary triplet described by harmonic with average period of 225 yrs occupies the 82-year spectral band of periods T= 202-284 yrs (fig. 3). At last we demonstrate long-term trend from the C-14 spectrum for the last 10,000 yrs (sum of harmonics a period of which is longer or equal to 1000 yr) [16] together with trend in global temperature in fig. 10. The variation of the 1000-yr trend in Tgl is in agreement with the long-term part of the C14 data for the analyzed time interval 1000-2000.

Authors of [27] argued that the next Grand Minimum probably will occur by 2015-2018. Moreover, their extrapolation indicates a significant decrease of the solar signal, and consequently a decrease of the global Earth's temperature in the forthcoming years. Note, decrease of solar signal does not mean decrease of the global Earth's temperature: we discussed above the solar-lunar 72-yr cycle in temperature and will discuss the difference more detail in section 8. Analysis of the 200-yr cycle temporal changes discussed above gives the next minimum in W and Tgl not earlier than 2075. In addition, we do not consider the minimum as cause of a Grand Minimum (such as Maunder). We showed that power 1000-yr cycles in Tgl and C14 show temperature increase and C14 decrease for present and future. Main contribution to Maunder minimum brought not the millennial cycle (that also concern centennial and bicentennial cycles) but the 2230-yr climate cycle, mean amplitude of which was four times larger than one of the 1000-yr cycle for the last 10,000 years [12,13]. It should to be noted that 550-yr oscillation in C14 (second peak according to power in the C14 spectrum, amplitude of which is about twice smaller than one of the 2230-yr cycle) is favorable for warming for present and future too. Authors of [28] found the 540-yr period in variations of angular moment of the Sun, i.e. it seems that the cycle has solar origin. At last it should be noted temporal change of 438-yr oscillation from our C14 spectrum, which can be interpreted as 5-th harmonic of the 2230-yr climate cycle: the cycle shows the C14 decrease since ~1985 that point to warming for long time. Without doubt long-term parts in spectra of C14 and Tgl point to warming for present and future (see also Fig.10).

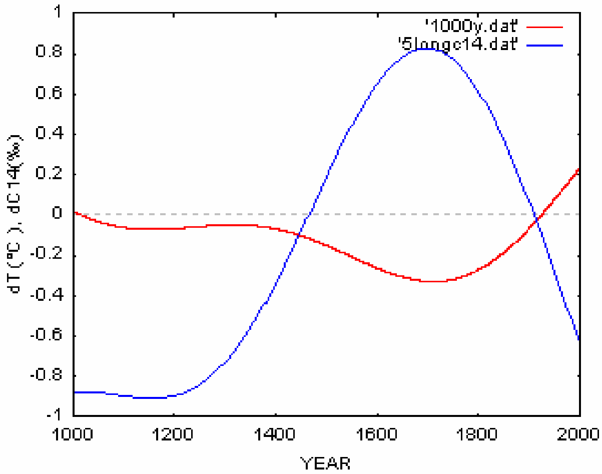

Fig. 10. Plots of trend in global temperature with period of ~1000 yr and trend in C-14 data [24, 25].

The predicted Minimum for the period 2015-2018 by the authors [27] we can connect with temporal change of high-amplitude non-stationary sinusoid in W with T=47 yr (fig.1). We described all parameters of the ~47-yr oscillation and detected their connection with generation of toroidal component in sunspot activity. In particular, time intervals of the amplitude extreme points of the cycle coincide with the time of a solar minimum; the next extreme points will be in ~2012.5 (possible final minimum of the 23-d cycle), after that in ~2023 (possible minimum of the 24-th cycle). Sharp phase shifts of the oscillation (influencing on all parameters of main solar cycle) occurred in ~1743 and ~1913 (Δt= ~170 yr), close to minima of the 0-th and the 15-th cycles [9]. The result points to the fact that such phase shift did not lead to a Grand minimum. Note, the cycle at T=48 yr is one the most power in our spectrum of the Earth's rotation too (fig. 6). The period ~50 yr was found in W by different authors. Moreover, we detected high-amplitude non-stationary harmonic with T=54±4 yr in the solar wind velocity, minimum of which hits the interval 2015-2018; similar decrease was in the middle of last century [17]. It is also interesting to note that ~100-yr cycle in W (fig. 1) is approaching to its minimum, similar to one occurred ~100 yrs ago (during 14-th solar cycle).

Cycles in sunspots and global temperature

Global phenomena on the Sun (such as sunspot numbers W) should be compared with global characteristics of the Earth (such as its global temperature). We used W as measure of direct solar activity due to the largest length of the data set that is very important for spectral analysis. Because W is not a physical value but an index (taking into account number of sunspot groups and total number of spots in all the groups) we studied correlation between all parameters of the solar wind measured during space measurements for physical sense to clear. Variations of W are correlated with ones in the IMF strength with Cc=0.95 [17]. The high correlation coefficient allows to consider W as a satisfactory indicator of the magnetic fields emerging from the Sun, causing variations in the total solar irradiance, interacting with terrestrial magnetic field, shielding the Earth from cosmic rays and etc. Thus, the Sun's variable sunspot activity (W) can be considered in terms of solar related forcing mechanisms (known or unknown).

In this section we study temporal changes of oscillations with the same periods from the spectra of solar activity (W) and of anomaly in global temperature (Tgl) to understand their connection. We attract temporal changes of the cycles from the spectrum of the Earth's rotation velocity (fig. 6) for physical mechanism to discuss. Spectra of W and Tgl (taking into account error bars) show components with the same periods T=200, T=130, T=48, T=30, T=24, T=22, T=10 T=5.3 years. Connection of temporal variations of sunspot activity W and Tgl has different character on different time scales. We have discussed above temporal changes of the 200-yr cycles in Tgl (fig. 8) and in the IMF strength (fig. 4) and came to conclusion that these cycles vary in phase with accuracy of definition of their periods. The 130-yr non-stationary sinusoids vary in phase for interval of 1700-1820 and in antiphase from 1820 (time of Dalton minimum) to present: W is decreasing but Tgl is increasing. We do not understand cause of such kind of the temporal variation and do not discuss it in this paper. But it has to be noted that Dalton minimum broke correlation between W and Tgl for the 130-yr oscillations. One of the most power cycles in the spectra (among multi-decadal cycles in Tgl) is a cycle with period of 30 yrs.

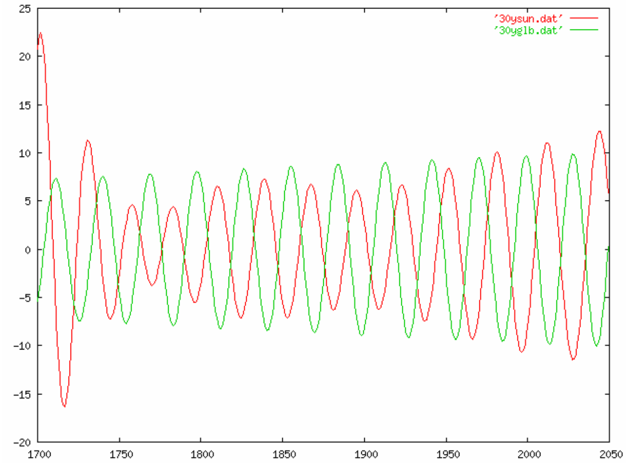

Fig. 11. Plots of the cycles from spectra of numbers W and global temperature Tgl with the periods of 30 yr [24,25].

Fig. 11 depicts plots of the 30-year solar and temperature cycles; for comparison of their variations we use relative units. We see that the cycles vary mainly in opposite phase after ~1800. Amplitude of both cycles is increasing with time at present; one was high at the beginning of ~1700 (and consequently at the end of Maunder's minimum). We presented temporal changes of non-stationary oscillations from the MGM spectra of Tgl and numbers W at periods T=10 yr in [24,25]. The 10-year cycles in W and Tgl vary in clear opposite phase since 1800 and for present.

We can not extract direct information on magnetic solar cycle from the W numbers set for reason of their positive sign. We can get only information on asymmetry of solar cycles relative to a sign of a magnetic field, since cause of difference of adjacent cycles from each an other is not only a magnetic field sign, but also varying conditions for generation of toroidal magnetic field. As result instead of rather narrow spectral band in vicinity of 22 years, the spectrum of W has broad maximum in range of periods 20-25 years. This complicated non stationary harmonic with period of ~22 year from spectrum of W varies in phase with the 22-yr non-stationary harmonic from spectrum of Tgl Figure 12 presents the temporal changes of the 22-yr cycles from our paper [24]. In addition, the 22-year variation in the Earth's rotation rate υ correlates with variation with the same period in Tgl [25]. This our result shows that necessary impulse moment (which is proportional to υ) for atmospheric circulation to be changed is not taken from the Earth. It is naturally to suggest that the impulse moment is taken from atmosphere. Really, it is known that periods of acceleration of the Earth's rotation (decrease of length-of-day) coincides with special epochs of atmospheric circulation. These epochs are characterized by weakening of zonal circulation (impulse moment of atmosphere is decreasing) and by rise of north hemisphere temperature [8]. A possible cause is a strengthening of inter-hemisphere atmospheric circulation. This mechanism we discuss below.

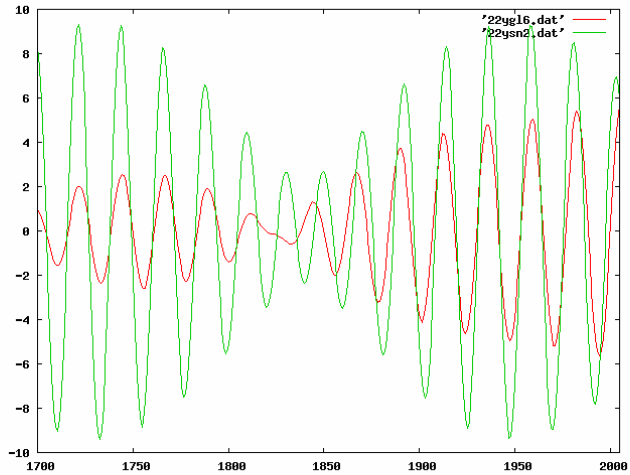

Fig.12. Plot of the 22-year cycles from spectra of sunspot numbers W and anomaly of global temperature [24].

22-yr cycles in sunspots, global temperature and a possible mechanism

To find difference between adjacent solar cycles we have carried out a special study. Length of solar cycle in our study was a time interval between two maxima in set of W (grouped traditionally into cycles with numbers 1-23 according to minima of W since 1755). We divide data of W into two groups with numbers n=1 or n=2 by the way that decline phase of solar cycle and rise phase of subsequent cycle come into the same group. Maximum of odd cycle is ascribed to group with n=1, but maximum of even one to group with n=2. In particular, the period between maxima of the 22-nd (t_{max}=1989.6) and the 23-d cycles (t_{max}=2000.3) was classified by the following way: if t >2000.3, then n=1; if t<2000.3, then n=2. Thus, decline phase of even cycle (the 22-nd) and rise phase of the next odd cycle (the 23-d) is attributed to group with n=2. But time interval of decline phase for odd cycle (21-st) and rise phase of the next even cycle (22-nd) we refer to group with n=1. Based on this method we showed that W for group with n=1 (W1) are larger than W for group with n=2 (W2) in annual variation of W [29].

Moreover, we found also that all electromagnetic parameters of the solar wind calculated on basis of measurements at near-Earth orbit (such as values of the solar wind electric field E and module of Poyting vector **P**=[**ExB**], where **B** is the IMF vector, **E** is the solar wind electric field vector) is larger for group W1 than corresponding parameters for group W2 in annual variation of these parameters [29]. Module of the P vector is instantaneous density of electromagnetic energy; direction of the vector points to direction of the energy propagation. Fig. 13 presents difference D in the electric field strength E calculated on basis of measurements at the Earth's orbit for two groups of data D=E(1)-E(2) [mV/m]; 1 corresponds to time intervals between maxima of the odd-even solar cycles (including maxima of odd cycles) and 2 corresponds to intervals between maxima of the even-odd cycles (including maxima of even cycles).

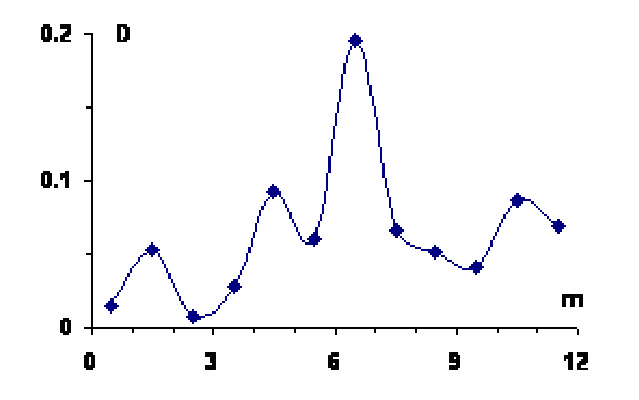

Fig. 13. Annual variation of difference D in the electric field strength E (mV/m) measured at the Earth's orbit between two groups of data D=E(1)-E(2), where 1 corresponds to time intervals between maxima of odd-even solar cycles and 2 to intervals between maxima of the subsequent even-odd cycles [29].

Fig. 13 presents difference D in the electric field strength E calculated on basis of measurements at the Earth's orbit for two groups of data D=E(1)-E(2) [mV/m]; 1 corresponds to time intervals between maxima of the odd-even solar cycles (including maxima of odd cycles) and 2 corresponds to intervals between maxima of the even-odd cycles (including maxima of even cycles). Fig. 13 demonstrates clear statistical maximum in D in July; mean value of E=1 mV/m. Difference in E between cycles W1 and W2 in July D=0.2 mV/m that makes the 20% rise of E from its mean statistical value. D in E between solar cycles of W1 and W2 in fig.13 in January is minimal, i.e. during summer in South Hemisphere (SH). In addition, contrast between two cycles in E displays strength in July, when machine works in atmosphere supported by temperature difference between illuminated polar cap of NH and dark polar cap of SH. The fact that E is one of the main parameters in the solar wind-magnetosphere interaction [30] points to a possible cause of the 22-year correlated variations in global temperature and sunspot numbers.

Well-known heat-engines raised by temperature difference between equator and poles are the most important. The first machine of this type works in the north hemisphere (NHM) and the second one in the south hemisphere (SHM). Sidorenkov [31] found out arguments to presence the other type machine in atmosphere: inter-hemisphere heat-machine (IHM). It is obvious, the larger temperature contrast between poles, the larger effect. Author [31] analyzed temperature disparity between north and south poles in the layer of lower atmosphere (1000 - 30 hPa) Dp= Tnp - Tsp (where Tnp is temperature at the north pole, Tsp at the south pole) and found that Dp=21^{0}C in January and Dp=34^{0}C in July. According to [8], the warmest region in this atmosphere layer is polar cap during summer. Such temperature distribution generates circulation cell between poles directed along meridian from summer hemisphere to winter one within upper atmosphere and from winter hemisphere to summer one within lower atmosphere. The season variation of impulse moment (angular moment) of zonal winds Az can be written in a form as Az ~ C - |Tnp -Tsp|, where C is constant (determined by mean temperatures at equator and poles); Tsp, Tnp are mean temperatures at poles [8]. The formula shows that the larger disparity in temperatures of poles, the smaller Az Due to the law of conservation of impulse moment the decrease of Az leads to increase to angular velocity of Earth ω. Thus, the IHM impedes work the main machines (NHM and SHM) and decreases impulse moment of atmosphere. The IHM works intensively in July (summer in NH) and in January (summer in SH). As result impulse moment of atmosphere zonal winds Az decreases up to minimal values in July, and the Earth's rotation rate ω reaches its maximal values. The second maximum in January in annual variation of the Earth's rotation rate is much smaller compared with one in July [8]. Moreover, based on observational data for the interval 1961-2000 Sidorenkov showed that annual variation of Az in SH and NH varies in anti-phase [8]. Because complete compensation of the SH and NH annual variations of Az does not occur (due to difference of their amplitudes), annual variation of Az in atmosphere on the whole is similar to the annual variation of Az in NH with its minimum in July. This result points to determining role of the NH warming to global warming.

Study of influence of mutual orientation of the Poynting vector P in the solar wind and the magnetic moment of the Earth Me on geomagnetic activity was carried out in our paper [30]. We showed that component Pm of the P vector along the Me vector (taking into account orbital and daily motions of Earth) has clear statistical annual variation (on basis of measurements near the Earth's orbit). The experimental data on high latitude geomagnetic activity, which is a response to changes in the mutual orientation of vectors P and Me are presented in our paper [30]. Electromagnetic flux determined by Pm-component is directed to polar cap of the NH for March-August and to polar cap of the SH for September–February. Current system arising in the polar cap ionosphere as response to input of the energy heats polar atmosphere. As it has been shown in the fig. 13, E reaches its high values in the cycles W1 in July, when P is directed to the NH. The overheating of the NH polar atmosphere in July during the W1 cycles compared with the SH polar atmosphere during the W2 cycles seems to explain correlated variations in Tgl and W.

Processes in magnetosphere controlled by the solar wind causes two main phenomena in the upper polar atmosphere: particle precipitation and convection of ionospheric plasma caused by the solar wind electric field E. The particle precipitation influences on conductivities and currents. High electron densities are caused by particle precipitation which in turn leads to high conductivities and currents. For example, a peak electron energy of a few kev causes a maximum in the lower E-region. Moreover, increase of plasma density is observed in the E-layer of ionosphere during day time. At high latitude this ionization can be more than an order of magnitude higher than the ionization by solar EUV radiation [32]. During night time the density can decrease to several degrees (from 10^5 to 10^3 cm^{-3}) [33]. Both the enhanced conductivity σ and E cause large electric currents mainly in the auroral zone and polar cap. Consequences of these currents are Joule heating of the ionosphere which is transferred to the neutral atmosphere and observational variations of the ground geomagnetic field. An observational fact connected with our mechanism is polar geomagnetic disturbance observed in summer in vicinity of local noon near geomagnetic pole. Intensity of the abnormal geomagnetic pole disturbance can reach ~500 nT and lasts for about one hour during quiet days; this polar disturbance has respond in the polar ionosphere [34]. In addition, annual variation of large geomagnetic disturbances shows an additional peak of high magnetic activity in July comparable with well-known peaks at near equinoxes [35, 36]. Aurora is a prominent visible aspect of influence of the particle precipitation discussed. Arcs of polar aurora is connected with field-align currents which mostly are caused by precipitated electrons with energy 1-10 kev (that corresponds to flux of 10^{-1}-10^{-2} Wt/m^2). Global FUV auroral imagers observed, for the first time, two similar auroral events in the southern polar cap due to intense (keV) polar rain electrons from the solar wind as observed by DMSP and Geotail. Such an aurora is called polar rain aurora. The aurora could fill the dayside polar cap initially and developed a dawn-dusk alignment. In data collected in July 2004, author noticed something unusual - a wave of polar rain with much higher energy than usual inside the aurora [37]. Zhang [37] has evidence that there may be more to polar rain than had been thought. The polar rain aurora appears over geomagnetic pole and move with very large velocity (~200 m/sec). Essential heating of upper atmosphere is observed in thermosphere during aurora. At polar latitudes the thermosphere temperature can rise up to 2000-3000^0 K. Based on the presented arguments we come to conclusions that electromagnetic energy is transferred mostly to the polar region by electric currents and accelerated particles. Both the enhanced conductivity σ and E cause large electric currents mainly in the auroral zone and polar cap. Convection of ionospheric plasma is also partly transferred to neutral atmosphere by frictional processes and influences on global circulation of the neutral gas. Annual difference in E for W1 and W2 cycles are determined mainly by their values during July ± 2 months: positive deviation of E, ω for W1 and negative deviation of E, ω for W2. Taking into account the fact that during W1 cycles increase of ω corresponds to decrease of impulse moment of Az (and consequently to rise of Tgl) we can formulate our result by the following way: positive deviation of E, ω and Tgl in annual averages for W1 cycles and negative deviations of E, ω and Tgl in annual averages for W2 cycles.

Amplitude of the cycle with T=22 yr in Tgl has relative small value. However, analysis of the components from spectra of temperature from NH and SH showed that the 22-yr cycles have sufficiently high amplitudes (but different values) and vary almost in opposite phase that is in agreement with the mechanism suggested. We could extract the 22-yr cycle in Tgl because compensation of their variations in both hemispheres is not complete. Power cycles in spectra of W and Tgl (such as with T=200 and T=30) can not be explained by this mechanism. Moreover, the multi-decadal cycles in rotation of the Earth (such as with period T=72 and T=33) demonstrate high rate in changes of temperature on the Earth. Problems arising in searching for a physical mechanism in the global temperature change with the decadal periods to be explained are discussed below.

Discussion: problem of climate change

Unfortunately, we have no clear understanding of causes of climate change. For instance, the multi-decadal variations in the rotation rate are connected closely with oscillations of the atmospheric circulation epochs, melting of glaciers in Greenland, Arctic and Antarctica, surface temperatures, content of greenhouse gas CO_2 and other climate characteristics. Because exchange of impulse moment between the Earth and the atmosphere is not enough to explain these multi-decadal variations it is suggested that the impulse moment of the Earth is redistributed between mantle and liquid core [8, references therein]. If it is so, the processes inside the core govern the geophysical systems controlled by the different physical mechanisms: the atmospheric circulation and climate, west drift of non-dipole component and secular variations of geomagnetic field and etc.

It is generally recognized that shifts in the climate regime are connected with sudden changes of other geophysical parameters, although in general every such system is controlled by different physical mechanisms. However, the speed and global synchronism of climate changes remains a major problem while attempting at understanding the links between the Milankovich forcing and climate. Berger [38] approached the Milankovitch theory along three directions: the accuracy of the astronomical solution of the planetary system, the calculation of the insolation available at the top of the atmosphere and its validation using paleoclimate records. We found in our spectra of C14 for the last 10,000 yrs long-term variations of the Earth's orbital parameters calculated by him: harmonics of the fundamental cycles of equinox precession and eccentricity [12]. Berger showed also the astronomical origin of the 100,000-yr periods and their instability, the frequency and amplitude modulations of the astronomical parameters. Really, in celestial mechanics the motions of celestial bodies are treated in terms of points with a mass and in approximation of minor perturbations. A linear response of the climate system to astronomical forcing could not explain entirely the observed changes. Abrupt changes refer to regional events of large amplitude, typically a few degrees celsius, which occurred within several decades – much shorter than the thousand-year time scales that characterise changes in astronomical forcing [3].

Avsjuk [39] presented quantitative evaluation of power of orbital and rotational motions of the Earth compared with power of geophysical processes (seismicity, volcanism, generation of geomagnetic field) showing that the energetic characteristics of the motions are considerably larger (of several degrees) than ones of the geophysical processes. Based on these estimates, one can consider all geophysical processes as different forms of manifestation of dissipative losses that accompany evolution of orbital and rotational motion of the Earth. The ratios of the periods of the orbital motions of the planets are related to their resonance (e.g. the resonance of Jupiter and Saturn was investigated by Laplace). Any mechanism of dissipation is absent in celestial mechanics, although, with no dissipation, no synchronization can be attained. The tidal forces play a role that regulates a system of gravitating bodies, and finally leads to a regime of minimum heat losses. The perturbations in the tidal force characterize that part of the force that is responsible, by some considerable amount, for attaining commensurability among the orbital motions. It is possible to separate, within the orbital motion of every celestial body, a non-perturbed (Keplerian) part, and a perturbed one. The first part is symmetric relative to the Sun center. The periods of asymmetric component are connected with the Sun motion around the mass center of the solar system. Based on method for periods of perturbed tide forces to calculate described in [39] we showed that components of our spectra of solar, geomagnetic and C14 data can be interpreted by the periods of the tidal forces of planets [11]. But the crucial point is to understand how and what mechanisms govern the transformation of the orbital signals into global changes of the geophysical systems.

A possible physical mechanism was suggested by us in [12] showing a possibility of a signal transformation of astronomical origin (arising during orbital motion of the Earth) to geophysical systems through small variations of dissipative parameters of dynamo system. It was suggested that cause of these small oscillations of dissipative parameters can be periodic tide forces of the planets. In this way, even a small change of the dissipative parameter of the dynamo can originate large changes of the current in the disk dynamo and, consequently, large increase of the magnetic field. Notwithstanding such disk dynamo can be much different, compared to the real processes that occur inside the Earth or the Sun, such simple non-linear model can simulate, in principle, the possible reaction of a dynamo system in terms of a feedback to the small variations of its dissipative parameters (its small amplitude plays no relevant role but ration between the small variations frequency and fundamental frequency of dynamo plays determining role). Our analysis in [12] is only the first step while seeking a solution for the complicated problem of the abrupt changes, and the appearance of large amplitude oscillations of the geophysical systems (including climate system).

The solar irradiance contributes directly to the Earth temperature, consequently its variability is of prime importance. Total solar output is now measured to vary (over the last three 11-year cycles) by approximately 0.1% peak-to-peak during the 11 year sunspot cycle. But irradiance variation varies by more a factor 2 in UV, and this has clear repercussions on the upper stratosphere [4]. One important mechanism can be the molecular dissociations in the UTLS region, which is likely the future key to understand some mechanisms [40].

At latitudes of 65 degrees the change in solar energy in summer and winter can vary by more than 25% as a result of the Earth's orbital variation. Because changes in winter and summer tend to be opposite, the change in the annual average insolation at any given location is near zero. Constant value of impulse moment of zonal winds in atmosphere is kept by work of the main atmospheric machines (NHM and SHM) caused by the solar irradiance. But the solar irradiation is not the only heat source of the upper atmosphere. Solar energy is captured by magnetosphere and ionosphere during interaction of the solar wind with terrestrial field. This paper focuses on changes in the inter-hemisphere atmospheric circulation caused by variations in the electro-magnetic parameters of the solar wind in the polar atmosphere, as resulting from the variations in the solar activity associated with the adjacent 11-year sunspot cycles (which have different season variation, fig. 13). The variations of electromagnetic parameters in W1 and W2 cycles can explain variation of Tgl from year to year. Dependence the Pm component (describing the energy flux to polar caps) from sign and value of the IMF Bx-component (changing during 22-yr cycle) was discussed in our paper too [30]. Based on our results we suggest a possible mechanism for the 22-yr variation in global temperature to be explained. The mechanism successfully reproduces the observed 22-yr variations in sunspots, global temperature and angular velocity of the Earth.

The analysis of processes in the Sun-Earth system leads to a better understanding of the influence of variations of solar activity on variations in global temperature and other fundamental parameters of the Earth on different time scales. Complicated problem of climate change can not be solved by one scientific discipline or one physical mechanism. When the Earth (with its spheres) as system alters its thermal balance, all geophysical systems undergo changes. Main problem is to find cause (and its consequences) which can explain observational results from different disciplines by a non-conflicting way. For a real understanding in climate change to reach synthesis of different scientific fields of knowledge and approaches is necessary.

Acknowledgements

I am grateful to organizers of IHY-ISWI Meeting “Heliophysical phenomena and Earth's environment”, 7-13 September 2009, Šibenik, Croatia for their invitation to present our results as review. My thanks are extended to an anonymous referee for his useful comments and co-editor of the journal Katya Georgieva for guidance the manuscript.

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