The "Sun–climate" relationship. III. Solar eruptions, north-south sunspot area asymmetry and earth climate

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Abstract. In this Paper III, the last one of the series, additional evidences are given that the fluxes of solar high energy particles, with energies higher than 100 MeV (the solar cosmic rays), are a very important component of the "Sun–climate" relationship (see also Paper I and Psper II). It is known that the total solar irradiance and the galactic cosmic rays produce an integral climate effect of cooling in sunspot minima epochs and warming in sunspot maxima epochs. Contrariwise, the powerful solar corpuscular events cause cooling predominantly during the epochs of their high levels. By this reason subcenturial global and regional temperature quasi-cyclic changes with duration of approximately 60 years could be tracked during the last 150 years of instrumental climate observations. This paper shows that this subcenturial oscillation is very important in the group sunspot number data series since the Maunder minimum up to the end of 20th century. Only a relatively short period, closely before and during the last centurial Gleissberg-Gnevishev's minimum (AD 1898-1923), when this cycle is totally absent, is an exception there. Thus the solar eruptive activity make the total "Sun–climate" relationship essentially more complicated as it could be expected if only the total solar irradiance and the galactic cosmic rays variations are taken into account. From this point of view the climate warming tendency after AD 1975 has rather natural than anthropogenic origin. It is also shown that the efficiency of the solar corpuscular activity over the climate strongly depends on the "north-south" asymmetry of the solar activity centers (as a proxy the sunspots area north-south asymmetry index A is used there). The climate cooling effect in the Northern hemisphere is most powerful during the epochs of predominantly positive values of A. This effect is very significant in combination with high level of the index of the group sunspot number. A strong quasi 120-130-year "hypercycle" has been detected in the A index during the period of AD 1821-1994. Most probably the observed 120-130-year cyclity in the climate and cosmogenic ^{10}Be continental ice core data (both "Greenland" and "Antarctic" series) is related to this cycle. In the end the expected climate changes during the next decades and especially the new solar sunspot cycle No 24 are discussed on the base of the "multiple" nature of the "Sun–climate" relationship.
Key words: Sun, sun-climate relationship, sunspots, sunspot asymmetry

Зависимостта "Слънце–климат". III. Слънчеви избухвания, северно-южна площна асиметрия на петната и земен климат.

Борис Комитов

В тази последна Статия III се дават допълнителни доказателства, че потоците слънчеви частици с енергия над >100 MeV, т.нар. слънчеви космически лъчи, са много важна компонента на връзката "Слънце-климат" (виж също Статия I и Статия II). Общата слънчева радиация и галактичните космически лъчи дават интегрален климатичен ефект на захлаждане при слънчеви минимуми и на затопляне при слънчеви максимуми. Обратно, мощните слънчеви корпускулярни явления предизвикват застудявания през епохите на техни високи нива. По тази причина се наблюдават субвекови квази-циклични изменения на температурата от глобален и регионален характер с приблизителна продължителност от около 60 години, които могат да бъдат проследени през последните

150 години на инструментални климатични наблюдения. В статията е показано, че тази субвекова осцилация е много важна в редицата от данни за броя на групите слънчеви петна от края на Маундеровия минимум до края на XX век. Изключение прави само един относително къс период малко преди и по-време на последния векови минимум на Глайсберг-Гневишев (1898-1923), когато този цикъл напълно отсъства. По този начин ефектът от слънчевата еруптивна активност прави значително по-сложна връзката "Слънце-климат", отколкото би следвало, ако се отчитат само вариациите на Общата слънчева радиация и на галактичните космически лъчи. От тази гледна точка тенденцията на затопляне на климата след 1975 година има по-скоро естетствен, отколкото антропогенен произход. Показано е и, че ефективността на въздействието на слънчевата еруптивна активност върху климата силно зависи от "северно-южната" асиметрия на центровете на слънчева активност (като индикатор е използван индексът на северно-южна асиметрия на площите на слънчевите петна A). Ефектът на климатично захлаждане в Северното полукълбо е най-силно изразен през епохи с положителни стойности на A. Ефектът е много силен в комбинация с високи стойности на броя на групите слънчеви петна. Установен е силен силен квази-120 годишен "хиперцикъл" в данните за A за периода 1821-1994 година. Най-вероятно цикличните процеси в климата с продължителност 120-130 години (Статия I) както и тези в данните за космогенния ^{10}Be от континенталните ледници в Гренландия и Антарктида, са свързани с този цикъл. Накрая, на базата на "много-компонентната" природа на връзката "Слънце–климат", се дискутират очакваните климатични промени през следващите десетилетия и по-специално по време на новия слънчев цикъл No 24.

1 Introduction

According the most perceived point of view the "Sun–climate" relationship during the present postglacial era (Holocene, the historical time scale) is realized predominantly by the total solar irradiance (TSI) variations (Solanki, 2002; de Jaeger & Usoskin, 2006). The TSI–index is well known since AD 1978 on the base of satellite observations (Frohlich et al, 1997; Pap et al., 2003). The last one has corresponded well to the overall sunspot activity (the International Wolf's number R_i and the Group sunspot number (GSN or R_h)since AD 1610(Lean et al., 1995; Lean, 2000, 2004; Krivova, 2007). There are also a significant number of theoretical (numerical), mixed type (statistical + theoretical) or "pure" statistical studies in which the relationship "sunspot activity $-->$ solar magnetic flux $-->$ TSI" is investigated (Lean et al, 2000; Solanki et al., 2002; Krivova et al., 2007 etc.).

On the other hand there are evidences that an additional mechanism of indirect Sun's forcing over the climate due to the modulation of galactic cosmic rays (GCR) by the solar wind exists. The first works in this field are by the middle of 1970s (Dickinson, 1975). The aerosols and clouds production rates forced in the lower atmosphere by the GCR-flux increasing during the sunspots minima epochs is discussed by Svensmark & Friiz-Christiensen (1997) and Yu (2002). There are also some interesting results of the work by Tinsley (2000), concerning the GCR-flux influence over the atmospheric electricity and circulation.

It has been marked by many authors that the "overall sunspot activity $-->$ TSI $-->$ climate" relationship is far not enough to explain the real climate dynamics during the last 400 years since AD 1610. As it is pointed out by Thompson (1997) only 25% of the global warming effect after AD 1850 could be explained by the TSI increasing during the this time. Additional factors should be searched to explain the remaining 75%. Especially after AD 1975/80 there is a total divergence between the TSI and the global temperature changes (Solanki, 2002; Usoskin et al., 2005; Lockwood & Frohlich, 2007). This phenomena could not be explained satisfactory even if the GCR-flux is taken additionaly into account. That is why for the last 30-35 years by the opinion of many researchers the human activity is the factor, which play the dominant role for the climate changes.

In Paper I it has been shown that the residual variations to the regressional models "sunspot activity – temperature data" both for the Northern hemisphere (AD 1610-1979) (Moberg et al., 2005) and for the World Ocean (1856-1995) (Parker et al., 1995) are far not occasional. There are well expressed cyclic oscillations in the quasi-centurial and subcenturial range. The spectra of the last ones is more complicated in the Northern hemisphere "residual" data series (powerful cycles by duration of 54-67 years (doublet) and 120-130 years), while in the World Ocean one there is only a strong cyclic 58-63-year oscillation (doublet) as well as essentially weaker trace of 88-year one. It has been summarized finally in Paper I that there is powerful quasi-60-year climatic cycle in the modern epoch. The last one plays a very important role in the climate , causing few waves of cooling and warming since the end of Maunder minimum. They are superimposed over the general regressional relationship "sunspot activity–temperature data" during this time. It has been also shown in Paper I that the climate warming epoch after AD 1975 up to 2005-2006 well correspond to the serial upward phase of this 60 years cycle.

In Paper II it has been found that a very powerful quasi-60-year cycle exists both in the middle latitude aurora (MLA) (Krivsky and Pejml, 1988) as well as in the "Greenland" ^{10}Be data series (Beer et al., 1990, 1998). It has been shown that there is a very good time coincidence between the corresponding 60-year cycle extremums in the both series. The local 60-year cycle maximums in the MLA and ^{10}Be series during the last 300 years since AD 1700 correspond to subcenturial temperature minimums. They are well expressed in the both studied temperature series, but essentially better in the World Ocean ones.

The MLA events occur in the upper Earth atmosphere and by this reason they are strongly independent from the troposphere processes and the climate. Their primary sources are active events such as the coronal mass ejections (CME). Consequently, this is related to the 60-year cycle in this series too. Due to this fact it has been concluded in Paper II that: (1) The quasi-60-year ^{10}Be cycle is mostly probably of solar origin and it is caused by an yield of solar high energetic protons $E > 100$MeV in the total production rate of this "cosmogenic" isotope in the stratosphere; (2) The quasi-60-year climate cycle is caused by the same one high energetic solar corpuscular events; (3) The increasing of the solar high energy particles (probably mainly protons) fluxes lead to the same effects in Earth atmosphere such as the galactic cosmic rays with the same energies, i.e. an increasing of the aerosols production rate and cloudness and as a final effect – to a climate cooling.

The aim of this last Paper III is to make a more detailed analysis and to give additional arguments for the important role of eruptive solar processes as a climate forcing factor. It is given a strong evidence that the north-south asymmetry of the eruptive events plays a very important role. It is demonstrated that the total "Sun–climate" relationship is much more complicated as it is follows if only the TSI and GCR flux changes are taken into account. However, it account fits much better the real observed climate variations both in the presence and in the past.

2 Data and methods

Five data sets are used in this study:

(1) The Northern hemisphere temperature data series from AD 1610 to 1979, especially the last 370 years from the data set of Moberg et al. (2005). The mean temperature between AD 1961 and 1990) is used as a "zero level".

(2) The World Ocean temperature data series from AD 1856 to 1995 (Parker et al., 1995). The "zero level" there is the mean temperature in AD 1940.

(3) The Group sunspot number data series from AD 1610 to 1995 (Hoyt & Schatten, 1998).

(4) The middle latitude aurora (MLA) annual number data series N_{Aur} from AD 1700 to 1900, i.e. the last two centuries from the catalog of Krivsky & Pejml (1988) with the most certain data. The catalog data for the period AD 1000-1900 are published in the National Geophysical Data Center ($ftp: //ftp.ngdc.noaa.gov/STP/SOLAR_DATA/AURORA$).

(5) The index of north-south sunspot area asymmetry A between AD 1821 and 1994, which is published in the Pulkovo Observatory archive

The main methods, which are used there are: the $T-R$ periodogram analysis for detecting of cycles in the time series (see Paper I), as well as a multiple correlation-regressional analysis.

3 The results and analysis

3.1 The temperature "residuals", middle latitude aurora and the north-south sunspots area asymmetry

The next step in our study (see also the previous Paper I and II) is to estimate how significant is the possible contribution of the solar "eruptive" component into the studied temperature series. For better revealing of this contribution we will study the correlation between the middle latitude aurora (MLA) annual numbers of such auroras (N_{Aur}) and the temperature "residual" series ($\Delta_2\Theta$) from the the "sunspot activity–temperature" regression model (4) in Paper I for the Northern hemisphere. The usage of MLA data as a rough solar eruptive activity proxy is limited between AD 1700 and 1900 by two circumstances: serious lack of data before AD 1700 and absence of data in the basic catalog for the 20th century as it has been mentioned in Paper II

The coincidence between the MLA activity maximums and the subcenturial local temperature minimums as opposite events is shown on Fig.1. All epochs of positive changes (relative warming) with mean duration of 25-30 years well correspond to MLA fading tendencies. Contrary, the relative cooling tendencies dominate during the periods of the auroral activity increase. As a result there is a well visible quasi- subcenturial (50-70-year) "cooling-warming" cycle in approximately anti-phase to the corresponding "auroral" cycle. The conclusions for the reversed relationship between the high energetic solar corpuscular radiation and the Northern hemisphere temperatures is confirmed and visualized on Fig.1.

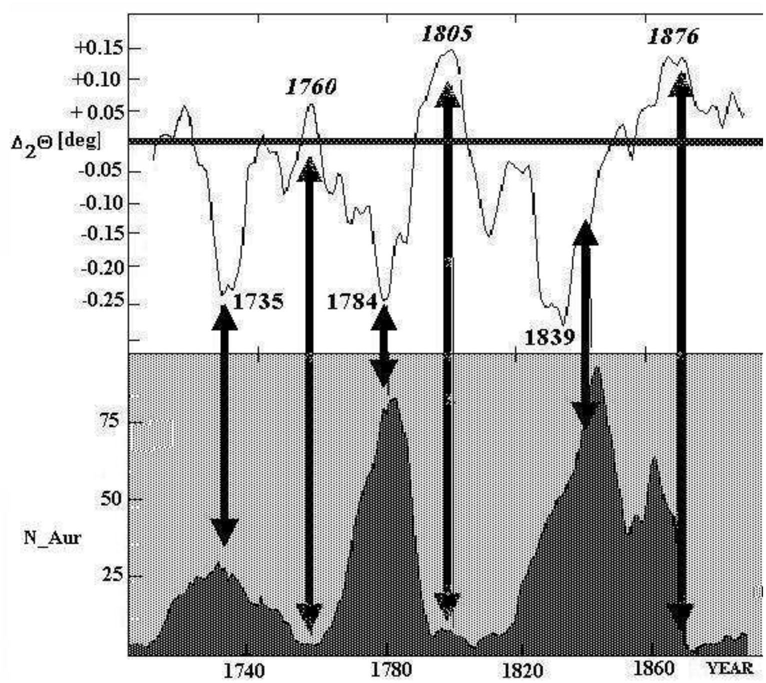

Fig. 1. Up: The smooth 11-year residual variations $\Delta_2\Theta$ of Northern hemisphere temperature data (Moberg et al., 2005) after removing of the regressional model "Group sunspot numbers – Northern hemisphere temperature" (Paper I). The last one corresponds to the zero-level (the thick horizontal line); Below: The smoothing 11-year annual MLA numbers

The coefficient of linear correlation between the both smoothed series is r = -0.43. It is about 7.5 times larger as its error and it corresponds to high statistical significance (the probability of the "zero hypothesis" is P less than 10^{-6}). The relationship is slightly better if a logarithmic type fitting for the relationship is used, i.e. $\Delta_2\Theta = a * ln(N_{Aur}) + b$. The correlation coefficient in this case is r = -0.45. Because the logarithmic relationship is less sensitive then the linear one it follows that the climate effect of the solar corpuscular events is significant if the activity of last ones is at enough high level.

It should be noted again that the MLA annual number N_{Aur} is very rough proxy for this activity. It could not to be estimated by N_{Aur} how powerful are the separate MLA events, their corresponding solar sources and the corpuscular fluxes. That is why the so founded coefficient of correlation could be much better as the obtained above if a better proxy for the eruptive activity is used. Consequently the value of 20-25% from the total variance of the residual series, caused by the eruptive solar factor should be taken as the possible lower limit of the same one.

On other hand this relatively weak value of r indicate that there is a very important factor (or factors) not taken into account. Is it the last one concern the Sun or it has a terrestrial origin?

Many studies have considered the spatial distribution of the active regions on the solar disk as an important component of the "Sun-climate" relationship since the middle of 20th century. The most useful proxy for such aims is the index

(1) $A = (S_N - S_S)/(S_N + S_S)$.

Here S_N and S_S are the total sunspots areas in the Northern and Southern hemisphere of the Sun, respectively.

The Northern Solar hemisphere should be essentially more geoeffective as the Southern one as it has been pointed out by Loginov (1973) by geometric causes. As a "geoefficiency" the ability of the solar eruptions to force over the Earth magnetosphere and atmosphere geomagnetic storms, aurora, ionospheric disturbances and other geophysical events in the stratosphere and troposphere is there considered. Consequently, if a climate forcing by solar eruptive events is assumed then the asymmetry index A included as an additional factor should lead to much better modeling of the total solar effect over the "residual" series (the $\Delta_2\Theta$–values), as if only the MLA annual number is taken into account. The new model should be a multi-factor type.

The best of sunspots area north-south asymmetry data series for our aims is published in the Pulkovo Observatory Extended Data Archive. It contains the mean annual data of A-index since AD 1821 up to 1994. As in the case of the all other data the 11-year smoothed values are used there. The plot of the both smoothed series of the asymmetry index A and temperature residuals $\Delta_2\Theta$ (the dotted line) are shown on Fig.2.

It is clearly visible that the strongest negative values of $\Delta_2\Theta$ near to AD 1839-1840 and in the end of 1950th are in avery good coincidence with the local maximums of A, when the values of the last one are strong positive. The local warming maximum near to AD 1940 corresponds to local minimum of A too, but the values of the last one are slightly positive. There is only one period between AD 1880-1910/1911 when the negative "residual" values corresponds to a weak local minimum of A. This period is interesting also by the last centurial solar minimum, which has been started at the end of 19th century. In generally there is a well expressed anti- correlation between the north-south sunspot area asymmetry index and the temperature changes in the Northern hemisphere of the Earth between the deepest phase of the solar Dalton minimum and AD 1980.

If the efficiency of the solar eruptive events over Earth climate depends on the north-south solar activity asymmetry and the Northern hemisphere is essentially more geoeffective (Loginov, 1973), than the Fig.1 and Fig.2 are a good confirmation for the last one. The very deep local minimum of of $\Delta_2\Theta$ near AD 1840 corresponds well the both maximums of N_{Aur} and A.

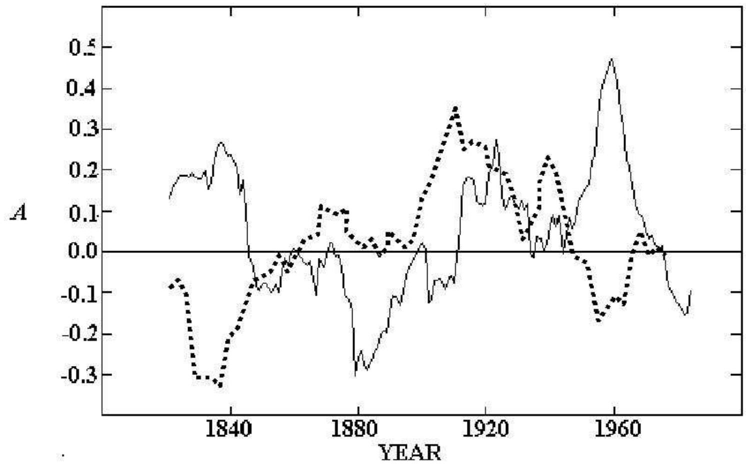

Fig. 2. The north-south sunspot area asymmetry index A during the period AD 1821-1994 (by the bold line) and the temperature residual $\Delta_2\Theta$ series in Celsius /Kelvin/ degrees (11-year smoothed values). The numerical values on the Y-axis for the both series are identical.

There are not catalog data for the MLA in the middle of 1950th, but out of doubt is the maximum of Zurich cycle No 19 in AD 1957 corresponding to a very high level of eruptive activity. The extrapolated maximums of MLA activity outside the end of Krivsky & Pejml catalog data series should be near to AD 1910/1911 and 1975, while near to AD 1940 should be a minimum as it has been pointed out in Paper II. This well corresponds to the very high MLA activity during the cycles 18, 19 and 20. The temporal climate cooling between AD 1940 and 1975/76 could be satisfactorily explained by the the combination with the strong maximum of A (a very expressive domination of Sun Northern hemisphere activity) in 1950th and its remaining positive levels in 1960th.

This preliminary conclusion should be tested on the base of multi-factor correlation-regressional analysis. This part of the study has been provided on two stages.

The Northern hemisphere: AD 1821-1900 The period before AD 1900 has been investigated on the first stage. This separation is taken due to the fact that before this calendar year the MLA annual number N_{Aur} could be used as a proxy for the solar corpuscular eruptions. The smoothed 11-year data series of A, N_{Aur} and R_h (the Group Sunspot Number) are used as possible factors for the changes of $\Delta_2\Theta$.

The first step is the determination of the coefficients of linear correlation r between the each pair of the parameters $\Delta_2\Theta$, A, N_{Aur} and R_h. They are: -0.407 for the pair $\Delta_2\Theta$ and N_{Aur} -0.722 for $\Delta_2\Theta$ and A, and -0.560 for $\Delta_2\Theta$ and R_h.

The values of correlation coefficient r between the potential factors R_h, N_{Aur} and A should also be estimated. The high module values of r in the last case are an indicator that they are not enough independent each other. Therefore, in a lot of the similar cases one of the both factors in the multiple model play minor role and it may excluded even if the coefficient of correlation between the factor and the prediction is high. The rule in this case is that in the model remain this factor, which is better correlated with the prediction. The correlation coefficients r between the potential factors are, as follows: +0.530 for the pair A and N_{Aur}, +0.621 for N_{Aur} and R_h, and +0.375 for R_h and A. All of the obtained values of r are statistically significant with probability >99.9%.

The very high anti–correlation between the "residual" temperature data $\Delta_2\Theta$ and the sunspot area asymmetry index A needs to be pointed out. On other hand there is a relative weak relationship between R_h and A and a good correlation between R_h and $\Delta_2\Theta$. The last one is better then the linear or logarithmic relationship between N_{Aur} and $\Delta_2\Theta$ (r=-0.407). However the correlation between N_{Aur} and R_h is higher (r=+0.621) then the correlation between A and N_{Aur} (r=+0.53). These results show that most probably in the multiple regression models the relationship between $\Delta_2\Theta$ and MLA could be totally captured and described by the terms describing A and R_h or their interaction.

A large number of one-, two- and three factor regressional models, including also different non-linear terms, has been obtained. The multiple coefficient of correlation R and the Snedekor-Fisher's F-test has been used for the selecting of the best of them. It has been found that the best of the all is

(2) $\Delta_2\Theta = 0.07625 + 0.499A - 1.224A^2 - 1.943.10^{-8}R_h^4 - 0.02334AR_h$, with R=0.888 and F=4.45.

The first important feature of this formula is the absence of any term, containing the annual number of middle latitude aurora, i.e N_{Aur}. The model (2) is a multiple function of two parameters – the group sunspot number R_h and the sunspot area asymmetry index A. Obviously, the influence of the solar high energetic corpuscules, for which the auroral activity index N_{Aur} as a proxy has used to this moment, is better approximated by the nonlinear terms of the types R_h^4 and AR_h. Both coefficients of these terms are negative. It is provided by the R_h^4 term that there is a small climate cooling effect in the range of 0.2K, if the sunspot activity is very high (the smoothed 11-year R_h value is >80-100). The strong nonlinearity of this term expresses by our opinion the fact that during the investigated period the intensity of the most powerful eruptive events roughly corresponds to the higher levels of sunspot activity.

The "interactive" two-factorial AR_h term is much more interesting. The sign of its climate effect depends by the sign of A: A negative value of the sunspot area asymmetry corresponds to a warming, while in the cases of higher sunspot activity in the Sun Northern hemisphere should be related to a climate cooling effect. If we use typical values for $|A|$=0.15 and R_h=50, the mean total amplitude effect over the $\Delta_2\Theta$ values is approximately 0.02334 x 0.15 x 50 x 2 = 0.35K. It expresses well the typical maximal deviations of the real smoothed 11-year Northern hemisphere and World Ocean temperatures to the corresponding "sunspot activity–temperature" models (Paper I). On this base it could be argued that the "interactive" term gives in the most of the cases the main yield for the $\Delta_2\Theta$ magnitude at least in the 19th century.

The last conclusion could be confirmed when an estimation of the both "pure" A-terms is made. The nonlinear A^2 -term gives always cooling effect, but it is significant only at high by module values of A (>0.2-0.3), while the linear term lead to cooling effect in range of 0.1 K if A=-0.2, or warming if A=+0.2. Thus the both "pure" A-terms are more important only during of the epochs of a very low sunspot activity when R_h tend to zero.

The F-parameter used there is defined as $F = S_t^2/S_0^2$, where S_t^2 is the total variance (the factors variance S_f^2 plus the residual variance S_0^2). Consequently for the model (2) S_f^2 = 4.45 -1 =3.45, i.e the both factors partition in the total variance is 3.45/4.45 =0.78. Thus there is an evidence that 78% from the variations of $\Delta_2\Theta$ during the epoch AD 1821-1900 are caused by a certain solar origin and only 22% are due to other, not taken into account factors, or occasional data errors.

The Northern hemisphere: AD 1913-1979 The catalog of Krivsky & Pejml ended in AD 1900, as it has been already noted above. On the other hand it has been pointed out by our multiple regressional analysis that the index of asymmetry and non-linear sunspot activity terms in the model are better proxy of the solar corpuscular events over the Northern hemisphere temperatures as the annual numbers of the middle latitude aurora. That is why for the multiple regressional analysis of the "residual" $\Delta_2\Theta$ temperature series during the 20th century only the A and R_h indexes as factors has been used. The aim is not only to estimate the yield of the solar corpuscular activity for the climate changes during the first 7-8 decades of the previous century, but also to compare the potential evolution of the relationship with the same one during the 19th century.

It has been decided AD 1913 to be chosen as a start year. By the opinion of many authors the new centurial solar cycle has been started then. This is the middle moment of the pair Zurich cycles No 14-15. On the other hand near to this date there is a breakpoint for the long time upward trend in the $\Delta_2\Theta$ data series, which has been started in AD 1839/40, very soon after the end of the Dalton minima.

The comparison of the pairs coefficients of linear correlation r shows for three significant differences relationed to the period AD 1821-1900: (1) The coefficient of correlation for the pair $\Delta_2\Theta$ and R_h is -0.793 vs -0.560 for the 19th century; (2) The corresponding coefficient is r = -0.26 between A and $\Delta_2\Theta$ vs -0.722 (19th century), but it remain statistically significant at level >95%; (3) For the pair A and R_h the coefficient r falls dramatically from -0.375 up to -0.008, i.e. unlike the 19th century a real relationship between the sunspots area north-south asymmetry and the sunspot activity is absent. By our opinion the total independence of the both solar activity indexes each other is the main cause for the changes of the other above mentioned relationships.

It has been found that the best among all the tested multiple regressional models is expressed by the formula

(3) $\Delta_2\Theta = 0.715 - 0.965A + 1.537A^2 - 0.00852R_h$,
with R=0.861 and F=3.67.

There is no "interactive" AR_h term in this formula. This is easy to be explained. The smoothed asymmetry index A is positive in the almost all studied interval, except only one smoothed value near to AD 1933. The yield of such term strongly depends not only by the sunspot activity level, but also in what Solar hemisphere this activity is predominated.

The factor variance in (3) is equal to 2.67/3.67 = 0.72, i.e. about 72% from the total variance of $\Delta_2\Theta$.

The World Ocean "residual" series (AD 1856-1994) The Pulkovo sunspot asymmetry data series is ended at AD 1994. That is why the last AD 1995 has been excluded in the provided multiple regressional analysis for the World Ocean residual temperature data series. The general statistical relationship "Group Sunspot Number – World Ocean temperature" is much closer as the corresponding one for the Northern hemisphere (r=+0.877, see formula (5) in Paper I). By the multiple regressional analysis procedure for the "residual" World Ocean temperature variations $\Delta_2\theta$ when A and R_h are used as factors (predictors), it has been found that the best fitting is:

(4) $\Delta_2\theta = 4.535 - 0.462A + 1.156A^2 - 0.327R_h + 0.08249R_h -$
$8.678.10^{-5}R_h^3 + 3.24.10^{-7}R_h^4 - 0.0132AR_h$, with R=0.814; F=2.79.

The model (4) is strongly non-linear, but it contains the main features, which has been described above, i.e. general anti-correlation between the temperature "residuals" by one side and A, R_h and AR_h by the other one. The factor variance S_f^2 is about 64% from the total variance S_t^2.

3.2 The cycles in the sunspot area asymmetry index A series (AD 1821-1994)

One of the steps in the present study is an analysis for the existence of cycles in the A-index data series. The main field of interest there is the possibility for existence of statistically significant cycles by subcenturial and near-centurial duration and their comparison with the corresponding temperature "residual" data series spectra. On Fig.3 the $T-R$ correlogram (see Paper I) of the A-index series (AD 1821-1994) is shown. The time step ΔT is 0.5 years. The starting period is T_0=2 years, the upper limit is at T_{max}=402 years.

As it is shown there are two main cycles with durations of 42.5 (4 Schwabe-Wolf's cycles) and 114.5 years. The second one is much more powerful. There is also an adjacent secondary peak at T=145 years, thus it could assume that there is a doublette structure which mean duration is about 125-130 years. However, it should be taken this result with some reserve by the fact that the duration of the founded cycle is comparable with the length of the all data series (174 years). By this one it could be determined rather as a "trend–hypercycle" as just a "cycle". On the other hand the very high correlation coefficient R=0.72 at T=114.5 years shows that most probable the quasi-120-year cycle is an important feature of the north-south sunspot area asymmetry dynamics.

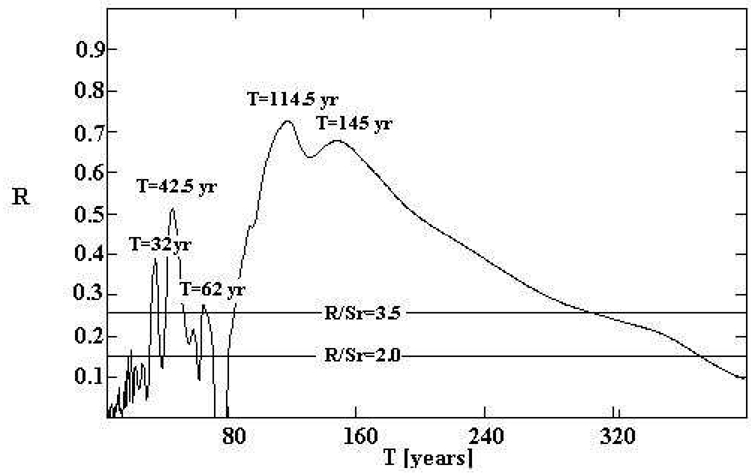

Fig. 3. The $T - R$ spectra of the north-south sunspot area asymmetry index A (AD 1821-1994; smoothed 11-year values)

As it has been already pointed out in Paper II that a hypercycle by duration of approximately 117 years has been found for the long-lived coronal filaments (Duchlev, 2001). Consequently, this is a variation of the solar corona dynamics, most probably not only for the filaments, but for other events (like CMEs) too. May be the north-south asymmetry of the sunspot activity centers lead to long term tendencies of north-south anisotropy in the corona and the coronal events. This could affect corresponding GCR-flux fluctuations in the Earth atmosphere and on this base to provoke fluctuations in the "cosmogenic" isotopes production rates, including the ^{10}Be too.

In this course it is interesting to mark also that a well expressed quasi 130-140-year cycle is visible in the radiocarbon tree rings data series (Dergachev, 1994). Obviously, the same phenomena should affect the high energetic proton and electron fluxes (the solar cosmic rays, SCR) reaching the planets. This also has taken effect over their atmospheres and climate. The presence of this powerful quasi-120-year oscillation in the A-index data series gives by our opinion a principle explanation why a cycle with the same duration exist both in the ^{10}Be and climate data series. The dendro-chronological data could be included there too (Komitov et al.,2003).

In Fig.3 a weak, but statistically significant oscillation at T=62 year is shown. However, by our opinion it seems almost non-possible that the weak quasi-60-year cycles in A could be a source of the such a powerful 60 years oscillations in the aurora, ^{10}Be or climate. Obviously a much stronger solar source of this phenomena should exist.

3.3 The Group sunspot numbers (R_h) and their subcenturial (quasi-60-year) oscillations (AD 1610-1979)

The multiple regressional analysis results clearly pointed out that the MLA annual number N_{Aur} have not any specific role as a factor proxy for the $\Delta_2\Theta$ during the 19th century and their participation as a factor is totally "captured" by R_h, A and the interactive term of the both last ones. On the other hand a weak, but statistically significant 62 year cycle in the dynamics of the asymmetry index A also exists. This is why the problem about the origin of the solar source of the subcenturial quasi-60-year cycle has been rested open.

It has been very unexpected for us when using of the $T-R$ periodogram procedure a strong quasi 67 year cycle for the epoch AD 1821-1900 has been detected in the smoothed 11 year R_h series (Fig.4). As it is shown, the corresponding correlation coefficient R value is >0.6. In the $T-R$ correlogram for the epoch AD 1913-1979 a totally dominant 59 yr cycle ($R > 0.9$; Fig.5)! No other traces of cycles in the subcenturial or quasicenturial range are visible in these both spectra.

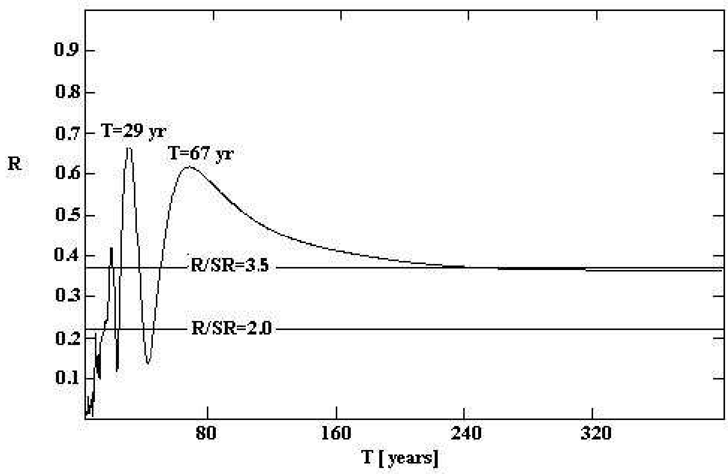

Fig. 4. The T-R spectra of the Group sunspot number (11-yr smoothing annual values; AD 1820-1900). Two powerful cycles by duration of 29 and 67 years are shown.

These results are very intriguing, because usually for the overall sunspot activity where as a proxy the International Wolf's number is used, the cycles by longer duration (78, 88-90, 100 years) are discussed (Gleissberg, 1944; Vitinski et al., 1976, Bonev, 1997). On the other hand there are brief comments for a 65-year cycle in the Schove's series (Schove, 1955) and weak variations in the subcenturial range (50-70 years) in the instrumental sunspot series R_h and R_i (Komitov & Kaftan,2003,2004). That is why it has been decided to search how stable is this 60 yr cycle in the Group sunspot number series, as well as is there some evolution of the sunspot cycles in the centurial and subcenturial ranges during the period 1610-1979.

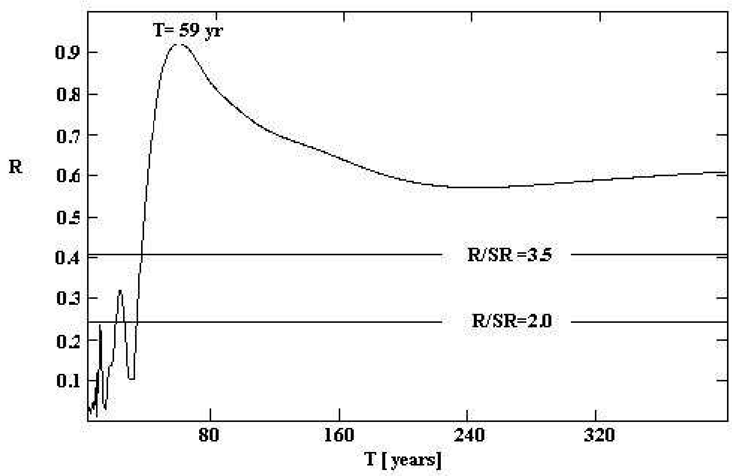

Fig. 5. The $T-R$ spectra of the Group sunspot number (11-yr smoothing annual values; AD 1913-1979).

For this aim a two-dimensional $T-R$ periodogram "moving window" procedure (MWTRPP, see Paper I) has been ran on. The moving window length has been choosen to be 60 year and the parameters of the single $T-R$ correlogram procedure are $T_0 = 2$ years, time step $\Delta T = 0.5$ years and T_{max} = 152 years correspondly. The evolution of the ratio $R/\sigma R$ (the ratio of R to its error) for the cycles in the range [$T_0, T_(max)$] is shown due to the map on Fig.6

The most interesting feature on fig.6 is related to the generally high level of presence of the subcenturial 50-70 yr oscillations in the R_h series before AD 1850. In the second half of 19th and the beginning of 20th centuries this type of cyclity has been sharply falling. This seems be much better expressed near to the Zurich sunspot cycle No 13, i.e. before the Gleissberg-Gnevishev's solar centurial minimum. It is also clearly visible a tendency for restoring of the quasi subcenturial cyclity after AD 1910. However as it was also shown there is slightly earlier also a tendency for longer quasi centurial ≈ 120 year trend -hypercycle. The last one seems to be caused by the centurial minimum (AD 1898-1923). It is absent in the most recent moving window spectra after AD 1925-1930 when the data from this minimum are not already included. This concern the last right columns of the map. A good confirmation for this is the strong peak at $T=$ 59 years in Fig.5. In contrary the T-R spectra on fig.4 is related to an transition period from epoch with good expressed 60 yr cycle before AD 1850 and such one when this cycle is totally absent. Thus it

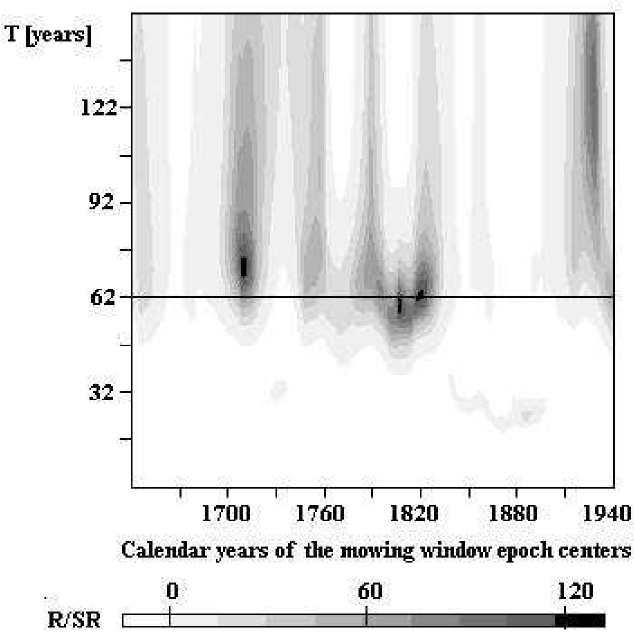

Fig. 6. The $T - R$ spectra evolution of the 11 year smoothed GSN data in the range of periods 2¡T¡152 years. By the horizontal line at T=62 years the typical duration of the subcenturial cycle is signed. The most white areas on the map to statistically non-significant values of -0. 11 ¡ $R/\sigma R$ ¡ 0 are corresponded.

could be said that the 50-70 year oscillations are much more typical for the Group sunspot number data series during the last 400 years as every of the non-stable quasi–centurial ones. It is even valid for the Maunder minimum epoch too, where the traces of subcenturial oscillations are weak, but even so, more visible as in the second half of 19th century. It should also be concluded that the abrupting of the 60 year cycle between AD 1850 and 1910 is the main cause for which it is not so visible in the general R_h series. It is necessary to note that the second half of the 19th century is also a period of strong decreasing of the MLA activity, negative values of the A-index and a fast climate warming (Fig.1 and 2).

There is no significant change of the results if the last 16 years up to AD 1995 of the R_h- series are included in the MWTRPP analysis.

A comparison with the Zurich series (the index R_i) could be very interesting, but it will be an object of a separate study.

4 Discussion

A few important conclusions should be derived by the presented in these three papers results and their analysis. There are also a number of questions, remaining still open or are new ones.

Most of all, the general influence of the Sun over the climate is much more rich and complicate as it is presented on the base only of the TSI variations or even if the additional solar depended mechanism - the galactic cosmic rays modulation over the aerosols and clouds production is taken into account. A third and very important Sun-climate forcing channel is related to the powerful eruptive events, which could generate high energetic protons ($E >$ 100 MeV). They are able to penetrate very deep in the Earth stratosphere and troposphere and even in the cases when $E > 1$ GeV to reach also the surface. A solar particles with such energies are labeled very often as solar cosmic rays (SCR).

Obviously it need to use statistical expressions of the Sun forcing over the climate not on the base only of one integral proxy factor such as R_h or R_i (de Jaeger and Usoskin, 2006; Paper I). Much better and correct will be to use multiple regressional function $F(X_1, X_2 ... X_N)$, where $X_1 \dots X_N$ are the most important for the climate forcing solar indexes. By our opinion such factors at least should be: 1.The overall sunspot activity index (R_h or R_i); 2. The sunspot area asymmetry index A and 3. Some index of the faculae activity, for example the integral area of solar faculae. The last one should be important for the better accounting of the TSI-variations. In this course it is important to note that the sunspot activity indexes R_h or R_i are far not the "ideal" proxies for the TSI variations, as it is very often argued. As it is followed by our analysis of the temperature "residual" series (Paper I and III) the overall climatic effect of sunspot activity is in generally nonlinear. From one side their changes are in positive correlation with the Earth temperatures in the long term (supercenturial) scale. On the other side in the cases of very high sunspot activity very powerful eruptive events also occurs and the last one are in anti-correlation with the temperatures. In contrary the faculae activity by very simple physical statements should be always in positive correlation with TSI. It is more correct to account the TSI variations as depending both of the sunspot and faculae activity.

The solar origin of the MLA events is out of doubt. As it has been shown in Paper II during the 18th -19th century a powerful 60 yr cycle is typical for these phenomena. The same one is valid for the Northern hemisphere temperature residuals and the Greenland ^{10}Be series too. The analysis in Paper II as well as in this paper III are shown that these oscillation in the last two series are not by terrestrial, but rather by solar origin. Most probably the ^{10}Be and $\Delta_2\Theta$ 60 yr cycles are connected to the same solar phenomena as MLA. And there is a question - where on the Sun these phenomena are occurred? Are they coronal events like the coronal mass ejections (CME), or other components of the solar eruptive activity are also taken a significant participation in this channel of the solar forcing over the climate?

It necessary to say that there are not enough clear evidences on this stage about the dominant role of the coronal events (and especially of CMEs) for the generation of quasi-subcenturial climate oscillations as well as for the overall dynamics of the temperature "residual" series $\Delta_2\Theta$ and $\Delta_2\theta$ at all. It is rather visible by the results of the multiple regressional analysis that the negative values (cooling) of the temperature "residuals" correspond in generally to an increasing of the overall sunspot activity index R_h. It is an indicator that the cooling effect is related to the increasing effect of the eruptive events , which are close connected to the sunspot groups. This concern strongly especially the Northern hemisphere residuals $\Delta_2\Theta$ (formulas (2) and (3)), while for the "oceanic" residual series the relationship with R_h it is much more complicate (4).

The high amplitude and statistical significance of the quasi 60 year oscillations in the GSN data series is an additional evidence that both the climate and ^{10}Be cycles with the same duration should be related to the overall eruptive activity. It is also indirectly shown that the R_h index is a very good proxy of the solar corpuscular activity. Unfortunately there are no any updates of the GSN data series after AD 1995. It could say on the base of the results in &3.3 that only by the relative short period at the end of 19th and the beginning of 20th century disturbs for the much better expression of the quasi-60 yr cycle in the GSN data series during the epoch after the Maunder minimum.

By our opinion the origin of the quasi-60 year cycle in the MLA events is now also clear. It is caused by the corresponding variations in the number of the active centers, which good proxy is the number of sunspot groups. No any additional specific solar activity sources for explanation of the 60 yr cycle of the auroral activity are strongly needed. So it is clear that our preliminary hypothesis for such sources (see Paper I and II) is not without fall necessary.

The obtained importance of 60 yr cycle in the GSN data series lead on the top the question , what sunspot index is better - the international Wolf's number R_i or R_h? On this stage we will only note that by the opinion of many researchers the R_h- index is much better proxy for the aims of solar-terrestrial physics at all , because it fitts more successfully the solar eruptive activity.

May be the most interesting result from this analysis is the obtained strong relationship between the Northern hemisphere temperature residuals and north -south asymmetry index A of the sunspot areas. The last one is generally not in a very strong relationship with the sunspot activity index R_h. By other words the A-index is a second and relatively independent factor, which plays very important role both for the $\Delta_2\Theta$ and $\Delta_2\theta$ dynamics. The linear correlation coefficent r is equal to - 0.336 for the all period since AD 1821 (the beginning of the Pulkovo archive data) to 1979. It point out for a generall statistically significant reversed relationship. The coefficient r is very high by module (r = - 0.72) during the 19th century. For the recent part of $\Delta_2\Theta$ data series since AD 1913 the relationship has been sharp faded (r = -0.26), but remain statistically significant over 95%.

The "interactive" terms (R_hA) in formulas (2) and (4) show that for the climatic effects is very important not only the total level of the solar eruptive activity , but also where on the Sun the active regions are placed. The established fact that the relative increasing of the Sun Northern hemisphere activity lead to a climate cooling effects is in good agreement with the Loginov's suggestions about 35 years ago (Loginov, 1973), namely that the flare activity centers northern from the Sun equator are more geoeffective as the southern ones. As it is shown from the relationships (2-4) there are two "pure" north-south asymmetry index terms of linear "A" and quadratic "A^2" types in the all three formulas. This is an indirect evidence that a climate forcing by solar activity processes, which are not very close connected to sunspot active centers should be also significant. Most probably these terms are connected directly to the coronal parameters and phenomena. It could not be related only to the CME events, but also to other coronal phenomena, including the large scale coronal structure too. It need to include in this course a possibility that the variations of the A-index could could also generate long time anisotropic variations of the interplanetary matter density and by this one lead to corresponding time and space variations of the falling in the Earth atmosphere GCR -flux. As a result there should be effects over "cosmogenic" isothopes production rates, aerosols and clouds generation etc.

The index of the north south sunspots asymmetry A is an object of studying namely in the field of the solar -terrestrial and especially solar-climatic relationships (Georgieva, 2002). It is interesting to point out for an interesting group of relationships between the north-south sunspot asymmetry, the Earth diurnal rotation rate and the atmospheric circulation changes (Georgieva, 2002). The physical hypothesis for these influences is connected to the "solar wind–geomagnetic field–Earth dynamo" relationship. If this could be true the relationship between the sunspot flare processes and sunspot asymmetry from one side and the Earth tectonic activity from other should exist. The possible relationship of the solar and Earth volcanic activity is briefly discussed by the author in his recent overview (Komitov, 2008).

The multi-factor statistical models (2,3 and 4) pointed out that between 60 to 80% of the temperature residuals $\Delta_2\Theta$ and $\Delta_2\theta$ are explained by the solar factors. The general anticorrelation both with the asymmetry index A and R_h, the very important participation of non-linear terms in these formulas as well as the "interactive" terms of type AR_h show that these factors are predominantly connected to the solar corpuscular activity.

It is necessary to remember that The general relationships "sunspot activity –> temperature changes" (formulas (4) and(5), Paper I) express mainly the overall effect of the large time scale electromagnetic flux variations over the climate (the TSIchanges). There could be also taken into account the possibility for a significant "hidden" participation in these models of the Forbush-effect and the GCR influence over the climate: The climate cooling effect of the GCR-flux increasing during the sunspot and TSIminimums should be made the overall cooling effect even more expressive. This is why the above mentioned models are explained very well by the coincidence between such significant phenomena like the solar supercenturial Maunder minimum (1640-1720) and the deepest phase of the last "Little ice epoch", the next one, also supercenturial Dalton minimum (1795-1835) and the temporal cooling during this time, as well as the Modern supercenturial solar maximum (1933-1996/2000) and the modern climate warming epoch.

However the climate effects of the solar eruptive activity are outside of these models. They are not taken into account in the most appropriated explanations for the climate changes in the modern epoch and especially during the last 35-40 years since the middle of 1970st. The results and the analysis in our study clearly pointed out that it is a very serious gap in the present dominant climate changes theories. Only if the solar eruptive activity in combination with its spacial distribution over the Sun surface is taken into account it could explain successfully the climate dynamics during the relative short "mirror epochs",when the sunspot activity and the temperature changes are in anti-correlation (see Fig.1 in Paper I). This concern also the last 30-35 years. It will be demonstrated below how the specific combination of the solar eruptive activity and north -south sunspot area asymmetry is the most probable factor for the fast warming both in the second half of 19th and in the end of 20th centuries and no additional cause (human activity) is needed for explanation there.

The solar activity and the climate changes during the 19th century Out of doubt the most important solar activity event at the beginning of 19th century is the supercenturial Dalton minimum (AD 1795-1830/35). The essential climate cooling during the this time is related to both the corresponding TSI decreasing and the increasing of the penetrating in Earth atmosphere GCR-flux. In generally this picture of the solar-climatic relationships during the Dalton minimum is correct. However there are some important details.

It is clearly shown on Fig.1 that there is an initial period at the beginning of the Dalton minimum, when an increasing of the temperature residuals $\Delta_2\Theta$ in the Northern hemisphere is observed. The critical moment is near to AD 1805, i.e. near to or slightly after the maximum of Zurich sunspot cycle No 5. So, there is an delaying of about 10 years after the beginning of Dalton minimum, when a sharp decreasing in the "residual" temperature series has been started. Consequently it should be said that there is an additional climate cooling effect over the long-term downward TSI tendency. The sunspot activity during this time is low, and it is reflected to the low level of MLA activity (Paper II). Even so in the course of our results and analysis it should be assumed that this cooling is caused by the solar eruptive factor and its increasing geoefficiency during this time. A very similar situation could be forced by relative rare, but strong eruptions, originated predominantly on the Northern hemisphere of the Sun. As it has been shown (Fig.2), the Pulkovo archive data series is starting at AD 1821 with positive values of the A-index. The smoothed A-values are positive during the next two decades and this correspond to even more deep cooling up to AD 1840, when the Dalton minimum has been already ended. However, the R_h increasing after AD 1830 is predominantly in the Northern hemisphere and this has been supported the cooling tendency else certain time. A qualitative extrapolation of the smoothed A-index data in the past before AD 1820 shows that most probably it has been positive since 1805-1810, i.e well corresponds to the observed decrease of the temperature residuals since AD 1805.

Near to the maximum of Zurich cycle No 9 a serious change in the long term solar activity tendencies has been occurred: (1— The "smoothed" asymmetry A-index sign has been changed for long time (up to 1910-1912) from positive to negative. (2) There is a clearly visible long term decreasing of the 11-year smoothed Group sunspot number data from Zurich cycles No 9-14. The local peak near to AD 1870 is not affected seriously by this long time tendency (Paper I, Fig.1). Simultaneously with these two events a long time $\Delta_2\Theta$ upward tendency from AD 1840 to 1910 has been occurred. There is only a short temporary stopping between AD 1870-1880. This dynamic of the climate changes is in a very good agreement to the presented in this study results, their analysis and the following conclusions.

The climate changes during the 20th century and the modern "global warming" Since the centurial Gleissberg-Gnevishev's minimum (AD 1898-1923) the solar activity has been very fast increased. Since AD 1934 when sunspot cycle No 17 has started, and especially after 1940, the solar activity has remained for a few decades on extremely high levels up to the end of sunspot Zurich cycle No 22 in AD 1995/96. This epoch (the Modern supercenturial solar maximum) is characterized not only with the higher for the last 1000 years Sollar luminosity, but also with an extremely high eruptive activity. The active centers has been located predominantly in the Northern hemisphere (Fig2.). As it is shown there, the "smoothed" positive sign of A has remained up to the middle of 1970st. During the last 20 years after AD 1975 of the Pulkovo archive data series the sunspot asymmetry index is predominantly negative. However, the sunspot activity and the TSI-index has remained at high long-term level during this time.

As a result of all these circumstances during the longest part of 20th century a maximum of the supercenturial climate warming tendency occur. It is connected to the supercenturial maximum of TSI on the first place and the supercenturial GCR-flux minimum. However, on the other hand the very high eruptive activity levels in interaction with the positive A-index lead to a secondary cooling effect for a part of this epoch. It is much better expressed between AD 1940 and 1975 when the flare activity has increased very fast. Since the 1970st in coincidence with the transition of A-index from positive to negative the secondary cooling has been stopped and the general climate tendency has been changed to warming. The high levels of TSI during this time as well as the downward tendencies in the eruptive activity after the maximum of cycle No 21 (Komitov, 2008; Paper II) are additional factors for forcing the warming during the last two decades of 20th century.

The Zurich cycle No 24. What could be expected? There are many indications that by the end of the solar cycle No 23 in 2008 a new supercenturial solar Dalton-type minimum is already started (Komitov & Bonev, 2001; Komitov & Kaftan 2003,2004; Shatten & Tobiska, 2003; Ogurtsov, 2005). That is why the next sunspot cycle No 24 should be essentially weaker by magnitude as the previous few ones. The near-maximal annual sunspot number R_i in AD 2012 or 2013 is expected to be less than 100, but there are also predictions for values near to or less than 50 (Cliverd et al., 2006). The extremly low level of sunspot activity near to AD 2020-2025 is pointed out by Hathaway(2006) on the base of "Great Conveiyor Belt" model estimations.

Consequently, a significant climatic decreasing of the TSI during the cycles No 24 relative to No 23, as well as an increasing of GCR-flux should be expected as a general tendency. By this one and according the relationships between sunspot activity and climate, a cooling effect in range of 0.2-0.3K is expected if a decrease of the 11 year smoothing R_h values from 65-67 (at the beginning of 1990th) to 25 between 2010 and 2020 is assumed (see Paper I, formula (4) and (5)). As far as there are not actual data for the Group sunspot number index R_h after AD 1995 any extrapolation should be made only on the base of some similarity with R_i.

However, the effect of solar eruptions should also be added. Except for a prediction of R_h it needs to have also a prediction for the index of sunspots area asymmetry index A too. If the active centers are predominantly in the Northern hemisphere during the sunspot cycle No 24, which is by our opinion the more probable scenario, then an additional cooling in order of 0.3 K for the Northern hemisphere over the above signed 0.25-0.3 K should be predicted. Thus a climate conditions could be returned back very fast after AD 2012/13 (the probable sunspot maximum of cycle No 24) to almost the same ones as during the Dalton minimum.

There are historical evidences that the relationship between the auroral activity and the weather conditions in Northern Europe has been noticed still by the Vikings in the Middle Ages (Weather Action 27/05/2009, www.weatheraction.com). On other hand there are many studies during the 1950-1970st, which are focused over the effects of the strong solar corpuscular eruptions for the climate. A good overviews of this studies are given by Rubashov (1963), Vitinskii et al.(1976) and Herman and Goldberg (1978). Our study shows that the understanding of this relationship is of the most higher importance for the correct understanding of the climate changes in the modern epoch at all.

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