Trees annual rings and "Sun-Climate" connection

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Abstract. The subject of the present work is an investigation of the relationship "Sun-Climate" for the territory of Central Bulgaria for the period from the end of 18th to the beginning of 21st century, based on dendro-chronoligical data. For this purpose the smoothed time series of the widths of annual rings of two beech samples from the region of Central Balkan Range are used. Special attention is paid to the 22 yr oscillations in the growth of tree mass and the relationship between the oscillation amplitude and the phase of solar cycles with sub-century and two-century duration. It is shown that the attenuation of 20-22 yr magnetic solar cycle during the hyper-centurial Dalton minimum (1795-1825/1830) is accompanied by strong drying and warming of the summers in Central Southern Bulgaria during this time. The onset of new Dalton-type hyper-centurial minimum in the beginning of the 21st century corresponds to an analogous climatic situation.
Key words: Sun, Solar cycle, Solar minimum, tree ring data, Earth's climate

Introduction

The idea to develop a method for climate reconstruction in the past, based on an analysis of the width of the trees annual rings belongs to the American astronomer Andrew E. Douglass. Therefore, he is considered "the father of dendro-chronology" (Frittz, 1973). Assuming that the climate depends on the corresponding levels of the solar activity in the past, Douglass considered dendro-chronological observations also as a method for analysis of the solar activity in the past. He reached these ideas during his long walks in the Arizona forests and the observations of the loggings there during the end of 19th and the beginning of the 20th centuries. His point of view and his first results he described in a number of papers and books published in the beginning of the 20th century. The emergence of a dendro-chronology investigations school and the corresponding Laboratory of Tree-Ring Research at the Arizona University, Tucson, is a direct consequence of the pioneer works of Douglass and his followers.

In the middle and the second half of the 20th century the dendro-chronological method considerably developed. It became a serious means for investigating the Sun-climate relations in the past. We will describe here three of the most interesting examples.

Data for the trees annual rings were used partially by Derek Schove for obtaining his sequence of 11 years Solar cycles during the last 2600 years, known as "Schove series" (Schove, 1955, 1983). The influence of the 20-22 years Solar cycle on the rain amount in the Western part of USA for the period between the middle of the 17th and the end of the 20th centuries has been established (Mitchell et al., 1979).

The influence of the 200-210 year solar cycle on the climate of the Central Asia has been analyzed and established using data from the rings growth of the Turkestan cypress (Rasspopov et al., 2008).

In November 2012 a project dedicated to dendro-chronology between the Institute of Astronomy with Rozhen NAO, Bulgarian Academy of Sciences and the Ministry of Agriculture and Food started. The main tasks of the investigations, connected with that project, are listed below:

1. Investigation of the trees growth laws in the period 1750-2010/12 AD. Investigation of trends and cycles present in the annual rings of the trees samples. Main tree sample - Beech (Fagus).

2. Investigation of statistical correlations between the annual growth of the annual rings and different indexes of solar activity, geophysical activity and the climate, correspondingly.

3. Climate calibration for each tree sample, i.e. finding empirical relations between trees annual growth and the climate data (rains and temperature) for the corresponding region.

4. Investigation of the influence of the deep (so called long term) solar minima on the climate of the corresponding regions and their effect on the annual tree growth. The long term solar minima during the last 400 years are Maunder minimum (1642-1715 AD) and Dalton minimum (1795/1798-1834 AD). Providing an analogous investigation of the effect of the long term solar minimum of Gleissberg-Gnevishev (1898-1923 AD).

5. Obtaining an information about long-term variations in the regime of solar dynamo, i.e. the source of the solar magnetic field and its variations.

6. Prognostic models for the climate change and for the tree growth rate during 21st century.

The achievement of these targets requires a preliminary information and clarity concerning the following questions:

1. What do we know about the long term (over century) dynamics and solar activity and the "Sun-climate" connection?

2. What do we know about the physical mechanisms responsible for the "Sun-climate" connection?

3. What are the future and near future trends in the Sun behavior?

4. What do we know about the "Sun-climate" connection on the territory of Bulgaria from instrumental data or/and historical documents?

1. "Sun-climate" connection

1.1. The solar cycles and their climate "echoes"

First let us make a short review of the basic solar activity cycles during the postglacial period (Holocene, the last 11 000 years) from the view point of different studies of their effect on the climate.

1. Short cycles between 2 and 6 years. They are relatively unstable - typical for the solar eruptive and corpuscular activity, for some types of protuberances, and they are less notable in the sunspot activity. They have analogues in the geomagnetic activity, the content of ozone, the atmospheric circulation and cyclogenesis, regional climatic indexes - temperature, pressure, rains

2. Cycles of Schwabe-Wolf ($\sim$ 11 yr) and Hale (20-22 yr). They are the best studied solar cycles. The theory of solar dynamo is based on the knowledge accumulated about them. They are clearly expressed in the regional climatic parameters.

3. Quasi-century "multiplet" (55/60-120 yr) - 55-60 years cycle is well expres-sed in many regional parameters, as well as in the climate of the Earth's

Northern Hemisphere; the cycle of Gleissberg and the 110-120 yr variations are more often met in regional climate parameters.

4. 200-210 and 2200-2400 year solar and climate cycles.

In Fig. 1 a visualization of the trend of sunspot activity during the last 400 years, based on telescope observations, is shown. It is seen that the short peaks, that represent the 11-yr cycles do not have equal height. A cyclic tendency of the increase and decrease of their amplitude during the 80-100 yr period is observed, which is considered to be due to the century (long term) variations. The periods of week 11-yr cycles are called Maunder, Dalton and Gleissberg-Gnevishev minima, corresponding respectively to the second half of 17th, the beginning of the 19th and the beginning of the 20th century. The deepest among them is the Maunder minimum, when the 11-yr cycle has been extremely week and hardly noticeable. The over century ascending trend in the level of sunspot activity is clearly seen. The epoch of high solar activity in the middle and the second half of the 20th century is often called in the scientific literature "Modern Maximum". The increase of the mean temperature of the Earth with about 1.2-1.5° C corresponds to the increase of the solar activity during the last 400 years. To the Maunder Minimum corresponds, the so called "Little Ice-Age" and to the Modern solar long term maximum corresponds the contemporary "global warming" (Fig. 1).

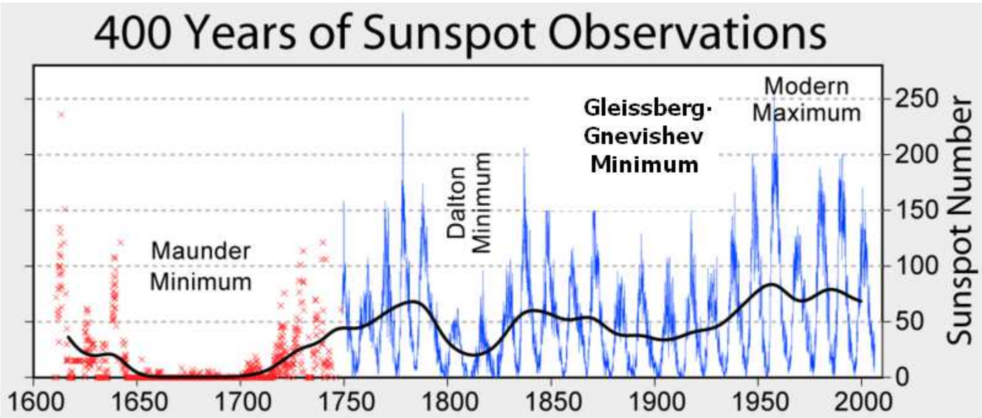

Fig. 1. The international sunspot number (Ri) during the instrumental telescopic observations (1610-2008). The blue line indicates data included in the Zurich series.

A general tendency exists - Longer solar cycles exert stronger influence on the climate and this influence has better expressed overall planetary character.

1.2. The 200-210 yr solar cycle and its influence on the Earth climate

The 200-210 year solar cycle has been found and studied mainly from indirect data - the analysis of historical documents for the solarand geomagnetic activity and the contents of the cosmogeneous radio isotopes ^{14}C and ^{10}Be in different ring and layer-type environments like annual rings of the trees, cave structures, continental glaciers, etc. (Schove, 1955; de Vries, 1958; Stuiver and Quay, 1980; Damon and Sonett, 1991; Dergachev and Chistyakov, 1993). It can be clearly traced in the Schove series. The clear, several decades long epochs of low solar activity following at around 200 yr period, are mainly connected with this cycle (Fig. 2). After 1000 AD they correspond to the odd calendar centuries and are known correspondingly as the Minima of Oort, Wolf, Spöerer and Maunder. The detail analysis shows that the Dalton minimum in the beginning of the 19 century is related to the 200 yr solar cycle minimum, however the Gleissberg-Gnevishev minimum is not related to it.

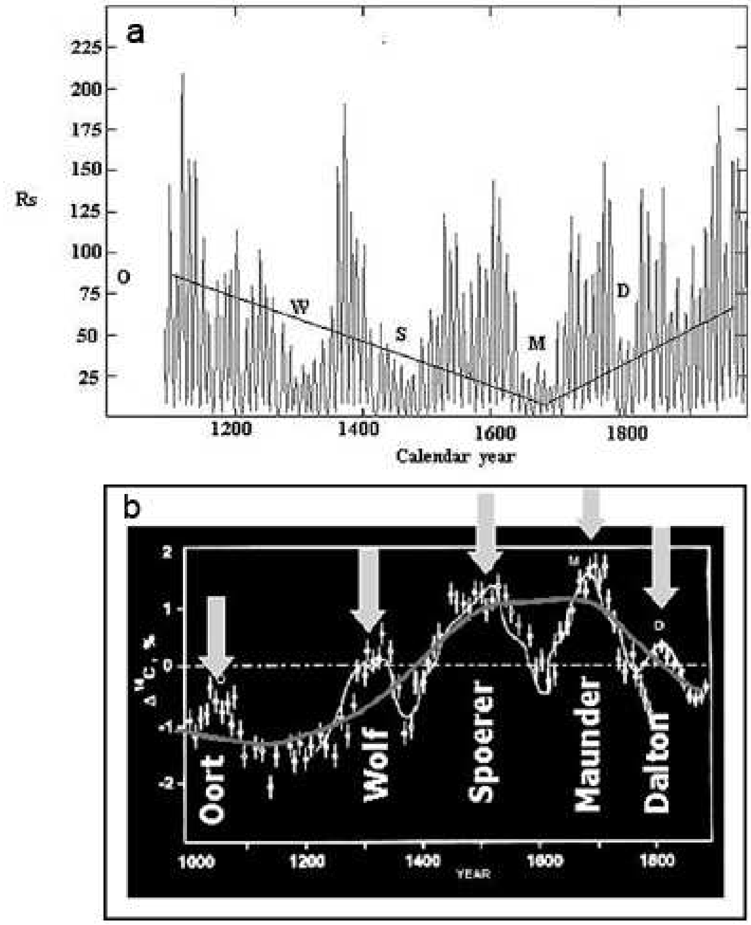

Fig. 2. Synthetic series of the sunspot numbers during the period 1099-2002 AD built on the basis of the "Schove series" (Nagovitsyn et al. 2006) (**a**). The letters "O","W","S", "M", and "D" indicate the minima of Oort, Wolf, Spörer, Maunder, and Dalton; Radiocarbon series of the annual tree rings for the last $\sim$ 1000 years (Stuiver and Quay, 1980) (**b**).

The 200-210 yr cycle is particularly well seen in the radiocarbon data for the tree rings, where the connected with it minima correspond to the maxima in the radiocarbon contents due to a phenomenon known as "Forbush effect" - the anti-correlation between the level of the solar activity and the galactic cosmic rays flux, from which the cosmogeneous radio isotopes are formed (Fig. 2) (Stuiver & Quay, 1980).

The 200-210 yr solar cycle climate effects have besides regional also planetary character. The Earth's average temperature variations in the range of 0.5 to 1.0 C are connected with it. It is detected in the width of the annual tree rings on the basis of data from different parts of the Earth. 200-210 yr cycle is a particularly stable feature of the Earth climate. It can be traced back until the late Paleozoic Era (i.e. before 250 million yr) from analysis of sedimentary rocks (see Rasspopov et al., 2008 and cites therein).

1.3. The 2200-2400 yr solar cycle (Hallstadtzeit) and the cycle of "little ice epochs"

2200-2400 yr solar cycle (Hallstadtzeit) is the most powerful cyclic phenomenon of the solar activity during Holocene. (Damon and Sonett, 1991; Dergachev and Chistyakov, 1993). It has been traced to over 100 000 yr back in time, including Wurm and Riss ice ages. It is established from studies of the radiocarbon content in the annual rings of trees, of corrals, cave formations. Its minima phases are "Maunder-type" minima, the last of which is the Maunder Minimum itself. Its climate analogue is the cycle of "Little Ice Ages", found at the end of 60ies by the American geologists Denton and Karlen (1973).

The climatic effect of the Hallstadtzeit is planetary. It causes temperature variations of around 2-2.5 degrees.

An important characteristic of the 200 yr cycle is that it's amplitude is modulated by Hallstadtzeit (Damon and Sonett, 1991; Bonev et al., 2004; Komitov and Kaftan, 2013). The best expressed is the 200 yr cycle in the descending phases of the last minimum and the Maunder type minima (Fig. 3). The two-century cycle in the near maxima epochs of Hallstadtzeit is least visible.

Figure 3 presents the approximate calendar moments of the last minimum and maximum of the 200-210 yr cycle, corresponding respectively to 1850-51 AD and 1956-1963 AD (Zurich 11 yr cycle No19 (SC19)), and the next will be around 2061 AD. On the other hand the cycle is in the descending phase though still very powerful. It is seen from the scheme also, that at the moment the Sun should be in the beginning of the Dalton-type minimum, resulting mainly from the decreasing phase of the two-century cycle. Let us prove this using the instrumental data for the solar activity from the last years.

1.4. The Sun is at the beginning of Dalton-type minimum

In Fig. 4 and Fig. 5 different indexes of solar activity are presented, for the whole period and for their continuous observations. In panel Fig. 4 the monthly values of the Wolf index (Ri) in the Zurich series from 1749 AD till March 2013 AD are given. The panel Fig. 5 presents the index TSI (total solar radiation), shown as a composite graph from the data of different satellites for the period 1978-2011 AD. Concerning Ri index, the present 24th cycle is certainly the weakest since the beginning of the 20th century, i.e. since the solar cycle No 14 in the beginning of the minimum of Gleissberg-Gnevshev. On the other hand the data from helio-seismology point that the next cycle SC 25 is expected to be even weaker than SC 25, i.e. it will be the weakest during the last 200 years.

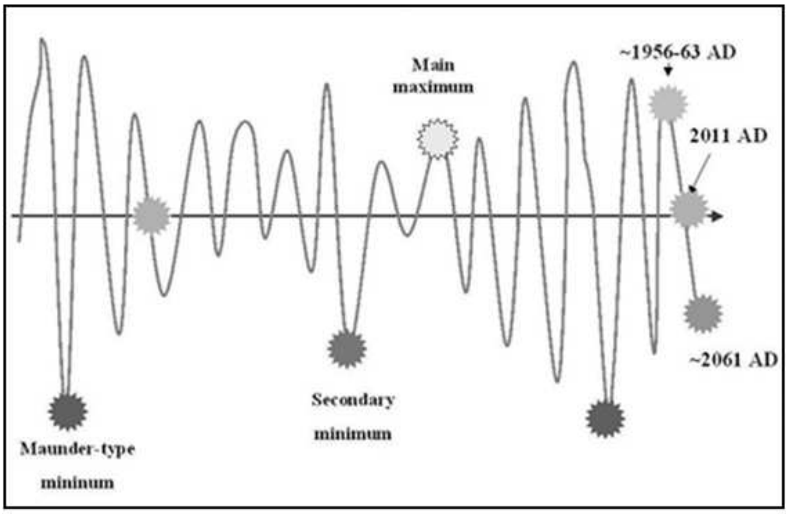

Fig. 3. The amplitude of the 200-210 yr solar cycle in different phases of Hallstadtzeit (Komitov and Kaftan, 2013).

Having in mind these facts, and also the results from the study of the long-term solar activity, which have been briefly presented in Sections 1.2 and 1.3, it should be concluded that the Sun is, most probably, in the beginning of a new Dalton-type minimum. Accounting not only for the 200-210 yr cycle, but also for the influence and the impact of the other long-term solar variations, it probably will be moderately deep, but at the same time quite long, encompassing most of the 21st century. This minimum has started during 2007-2008 yr, and the 24th 11-yr cycle in the Zurich series is the first that falls in this long-term (century) minimum. Meanwhile, some scientists present well grounded opinions, that the tendency of a new long-term minimum has started during the descending phase of the solar activity, 22th 11-yr cycle, during 1993 (Duhau, 2003).

The fact that the Sun enters a new Dalton-type minimum inevitably requires the analysis of sufficiently old tree samples for the dendro-chronological analysis, i.e. such that contain information about the Dalton Minimum and at least older than 200-250 yr.

1.5. Physical mechanisms of the "Sun-climate" relationship

The influence of the solar activity on the Earth climate is not only covered by the effect due to the change of TSI index, as is usually believed (Lean et al, 1995, 2002; Lean 2000, 2004). Quite often the role of solar activity for climate changes is connected with its effect on the galactic cosmic rays (Svensmark and Friiz-Christensen 1997; Yu 2002). The detail analysis of the available data shows that the variations of TSI consists only up to 15-20% of the total effect of the solar activity on climate. This fact was specially noted at the Meeting under the auspices of the USA National Scientific Council, dedicated to climate problems, that took place in the beginning of January 2013 (Fig.4,Fig.5).

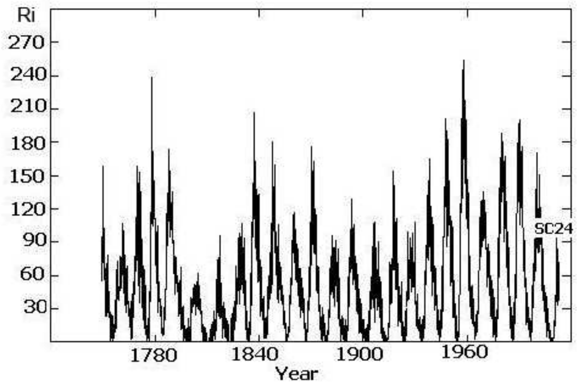

Fig. 4. Monthly values of the sunspot numbers Ri (January 1749 - April 2013).

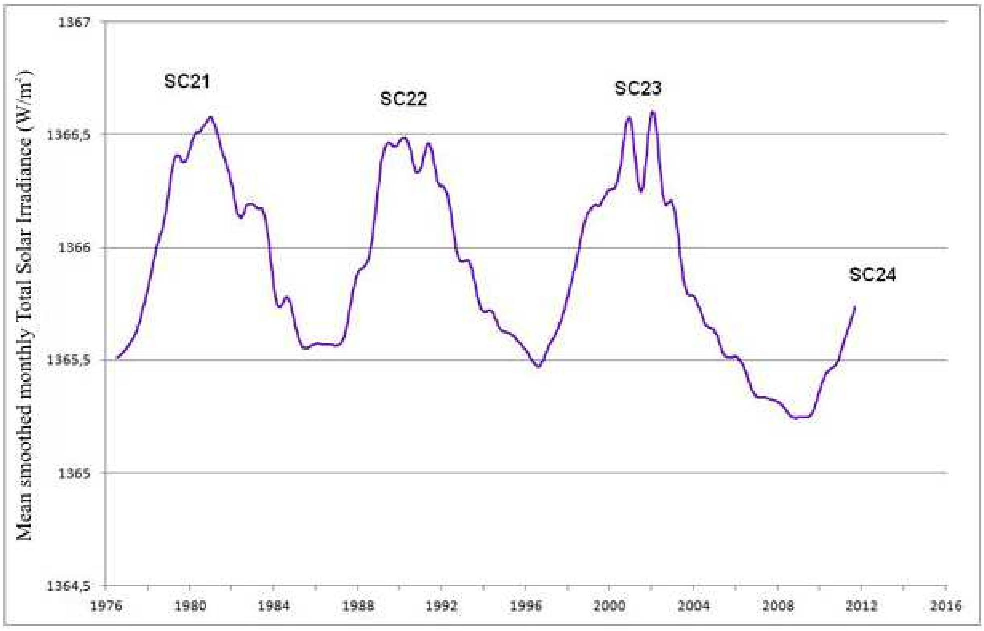

Fig. 5. Monthly values of the index TSI in the period November 1978 - December 2011.

The analysis of data points, that indicators, connected with solar eruptions and coronal mass ejections and the solar high energy protons, which often accompany these phenomena, have a comparable, and in some cases stronger, influence than TSI and radiation indexes. There is already serious statistical evidence that the Earth tectonics, including the volcanic activity, is considerably influenced by the solar activity (Rogozhin and Shestopalov, 2007).

The solar activity plays the role of a trigger for many tectonic phenomena - strong earthquakes and volcanic eruptions (Komitov, 2011). That is an additional indirect channel of solar influence on the climate. These circumstances represent an important landmark for the investigation of direct statistical relations between dendro-chronological data and different solar and geophysical indexes.

2. The data, pretreatment and methods of analysis

The new results, presented in this work, are based on the study of two old lived beech samples. Both are more than 200 yr old and have been taken from two different regions of Central Balkan Mountain Range from regions with commercial logging.

The first beech sample ("Paisii-01"), which is an object of our analysis, has been cut 30 years ago - in 1983 AD near the coal mine "Paisii", in the region of the pass Hainboaz, to the North of the town Gurkovo, Stara Zagora district, at an altitude of 500 meters, to the south of the main ridge of the Balkan Range.

The mechanical treatment and the detail measurements of the annual rings width have been done 17 years later - in the period 2000-2001 AD. The sample age have been determined to be 212 ± 1 years. The measurements have been done at 8 different radial directions, at approximately 40-45 degrees. The precision of each measurement was 0.1 mm. For the sake of accuracy the oldest rings situated at the central part have not been included in the analysis. The measurements have been conducted from the outer part of the tree sample towards the center. For each annual ring its average width has been obtained as a mean on the basis of all 8 radial profiles. This has been done to decrease the effect of fluctuations due to factors distorting the influence at different directions. 1982 AD was accepted as a first calendar year of the series, i.e. the year of the outermost fully built annual ring. The oldest annual ring used corresponds to 1780 AD. The obtained average radial profile was further smoothed on 5 values.

This has been done to decrease the effect of the time fluctuations, and to present better manifestation of the 10-11 yr cycles and the longer ones. First preliminary results have been described by Komitov and Vladimirov (2001).

In the beginning of April, 2013 for the realization of the contract between the Institute of Astronomy with NAO Rozhen and the Ministry of Agriculture and Food with the collaboration and direct support of the administration of the North-Central timber company in Gabrovo and state forestry "Rositsa", village Stokite, Gabrovo district, two beech samples have been taken from the region of the Sevlievski Balkan - "Rositsa-01" and "Rositsa-02". These samples have been delivered to PAO-Stara Zagora for mechanical treatment and analysis in the Center for preliminary technical preparation and measurement of the tree samples.

The age of "Rositsa-01" was determined to be 245 ± 2 years, and correspondingly the age of "Rositsa-02" is ~ 160 years. The study was concentrated on "Rositsa-01" (Fig. 6), while "Rositsa-02" was used only for comparison because of its insufficient age.

The investigation and the correct interpretation of the climate trends in Bulgaria on the basis of the annual rings requires data about the climate of the regions of the tree samples and the corresponding calibration. Such information was taken for the period 1982-83 AD for 42 rain gauge stations and 31 climatic stations, distributed at the country territory in connection with a study carried out by Gogoshev and Komitov (1983) dedicated to the influence of the solar activity on the climate of Bulgaria. There are available information for almost half of them encompassing the period from 1899 to 1979 AD. The data have been published in the yearly almanacs of the Central Hydrology and Meteorology Administration of BAS. The preliminary treatment included obtaining the semiannual values of the precipitations and temperatures for each station. The period November-April was chosen as the cold semi-annual period, while the period May-October corresponds to the warm one. In 1997 AD the information for some of the stations was completed with data for the next 15 years, i.e. till 1994 AD.

Fig. 6. Tree sample "Rositsa-01".

The obtained from the measurements time series of the annual rings of the tree samples have been tested for statistically significant trends and cycles. T-R periodogram procedure has been used as method for studying of cycles and their rigidity (stability) in time. It has been described in our previous papers (Komitov 1986; Komitov 1997, 2007), therefore it will not be discussed here in detail. The obtained results have been used to build models of the corresponding time series. On their turn, the latter have been extrapolated outside the time intervals of the data samples, inorder to be used for forecast.

The climate calibration of the samples has been done using regression and correlation analysis. Attempts have been maid to improve the obtained relations using nonlinear approximations. The nonlinear effects have been proved to be statistically insignificant .

3. Results and analysis

3.1. "Paisii-01"

The obtained smoothed time series are presented in Fig.7. On one hand the 20-22 yr cycle is well noticeable in the data. The local minima of the smoothed ring widths (parameter Dm) are connected with this cycling. The corresponding minima, with the exception of one from the end of the 19th century, correspond to the maxima of the 11 yr solar cycles with even numbers in the Zurich series.

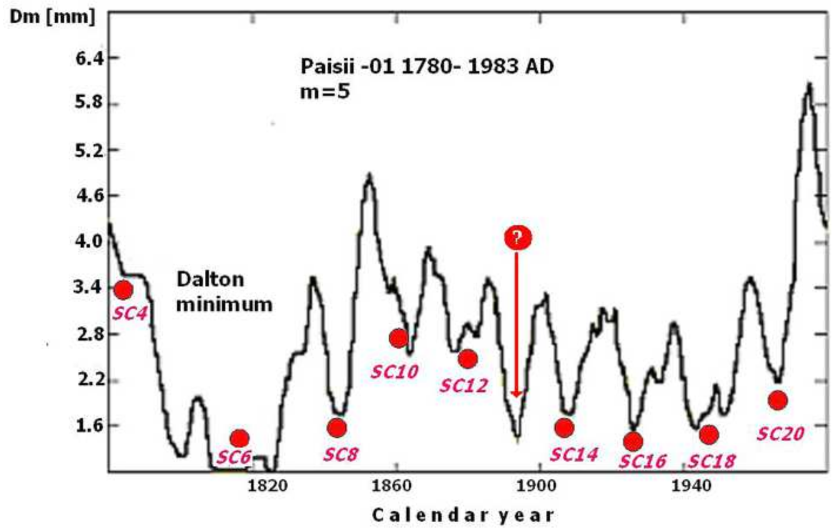

Fig. 7. Smoothed time series of the widths of the annual rings for tree sample "Paisii-01".

On the other hand, it is clearly seen that the amplitudes of this $\sim$ 20 yr climatic cycle are not equal. It is powerful in the middle of the 19th century, but after it considerably weakens till 1940 AD, and then it strengthens again and reaches high amplitudes during the 60s and 70s of the 20th century. The trend of the graph towards the end of the 18th century is intriguing. The values of Dm are initially high and begin to decrease until the near-maximum phase of the 11 yr solar activity cycle with an even number 4 (SC 4), where a "step" forms. However, instead of going up again, as the typical behavior is for other cases of even cycle after maximum, the smoothed widths quickly go down. This means that a strong additional factor begins to act after the SC 4 maximum. Without doubt this factor is the start of Dalton Minimum.

From heliophysical point of view this phenomenon is connected with the considerable and sharp reduction of the solar magnetic flux, which on its turn leads to a decrease of the amplitude of the next two 11 yr cycles and to an almost total suppression of the 22 yr cycle. This on its turn reflects on the climatic conditions of the region, from which the probe has been taken and corresponds to a very slow pulp growth. Things change towards 1830 AD, corresponding to the exit of the Sun from the Dalton Minimum.

The climate, and correspondingly the annual rings of this sample have reacted somehow also to the minimum of Gleissberg-Gnevishev (1898-1923

AD). It seems that the deep minimum around 1895-1900 AD is related to the same one, but it is out of the usual frame for this series 20-22 yr periodicity.

Using the procedure of the "T-R periodogram analysis" we have analyzed the time series of the averaged and smoothed values of the annual ring widths of the sample "Paisii-01". The 18-24 yr (mean $\sim$ 21 yr) plus 50 yr, 67 yr, and 116 yr cycles have been found to be statistically significant (Fig. 8). It was to some extend striking that 200 yr long cycle has not been detected, though the Minimum of Dalton has been clearly seen in the data. The reason for that will be revealed after more thorough investigation of samples from the southern slopes of the Balkan Range.

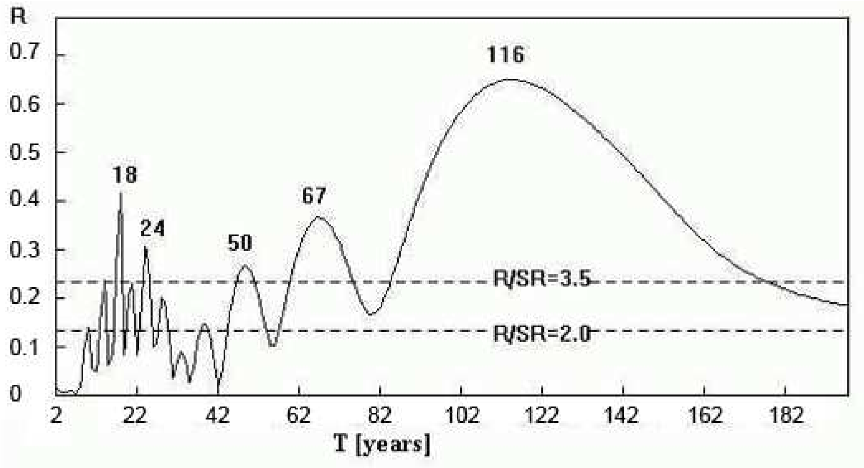

Fig. 8. T-R correlogram of the smoothed widths time series of the annual rings for tree sample "Paisii-01".

Fig. 9 shows a parameter, determined on the basis of T-R periodogram procedure and which characterizes the changes of the amplitude of the deviations in the range 18-24 years, i.e. a range which is centered at a period 21 yr. The plot illustrates the three periods of the 20-22 yr cycle between 1780-1980 AD, during which it is the weakest. They correspond to the Dalton Minimum, to the end of 19th century (i.e around 1880-1900 AD) and around 1940 AD. It is interesting that the dynamics of this parameter during the 20th century corresponds well to certain changes in the regime of matter transfer in the convective zone of the Sun, described by Georgieva and Kirov (2011). As can be seen, this is a cyclic process and its average duration is $\sim$ 60 years.

The statistical relations between the smoothed values of the annual rings widths of the sample "Paisii-01" and the smoothed 5 year data for the temperatures and rains in nearby stations have been studied. The target was to make a climatic calibration for the sample using one of the two parameters (or both). Five closer by stations have been chosen, namely Stara Zagora, Kazanlak, Gabrovo, Veliko Tarnovo and Sliven.

It has been established that the strongest correlations with the precipitations and the temperatures during the warm semi-annual period correspond to the stations Kazanlak and Stara Zagora. The data correlations have been found equally good for both stations. A positive correlation was found (r =

+0.71) between the widths of the annual rings of "Paisii-01" and the amount of precipitations in Stara Zagora. The corresponding coefficient (factor) for Kazanlak is $r = +0.72$. The correlation factor with the temperature was found to be smaller and with similar values for the two stations ($r = -0.69$). Thus, it became clear that the intensive growth of the tree, from which the sample "Paisii-01" has been taken has occurred during the periods with colder and rainier summers.

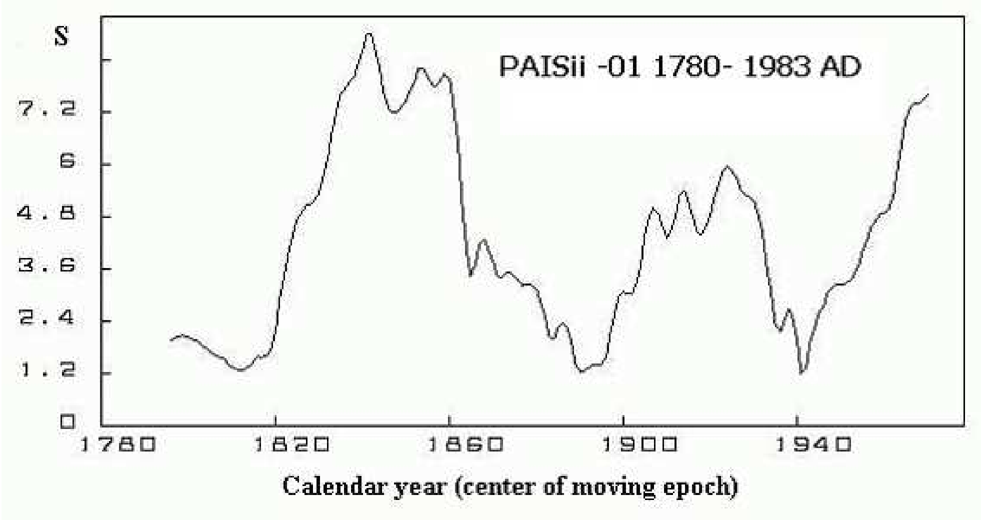

Fig. 9. Integral power parameter S (see Komitov, 1997) of quasi 20-yr oscillations in time series of the smoothed widths of the annual rings for the tree sample "Paisii-01".

Vice-versa, the narrow annual rings show a tendency to group towards the hotter and drier summer periods. However, the fact that the local minima of the summer rains and correspondingly the hottest summers are grouped around the maxima of the even 11 yr solar cycles, is in good agreement with the conclusions of our studies during the 80s about the influence of the 20-22 yr solar cycle on the climate of South Bulgaria, based on instrumental data.

It seems that the Dalton Minimum was a period of hot and dry summers in the Southern Bulgaria. Is it possible, however, to obtain some conclusions about the winter period?

Unfortunately the beech is a deciduous tree and its vegetation period corresponds to the warm semi- year period. Nevertheless, a correlation, though smaller, has been found with the winter temperatures of Veliko Tarnovo and the corresponding correlation factor was found to be $r = +0.56$. This coefficient is too weak for firm conclusions, but it still shows a tendency that narrower annual rings correspond to the lower temperatures during the cold semi-annual period. Most probably the cold and longer winters slow down the growth of the tree in spring.

If this is really the case, then the Dalton Minimum in our lands is characterized except with the hot and dry summers also with colder winters or (most probably) colder early spring. This on its turn means more continental climate. This conclusion should be checked on the basis of analysis of numerous tree samples.

Using the statistically reliable cycles, determined from T-R periodogram analysis, a model of the time series of the smoothed widths of the annual rings of the sample "Paisii-01" has been built (Fig. 10). The correlation factor between the model and actual values is 0.82. It is denoted in the figure by solid line. The model has been extrapolated for the next 30 years after 1980 AD, the year for which the last smoothed value of the original data is available.

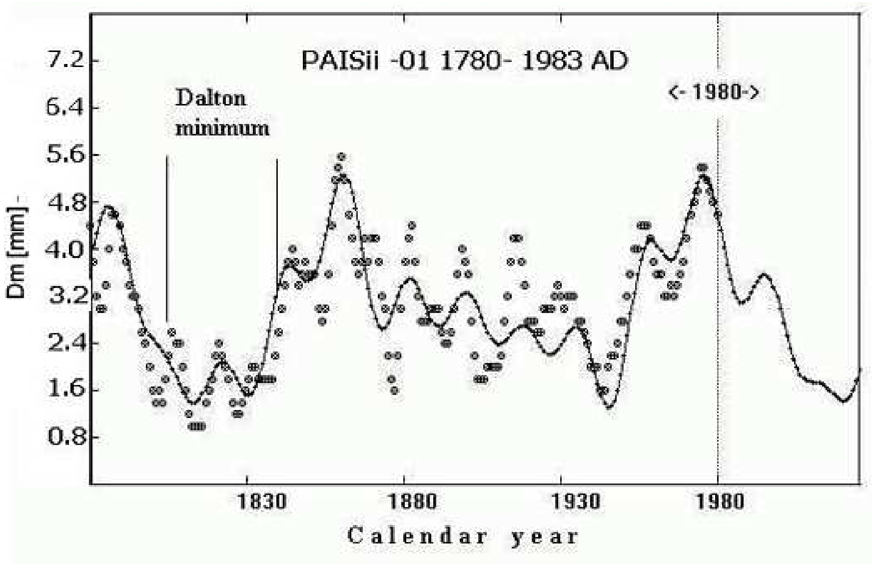

Fig. 10. Model of the time series of the smoothed widths of the annual rings for tree sample "Paisii-01", obtained on the basis of T-R correlogram, given in Fig. 8.

As it can be judged from Fig.10, the extrapolation points to a quick decrease of the annual rings widths from the beginning of the 80s till around 2010 AD. Taking into account also the results of the climate calibration, this extrapolation can be accepted as a forecast for upcoming long period of dry and hot summers, which starts after the maximum phase of the solar 11 yr cycle No 21 (SC 21). In the beginning it follows a quick decrease until the maximum of the even cycle No22 and some increase during the 90s, which however is much weaker than the one during the 70s. This shows that very soon after the maximum of the 22 cycle a process has started, very similar to the situation after the maximum of the solar cycle 4 at the end of the 18 century. Indeed, as it has been already stated in Section 2.4., some researchers have provided strong arguments pointing that the transfer to the new Dalton-type minimum has started not at the end of cycle 23, but during 1993 AD, i.e. soon after the maximum of SC 22.

Thus the extrapolation of our model presents not only a forecast for upcoming dry and hot summer period in Southern Bulgaria, but also for new Dalton-type minimum. Naturally, this result increases the interest for further studies of other beech samples. Such a possibility has appeared in 2013 AD and is directly connected with the present project.

3.2. "Rositsa-01"

The innermost central part of the tree has not been included in the analysis because of the abnormal structure of "Rositsa-01" in the central part of the sample as well as due to different nonlinear effects and deviations in the earliest period of the tree growth. The results were actually obtained on the basis of 4 radial profiles. Two of these were 221-yr old, while the other two - 200 yr. The 200 yr profile for the period 1811-2011 AD, averaged on 5 radii and smoothed over 5 yr, is shown in Fig. 11.

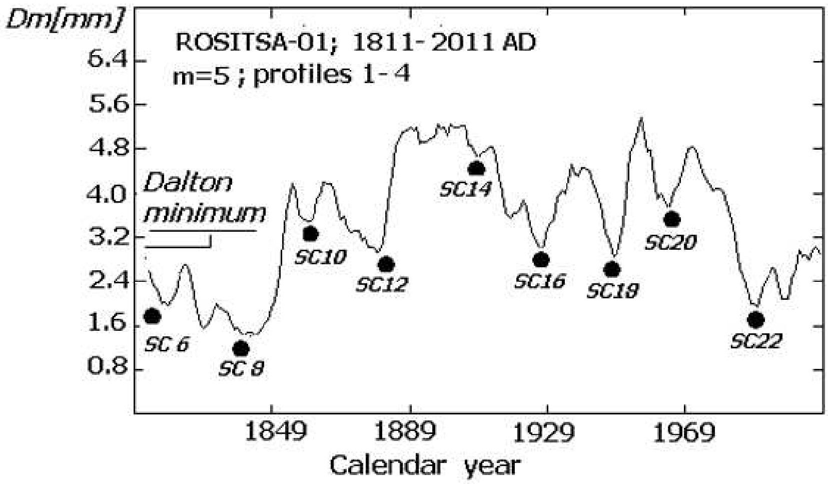

Fig. 11. Smoothed time series of the widths of the annual rings for the tree sample "Rositsa-01": 200-yr profiles 1-4.

The main difference between it and the corresponding plot for the sample "Paisii-01" is the clearly observable 200 yr wave, starting with a deep minimum in the beginning of 19th century (Dalton Minimum) and ending with another well expressed minimum at the very end of the 20th and the beginning of the 21st century.

On the plots in Fig.11 the local minima around the maxima of the even 11 yr cycles are clearly seen. In contrast to the sample "Paisii-01" the depths of these minima differ much strongly. It is obvious, that these depths depend strongly on the phase of the 200 yr wave. The amplitudes of the 20-22 yr cycle, corresponding to the ascending and descending trends of the 200 yr cycle, are the strongest. These amplitudes almost disappear around its maximum, which coincides approximately with the solar century minimum of Gleissberg-Gnevishev. Apropos, the peak of the annual rings growth during this minimum clearly stands out and dominates over the other two epochs of strong growth of the sample around 1860-1870 and 1960-1980 AD.

This is the second essential difference from the sample from Hainboaz, however it is the main reason the 200 yr cycle in the region of the Sevliev Balkan to have so strongly expressed quasi-periodic trend. In contrast, the quasi-century and sub-century periodicities are considerably worse expressed.

This is also confirmed by the T-R spectrum of the smoothed series of the ring widths of "Rositsa-01" sample (Fig. 12). The two century 200-210 yr cycle is present in this spectrum with a powerful peak with a period equal to 207 yr with a high correlation factor - almost 0.8.

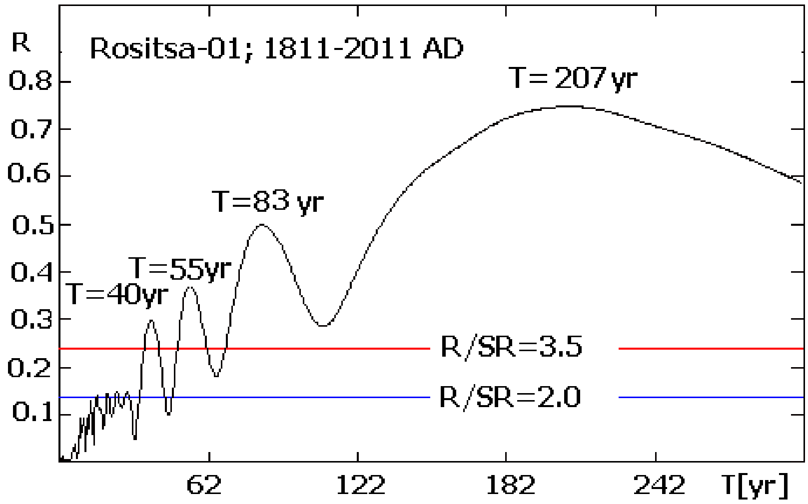

Fig. 12. T-R correlogram of the time series of the smoothed widths of the annual rings forthe tree sample "Rositsa-01": 200-yr profiles 1-4.

On the other hand, the quasi 120 yr cycle here is replaced by another component of the century "multiplet", namely the analogue of the solar cycle of Gleissberg. The quasi 60 yr cycle here is presented by its shorter variant as a 55 yr cycle, as it actually has been found in the summer precipitations of the Southern Bulgaria. The presence of statistically significant double Hale 40 yr cycle ($\sim$ 40 $-$ 44 yr) is striking. Its robust presence in the Solar behavior has been finally proven by Javaraiah (2003).

In Fig. 13 the averaged and smoothed data are shown, obtained only on the basis of the longer 221 yr profiles. We wanted to check the importance for the results of the inclusion or exclusion of an extra profile in case of small number of averaged radial profiles. It can be seen from the plot that there is no difference between the cases of averaging on 2 or on 4 radial profiles, and the data values differ slightly as well. The only one more considerable difference consists in the better representation of the 20-22 yr cycle in the case of 2 averaged profiles.

The data from the nearby meteorological stations Gabrovo and Pleven were used for climate calibration of the sample "Rositsa-01".

Statistically significant relationships with the summer rainfalls and temperatures in both stations have been found. However, only the relationship with the average temperatures during the warm semi-annual period of Pleven station was found to be of prognostic significance, though almost at the minimal threshold of the F-criteria of Snedekor-Fisher. The found relationship points that the annual ring width of "Rositsa-01" is inversely proportional to the temperature, i.e. slow beech growth corresponds to hot summers (Fig. 14). This result is in accordance with the analogous one for the sample "Paisii-01" of the Southern slope of the Balkan range.

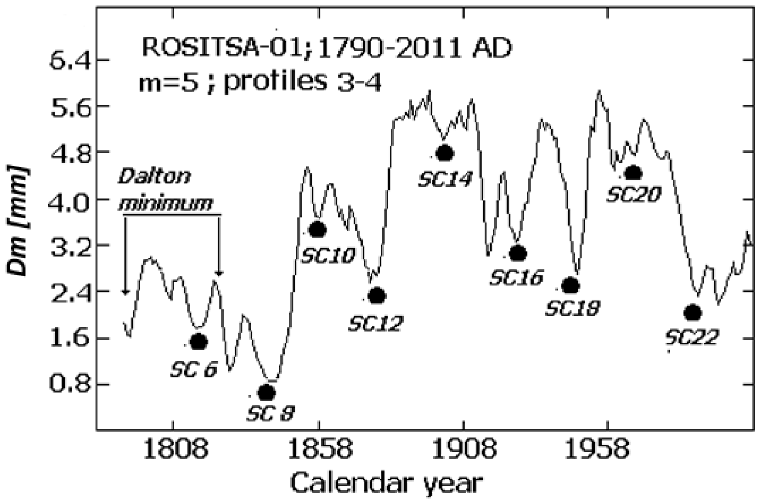

Fig. 13. Smoothed time series of the widths of the annual rings for the tree sample "Rositsa-01": 200-yr profiles 3 and 4.

The considerable decrease of the width of the annual rings of "Rositsa-01" at the end of the 20th century is actually an independent confirmation of the forecast for summer drought and for the onset of the Dalton-type solar minimum around the end of the 20th and the beginning of the 21st century, obtained from the "Paisii-01" sample on the basis of data till 1982 AD. From this point of view this can be interpreted as a successful example of "epignose" (i.e. a test forecast on previously known trend of the studied parameter).

As in the case of "Paisii-01", a model of the time series has been built for "Rositsa-01", based on the discovered statistically significant cycles (Fig. 15). This model has a high correlation factor with the original data, namely 0.91. It is extrapolated for the period between 2011 and 2040 AD. It is clearly observable from it that the minimum of the annual rings (i.e. the maximum of the summer warming) has already been reached around the beginning of the even 24 yr solar cycle. There follows a period of a gradual cooling of the climate, which is expected to increase rapidly after 2030 AD.

4. Discussion

The obtained and presented results till now concern two tree samples of one and the same type. Still, though not numerous, even at this stage of the study they allow us to make some interesting preliminary interpretations.

First, 20-22 yr cycle is seen in the annual rings widths of both samples. It is strongly expressed and the corresponding T-R spectrum is well noticeable in the data of the sample "Paisii-01", which is taken from a site, situated at the southern slopes of the Balkan Range. Also it has been shown that although seen in the data of "Rositsa-01", it is strongly "damped" by the powerful 200 yr wave, obviously connected with the 200-210 yr solar climate cycle.

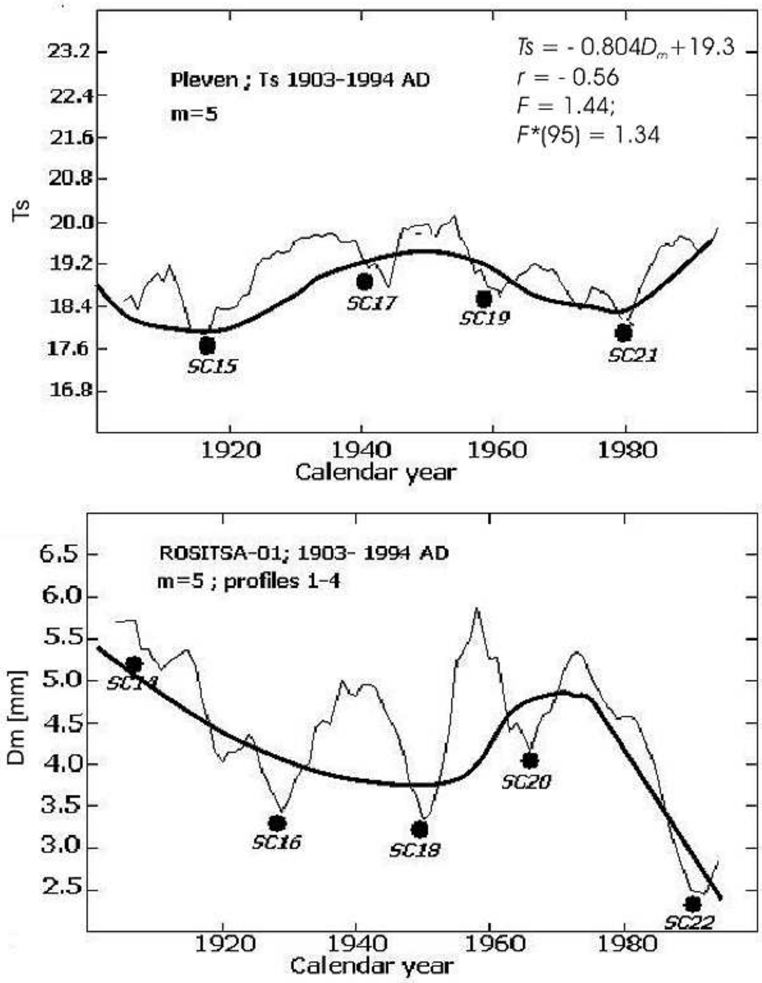

Fig. 14. Relationship between the smoothed values of the width Dm of the annual rings of the tree sample "Rositsa-01" and the average temperature during the warm semi-annual period Ts in a station Pleven in the period 1899-1994.

At the same time, as it can be seen on the corresponding T-R correlogram, it is around the critical threshold at 95% C.L. ($R/SR \approx 2$; SR is the error of the corresponding correlation factor R). Does that mean that during the warm semi-annual periods in the climate of Southern Bulgaria during the last two centuries the 20-22 yr cycle has been more expressed than to the North of the main chain of the Balkan Range?

Let us look at independent results concerning that, obtained in the 80s. At that time, at the Basic observatory "Yurij Gagarin" - Stara Zagora of the

Central Laboratory for Cosmic Research of BAS a three year program was realized. This program is dedicated to the study of the influence of solar activity on Bulgaria climate during the 20th century on the basis of a maximally complete sample of instrumental data for the period 1899-1979 AD.

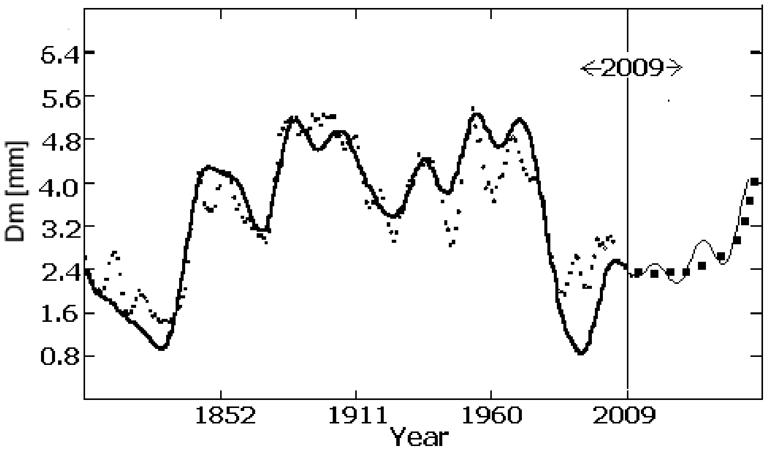

Fig. 15. Model of the time series of the smoothed widths of the annual rings for tree sample "Rositsa-01", obtained on the basis of the T-R correlogram, given in Fig. 11.

Actually, the net of stations used at that period is used for the climate calibration of the tree samples of the current program. The obtained results by Komitov (1981, 1986) and Gogoshev and Komitov (1983) showed that during the studied period (almost 80 yr long, namely 1899-1979 AD), on most of the Bulgaria's territory the 20-22 yr variations of the precipitations and the temperature during the warm semi-annual period, related with the solar magnetic Hale cycle, have been observed. In Northern Bulgaria, however, such variations were almost absent and practically they have been found with some statistical significance only in the data of three of the studied stations, namely Pleven, Suhindol and Varshets (Fig. 16).

The obtained results from the present study certainly confirm the difference in the level of climate influence of the solar Hale cycle on different sides of the Central Chain of the Balkan Range, which difference have been found three decades ago. Again, similar to the case of instrumental data, it is more strongly expressed to the South of the Central Chain. What might be the reason for that?

Most probably it is due to the dynamics of the Mediterranean cyclones. As far as can be judged from the instrumental and the dendro-chronological data of the studied tree samples, during the last two centuries, its influence has been considerably stronger in Southern than in Northern Bulgaria. This seems logical even from simple physics-geographical considerations. Due to the fact that cyclogenesis in the Western Mediterranean is directly related to the activity of the Iceland baric minimum, these results present an indirect independent confirmation of the influence of 20-22 yr solar cycle on the dynamics of this big baric center of the Northern Hemisphere.

This fact has been found and investigated by many researchers since the Second World War till now (Rubashev, 1963 and the citations there in; Shourmans and Oort, 1969; Vitinski et al., 1976 and the citations there in; Herman and Goldberg, 1978 and the citations there in).

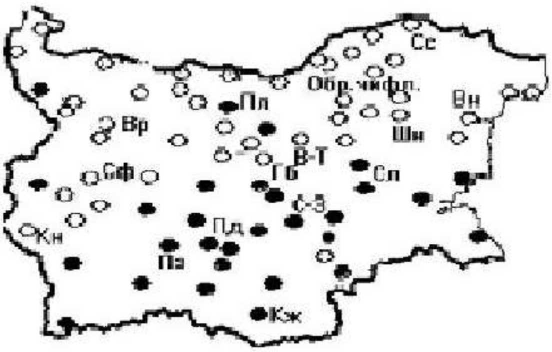

Fig. 16. 20-22 yr cycle during the warm semi-annual period in the climate of Southern Bulgaria by instrumental data for the period 1899-1979. The dark circles indicate the stations, in which that cycle is determined with confidence level $\geq$ 95% (Gogoshev and Komitov, 1983).

The better manifestation of the 200-210 yr solar climate cycle during the warm semi-annual period of Northern Bulgaria perhaps is a consequence of the fact, that this cycle is less expressed (or specifically expressed) in the behavior of the Iceland baric minimum and, respectively, of the Mediterranean cyclones. As it has been mentioned already, this question will be discussed in more detail after the processing of the data from more tree samples, which will be compared with the dendro-chronological data from other parts of the Northern Hemisphere. Here we would like only to remind again, that the climate effect of the 200-210 yr cycle is observable both at regional and planetary scale, while the influence of the 20-22 yr cycle has regional character and it shows in regions with transitional continental and subtropical climate.

From the presented results it can be concluded that the over century long Dalton-type minima are periods during which 20-22 yr climate cycle not only considerably decreases but practically temporarily disappears. As discussed already, this is most probably connected with the long term decrease of the magnetic flux of the Sun and the formation of series of weak (two or more) 11-yr cycles. The results of Mitchel et al. (1979) led to the same conclusion. These authors, on the basis of a study of the annual tree rings of numerous redwood samples from the Western part of USA, have found that 20-22 yr cycle is robustly presented in the climate of this region, at least since 17th century till now. Meanwhile they have found that it considerably decreased during the minima of Maunder, Dalton and Gleissberg-Gnevishev, corresponding respectively to the second half of the 17th century, the beginning of the 19th century and the beginning of the 20th century.

Here is the place to note also that an observable decrease of the 20-22 yr cycle amplitude in the data for the annual rings widths of "Rositsa-01" exists also during the Gleissberg-Gnevishev Minimum (1898-1923 AD). However, as can be seen from Fig.11, in contrast to the Dalton Minimum and the new over century long minimum in the beginning of the 21 century, Gleissberg-Gnevishev Minimum is connected to big annual ring widths and weakly expressed minimum of the solar cycle No14 (SC 14), i.e. to cool summers.

It is quite possible that the Minimum of Gleissberg-Gnevishev has been a period during which the climate contrasts during the warm semi-annual period between Northern and Southern Bulgaria were big. In Northern Bulgaria they were cool, while to the South of the Balkan Range they were rather dry and hot, and the synchronization with 20-22 yr cycle was comparatively good. Still, there also exists certain collapse and an evidence of the "excess minimum" in the tree rings of "Paisii-01" at the end of the 19th century. The latter perhaps is an indication of the occurrence of a Sun event analogous to the one which happened after the maximum of even solar cycle No 4 in the beginning of the Dalton Minimum. However, it has been short lasting.

Conclusion

The ascertainment that at present the climate of Bulgaria is in a period similar to the one corresponding to the solar Dalton Minimum, leads to three important conclusions.

1. The contemporary period of hot and dry summers is a result of consequential quasi-periodic processes, related to the long term behavior of the Sun. This concerns time scales beyond the 11 and 22 yr cycles, corresponding to climate effects caused by the concrete phase of the 200-210 yr solar cycle. To some extend the situation is connected also with the current phase of the over millennium 2200-2400 yr solar cycle (Hallstadtzeit), which role, however, we have only briefly touched. Therefore, we consider it unnecessary to include the hypothesis of an additional source of warming during the last 30 yr, as it has been done by some authors (Lockwood and Frolich 2007).

2. The period of the contemporary warming of the summer periods has occurred in two phases. During the first phase after the maximum of the solar cycle with Zurich number 21 (SC 21) during 1980-81 AD the "regular" heating and drying of the warm semi-annual period have started. It continued till the maximum of the solar cycle No 22, i.e. until 1989-91 AD. However, soon after that long term changes in the regime of the solar matter transfer in the convective zone have started. This lead to the shortening of the SC22, which lasted only 9.6 years. Therefore this cycle ended too early, namely in May 1996 AD. Practically, this has led to the onset of the Dalton-type minimum, observed after the end of the solar cycle No 23 (SC 23) during 2007-2008 AD. The process has been accompanied by sharp reduction of the 20-22 yr solar cycle during the descending phase of SC 22. This reflected on climate, leading to considerable decrease of the activity of the Iceland Minimum and to the establishment of a long period of dry and hot summers in the South-Eastern Europe at the end of the 20th and the beginning of the 21st century. The maximal phase of this process has been reached around 2007 AD, i.e. just before the actual observable start of the new Dalton-type maximum.

3. In the long term a slow restoration of the amplitude of the 20-22 yr solar cycle is expected. However, the process will become noticeable after the end of the solar cycle with Zurich number 25 (SC 25), i.e. after 2028-2030 AD. A weakly expressed cooling and humidification of the summer periods is to

be expected between the maxima of the current and the following 11-yr solar cycle, i.e. between 2013/2014 and 2025 AD.

4. The known instrumental data series, here and abroad, are too short to be used as the sole basis for interpretation of the climate current state and its future changes. The use of the indirect data can provide good results only when the corresponding series have minimum 200 yr length. This concerns the dendro-chronological data, as well.

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