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The Climate of Bulgaria during 19th and 20th Centuries by Instrumental and Indirect Data: Solar Modulated Cyles and Its Evolution

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Abstract. At the beginning of 80s a very detailed studies of bulgarian climate changes during 20th century has been provided. In this work we give an evidence that the climatic phenomenas during last two decades are caused rather by solar activity variations effects as by any other factor. The new study is based on meteorological measurements data for the period 1980-1994 in addition to the previous information as well as on indirect climatic data (tree rings width data series from AD 1780 to AD 1982) and new solar activity data, including the indirect "cosmogenic" ^{10}Be series.

1 Introduction

At the beginning of 80s a very detailed studies of bulgarian climate changes during 20th century has been provided [1]. The last one was on the base of a time series analysis of 73 meteorological stations for interval of AD 1899-1979. On the base of these studies the following conclusions has been made:

1. On $\sim$ 3/4 of South Bulgaria territory and separate stations in North Bulgaria a well expressed 20-22 year climatic cycle in the "warm" half-year (May-October) during the investigated period exist. Most probably it is caused by solar 20-22 year magnetic (Hale) cycle influence. The cases most warmer and dryer summers are predominantly centered to ascedent phases of even quasi-11year Schwabe-Wolf solar cycles.

2. A statistical significant quasi-11 year winter temperature cycle on almost all bulgarian territory for investigated period has been detected. The most colder winter cases are centered predominantly near to solar Schwabe-Wolf cycles minimums.

3. There are some evidences about evolution of solar modulated climatic oscillations during 20th century.

In this work we give an evidence that the climatic phenomenas during last two decades are caused rather by solar activity variations effects as by any other factor. The new study is based on meteorological measurements data for the period 1980-1994 in addition to the previous information as well as on indirect climatic data (tree rings width data series from AD 1780 to AD 1982) and new solar activity data, including the indirect "cosmogenic" ^{10}Be series. New statistical methods for cyclic oscillations evolution analysis are used too in this paper. Because of the limited print volume only a part of the most interesting results and conclusions are presented there.

2 The Data and Methods

For the aims of present study following types of data are used:

1. Instrumental data of mean monthly temperatures and monthly rain sums in 26 meteorological stations for the period 1980-1994 On the base of last ones the mean temperatures and rain sums for "winter"(cold) and "summer"(warm) half-years has been builded. The are added to the corresponding data series before 1980 [1].
2. Tree ring width data series a beech sample, (Fagus, place near Gurkovo, District of Stara Zagora, Stara Planina Mountain) for period of 1780-1983-as an indicator for climate changes in Central Bulgaria during the last $\sim$ 200 years.
3. The "cosmogenic" ^{10}Be Greenland ices contents series ("Dye-3" probe) for period of 1780-1985. Due to the anticorrelation between the galactic cosmic rays and solar wind fluxes ("Forbush effect") there is an opposite relationship between "cosmogenic isothopes" like ^{10}Be, ^{14}C , ^{18}O etc. and solar activity level.

For time series analysis and cycles evolution two modifications of the numerical procedure labeled as "T-R periodogramm analysis" has been used. The first one is the "standard" T-R periodogram analysis [1, 3, 4]. On its base a "mean" spectra of oscilations for the all time series can be obtained. The second one is "two-dimensional" T-R periodogramm analysis (a "moving epoch" procedure) and it is used for cycles evolution study. This procedure is described in details by [5]. For factor relationships study a one and multiply regressional as well as cross-correllaton analysis has been used. All abovesaided procedures are realised in 6D-STAT v. 7.0 /7.05/7.1 software package (see: www.astro.bas.bg/$\sim$komitov/6d-stat.htm).

3 Results and Analysis

3.1 The instrumental climatic data (AD 1899-1994)

3.1.1 The “standard” T-R periodogram analysis

As has is already pointed in paragraph 2 we have obtained instrumental data in interval AD 1980-1994 for 26 from the all 73 stations which have been used in previous study [1]. Unfortunately there are not published data for the recent years after 1994

In Figure 1 the smoothing 5-year average values of warm half-year rain sums in Plovdiv (epoch AD 1899-1994) is shown. In Figure 2 the corresponding T-R correllogramm is presented. For the last one the following parameters are choiced: initial period T_0=2 years, scan step ΔT= 0.25 years and the total scanning steps is 400. As a result the correllogram show all statistical significant cycles in range of 2-102 years. As it is visible enough, the 20-22 year cycle remain stable after AD 1980 too. The summer dry period starting near to AD 1984 is in good coincidence with the transition epoch from the odd Schwabe-Wolf cycle with Zurich number 21 to the even 22nd one. This is in very good agreement with our earlier conclusions [1, 2]. However it need also note that the dry period after 1984 is the deepest relatively all similar epochs during the instrumental measurements in Bulgaria since AD 1899. On other hand the corresponding summer warming is no so expressive. It is on third place after the summer warming peacks near to AD 1928-1930 near to even Schwabe-Wolf cycle No 16 maximun and more earlier temperature maximum during the first decade of 20th century (Figure 3).

A new feature in Figure 2 is the weak peak near period $T = 54$ years. By high

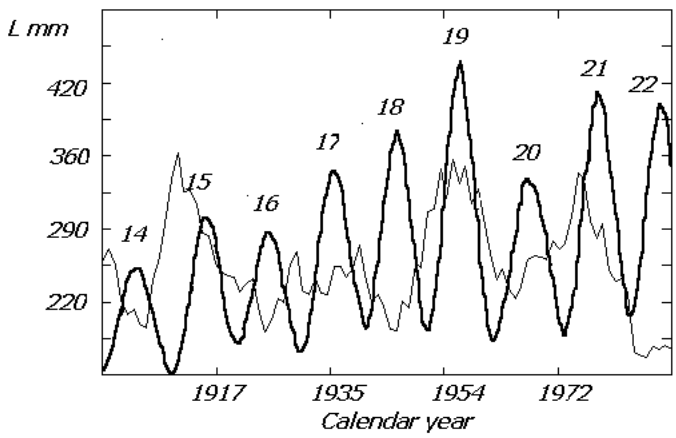

Figure 1. Plovdiv (AD 1899-1994) Smoothing 5-year warm halfyear rain sums (thin line) and Group Sunspot Number Index “Rg”(thick line)

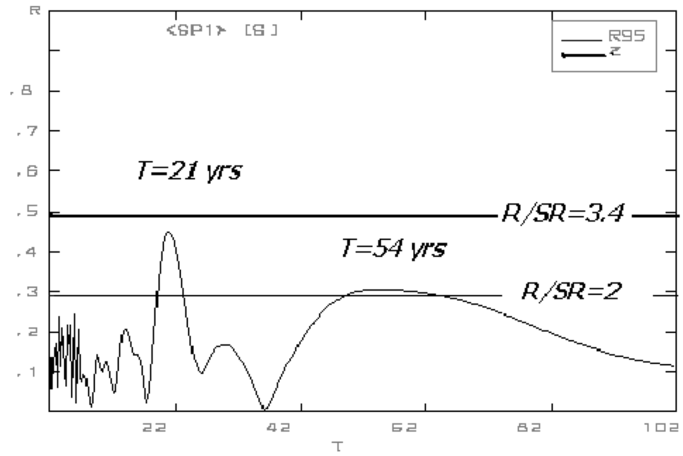

Figure 2. Plovdiv (AD 1899-1994) Warm half-year rain sums: T-R correllogram

level of certainty the last one is solar modulated. A cycle with such duration present in some solar phenomena, in "cosmogenic" ^{10}Be series, as well as in auroras [6]. Because of the fact that this cycle is relatively long it was not an object of our present studies in 80s.

On the base of this facts it may to conclude that there are not evidences for essentially different behaviour of warm half-year climate in South Bulgaria during AD 1980-1994 as in the previous investigated epoch (AD 1899-1979).

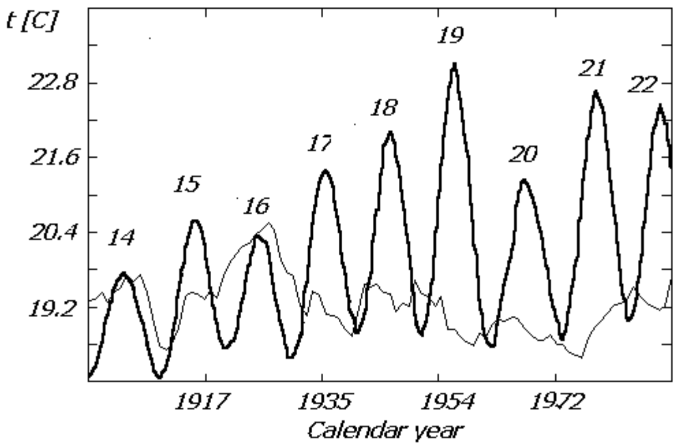

Figure 3. Plovdiv (AD 1899-1994) Smoothing 5-year warm halfyear mean temperatures (thin line) and Group Sunspot Number Index "Rg"(thick line)

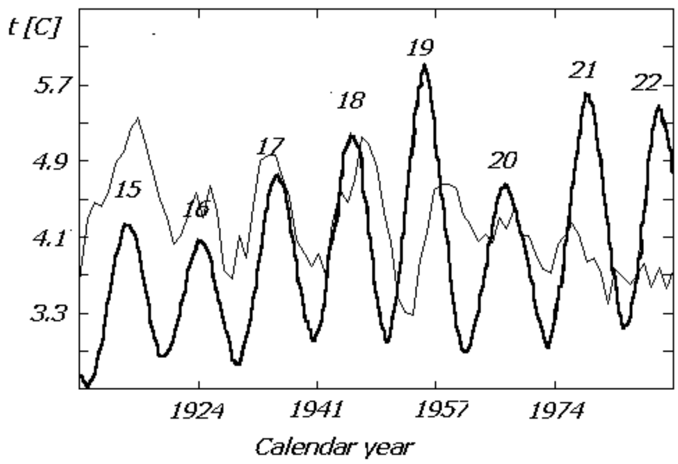

Figure 4. Dupnitsa (AD 1909-1994) Smoothing 5-year winter halfyear mean temperatures (thin line) and Group Sunspot Number Index "Rg"(thick line)

As we already are pointed in paragraph 1 in the region of West Valleys quasy-11 year winter temperatures oscillations are best expressed during epoch 1899-1979 [1]. After an adding of data for epoch 1980-1994 a new analysis has been made.

The smoothing 5-years cold half-year mean temperatures for a typical West Valleys station - Dupnitsa to epoch AD 1909-1994 is shown in Figure 4. It is visible that during the last three decades of the investigated period the quasi-11 year oscillation is going down and it is almost totally absent after AD 1980. Unlike the warm half-year most probably there is an influence of some additional factor. On the other hand there is no certain general trend in this series and the possibility that the so mentioned 11-year oscillation deceasing is a result of "global antropogenic warming" by our opinion must to exclude. An possible alternative cause may connected to large scale solar activity regime changes.

3.1.2 The two-dimensional T-R periodogram analysis (a "moving epoch" procedure)

To test the hypothesis for large-scale solar activity regime influence over climate changes we use two methods in this study. The first one is by using a T-R periodogram "moving epoch" procedure, i. e. "two-dimensional" T-R periodogram analysis [5]. It is based on the "standard" T-R procedure, which is used not over the all series, but in small its parts with equivalent length. Every one part is shifted relatively to the adjacent ones by equidistant time step "delta-t". In our case this time step of shifting is equal to 1 year. By this method we derive

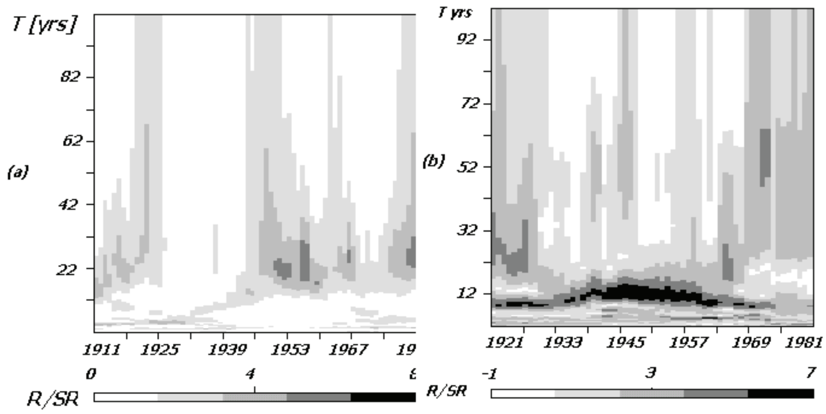

Figure 5. The two-dimensional T-R correlograms; left -Plovdiv (1899-1994)-rain sums, warm half-year; right -Dupnitsa (1909-1994) -mean temperatures,cold halfyear. On X-axis the centers of moving epochs are presented

from the general time series a large number of shorter parts ("moving epochs") Over every one such "moving epoch" a standard T-R periodogram analysis with constant parameters T_0, δT and scanning steps number is proceeded. As a result a map, presented coefficients of correlation between $F(t)$ and $\varphi(t)$ is derived. $F(t)$ are the original, observed data values and $\varphi(t)$ is a simple periodic function with current period T, obtained by mean least squares procedure [1, 3, 4]. Every column in this map correspond to single standard T-R correlogram for separated "moving epoch". The last one is presented by number of column. The coefficients of correlation values R are presented on map by colors or gray halftones scale. A more expressive variant is to show map no of R values, but of corresponding R/SR, where SR is the error of R.

For the aims of present study we use a standard "moving epoch" length of 25 years and following parameters of the "standard" T-R correllogram: $T_0 = 2$ years, $\Delta T = 0.25$ years and 100 scanning steps.

The results for Plovdiv (warm halfyear rain sums) and Dupnitsa (mean cold halfyear temperatures) are shown in Figures 5a and 5b respectively. It may conclude, that the amplitudes and significances of quasi 11 and 20-22 years cycles (presented by R/SR ratio) are varied essentially during 20th century. One may say that generally at the beginning of the century, which approximately coincided with the start of last centurial solar cycle the both solar modulated climatic cycles are relatively weaker as at the middle of century, corresponding of centurial as well as of quasibicenturial solar cycles maximums [7]. After $\sim AD$ 1960 (i. e. after Schwabe-Wolf cycle No19 maximum) the amplitudes of both cycles is going down and this is more visible for the quasi 11-year climatic oscillation. The absolute minimum of 20-22 year cycle magnitude is near to AD 1930. During the last three decades of century a new increasing of 20-22 years oscillation in warm half-year is observed. However there is no similar behaviour of cold half-year ("winter") temperatures 11-year oscillations.

The results mentioned above indicated that the shorter (11 and 22 years) solar-climatic cycles amplitudes are depended by large time scale solar-climatic relationships tendencies.

3.2 Solar-modulated cycles in the climate of Central Bulgaria (AD 1780-1982) by dendrochronological data

In this paragraph we give brief comments of main results concerning data analysis of a beech sample tree rings widths. The age of last one is 209 years. The initial six years are removed from investigated time series because of the high level uncertainty. The final series is related to epoch of AD 1780-1982. The measurement precision is ~ 0.05 mm. The first results and analysis have been presented in 2001 [8].

The smoothing 5-years tree rings widths are shown in Figure 6. The corresponding T-R correllogram is in Figure 7. The quasi-20 year oscillations with various amplitude are presented in almost all time series, except at the beginning of 19th century. The last one period is characterized by very small values of tree rings width ($\sim$0.1-0.15 mm). It is an interesting epoch for large scale variations of solar activity - the so called Dalton minimum. The last one is a supercenturial solar minimum , coincided with the decreasing phase of solar quasibicenturial ($\sim$205 year) cycle.

In T-R spectra (Figure 7) a cycles with duration of 54, 67 and 115 as well as a

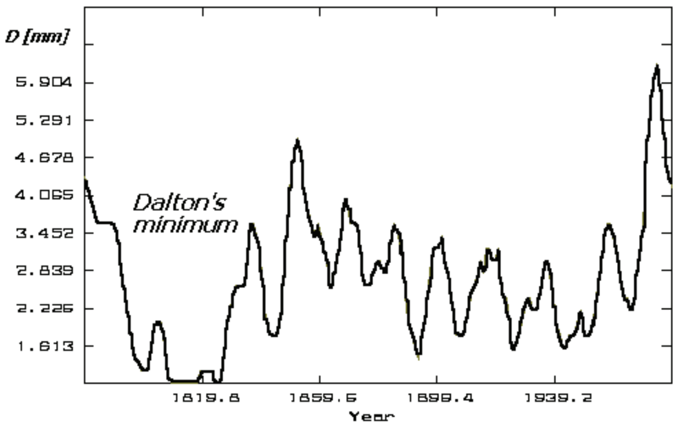

Figure 6. Beech tree rings width (AD 1780-1982) (Gurkovo,District of Si.Zagora) smoothing 5-year values

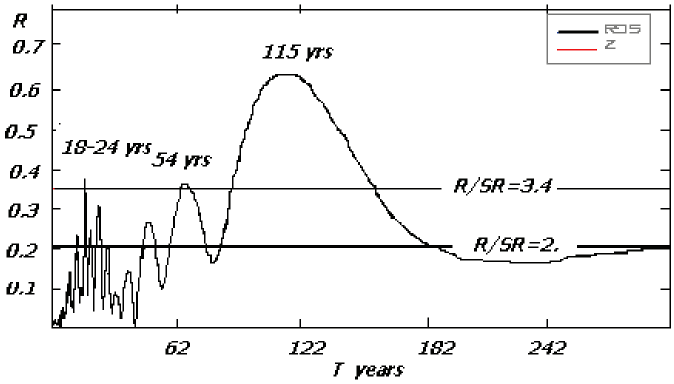

Figure 7. Beech tree rings width (AD 1780-1982) ;T-R corellogram

multiplet in the range 17-24 years are statistically significant. It need note that oscillations by duration of 54 and 67 and 115-120 years are detected in ^10Be Greenland series (1423-1985) [9]. The last ones (67 and 115-120 years) are very strong in this series. The 115-120 year cycle is found by Duchlev [10] as a quasiperiodic trend -"hypercycle" in the Meudon time series of quiescent prominences. These facts are indicated that in corona and solar wind activity are very important also some processes ,where are with essentially different nature and time behaviour as these ones in photosphere. Most probably this type of activity is related to the large time scale solar variations and is characterized by high climatic efficiency.

An additional evidence in this course is the fact that 20-22 cycles magnitude is modulated in our beech tree ring width data by 67 year cycle. The minimal 20-22 years oscillation magnitudes are near to Dalton minimum, AD 1870 and 1930-1940 respectively. The last one is in good coincidence with the 20-22 year warm half-year rain cycle magnitudes behaviour by instrumental data (see paragraph 3.1.2.).

On the base of all significant cycles, which are shown in T-R correlogram in Figure 7 a time series model of tree ring width data has been built using technique, described by [4]. Its extrapolation after AD 1982 close to 2030 show a rapid tendency to for decreasing of tree rings widths to values of $\sim$0.1 mm, i.e. very similar to these during Dalton minimum. This result is very significant and interesting if it take into account that that a forthcoming of supercenturial solar minimum during 21st century is predicted by [7, 8, 11, 12]. In climatic aspect it may indicated a cooling and more continental tendencies.

4 Conclusions

On the base of presented in this study results and its analysis the following conclusions can be made:

1. The solar modulated climatic cycles by duration of 10-11 and 20-22 years exist in climate of Bulgaria and it can detected in instrumental as well as in indirect data series. Its magnitude varied by the modulation of longer solar -climatic cycles by subcenturial and quasicenturial duration.

2. The 54, 67 and $\sim$ 115 year climatic cycles have analogies in solar corona, solar wind and geomagnetic phenomenas behaviour. They indicated that a significant part of solar influence over Earth climate may be related to processes where are running not in photosphere, but in outer parts of Sun atmosphere.

3. The dendrochronological data model extrapolation predicted a climatic conditions in Central Bulgaria during first half of 21st century, very similar to these of solar supercenturial Dalton minimum in first half of 19th century. The last one correspond of cooling and more continental climatic tendencies.

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