The investigation of solar activity signals by analyzing of tree ring chronological scales

M.G. Nickiforov[1]
[1]Sternberg Astronomy Institute of the Moscow State University, Universitetskiy pr. 13, 119991, Moscow, Russia
michael.nickiforov@gmail.com

(Submitted on 12.12.2016. Accepted on 9.05.2017)

Abstract. The present study examines the ability of detecting short-cycles and global minima of solar activity by analyzing dendrochronologies. Starting with the study of Douglass, which was devoted to the question of climatic cycles and the growth of trees, it is believed that the analysis of dendrochronologies allows to detect the cycle of Wolf-Schwabe. According to his results, the cycle was absent during Maunder's minimum and appeared after its completion.

Having checked Douglass's conclusions by using 10 dendrochronologies of yellow pines from Arizona, which cover the time period from 1600 to 1900, we have come to the opposite results. The verification shows that: a) none of the considered dendroscale allows to detect an 11-year cycle; 2) the behaviour of a short peroid-signal does not undergo significant changes before, during or after Maunder's minimum.

A similar attempt to detect global minima of solar activity by using five dendrochronologies from different areas has not led to positive results. On the one hand, the signal of global extremum is not always recorded in dendrochronology, on the other hand, the deep depression of annual rings allows to suppose the existence of a global minimum of solar activity, which is actually absent.

Key words: signal analysis of tree rings, solar activity

1 Introduction

The dendrochronological method of dating in archeology has been used for a long time [Kolchin, Chernih, 1977]. Its idea is to compare a sample with wooden dendroscale built for the set of similar trees in the region. It's known that climate undergoes local and global variations at any point of the globe. The average temperature, humidity and illumination change from summer to summer or from one decade to another affecting the width of tree rings. Favourable years for a tree growth correspond to broad rings, adverse years - to narrow rings. [We have to note, that the response to changing climatic factors is various for different species of trees.] From the mathematical point of view, a set of ordered tree rings corresponding to the cutting of the tree form a numerical number or a signal that can be formally processed.

It was established experimentally that the signals of the trees of the same species growing in the same area are close and have high correlation. Having considered a large number of trees of the same breed growing in one area, we are able to build a local dendroscale. The periods of life of different samples can overlap allowing us to construct a long dendrochronology which covers the time interval from the oldest tree in the sample, to the youngest one. The length of modern dendrochronologies reaches hundreds of years and more.

The method of dendrochronological dating consists in comparing the extremes of signal of the given sample with the signal of archaeological sample. The sample should have a sufficient number of annual rings and consist of the same wood species as dendroscale. In case of success, we can correlate the signal of a sample with the signal of dendroscale and thus obtain a relative dating of the sample. If we know the exact time of cutting of the trees, which were used for the building of the dendroscale, it is possible to associate each annual ring with a calendar year, and thus get an absolute dendrochronology.

In practice, very often it is necessary to convert the existing local dendrochronology, which was built based on the analysis of archaeological materials to the absolute dates. Here, some problems arise. The method of radiocarbon dating gives, at best, an error of tens of years with a standard deviation 1σ. At a confidence interval of two standard deviations (2σ) the accuracy of the dendroscale dating is about $\pm(150 \div 200)$ years that is in most cases an unacceptable result. In addition, there is every reason to believe that the accuracy of the estimation of the error of radiocarbon dates is overstated. For example, in the paper Bonani et al. [2001], the set of radiocarbon dates related to the certain monuments of ancient Egypt is given. The authors calculate radiocarbon ages for a large number of samples and receive the result with the indication of an error. In addition, they estimate the value of the error. However, the proportion of explained variance for the majority of dates is from 0 to 20%. This suggests that either the distribution of errors does not obey Gaussian's distribution or the accuracy of radiocarbon dates has been underestimated. A.M. Tyurin drew our attention to this important detail.

Due to the lack of precision of the radiocarbon method, the idea to synchronize extremes of a dendroscale with maxima and minima of solar activity was suggested. For this purpose, different researchers use synchronization as the 11-year cycle of solar activity [Chernih, Karpukhin, 2006], as well as signals of historic minima of solar activity [Prokudina, Rozanov, 2002]. The idea of searching the signals of solar activity by using tree rings belongs to Douglas. He was the first who found these signals, so we have to consider his results.

2 Searching of short periodical signals of solar activity

The main results of A.E. Douglass's study are detailed in the recent book by Zoon and S. Yaskel which is dedicated to the investigation of Meander's minimum. For 15 years he has examined about 230 different tree species and measured about 75 thousand samples. The authors present Douglass's results [Zoon, Yaskel, 2008, p. 203] by citing the book of Webb [1983, p. 113]:

> *Douglass found out that in spring and in summer tree rings grow fast, in autumn, they become more subtle, and during the spring drought, they form a double ring. The accurate measurements of tree rings allowed to create the database. However, Douglass had to make something else - he had to calculate the periodicity of the rings. In the same article, he showed strong evidence of cyclical changes in these data with 32.8 years 21.2 years and 11.3 years. His measurements were so accurate that he was able to predict the droughts in 1748, 1780 and 1821 years without any extra information.*

In 1919, as a result of a 15-year research Douglass published the article "Climatic cycles and tree-growth. A study of annual tree rings in relation to climate and solar activity".

To establish the influence of the Sun, Douglass investigated the width of annual rings and found a reference to a regular 11-year cycle. [In Zong and Yaskell's book on page 156 there is a separate note that we speak about an 11-year cycle, rather than a 22-year cycle which will be discovered later.]

According to Douglass's results, redwoods and yellow pines reflect an 11-year cycle of solar activity very confidently. Both tree species indicate that in the period from 1650 to the 1720s, this cycle was absent. Let us verify how accurate his conclusions are, and in what way it is possible to obtain his results. To do this, we have used the interactive resource of paleoinformation NOAA. As initial data, we used the dendrochronologies of yellow pine, which were built on the samples of Arizona (USA) (see Appendix 1). We made such a choice because the majority of samples of Douglass's set were collected in Arizona. We have special interest to yellow pine because unlike sequoia, this tree is widespread in Europe.

In total, we examined ten Arizona's dendroscales of yellow pine, which were selected from the database according to their serial number. So we used the scales of the following names: az026, az036, az042, az043, az045, az049, az069, az072, az077, az089. We did not consider az088 because it begins in 1688 and, therefore, it misses more than a half of the Maunder's minimum. Fig. 1 and Fig. 2 show the temporal signals from dendroscales between 1600 and 1900 A.D. [In order to download the data related to the scale with name "az026" it is necessary to dial the following text in a browser: $ftp : //ftp.ncdc.noaa.gov/pub/data/$ $paleo/treering/chronologies/northamerica/usa/az026.crn$]

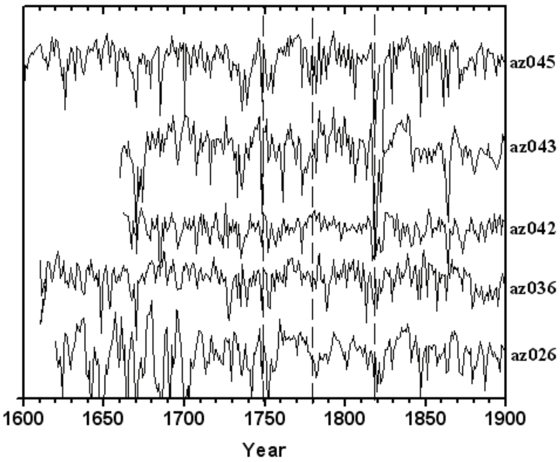

Fig. 1. *Arizona's dendroscales of yellow pine 026, 036, 042, 043, 045.*

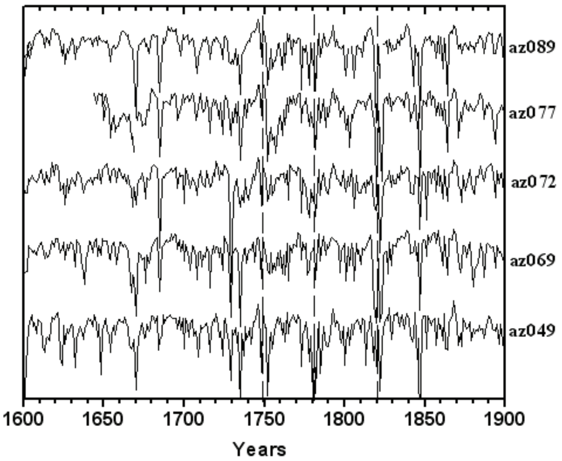

Fig. 2. *Arizona's dendroscales of yellow pine 049, 069, 072, 077, 089.*

Dendroscales and signals of droughts. Douglass found out that excessive humidity corresponds to a broad ring, and a lack of moisture - to a narrow ring. Let us verify whether he could detect droughts in 1748, 1780 and 1821's. To do this we consider the signal, which corresponds to selected dendroscales for each of these years. In 1748, the signal of drought is present on the scales az043, az045, az049, az077 and az089, that is exactly in a half of the cases. For the rest of the scales the local extremes are absent near 1748. The drought of 1780 cannot be traced by using the first five scales (Fig. 1), furthermore, on the scale az042 this point corresponds to a local maximum. If we rely on dendroscales az049-az089, we can assume that the drought occurred not in 1780, but a few years earlier. A minimum of 1821 can clearly be seen on all dendroscales and therefore it does not cause any questions.

Let us consider the inverse problem. If we analyze the signals recorded in dendroscales, we can suppose that there were droughts near 1685 and 1848, because in these years there are deep minima in Fig. 2, which can partially be traced in Fig. 1. From a formal point of view, the minima of 1685 and 1848 are not worse than the minima of 1748 and 1780; however, we do not have any information about droughts in Arizona in these years.

Therefore, we can draw the following conclusion. The variation of solar activity does not always lead to a climate response, which can be "read" in dendroscales. On the other hand, a deep minimum in a signal does not necessarily correspond to climatic features.

Short-period signals in Maunder's minimum. Douglass claims that high-frequency (or short-period) signals are absent during the period of 1650-1720 years. However, even a visual analysis of dendorscales shows that it is not true. The behaviour of signals does not undergo significant changes before, during and after Maunder's minimum, Fig. 1, Fig. 2.

Analysis of high-frequency cycles by using dendroscales. We carry out a formal analysis of the correlation dendroscales in the interval from 1720 until 1900. The lower boundary of this range corresponds approximately to the end of the period of Maunder's minimum, and the upper limit is related to the time when Douglass made his investigation. That is, Douglass discovered the solar cycles with duration of 11.3, 21.2 and 32.8 years by using analysis of dendroscales in this interval. Table 1 shows the calculated values of Spearman's coefficient correlation which shows how close two different dendroscales are to each other.

	026	**036**	**042**	**043**	**045**	**049**	**069**	**072**	**077**	**089**
026	**0.040**	0.472	0.225	0.397	0.610	0.645	0.542	0.549	0.560	0.378
036		**-0.040**	0.270	0.425	0.458	0.550	0.446	0.377	0.428	0.256
042			**0.106**	0.346	0.345	0.334	0.369	0.310	0.442	0.322
043				**0.037**	0.531	0.463	0.514	0.491	0.527	0.499
045					**0.078**	0.717	0.762	0.803	0.688	0.674
049						**-0.031**	0.670	0.726	0.764	0.646
069							**0.079**	0.712	0.733	0.681
072								**0.070**	0.628	0.701
077									**-0.022**	0.766
089										**0.068**
T	31-34	**4**;**6** 10; 28	-	**4**; 5-6 37-46	4; 23	4; 24	**4** 20-24	4; 21-25 41; 46	4; 21-24 44-46	**23**; 21-25 44; 46
T_M	16	-	11; 19	4; 8-9	**4**; $\underline{8}$	-	4-5	-	4; 8-12	-

Table 1. *Table 1. Correlation of dendroscales. Correlation coefficients between the signal of corresponding dendroscale and the annual Wolf numbers are shown on the main diagonal.*

The correlation coefficient characterizes how well the extremes of one scale correspond to the extremes of another scale. The minimum value of the correlation coefficient corresponds to the scales az026 and az042, but taking in account the size of samples, all coefficients with value $r \geq 0.145$ are significant at $\alpha = 0.05$.

The correlation coefficients between the signal of corresponding dendroscale and the annual Wolf numbers are calculated on the main diagonal. The data on annual Wolf numbers since 1700 to modern time were taken from the site SIDAC. Let's note that all these coefficients are statistically insignificant.

To find alleged cycles of solar activity variation we calculated the autocorrelation function for each dendroscale. The results of calculation are shown in rows "T" and "T_M", where every number corresponds to the largest positive value of correlation coefficient. In row "T" the values of correlation coefficient were calculated based on the information from 1720 to 1900. In row "T_M" we considered the signal in the period from 1650 to 1720 which corresponds to Maunder's minimum.

The calculations show that there are few statistically significant lags at the confidence level of 95%. In Table 1, all such values are marked by bold font. Therefore, to be able to get more information we took into consideration the cycles for which the value of autocorrelation coefficient exceeds the estimate of its error $r/\sigma_r \geq 1$. It should be noted that we did not consider the cycles at $lag = 1-3$ years, most of which correspond to the significant values of autocorrelation coefficients. There are two reasons why we have done it. Firstly, we suppose that the presence of autocorrelation is explained by the duration (or width) of local maxima and minima. Secondly, the main purpose of our investigation is the search for 11-year, 22-year and 33-year cycles.

The analysis of row "T", where we considered ten dendroscales, shows that statistically significant periods of solar activity cannot be detected in the interval from 1720 to 1900. In 3 out of 10 cases we obtained a 4-year cycle, and in 1 out of 10 cases we established the presence of a 23-year cycle. But we were not able to find an 11-year and a 33-year periods which were expected. If we consider the enhanced variant (for $r/\sigma_r \geq 1$), then in 6 out of 10 dendroscales it is possible to suspect the presence of the cycle lasting about 21-24 years. At the same time in 4 out of 10 cases we can trace the cycle with the duration of 40-46 years. Assuming the presence of a 21-24 year cycle, the last period should be considered as a double one.

The result of the analysis of solar activity cycles during Maunder's period (1650-1720) is shown in row "T_M". Let's note that the length of this time series is about 2.5 times less compared with the previously time period from 1720 to 1900 which we investigated in row "T". It is obvious, that the detection of statistically significant cycles of solar activity is a more difficult task when we have a shorter period of time. Perhaps, for this reason no signal was detected in 4 out of 10 cases. Statistically significant is the cycle at $lag = 4$ which corresponds to dendroscale az045. The doubled period at $lag = 8$ barely misses the significant range. If we take into account the extended version ($r/\sigma_r \geq 1$), some cycles can be found in 6 out of 10 cases.

As a result we have the following situation. From the formal point of view, the analysis of dendroscale's signals does not allow to allocate statistically significant cycles of solar activity during Maunder's minimum (1650-1720) or after it (1720-1900). We investigated ten dendroscales from Arizona but we were not able to detect cycles with the duration of 11, 22 and 33 years which were found out by Douglass. At lower requirements ($r/\sigma_r \geq 1$), it is possible to suspect the presence of a 4-year and 21-24-year cycles during the period of 1720-1900.

The similar pattern is observed during Maunder's minimum. As a result of processing of 10 samples we could not establish statistically significant periods, however, at a less confidence level, it is possible to suspect the presence of the cycles with the duration about 4 and 8-11 years. Thus, Douglass's statement that an 11-year Schwabe's cycle disappears during Maunder's minimum and appears after it, is erroneous. The calculations show that Schwabe's cycle is not detected at all in our data. Let's note that Douglass has defined the periods with an improbable accuracy up to one tenth of the year, while our estimates turned out to be ten times worse.

The most probable is that his conclusions are based on a preliminary selection of original data. He was really able to build dozens of dendrochronologies, selecting for the analysis well-recorded extremes. However, even a small selection of the source data will provide the necessary statistical significance of correlation coefficient at a large sample size.

For example, we can mention the study of A.L. Chizhevskiy, who showed the coincidence of maxima of solar activity with epidemics and conflicts. The author did not know the years of maxima, so he extrapolated a 10-year cycle for the time gap of several centuries. Obviously, the similar calculations are an unacceptable option, because 11 years is the average value which was determined by a large number of periods. The current data suggest that the duration of one Wolf-Schwabe's cycle varies from 7 to 15 years. As a result, the calculated maxima occasionally coincide with the moments of true maxima of solar activity.

Finally, let's pay attention to the study of Japanese authors [Muraki et al. 2011], who analyzed the signals of solar activity in the trees growing in Japan. As a result of Fourier analysis, they discovered the cycles with the duration of 12 and 25 years. They were detected during Maunder's period and no cycles were found in other time. This result directly contradicts Douglass's conclusion (although it's necessary to remember that his results are based on analyzes of Arizona's yellow pines), but has a simple explanation in the framework of our assumptions. It is possible to detect accidentally any signal at any time.

The similar approach is used in the investigation of N.B. Chernykh and A.A. Karpukhin. The authors made an attempt to build a local dendrochronology of Elias Church and to synchronize the signal of dendroscale extremes with the high-frequency signal of solar activity. The only one difference from A.L. Chizhevskiy's study is that they used a 20-year cycle and calculated the dates of supposed maxima for dozens of years. As a result, the reconstructed dates of maxima do not coincide with the actual moment of maxima, which are well known from observations. It is quite natural that the authors were unable to get the absolute dating of the dendroscale and, consequently, the absolute dating of Elias Church.

3 Searching of global minima of solar activity

Let us check how well the dendrochronology analysis allows to allocate global extremes of solar activity. V. Prokudina and M. Rozanov carried out the analysis of dendrochronology which was built on California pine tree. The authors claim that they could confidently detect the minima of Oort, Wolf, Sporer, Maunder and argue that the analysis of dendrochronological series makes it possible to determine the periods of global cooling and warming, as well as to determine the date of extreme weather conditions. Let us verify the correctness of the findings.

Despite the abundance of Paleoclimatology information (NOAA) there are few dendrochronologies totally covering the period from 1000 to 1900. As a result, we could not investigate the regions which are of greatest interest to us, so we analyzed the regions with necessary information where the necessary information was available.

In order to suppress a short-term signal, we averaged the original data in a sliding window width of 50 years and then compared the smoothed dendrosignal with known periods of maxima and minima of solar activity. Table 2 shows the periods of historical maxima and minima of solar activity. The results of comparison of a smoothed signal with the moments of solar activity signal are shown in Appendix 2, Fig. 3-7 and in Table 2. To check the compliance of a smoothed dendrochronology signal with the periods of minima of solar activity, we introduce a rating system. Let's assume that if the value of the dendrochronology function at the boundaries of the time interval $f(t_{1;2} \pm \Delta t)$ exceeds the value of function within the interval $f(t)$: $f(t_{1;2} \pm \Delta t) > f(t)$, where $\Delta t = 10 - 20$ years, a local minimum of dendroscale signal is present on this interval and corresponds to the minimum of solar activity. This coincidence is estimated by the symbol "+". In the opposite case, $f(t_{1;2} \pm \Delta t) < f(t)$ the period of minimum of solar activity corresponds to the local maximum of dendrochronology signal. If the relation $f(t_{1;2} \pm \Delta t) < f(t) < f(t_{2;1} \pm \Delta t)$ is true, then the extreme of solar activity signal is not detected on the scale. We estimate the last two variants by the symbol "-". Finally, in some cases a local minimum and a local maximum are detected during the considered period $(t_1; t_2)$. Such correspondence cannot be considered as unique, so we denote it with a symbol "?". The results of the analysis are shown in Table 3.

Name of the extreme	**Beginning** t_1	**Finalization** t_2	**Symbolic** designation
Oort's minimum	1040	1080	O
Medieval maximum	1100	1250	Max
Wolf's minimum	1280	1350	W
Sporer's minimum	1450	1550	Sp
Maunder's minimum	1645	1715	M
Dalton's minimum	1790	1820	D

Table 2. *Periods of global extremes of solar activity.*

The verification shows that global minima were found in 15 out of 25 cases and that is 60% out of the total. Sporer's and Dalton's minima are detected best of all, while Oort's minimum is present only on one dendroscale. Maunder's minimum, which is known as the period of the largest climate anomalies cannot be observed on the dendrochronologies "Sweden" (Fig. 5) and "Turkey" (Fig. 6).

A similar way can be used to evaluate the medieval climatic maximum which occurred from 1100 to 1250. The only difference from the previous cases is that a local maximum should be found by the analysis of dendroscale signal. This maximum is confidently detected only on the dendrochronologies "France" (Fig. 4) and "USA" (Fig. 7). In the signals cor-

Denrochronology	**O**	**Max**	**W**	**Sp**	**M**	**D**
Argentina	-	-	-	-	+	+
France	-	?	+	+	+	+
Sweden	-	?	-	+	-	+
Turkey	-	?	+	+	-	+
USA	+	+	+	+	+	-

Table 3. *The detection of global extremes of solar activity by analyzing of dendrochronology's signals.*

responding to the scales "Argentina" (Fig. 3) and "Turkey" one can detect small local maxima within the given time range, but the magnitude of the signal at the boundaries greatly exceeds the value of maximum. Equally ambiguous is an assessment of the medieval maximum on the scale "Sweden". In the beginning of the control time gap there is a distinct local minimum, but after it a maximum follows. Summarizing, we can conclude that from all considered signals the greatest number of discrepancies is observed on the dendroscales "Argentina" and "Sweden", and the most successful is the dendroscale "USA". However, it does not allow to detect all six extremes.

We have considered the problem of checking of the compliance of dendrochronology signals to historical minima of solar activity. But it is possible to set the task of searching of solar activity's minima by means of dendro signal, and that is the inverse formulation of the previous problem. From a formal point of view, the dendrochronology "USA" allows to detect three fictitious minima in the vicinity of 1350, 1750 and 1850. In this case the duration and depth of the minimum of 1770 are the largest of all considered historical minima. False minima present on the dendroscales "Argentina" (1420; 1850), "Turkey" (1245; 1620) and "Sweden" (1740). Fictitious minima were not found on the scale "France". Let's note that false minimum of the year 1750 on the scale "USA" "can be confirmed" by using the scale "Sweden" and another false minimum of the year 1850 on the scale "USA" "is confirmed" by using the scale "Argentina". In other words, one false minimum could be confirmed by another one.

The entire globe maps, which show the estimation of the temperature response to the changing of the total solar flux, are given in the investigation of Waple [Waple et. al. 2002, p. 503; 505.] The maps were obtained by averaging the signals accumulated during 40-45 years. (The article deals with the cycle close to 90 years, so the authors make an averaging over half of the period. Let's note that this period is well correlated with the width of our sliding window.)

The highest positive correlation between changes in solar radiation and temperature is observed in the United States, Central and South-East Asia. Let's remember that the best conformation between the signal of dendroscale and the signal of solar activity was observed on the dendrochronology "USA". In the North Atlantic, in the Near East and the Arabian Peninsula there is a negative correlation, and for the centre of the South American continent, there is a weak negative correlation. For this reason, the dendrochronologies "Argentina", "Turkey" and "Sweden" showed a poor correlation with the extremes of solar activity.

Now let's return to the study of B. Prokudina and M. Rozanov, where the authors detected four global minima of solar activity by analyzing the annual rings of California pine. In principle, their result does not contradict our conclusion. Global minima of solar activity can be found in dendrochronology signals. But if we consider several dendroscales, which belong to different regions, it appears that the global minima of solar activity could not be found in every case. The region of North America has a positive correlation of climatic response to the long-period of a solar activity signal. That is the main reason why we have obtained a good enough result for the dendroscale "USA".

The main disadvantage of B. Prokudina and M. Rozanov's study is that they did not suggest any formal procedure for identifying of global minima. The authors identify minima by using two factors: 1) the decreasing of an average annual growth index and 2) the presence of extremely low values of the annual index in the signal. The mathematical procedure of allocation of the extremum is absent, and the authors are limited to the visual analysis of a signal. As a result, such an approach played a malicious trick on them. They dated Sporer's minimum in the interval of the years 1545 - 1590, and Maunder's minimum in 1790-1840. Although the latter period can be associated with Dalton's minimum, the authors made three errors. They were not able to find out Sporer's and Maunder's minima and they found a false minimum, which corresponds to a normal solar activity. Thus, actually, the final results are worse than they think.

The analysis leads to the following conclusion. The variation of solar activity provides unpredictable response to the signal of dendrochronology. This is true for all regions including the areas with a positive temperature response to the variation of solar activity signal. Even for the regions with positive response, the known historical minima of solar activity do not always have a positive correlation with a signal of dendroscale. At the same time, a deep and prolonged minimum of dendrochronology signal does not necessarily correspond to the minimum of solar activity. The similar conclusion is true for short periods, including Wolf-Schwabe's cycle.

References

Bonani G., Haas H., Hawass Z., Lehner M., Nakhla S., Nolan J., Wenke R. and Wolfli W., 2001. *Radiocarbon, 43, 3, 1147.*

Chernih N.B., Karpuhin A.A., 2006. *Kratkie Soobsheniya Instituta Archeologii 220, 127-134.*

Chizhevskiy A.L., 1976. Zemnoe eho solnechnih bur', Moskva.

Kolchin B.A., Chernih N.B., 1977. Denrohronologiya vostochnoi Evropi. Moskva.

Muraki Y., Masuda K., Nagaya K., Wada K., Miyahara H., 2011. *Astrophys. Space Sci. Trans., 7, 395-401.*

NOAA. National Oceanic and Atmospheric Administration. Paleoclimatology. http://www.ncdc.noaa.gov/paleo/treeinfo.html

Prokudina V., Rozanov M., 2002. Izuchenie klimaticheskih anomaliy XI-XX vv. Po dendohronologicheskim dannim. / Astronomiya Drevnih Obschestv. Moskva.

SIDAC. Solar Influences Data Analysis Center. http://sidc.oma.be/silso/datafiles

Waple A.M., Mann, M.E., Bradley R.S., 2002. *Climate Dynamics 18, 563-578.*

Webb G.E., 1983. Tree Rings and Telescopes: The Scientific Career of A.E. Douglass / University of Arizona.

Zoon V., Yaskell, S., 2008. Minimum Maundera i peremennie solnechno-zemnie svyzi. Moskva. Izhevsk.

Appendix 1. Initial data

1. Dendrochronology ”Argentina”.
ftp://ftp.ncdc.noaa.gov/pub/data/paleo/treering/chronologies/southamerica/arge094.crn

2. Dendrochronology ”Turkish”.
ftp://ftp.ncdc.noaa.gov/pub/data/paleo/treering/chronologies/europe/turk016.crn

3. Dendrochronology ”France”.
ftp://ftp.ncdc.noaa.gov/pub/data/paleo/treering/chronologies/europe/fran029.crn

4. Dendrochronology ”Sweden”.
ftp://ftp.ncdc.noaa.gov/pub/data/paleo/treering/chronologies/europe/swed021w_crns.crn

5. Dendrochronology ”USA”.
ftp://ftp.ncdc.noaa.gov/pub/data/paleo/treering/chronologies/northamerica/usa/la001.crn

Appendix 2. The searching of global minima of solar activity by using dendrochronologies (or dendroscales).

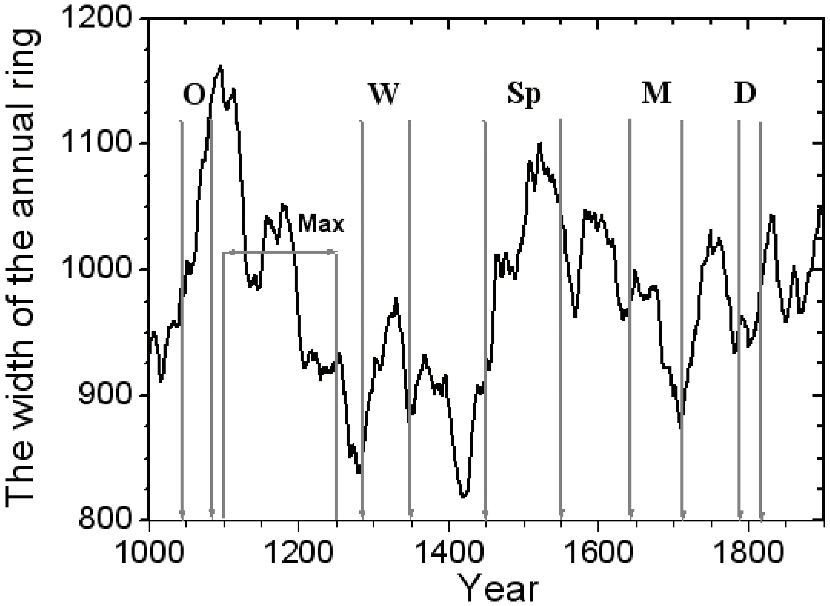

Fig. 3. *The dendroscale "Argentina".*

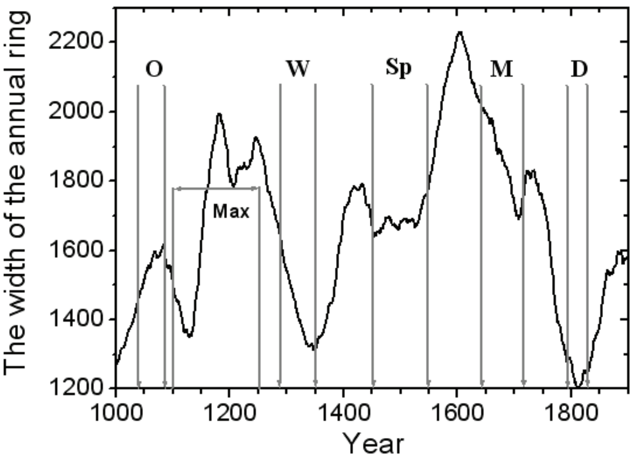

Fig. 4. *The dendroscale "France".*

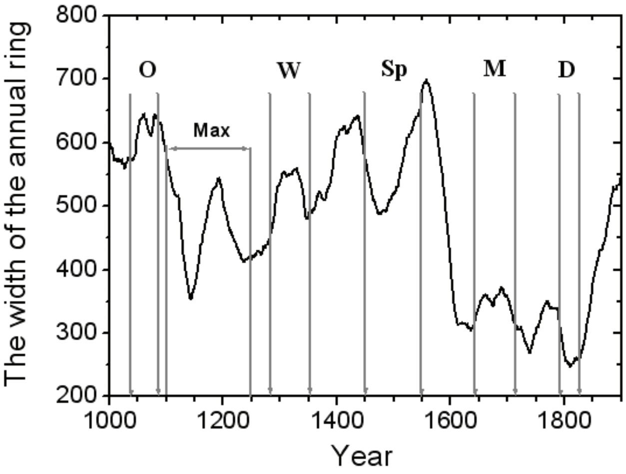

Fig. 5. *The dendroscale "Sweden".*

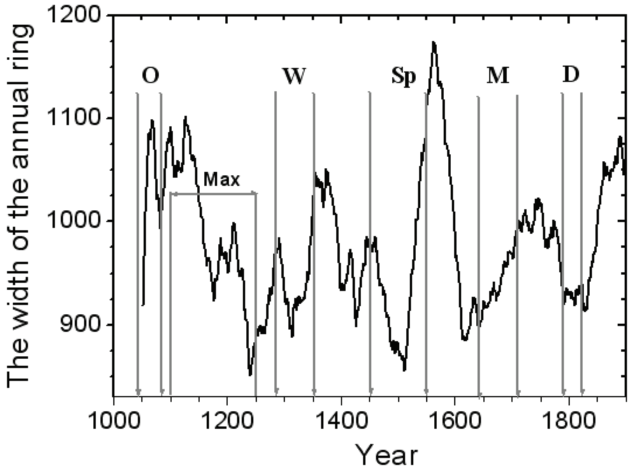

Fig. 6. *The dendroscale "Turkey".*

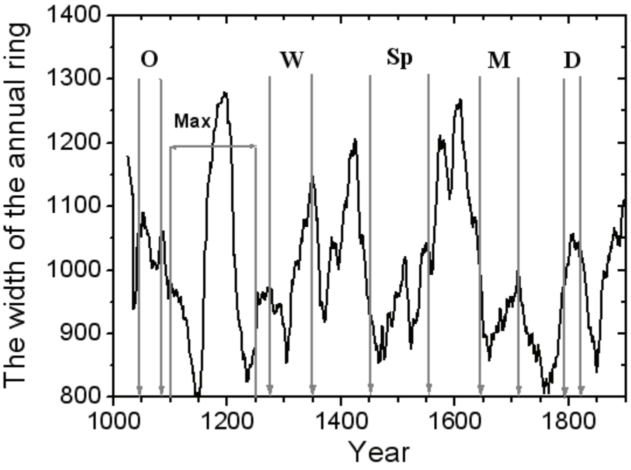

Fig. 7. *The dendroscale "USA".*