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Jerzy Boryczka, Maria Stopa-Boryczka
University of Warsaw – Faculty of Geography and Regional Studies – Department of Climatology
00-927 Warsaw, Krakowskie Przedmieście 30
e-mail: jkborycz@uw.edu.pl

Szymon Bijak
Warsaw University of Life Sciences – Faculty of Forestry – Department of Dendrometry and Forest Productivity
02-776 Warsaw, Nowoursynowska 159

CYCLIC CHANGES OF CLIMATE IN EUROPE DURING THE LAST MILLENIUM ACCORDING TO DENDROLOGICAL DATA

Abstract. The paper discusses periodic climate changes in Europe determined on the basis of dendrochronological data dating back one thousand years. In tree-ring width sequences of trees growing in Poland there are approximately 8-, 11-, 100- and 180- year periods. The tree-ring widths of oaks growing in Poland for the last centuries are characterised, without any significant amplitude, by 8- and 11-year periods (Tab. 1). In turn, chronologies of pine, spruce, larch, oak and fir growing in Europe are characterised by 100- and 180-year periods (Tab. 2). Cycles of dendrochronological variables approximate cycles of air temperature and North Atlantic Oscillation NAO as well as those of solar activity. The forecast of annual growth (ring width) for 2001-2100 was calculated by interference of the tree-ring width cycles determined by the sinusoidal regression method. Because of much longer empirical sequences of specific periods, the credibility of forecasts for tree-ring widths is greater than that for air temperature.

Key words: air temperature, NAO, solar activity, spectrum, periods, tendencies, forecast, tree-rings

INTRODUCTION

Because of the constraints of biochemical processes, climate is one of the most significant factors determining annual tree growth (Zielski, Krąpiec 2004). During the year, favourable thermal and pluvial conditions generate wide tree-rings and unfavourable conditions result in very narrow rings. The relationship between the ring width and climate is very complex due to other important natural, e.g. soil, and anthropogenic, e.g. atmosphere pollution, factors. The greatest cooling of Europe's climate occurred during the century minima of solar activity, i.e. during periods of very limited solar energy inflow to the surface of the Earth. Europe's climate cycles are caused by periodic changes of two negatively correlated fields of air pressure centres, i.e. the Iceland Low and the Azores High. They are related to the annual temperature fluctuations between North Atlantic waters and land of the European continent. The NAO index (Jones et al. 1997) was accepted as the measure of parallel transport of air mass to the west and in the meridional direction.

PERIODS OF 8- AND 11-YEAR RING WIDTH OF OAKS GROWING IN POLAND IN THE XVIITH- XXTH CENTURIES

The ring widths of trees growing in Poland are characterised by 8- and 11-year periods (Tab.1).

Table 1.
Periods (Θ years) of about 8- and 11-year ring width cycles of oaks growing in Poland (R – correlation coefficient, F_{obl} – Fisher-Snedecor statistics)

Location	Periods	Θ	R	F_{obl}	Θ	R	F_{obl}
Gdańsk	1762-1985	8,0	0,127	1,83	11,6	0,219	5,60
Gołdap	1871-1986	7,8	0,154	1,37	10,8	0,130	0,97
Hajnówka	1720-1984	7,9	0,144	5,91	11,2	0,258	20,10
Koszalin	1782-1986	8,6	0,193	3,89	11,1	0,127	1,65
Cracow	1792-1985	7,7	0,235	5,57	11,7	0,137	1,83
Poznań	1836-1986	8,0	0,223	3,87	12,0	0,138	1,43
Roztocze	1872-1988	9,0	0,145	2,18	13,0	0,259	7,36
Suwałki	1861-1986	7,5	0,278	3,06	11,8	0,172	2,86
Toruń	1713-1986	7,7	0,161	3,61	11,4	0,181	4,59
Warsaw	1690-1984	7,7	0,175	4,61	11,1	0,124	2,28
Wrocław	1727-1986	8,3	0,206	5,69	11,6	0,162	3,46
Zielona Góra	1774-1986	8,6	0,254	7,22	-	-	

It must be noted that in Europe (and in Poland) dominates an about 8-year period of air temperature with high amplitudes $\Delta T = T_{max} - T_{min}$ (Tab. 2).

Table. 2.
Periods of about 8-year air temperature in Europe

Location	Winter		Summer		Location	Winter		Summer	
	Θ	ΔT	Θ	ΔT		Θ	ΔT	Θ	ΔT
Warsaw	8,3	1,59	7,1	0,66	Geneva	7,7	0,62	7,8	0,40
Cracow	8,3	1,87	7,8	0,33	Vienna	8,3	0,87	8,4	0,38
Wroclaw	8,3	1,53	7,8	0,27	Rome	7,9	0,30	8,4	0,32
Lviv	8,3	1,30	7,9	0,56	Stockholm	7,8	1,33	7,8	0,40
Prague	8,3	1,06	7,8	0,44	Copenhagen	7,8	1,24	8,3	0,51
Berlin	7,7	1,54	7,8	0,55	Moscow	7,9	0,76	8,3	0,60

The air temperature fluctuation range, for example, in Warsaw in winter in an 8.3-year cycle, is $\Delta T = 1{,}5^{o}C$ and the annual mean temperature (for period of 7.7 years) – 0,6°C.

Correlation between 11-year sun spot and air temperature cycles has been known for a long time. About 11-year periods of air temperature and amplitude ΔT (°C) in chosen locations, in winter and summer, are listed in Tab.2

Table 3.
Periods of about11-year air temperature in Europe

Location	Winter		Summer		Location	Winter		Summer	
	Θ	ΔT	Θ	ΔT		Θ	ΔT	Θ	ΔT
Warsaw	11,6	0,53	11,3	0,22	Geneva	11,0	0,40	11,3	0,28
Cracow	11,3	0,84	11,4	0,26	Vienna	11,0	0,44	11,0	0,12
Wroclaw	11,4	0,74	11,5	0,42	Rome	11,8	0,44	10,7	0,39
Lviv	11,2	1,11	10,7	0,06	Stockholm	11,3	0,29	11,6	0,38
Prague	11,0	0,42	11,1	0,19	Copenhagen	11,1	0,26	11,5	0,48
Berlin	11,0	0,42	11,6	0,18	Moscow	11,4	1,62	11,3	0,30

Also, the about 11-year natural cycle of the total atmospheric precipitation in Poland is statistically significant (Tab.3).

Table 4.
Periods of about 11-year atmospheric precipitation in Poland

Location	Winter		Spring		Summer		Autumn		Year	
	Θ	%	Θ	%	Θ	%	Θ	%	Θ	%
Warsaw	10,1	25,9	12,0	23,7	11,2	13,8	10,2	10,6	11,3	9,5
Cracow	9,8	12,3	10,2	18,7	10,3	12,9	10,9	17,1	9,8	5,4
Wroclaw	9,9	17,4	10,2	27,4	9,7	16,7	9,9	13,2	9,8	13,9

The variability range of the total seasonal precipitation in about 11-year cycles in reference to the mean values (P) is greater in winter than in summer. The relative amplitude $(P_{max}–P_{min})P^{-1}$ is usually greater in winter than in summer as well.

The reason for the about 11-year cycles of air temperature and atmospheric precipitation is the 11-year cycle of solar activity (the solar constant).

The synchronicity of winter cycle maxima, 8-year NAO and solar activity in the years 1825-2000 should also be of interest:

$$NAO = 0,1315 +0,4778 \sin(2\pi t/7,8 -0,1266), \quad R=0,27$$
$$W = 51,93 + 10,40 \sin(2\pi t/8,1 +2,8659), \quad R=0,17$$

It should be stressed that a 7.8-year cycle dominates in the Sun acceleration spectrum, in its movement around the centre of the Solar System mass, in 1749–1980:

$$\acute{s}= 0,667 + 1,130 \sin(2\pi t/7,75 +1,21), \quad R=0,245$$

In time sequences: the *NAO* index (winter – 11.3 years, R=0,14, summer – 10.3 years, R=0,20, year – 11,2, R=0,18) there is also an about 11-year natural cycle synchronized with an 11-year Sun spot cycle:

$$NAO = 0,135 +0,2381 \sin(2\pi t/11,3 +2,2315), \quad R=0,135$$
$$W = 51,68 +29,89 \sin(2\pi t/11,0 + 0,9238), \quad R=0,488$$

All chronological sequences of the Wolf numbers (number of sun spots), oak tree-ring widths and air temperature indicate that during maxima of solar activity in the 11-year cycle, it is warmer than during the minima periods. With a greater number sun spots, tree-rings are thicker than during years when the Sun is calmer.

Permeation of solar energy into the Earth surface depends upon solar activity. During the 11-year solar activity cycle the solar constant changes. It is the greatest within vicinity of the sun spot maxima (Kondratiev and Nikolski 1970).

100- AND 180-YEAR PERIODS OF RING WIDTHS OF TREES GROWING IN EUROPE IN IX^{TH} – XX^{TH} CENTURIES

Short term changes in solar activity are not significant in shaping the Earth's climate due to the very slow process of heat permeation into deeper layers of the Earth.

A more important role in formation of the climate is played by long, i.e. 102- and 187-year solar activity cycles. Large amounts of energy are accumulated near the cycle maxima in deeper layers of the Earth. They influence directly about 100- and 180-year cycles of tree-ring widths of European trees (pine, spruce, larch, oak and fir) (Tab. 6).

Table 5.
Periods **(**Θ years) of about 100- and 180-year ring width of trees growing in Europe (*R*- correlation coefficient, F_{obl} – Fisher-Snedecor statistics)

Location	Periods	Θ	R	F_{obl}	Θ	R	F_{obl}	Θ	R	F_{obl}
<u>Pine:</u>										
Forfiorddalen, Norway	877-1994	112	0,178	162,7	189	0,121	73,4	-	-	-
Kola, Russia	1577-1997	109	0,394	39,1	186	0,277	17,8	-	-	-
<u>Spruce:</u>										
*Falkenstei*n, Germany	1540-1995	110	0,298	23,0	189	0,414	47,4	429	0,399	42,9
Fodara Vedla , Italy	1578-1990	99	0,083	1,36	191	0,718	207,4	-	-	-
Stonngrandes, Norway	1403-1997	114	0,191	11,2	201	0,243	18,6	-	-	-
<u>Larch:</u>										
Pinega 1, Russsia	1598-1990	103	0,184	7,2	217	0,286	18,4	-	-	-
<u>Oak:</u>										
Hamburg	1340-1967	111	0,265	23,6	195	0,280	26,6	353	0,666	249,4
Bodensee	1275-1986	112	0,248	23,2	197	0,373	57,2	333	0,577	176,7
Franche-Comté	1294-1987	108	0,217	17,0	225	0,395	63,9	338	0,305	35,3
<u>Fir</u>										
Fodara Vedla,	1474-1990	91	0,159	6,64	196	0,419	54,7	420	0,763	357,4

Changes in tree-ring widths of trees growing in Europe (in Tab. 5), from the earliest time up to the year 2100 are presented in Fig. 1-6. The spectrum of Pinega 1 larch rings (Russia), with a dominating 217-year period, characterised by a profound minimum variance ε^2 (Fig.7), is presented as an example.

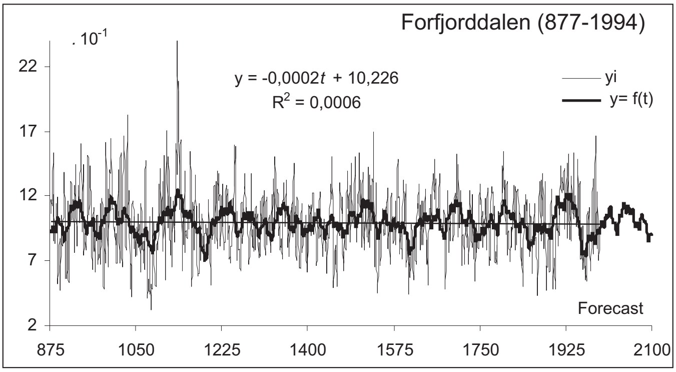

Fig. 1. Changes of width of the *Forfiorddalen* pine tree-rngs (Norway) in 877-2100

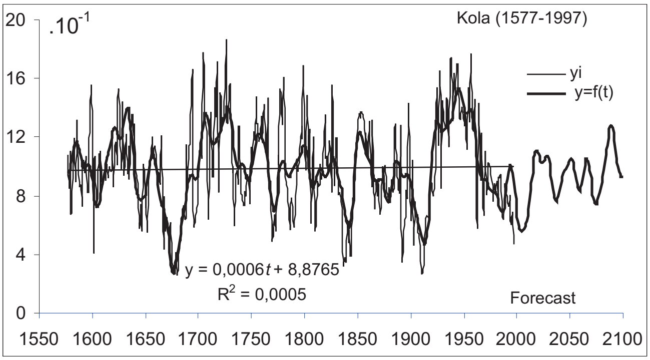

Fig. 2. Changes of width of the *Kola* pine tree-rings (Russia) in 1577-2100

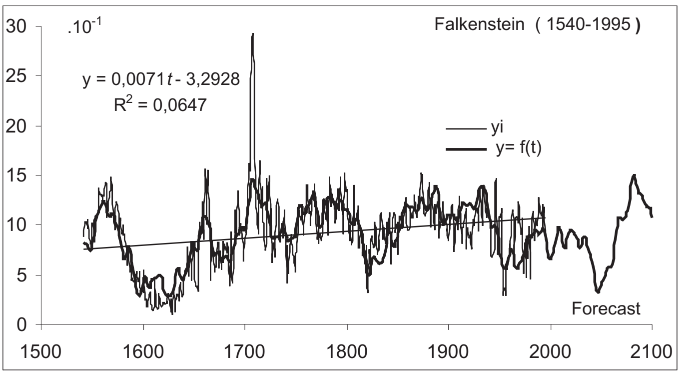

Fig. 3. Changes of width of the *Falkenstei*n spruce tree-rings (Germany) in 1540-2100

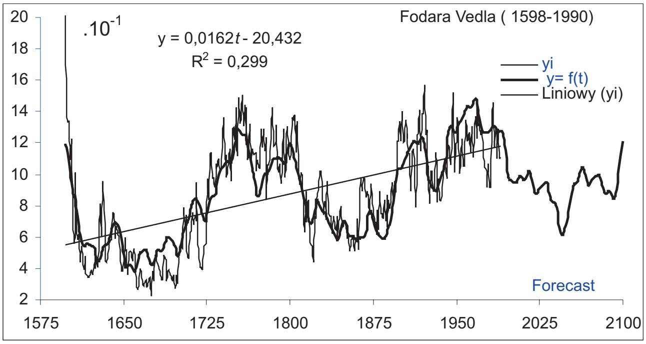

Fig. 4. Changes of width of the Fodara Vedla spruce tree-rings (Italy) in 1578-2100

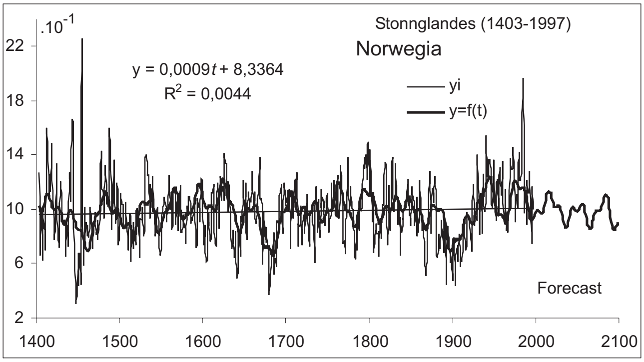

Fig. 5. Changes of width of the *Stonngrandespruce tree*-rings (Norway) in 1403-2100

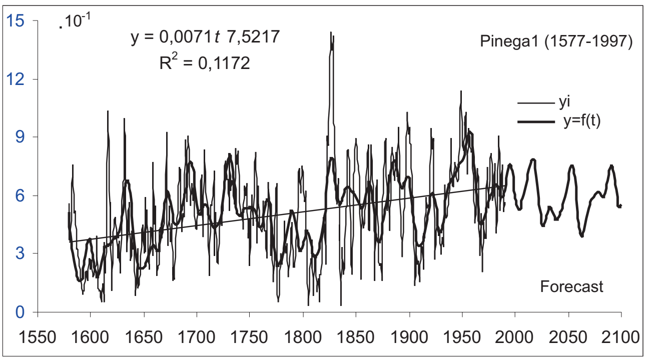

Fig. 6. Changes of width of the Pinega 1 larch rings (Russia) in 1578-2100

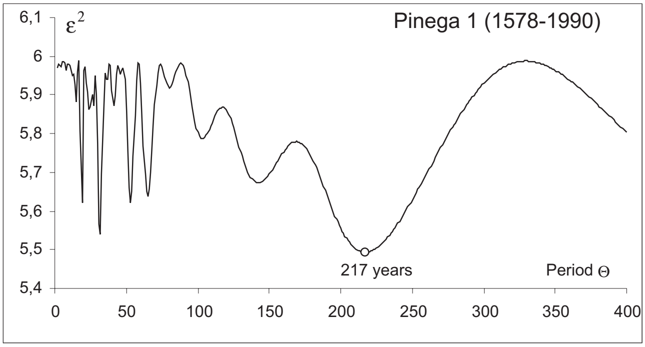

Fig. 7. Spectrum of Pinega 1 larch rings (Russia) in 1578-1990

These periods are similar to the about 100- and 180-year periods of air temperature in Europe (Tab. 6 and Tab. 7).

Table 6.
About 100-year periods of air temperature in Europe

Stations	Winter		Summer		Stations	Winter		Summer	
	Θ	Δ*T*	Θ	Δ*T*		Θ	Δ*T*	Θ	Δ*T*
Warsaw	113,4	1,22	75,0	0,88	Basel	85,5	0,14	87,6	0,64
Cracow	90,0	0,48	88,0	0,67	Copenhagen	80,5	0,22	89,6	0,27
Wrocław	123,3	1,66	75,0	0,50	England	99,3	0,44	102,5	0,20
Lviv	108,8	1,30	74,1	1,33	Stockholm	86,3	0,55	89,4	0,51
Prague	116,3	1,44	118,3	0,68	Uppsala	102,7	1,48	94,0	0,79
Vienna	89,8	0,79	96,1	0,58	Innsbruck	69,9	0,80	84,6	0,50

An about 180-year cycle of tree-ring widths is present in the longest air temperature measuring series in Europe.

Table 7.
About 180-year periods of air temperature in Europe

Stations	Winter		Summer		Stations	Winter		Summer	
	Θ	Δ*T*	Θ	Δ*T*		Θ	Δ*T*	Θ	Δ*T*
Warsaw	179,0	0,44	208,2	0,66	Basel	–	–	227,4	0,26
Cracow	168,3	0,43	–	–	Copenhagen	–	–	211,6	1,19
Lviv	–	–	195,3	1,00	England	166,9	0,48	204,6	0,34
Geneva	144,1	–	248,3	1,09	Stockholm	184,6	0,49	–	–
Berlin	212,8	1,18	–	–	Uppsala	182,3	2,50	192,8	0,39
Rome	–	–	224,9	1,40	Innsbruck	169,8	1,45	–	–

For example, about 100-years periods of air temperature in winter are: Warsaw – 113.4, Cracow – 90.0, England – 99.3, Vienna – 89.8, Stockholm – 86.3, Uppsala – 102.7 years. Similar about 100-year periodicity also takes place in July: Warsaw – 75.0, Cracow – 88, Vienna – 96.1, England – 102.5, Stockholm – 89.0, Uppsala – 94 years.

Air temperature in Europe is characterised by natural cycles similar to the North Atlantic Oscillation (NAO) with a dominating winter period of 7.8 years (Tab.6).

Table 8.
Periods of North Atlantic Oscillation (NAO) in 1825–2000

Winter		Summer		Year	
Θ	R	Θ	R	Θ	R
7,8	0,27	7,8	0,17	7,8	0,29
11,3	0,13	10,3	0,20	11,2	0,18
105,1	0,17	83,2	0,17	119,9	0,12

An about 11-year periodicity synchronised with an 11-year sun spot cycle also occurs in time sequences of the *NAO* index (winter – 11.3 years, R=0,14, summer – 10.3 years, R=0,20, year – 11,2, R=0,18)

FORECAST OF CLIMATE CHANGES IN EUROPE IN THE XXIST CENTURY ACCORDING TO TREE-RING WIDTHS

Forecasts were made on the basis of interference of detected cycles by the sinusoidal regression method proposed by Boryczka (2003): $y=f(t) = a_o + at + \sum b_j \sin(2\pi t/\Theta_j + c_j)$, where: Θ – period, b – amplitude, c – phase displacement. Diagrams of prediction functions $y = f(t)$ of annual increments of certain trees are characterised by the principal minima in the middle of the XXIst century (Fig. 1-6). For example, in the case of the spruce from Falkenstein (1540-1995), forecasts take into consideration strong cycles of 110, 189 and 429 years (with the following correlation coefficients R= 0,30, 0,42 and 0,40).

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