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REGULARITIES IN THE POLISH TEMPERATURE TIME SERIES AND CLIMATE PREDICTION OR RECONSTRUCTION

Abstract: In the paper regularities in the long Polish temperature records were investigated with the aid of wavelet analysis. The data consist of monthly mean temperatures from Warsaw, Cracow, Wrocław and Gdańsk from the beginning of 19th century. The analysis focuses on the regularities of the time scale from a few years to a few decades. The method allows to precisely detect regular fluctuation in the time series: their frequency and persistence. Results show that the regular fluctuations in the temperature time series (like quasi-seven-year or quasi-five-year cycles) raise and vanish in quite uneven manner. The wave usually disappears after a few oscillations. Such waves are detected by classical spectral analysis as the strongest periodicities. However, they are not stable in time and thus can not be directly used for realistic climate prediction and reconstruction.

Key words: monthly temperature, periodicity, Poland.

During the last few decades regular, periodic fluctuations in climatological time series have been studied by many researchers and numerous investigations testify the existence of various periods in climatological data (Burroughs 1994). Non-trivial weather cycles, if exist, have fundamental meaning for climate prediction or reconstruction. For such purpose the cycles must remain unchanged in time. This feature seems to be even more important than a cycle strength itself. In this paper the longest records of mean monthly temperature from four Polish cities (Warsaw 1779-1990, Cracow 1826-1990, Wrocław 1831-1990 and Gdańsk 1851-1990) are investigated from the point of view of their periodicity. An annual rhythm was excluded from the series by Fourier subtracting of the sinus wave with the period of 12 months. The data was examined with the aid of classical Blackman-Tukey method (Blackman and Tukey 1956), and a wavelet analysis (Torrence, Compo 1998; Lau, Weng 1995) which stress cycles stability. Wavelet analysis (WA) transforms a one-dimensional time signal (or frequency spectrum) to a two-dimensional time-frequency image. The technique is similar to windowed Fourier transform (WFT) but it use a flexible instead fixed time-frequency window. In spite of WFT which stretch in time high-frequency components and under represent low-frequency components, wavelet base functions narrow while focusing on high-frequency signals and widen when searching the low-frequency ones leading to optimal resolution. Such perturbation like amplitude and frequency modulation, abrupt frequency changes, or single impulses can be easy detected using wavelet analysis. Mathematically wavelet transform of a signal, *s(t)*, may be defined as a integral:

$$W_{a,b} = a^{-\frac{1}{2}} \int \psi * \left(\frac{t-b}{a}\right) \cdot s(t)dt$$

where b denotes the position (translation) and a the scale dilatation of the base function (wavelet), ψ. In this paper the continuous decomposition with the Morlet wavelet ($\psi(t)= cos(2\pi \cdot t) \cdot exp(-t^2/2)$) was done. The wavelet power spectrum was defined as $|W_{a,b}|^2$. For the Morlet wavelet parameter a approximately represents a period length, whereas b indicated localization of the wavelet in time. Values of the wavelet power spectrum, $|W_{a,b}|^2$, are ploted on the $\{a,b\}$ plane.

Figures 1-4 present wavelet time-frequency decomposition together with classical power spectrum and time series of annual mean temperatures. At all stations 7-9 years quasi-periodicities belong to the most pronounced. This cycles become significant since 1940 but could be also observed in the earlier periods (1820-1840 and slightly in all period 1810-1880 in Warsaw). Other cycles seem to be less stable. Out of the 1860s a 17-20 years oscillations appear in Gdańsk and remain maintained up to the present, being significant in the periods 1870-1905 and 1930-1980. The same oscillations could be observed at other stations except Wrocław, however in Warsaw they are statistically significant only in the earliest observations (1780-1810). In Cracow 17-20 years oscillations vanish about 1960 (significant in 1900-1940). Total power spectrum does not detect this fluctuation, pronouncing shorter about 14 years quasi-cycles. In wavelet analysis this oscillation appears as a strong wave in years 1930-1960. In fact only two 14 years length waves contribute to high values of the spectrum in these three decades. Similar behavior might be observed for shorter, ~5-yr oscillations. On the two-dimensional map they appear as a spots of strong fluctuations especially during 1800s, 1870s, and 1940s. For the shortest periods (< 4 years) it is hard to separate stable, or even frequently repetitive, regularities. Even if sometimes they are statistically significant, in general they do not compose clear picture of periodic behavior for this frequency band.

Results lead to the conclusion that stable periods are not an attribute of the temperature variability in Poland. These restricts possibilities of climate prediction with the aid of simple spectral decomposition. Quasi-periodic temperature fluctuation in Poland seems to be a "ghost limit cycle" (Ghil and Yiou 1996) – a state of dynamic system on the road to chaos from a fixed point to a strange attractor. However, even in

Fig. 1. Wavelet analysis of the Warsaw (1779-1990) mean monthly temperatures (solid and dashed lines indicate 95% and 99% confidence limits respectively) together with classical Blackman-Tukey spectrum (bottom) and annual means temperatures (right).

Fig. 2. The same as for Fig. 1 but for Wrocław (1831-1990).

the case of dynamic governed by a strange attractor limit cycles could persist for a relatively long time. It gives hope for a short climate prediction using such frequencies, but the problem how to predict a cycle persistence still remains open. On the other hand for a low signal to noise ratio the spectral methods do not distinguish weak periodic fluctuation from the random spectral peaks (Fortuniak 1999). Because of that quasi-periodicities having strong physical background, like 11-yr solar cycle (not

Fig. 3. The same as for Fig. 1 but for Cracow (1826-1990).

detected in analyzed Polish temperature records) or 18.6-yr cycle characteristic for a luni-nodal cycle (e.g. Currie 1992) as well as fluctuations observed in other Earth systems, like ~5 or ~8 years oscillation (e.g. Kożuchowski 1993; Miętus 1996) should be analyzed more carefully. Even if they are very weak and undetectable by spectral methods, they could play a key point role in climate evolution in the longer time scale.

Fig. 4. The same as for Fig. 1 but for Gdańsk (1851-1990).

References

Blackman R.B., Tukey J.W., 1958, *The Measurement of Power Spectra*, Dover Publications, New York.

Burroughs W.J., 1994, *Weather Cycles. Real or Imaginary?*, Cambridge University Press.

Currie R.G., 1992, *Deterministic Signals in USA Precipitation Records: Part II*, Int. J. Climatol., 12, 281-304.

Fortuniak, K., 1999, *Porównanie wybranych metod badania cykli klimatycznych*, [in:] *Streszczenia referatów, komunikatów i posterów konferencji „Zmiany i Zmienność Klimatu Polski"*, Łódź, 4-6.XI.1999, 41-43.

Ghil M., Yiou P., 1996, *Spectral Methods: What They Can and Cannot Do for Climate Timeseries*, [in:] *Decadal Climate Variability: Dynamic and Predictability*, Anderson D. L. T., Willenbrand J. (eds.), Springer-Verlag, 445-482.

Kożuchowski K, 1993, *Variation of Hemispheric Zonal Circulation Index Since 1899 and its Relationships With Air Temperature*, Int. J. Climatol., 13, 853-864.

Lau K.-M., Weng H., 1995, *Climate Signal Detection Using Wavelet Transform: How to Make a Time Series Sing*, Bull. Am. Meteor. Soc., 76, 2391-2402.

Miętus M., 1996, *Zmienność temperatury i opadów w rejonie polskiego wybrzeża Morza Bałtyckiego i jej spodziewany przebieg do roku 2030*, Mat. Bad. IMGW Ser. Meteorologia, 26.

Torrence Ch., Compo G.P., 1997, *A Practical Guide to Wavelet Analysis*, Bull. Am. Meteor. Soc., 79, 61-78.

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