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Spectral analysis of the "Koshava" wind

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With 6 Figures

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Summary

"Koshava" is a gusty wind of changeable intensity, blowing from a south-easterly direction, over Serbia, Romania and Bulgaria. It is caused by the interaction between the synoptic circulation and the orography of the Carpathian and the Balkan mountains.

This paper analyzes wind data measured at the Belgrade-Observatory during the longest period of consecutive days of "Koshava" which occurred from 14 January to 13 February 1972. Mean hourly wind speed data has been examined using spectral analysis. The power spectra are calculated using autocorrelation spectral analysis, the multi-taper method and wavelet transform. The maximum of which is about 122 h (5 days) corresponds to the time span of synoptic processes.

1. Introduction

In synoptic situations when the pressure gradient is directed from the western Mediterranean towards eastern or south-eastern Europe, a gusty wind known as "Koshava" blows from a south-easterly direction over Serbia. These situations are most common when there is a cyclone in the western Mediterranean (Fig. 1a) or when the centre of an anticyclone is located over eastern Europe (Fig. 1b). In the first case, the direction of "Koshava" is mainly southerly, and is called a warm "Koshava", whereas in the second case there is a mainly easterly "Koshava", referred to as a cold "Koshava".

The cold "Koshava" wind causes negative temperature and cloudiness deviations from average values during spring and autumn, and during summer and autumn, respectively. In contrast, the warm "Koshava" wind causes positive temperature and vapor pressure and negative relative humidity deviations from average values during the summer. The differences in the characteristics of "Koshava" during the seasons are caused by various thermal characteristics of air masses which penetrate the region. Namely, during spring and autumn, cold air blows from eastern Europe over Serbia which causes negative temperature deviations, and during the summer, warm continental air causes positive temperature and negative relative humidity deviations (Stanojević, 1959; Unkašević et al., 1998).

"Koshava" is a typical wind for the greater part of Serbia. "Koshava" dominates most of the year, except during June and July, when westerly winds prevail (Table 1a). The strongest wind speeds recorded over Serbia originate from the "Koshava" directions (Table 1b). "Koshava" winds persisting for longer than 5 days are most frequent in November and December, i.e. at the end of autumn and at the beginning of winter. During March, "Koshava" persists most commonly for 2, 3 and 4 days, as well as for periods of 18, 21 and 22 days. It is interesting

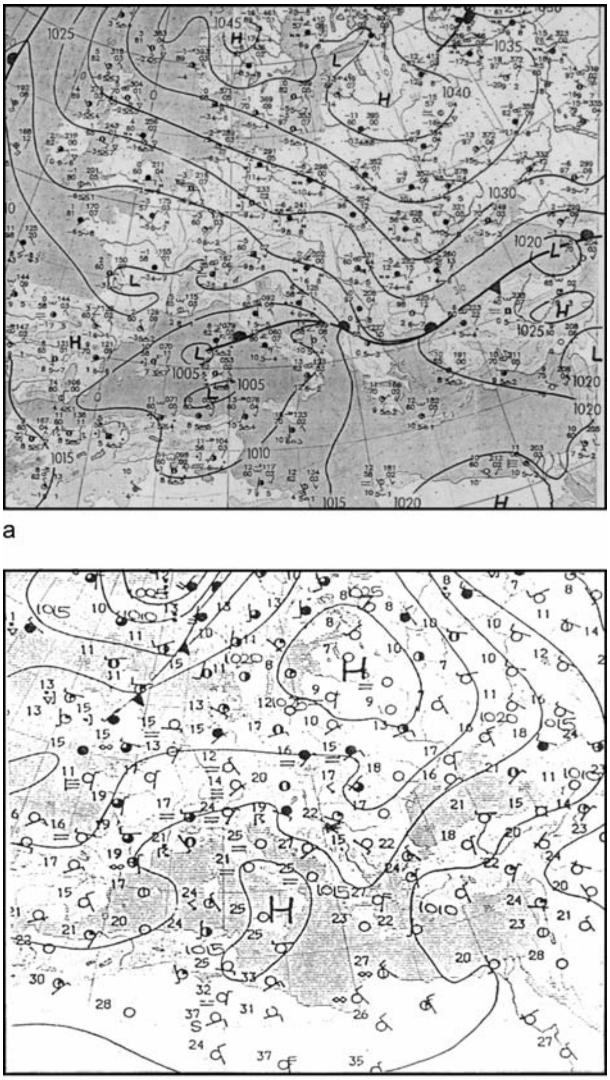

Fig. 1. Surface synoptic situation in Europe on: (**a**) 6 December, 1995 and (**b**) 22 August, 1974 at 00 UTC

that the number of the ‘‘Koshava’’ days in November is twice that in January (Milosavljević, 1950).

A schematic representation of the ‘‘Koshava’’ path is shown in Fig. 2, revealing an air mass divided into two parts. One part blows along the river Danube (Fig. 2a), while the other overturns the mountain ravines of eastern Serbia (Fig. 2b). ‘‘Koshava’’ is usually explained as a jet-effect wind through Iron Gate, producing speeds much above the gradient. The low level jet-effect wind increases speed through the channeling of air by some orographic configuration such as a narrow mountain pass or canyon. When air stratification is stable, usually in the summer, air tends to flow through the gap from high to low pressure, emerging as a ‘‘jet’’ with large standing eddies. The excess pressure on the upwind side is attributed to a pool of cold air supported by the mountains (Lazić and Tošić, 2000).

The ‘‘Koshava’’ gusts in the surface layer in Belgrade may approach 25–31 m/s (Unkašević et al., 1999). The highest maximum wind speed has been recorded in autumn and winter, while in spring and summer maximum wind speeds are much lower. Pressure gradients that are formed towards the western Mediterranean are stronger during autumn and winter than during spring and summer. Because of the strength and depth of the atmospheric layer (about 2000 m) in which it appears, ‘‘Koshava’’ can ‘‘clean’’ the atmosphere very efficiently (Vukmirović, 1997).

The physical characteristics of the ‘‘Koshava’’ wind are well known, but spectral characteristics of ‘‘Koshava’’ have never been investigated. The focus of this paper is an estimation of the time scale of the ‘‘Koshava’’ wind, as the typical and prevailing wind in Serbia, using three methods of spectral analysis: the Blackman–Tukey method, the Multi-taper method and the Wavelet transform. Recently, Wavelet transform has been used in an analysis of wind speed time series (Gurley

Table 1. Frequencies of (**a**) wind directions (‰) and (**b**) mean wind speeds, calculated over the period 1887–2000 at Belgrade

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
a)													
ESE	131	137	155	114	92	63	50	75	104	141	144	144	112
SE	158	165	168	144	130	87	78	116	150	186	189	174	145
W	91	92	84	81	100	120	123	101	83	70	76	86	92
b)													
ESE	5.0	5.5	5.9	5.5	4.1	2.9	2.5	2.9	3.5	4.6	5.5	5.2	4.4
SE	4.1	4.6	4.8	4.6	3.3	2.7	2.5	2.9	3.3	4.1	4.3	4.3	3.4
W	2.2	2.2	2.5	2.9	2.5	2.7	2.5	2.4	2.4	2.2	2.5	2.2	2.4

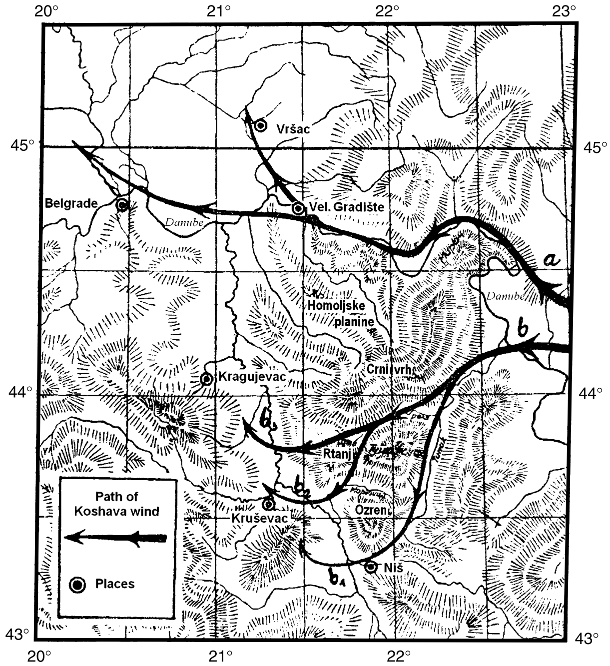

Fig. 2. Typical path of the "Koshava" wind

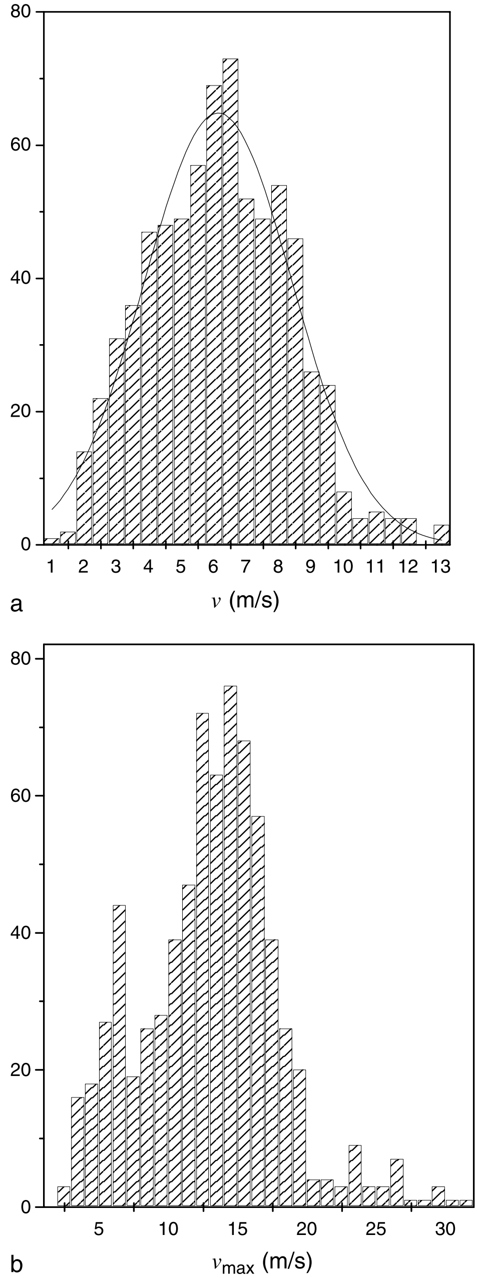

Fig. 3. (**a**) Empirical and theoretical mean hourly and (**b**) empirical maximum hourly wind speed distributions for the Belgrade-Observatory station during the 31 consecutive days of "Koshava"

and Kareem, 1999; Hunt and Nason, 2001; Liu and Babanin, 2004).

2. Data

This paper analyzes data from the Belgrade-Observatory station ($\varphi = 44°48'$, $\lambda = 20°28'$, $h = 132$ m above sea level with an anemometer elevation of 24 m), located in the city centre. Usually, "Koshava" blows for two or three days. The longest period when in the Belgrade the "Koshava" has continuously blown is 31 days (from 11 October to 10 November, 1953 and from 14 January to 13 February, 1972). Hence, we have chosen the last recorded period for investigation. The mean hourly wind speeds are between 1.2 and 13 m/s, while the maximum hourly wind speeds are between 2.5 and 31 m/s. The highest empirical frequencies are observed in the interval of the mean hourly wind speed from 6.25 to 6.75 m/s (Fig. 3a) and from 14.0 to 15.0 m/s (Fig. 3b) for the maximum hourly wind speed. Testing the fit of a probability density function of sampled data to several theoretical density functions has been done using the chi-squared goodness of fit test. From Fig. 3a we can see that the normal distribution represents the empirical data with a significance level of 98% ($\chi^2_{\alpha;0.98} = 14.851$). There are no known distributions that fit maximum hourly wind speed well (Fig. 3b).

3. Spectral analysis of the "Koshava" wind

Spectral analysis is a powerful tool which has been used to reveal information about the scales of the "Koshava" wind. Power spectra of wind data have been analyzed using autocorrelation spectral analysis, i.e. the BT method (Blackman and

Tukey, 1958), the Multi-taper method (Thompson, 1982) and the Wavelet transform (Daubechies, 1988; Farger, 1992). There is no prominent daily cycle, since data are normalized prior to analysis.

3.1 The Blackman–Tukey method (BT)

The BT method applys the discrete Fourier transform (DFT) algorithm to correlation functions estimated from time series, and takes the classical Hamming window as the smoothing function. The averaging operation of raw spectral estimate is necessary in order to obtain a consistent estimate of the spectrum in terms of discrete estimates. In order to determine the significant peaks in the calculated spectra, the theoretical curve (null continuum) along with its associated 95% confidence level has been fitted as described by Mitchell et al. (1966).

3.2 The Multi-taper method (MTM)

One of more sophisticated methods is the MTM approach which uses multiple orthogonal data tapers to describe structures in a time series. The purpose is to compute a set of independent and significant estimates of the spectral density in order to improve the results obtained with single-taper methods. The statistical information discarded by the first taper is partially recovered by the second taper, the information discarded by the first two tapers is partially retrieved by the third, and so on. Only a few low-order tapers may be employed, as spectral leakage increases with increasing order.

The significance of periodic signals or quasi-periodic signals was measured with respect to the noise background. The confidence levels of the noise estimate were calculated assuming that the spectrum has a χ^2_ν distribution (Mann and Lees, 1996). The ratio of the power associated with a peak in the spectrum to the local power level of the background is assumed to be distributed as χ^2/ν, and can be compared to tabulated χ^2 probability distributions to determine peak significance.

3.3 The Wavelet Transform (WT)

The convolution of the time series $x(t)$, $t = 1, \ldots, N$, with the set of wavelets $G_{a,b}(t)$ for different parameters a and b, defines WT:

$$T(b,a) = \frac{1}{\sqrt{a}} \sum_{t=1}^{N} G^* \left(\frac{t-b}{a} \right) x(t),$$

where the asterisk denotes complex conjugation, and parameters a and b are allowed to vary continuously. A set of functions $G_{a,b}(t)$ are derived from a mother wavelet $G(t)$ where:

$$G_{a,b}(t) = \frac{1}{\sqrt{a}} G\left(\frac{t-b}{a} \right).$$

The real scalar b is called the translation parameter and corresponds to the central point of the wavelet in the time series. The real and positive scalar a is the scale dilation parameter and determines the width of the wavelet. The factor $1/\sqrt{a}$ normalizes the wavelets so that they have unit energy and hence are comparable for all scales a. By transforming a time series from the time space into the time-frequency space, wavelet analysis is able to determine both the dominant timescales of variability and how they vary with time (Torrence and Compo, 1988).

In this study we used the Morlet Wavelet:

$$G(t) = e^{-t^2/2} e^{ict}.$$

This method consists of a plane wave e^{ict} of frequency $c = f$, which is modulated in time by a Gaussian envelope of unit width $e^{-t^2/2}$.

4. Analysis of the results

This section represents the results obtained using the Blackman–Tukey (BT), the Multi-taper method (MTM) and the Wavelet transform (WT) of the mean hourly wind speed during the 31 consecutive days of "Koshava" (from 14 January to 13 February 1972) at the Belgrade-Observatory. The average number of "Koshava" days in January was 6.5 and in February 7.3.

For the first two methods, the x-axis shows period in hours, while the y-axis shows spectra. For the WT, the x-axis shows time in hours, the y-axis period in hours, and third axis shows Wavelet spectra.

The most important element is the maximum with a period of about 120 h at the 95% confidence level, obtained using all three methods. From Figs. 4 and 5 we can see that the

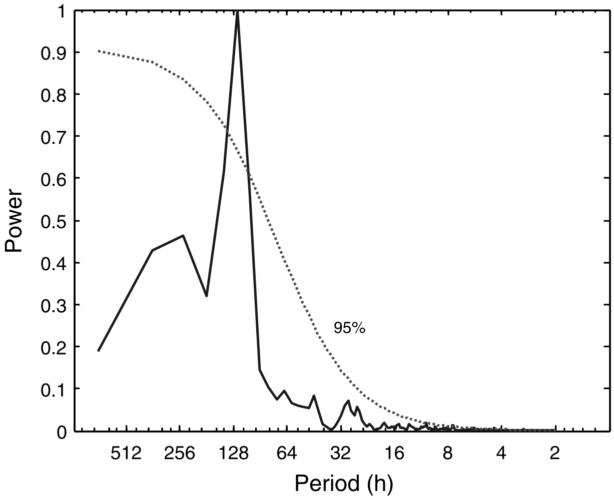

Fig. 4. Autocorrelation spectral analysis of the mean hourly wind speed and the 95% confidence level

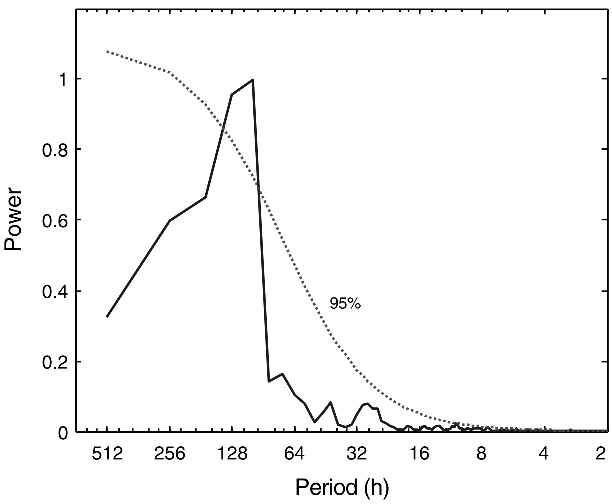

Fig. 5. As in Fig. 4 but using MTM

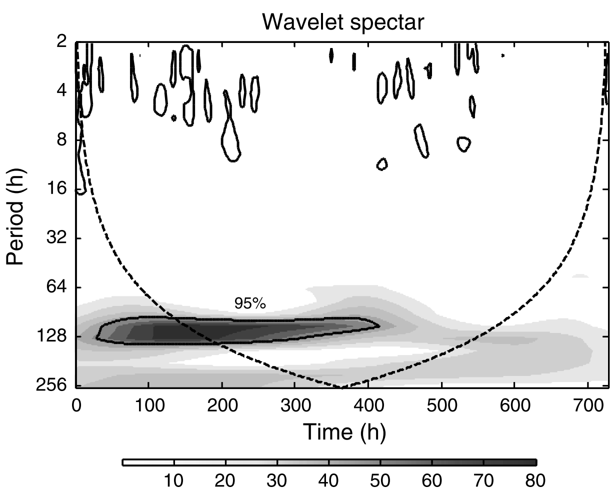

Fig. 6. As in Fig. 4 but using Wavelet transform

spectra obtained using the BT and MTM are very similar.

Using the BT method (Fig. 4), we obtained oscillations of about 121.9 h for the mean hourly wind speed. Applying the MTM (Fig. 5), oscillations of about 102.4–128 are obtained. We identified an organized structure of about 120 h using the WT (Fig. 6). The period of about 120 h appears in the first 400 h. This means that there are about three realizations of this quasi periodic phenomenon in the first 16 days. This is probably caused by the weakening of synoptic processes towards the end of the period examined. In addition, from Fig. 6 we can see smaller oscillations from 2 to 7 h in the first 200 h, and from 400 to 600 h.

From the previous analysis we concluded that the dominant period is about 120 h or 5 days, i.e. ''Koshava'' is a synoptic scale process. Also, an existence of local effects is confirmed by the oscillations with period between 2 and 7 h.

5. Conclusions

An analysis of 31 consecutive days of ''Koshava'' (from 14 January to 13 February, 1972) have shown that the highest empirical frequencies are observed in the interval of the mean hourly wind speed from 6.25 to 6.75 m/s and from 14.0 to 15.0 m/s for the maximum hourly wind speed. Mean hourly wind speed data are normaly distributed. However, there is no known distribution that fits maximum hourly wind speeds well. The results obtained are typical for the ''Koshava'' wind according to intensity and gustiness, but not for the distribution function for maximum wind speed (Unkašević et al., 1998).

Similar results were obtained using three different methods – the Blackman–Tukey method, the Multi-taper method and the Wavelet transform. The maximum, with period of about 120 h or 5 days at the 95% significance level, corresponds to the time period of synoptic processes. Comparison of the Wavelet transform with the Blackman–Tukey method and the Multi-taper method have shown that the Wavelet transform is a powerful tool for the analysis of non-stationary series. We can see that the period of about 120 h appears in the first 400 h. This means that there are about three realizations of this quasi periodic phenomenon in the first 16 days. This is probably caused by weakning of the synoptic processes towards the end of the period examined.

Acknowledgement

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