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Temporal change of some statistical characteristics of wind speed over the Great Hungarian Plain

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With 7 Figures

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Summary

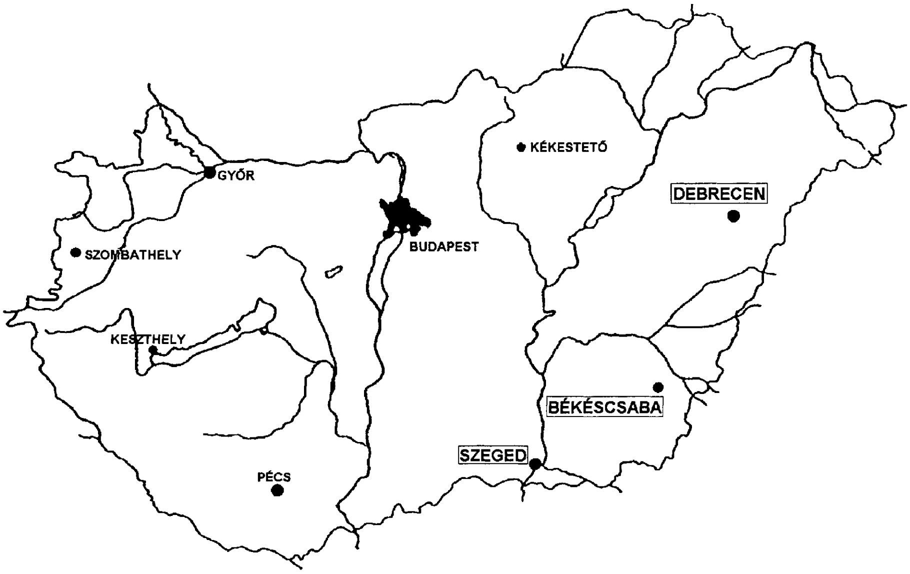
The objective of this study is to assess whether changes in the surface pressure field over Europe are reflected in the statistical structure of the wind field over the Great Hungarian Plain. The data basis consists of hourly wind speed data from 1968–72 and 1991–95, from three meteorological stations (Debrecen, Békéscsaba and Szeged) located in the Great Hungarian Plain. A new statistical test and its application for determining the statistical significance of differences between expected values of non-independent wind speed time series is presented in the paper. The summer wind field over the Great Hungarian Plain shows evidence of change: wind speeds have been decreasing and a tertiary maximum, in July, has become less pronounced.

1. Introduction

The rise in global surface air temperature, due to the increase of greenhouse gases, has probably induced a redistribution in the surface pressure field. According to Schönwiese et al. (1994) and Meyhöfer et al. (1996), this process has occurred in Europe: in the winter half-year the average values of surface pressure, converted to sea level, increased in the south and decreased in the north of the continent between 1961 and 1990, whereas in the summer half-year there were no significant changes. On the other hand, Metaxas et al. (1991) and Bartzokas and Metaxas (1996) found that the average intensity of influx of cold air masses in summer, coming from the north and north-west to the south-east of Europe, had increased. Therefore, according to their investigation, the summer circulation system is also changing, as a consequence of the redistribution of the surface pressure field in summer, as well. In the authors' view, it is clear from the above-mentioned results that such changes may affect Middle-Europe to a relatively lesser degree than the north-western and south-eastern regions of the continent.

In continental Europe, in winter, the direction of the average pressure gradient is from south to north (Justyák, 1994). Thus, according to the previously mentioned results, this gradient itself is also increasing, which might also give rise to changes in the circulation system, e.g. the frequency or the average speed of southerlies winds may increase during this season. The spatial distribution of annual and monthly average sea level pressure fields in Hungary is due to the so called "basin character": roughly in the middle of the Great Hungarian Plain, a pressure minimum can be found. This is caused by strong warming in summer and the frequent passing through of Mediterranean cyclones in winter (Dobosi and Felméry, 1971).

The aim of our former investigations (Tar, 1998a, 1998b, 1999; Mika et al., 1999; Tar et al., 2000; Makra et al., 2000a, 2000b) was to decide whether or not the observed changes in the



station	latitude	longitude	height a.s.l. (m)
Debrecen	47°36'	21°39'	111
Békéscsaba	46°40'	21°04'	88
Szeged	46°15'	20°09'	82

Fig. 1. Location of the meteorological stations and their geographical coordinates

pressure field over Europe could be detected in the statistical structure of the wind field over Hungary, in spite of the specific pressure field over the country. Our aim in this paper is to demonstrate possible marked changes in the statistical structure of the wind field over the Great Hungarian Plain. Since the data series available are not continuous, trends, autocorrelations, etc. can not be determined.

Change in the wind field, apart from climatic effects, also produces change, among other things, of deflation and wind energy. Both of the latter-mentioned phenomena are proportional to the cube of wind speed and consequently important practical information can be obtained from analysing this data set. The data basis of our investigations consists of hourly wind speed data from three meteorological stations (Debrecen, Békéscsaba and Szeged) located in the Great Hungarian Plain with data coverage between 1968–72 and 1991–95. Figure 1 shows the location and the geographical co-ordinates of the stations.

2. Time series of the daily average wind speeds

Annual time series of daily average wind speeds were derived in the following way: the average wind speed was calculated on the basis of hourly (1–24 hours) wind speeds for each day during both five-year periods. The mean daily average wind speeds for the same day in each year in the given five-year period is considered to be the average wind speed of the i^{th} day of the five-year period studied ($i = 1, 2, \ldots, 365$). The resulting two time series are then subjected to statistical analysis without filtering out seasonal differences.

Table 1 contains annual average wind speeds, maximum and minimum daily average wind speeds and their annual range (annual maximum – minimum daily average wind speed) as well as the values counted as averages from the two five-year periods. Table 1 shows that annual average wind speeds at Debrecen have been continuously decreasing since 1971 and, as a result of this, the values were well below 3 m/s in the period between 1991–95. In this latter period, the annual average wind speed decreased by 0.3 m/s (10%) as compared to that in the first period. A less pronounced decreasing tendency can be observed at Szeged. The five-year average wind speed in the second period at Szeged is 0.2 m/s less than in the first period. There is no change at Békéscsaba. On the other hand, the range of daily average wind speeds, counted for the two five-year periods,

Table 1. Yearly average, maximum (max) and minimum (min) daily average wind speeds as well as range (max–min) per year and those for means of five-year averages

Year	Yearly average	Max.	Min.	Range	Year	Yearly average	Max.	Min.	Range
Debrecen									
1968	3.0	9.6	***0.4***	9.2	1991	***2.6***	***6.9***	**0.8**	***6.1***
1969	3.1	**10.4**	0.8	**9.7**	1992	**2.8**	8.2	0.7	7.6
1970	**3.2**	***8.4***	**0.9**	***7.5***	1993	**2.8**	**8.9**	**0.8**	**8.2**
1971	3.0	9.8	0.5	9.4	1994	2.7	8.2	0.6	7.6
1972	***2.6***	9.2	0.7	8.5	1995	2.7	7.5	***0.5***	7.0
5-year	3.0	5.2	1.5	3.7	5-year	2.7	5.4	1.3	4.1
Békéscsaba									
1968	2.8	**9.3**	0.6	**8.8**	1991	***2.6***	7.8	0.3	7.5
1969	2.6	8.0	***0.4***	7.5	1992	**3.0**	**8.6**	0.3	**8.3**
1970	**2.9**	9.1	**0.7**	8.5	1993	2.8	8.3	***0.1***	**8.3**
1971	2.7	8.3	**0.7**	7.6	1994	**3.0**	7.6	**0.7**	7.0
1972	***2.4***	***7.4***	***0.4***	***7.0***	1995	2.7	***7.4***	0.5	***6.9***
5-year	2.7	4.8	1.4	3.4	5-year	2.8	5.5	1.3	4.2
Szeged									
1968	**3.5**	**12.6**	**0.9**	**11.7**	1991	3.1	**9.7**	***0.6***	**9.1**
1969	3.3	10.1	***0.7***	9.5	1992	**3.3**	8.9	0.8	8.1
1970	3.4	10.5	**0.9**	9.6	1993	3.2	9.0	**0.9**	8.2
1971	3.2	9.6	0.8	8.8	1994	***3.0***	8.9	0.8	8.1
1972	***3.0***	***8.6***	**0.9**	***7.7***	1995	3.1	***8.8***	**0.9**	***7.9***
5-year	3.3	6.5	1.5	5.0	5-year	3.1	6.0	1.6	4.4

increased at Békéscsaba mostly in the second period, which means that the annual daily average wind speeds became more extreme at this site.

For the analysis of regularities appearing in the annual regime of daily average wind speeds some smoothing should be applied to the series, even in the five-year average time series.

Smoothing was performed using Fourier series. Let mark $v_{d,i}$ time series of means of daily average wind speeds for a given five-year period ($i = 1, 2, \ldots, 365$) which was, hence, smoothed by the following sum:

$$v_{d,i} \approx f_4(i) = \\ = a_0 + \sum_{m=1}^{4} \left(a_m \cos \frac{2\pi mi}{N} + b_m \sin \frac{2\pi mi}{N} \right) \quad (1)$$

By using Eq. (1), the original data set is reconstructed with four series, i.e. with four waves. In Eq. (1) a_0 is the average of the data set, while the amplitude of the m^{th} wave is $A_m = (a_m + b_m)^{1/2}$. The goodness of fit by Eq. (1) is given by the following expression of residual variance: $s_m^2 = s_{m-1}^2 - 0.5A_m^2$, where $m = 1, 2, 3, 4$; $s_0^2 = \frac{1}{N}\sum_{i=1}^{N} (v_{d,i})^2 - a_0^2$, $N = 365$ and $A_0 = 0$ (Dobosi and Felméry, 1971). It is clear that the higher the number of waves, the better the correspondence of the reconstructed data set to the original one. Hence, from the decrease of s_m, the importance of the wave-lengths (periods) $\frac{N}{m}$ of each wave can be concluded. Wave-lengths expressed in whole days are as follows: 365 days (yearly period); 183 days (half-yearly period); 122 days and 91 days (seasonal ones).

The most important parameters of this reconstruction are included in Table 2. Considering amplitudes A_m ($m = 1, 2, 3, 4$), in the first five-year period, the first and third (the annual and the 122-day) waves are the most characteristic at each station. In the second five-year period, the first wave remains the most important, while the third one weakens considerably at all three sites. On the other hand, the fourth (seasonal) wave strengthened at all three stations, mostly at Békéscsaba and Szeged. At the last station the second wave is stronger than the fourth one. An index in the last line of the table shows how much smoothing

Table 2. Most important parameters of means of daily average wind speed time series reconstructed by four waves (a_0: mean, 0-step reconstruction; s_0: absolute value of 0-step reconstruction; A_1, A_2, A_3, A_4: amplitudes of the given waves; s_1, s_2, s_3, s_4: goodness of the smoothing with given waves)

	Debrecen		Békéscsaba		Szeged	
	1968–72	1991–95	1968–72	1991–95	1968–72	1991–95
a_0 (mean)	3.0	2.7	2.7	2.8	3.3	3.1
s_0	0.72	0.64	0.66	0.66	0.85	0.70
A_1	0.34	0.40	0.42	0.38	0.71	0.41
s_1	0.68	0.57	0.59	0.60	0.69	0.63
A_2	0.20	0.10	0.21	0.16	0.09	0.27
s_2	0.66	0.57	0.57	0.59	0.69	0.60
A_3	0.32	0.06	0.28	0.07	0.27	0.06
s_3	0.62	0.57	0.53	0.59	0.66	0.60
A_4	0.11	0.12	0.06	0.16	0.07	0.14
s_4	0.62	0.56	0.53	0.58	0.66	0.60
$(s_0 - s_4)/s_0$	0.14	***0.12***	0.19	0.13	**0.23**	0.15

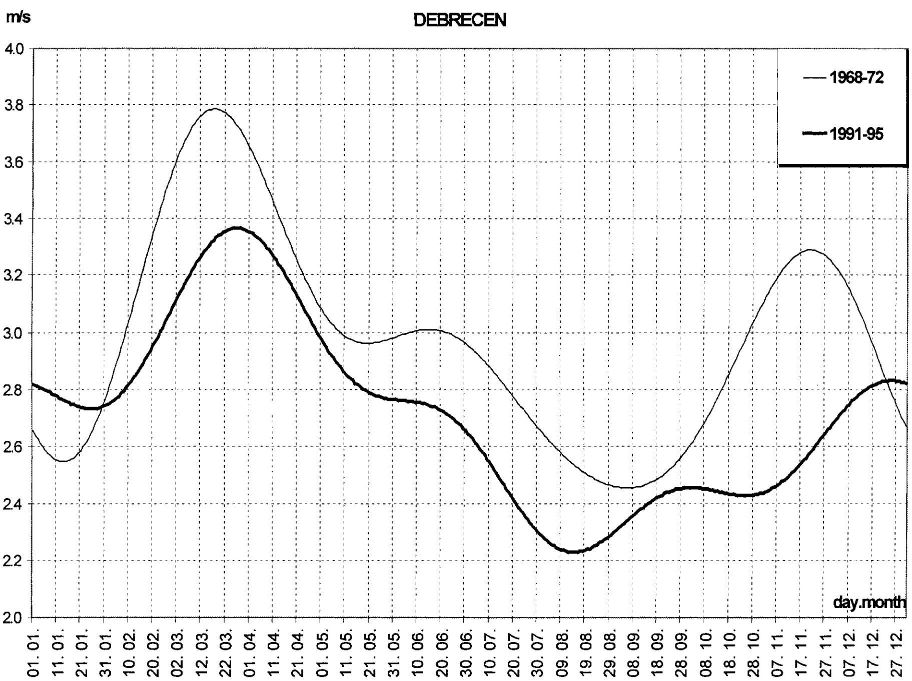


Fig. 2. Yearly course of means of daily average wind speed time series, reconstructed by Fourier polinoms, Debrecen

improved, compared to 0th smoothing with the average a_0. This index decreased at all stations, e.g. correspondence is better in the second five-year period.

These parameters are interpreted and conclusions drawn from their values as demonstrated in Figs. 2, 3, and 4; which show $v_{d,i}$, namely the reconstructed data set, counted on the basis of Eq. (1) by the help of four waves at the three examined stations.

According to Figs. 2–4, values of $v_{d,i}$ have “regular” annual regimes characterising the climate of Hungary in the period between 1968–72. Namely, maximum is in spring, in the middle of March, and a secondary maximum occurs in November. At Debrecen a tertiary maximum can be observed in summer, in the middle of June. At Szeged and Békéscsaba, this tertiary maximum occurs at the end of December and at the beginning of January; however in summer, between

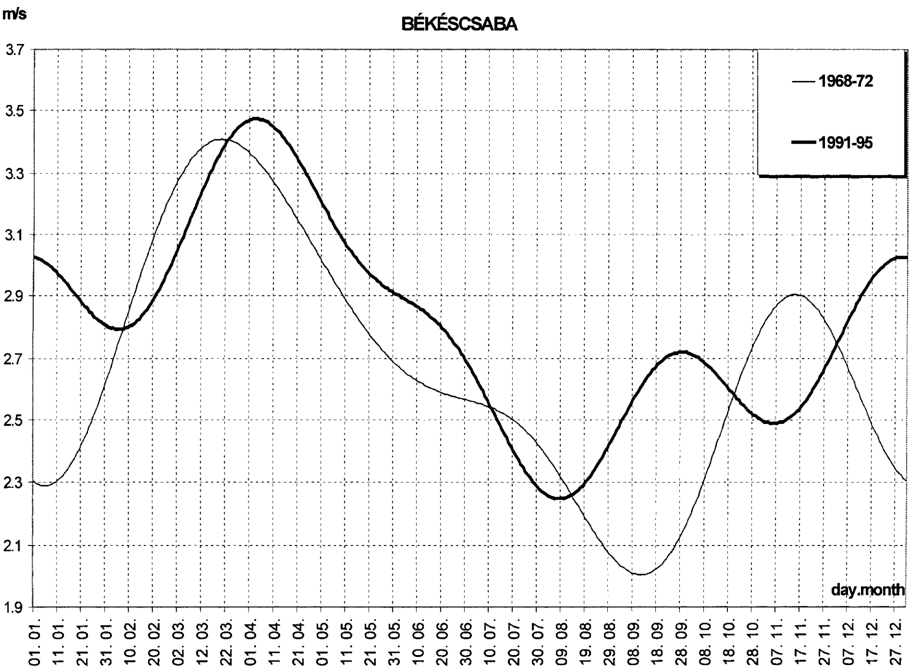


Fig. 3. Yearly course of means of daily average wind speed time series, reconstructed by Fourier polinoms, Békéscsaba

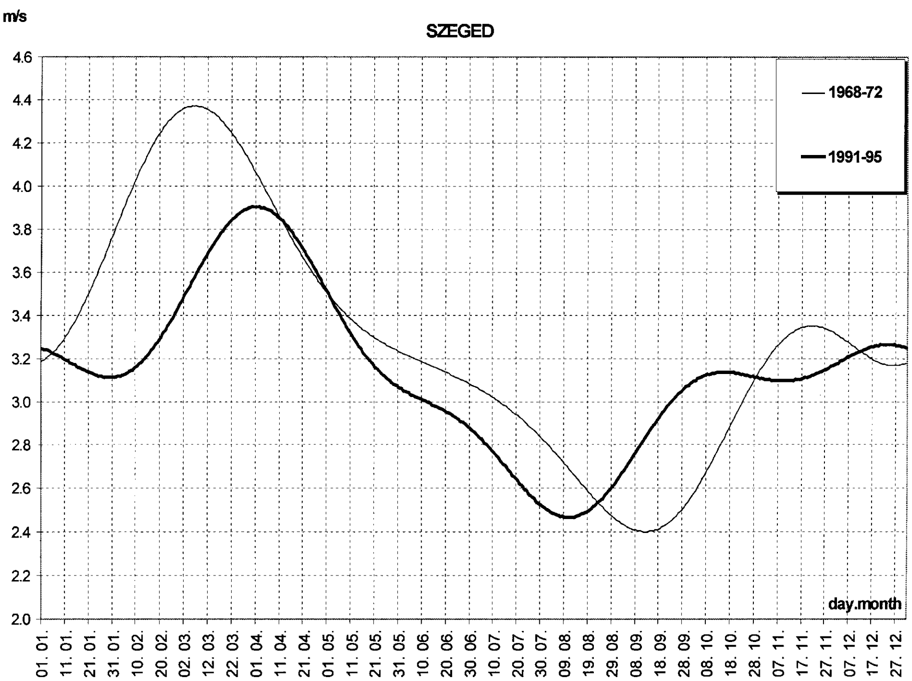


Fig. 4. Yearly course of means of daily average wind speed time series, reconstructed by Fourier polinoms, Szeged

June 10th and July 10th, a plateau can be observed in the yearly course. Namely, change of daily average wind speed decreases in this period compared to those before and after.

The absolute minimum occurs at all three of the stations in the first half of September. Of course, further, less definite minima, higher than this one, are found within the maxima listed previously. This annual regime, comprising statistical waves with periodicities of one-year (365 days), half-year (183 days) and one-third year (122 days), respectively, is indicated by the parameters in Table 2.

The annual regime changes totally in the second five-year period (1991–95) compared to that in the first period (1968–72).

The absolute maximum occurs about two weeks later during the first third of April, while the secondary maximum moves to the second half of December at all three of the stations. The summer period of the annual regime also changes considerably, since the absolute minima move to the first third of August. At Debrecen, the tertiary maximum in June softens to a plateau; while at the other two stations the summer plateau becomes more definite.

3. The new statistical test

A statistical test, developed by Makra, is new and can, to some extent, be associated with the two-sample t-test. The basic question of this test is whether or not significant difference can be found between the average of an optional share sample of a given time series and that of the whole sample itself.

Let $\xi_1, \xi_2, \ldots, \xi_n, \ldots, \xi_N$ represent independent probability variables of normal distribution. Suppose that their expected values are $m(\xi_1)$, $m(\xi_2), \ldots, m(\xi_n), \ldots, m(\xi_N)$, respectively.

Suppose that standard deviations of ξ_i–s are common and let them be σ. Now, choose an optional share sample of n elements from the whole given time series of N elements ($n < N$). Let $\bar{m} = \frac{\xi_1 + \cdots + \xi_n}{n}$ and $\bar{M}$ $\frac{\xi_1 + \cdots + \xi_N}{N}$, where $n < N$.

Form the following difference: $\bar{M} - \bar{m}$. In this case:

$$\bar{M} - \bar{m} = (\xi_1 + \cdots + \xi_n) \cdot \left(\frac{1}{N} - \frac{1}{n}\right) + \\ + \frac{\xi_{n+1} + \cdots + \xi_N}{N} = \\ = -\frac{N-n}{N} \cdot \frac{\xi_1 + \cdots + \xi_n}{n} + \frac{N-n}{N} \\ \cdot \frac{\xi_{n+1} + \cdots + \xi_N}{N-n} \quad (2)$$

By this transformation, the resultant sum of two parts consists of two independent probability variables.

Now, suppose that $\bar{m}$ doesn't differ significantly from $\bar{M}$. Namely, a Null-hypothesis can be set up, according to which: $\bar{M} = \bar{m}$. In this case $M(\bar{M} - \bar{m}) = 0$, which is obvious. Furthermore:

$$D^2(\bar{M} - \bar{m}) = \left(-\frac{N-n}{N}\right)^2 \cdot \frac{1}{n^2} \cdot n \cdot \sigma^2 \\ + \left(\frac{N-n}{N}\right)^2 \cdot \frac{1}{(N-n)^2} \cdot (N-n) \cdot \sigma^2 \\ = \frac{N-n}{N \cdot n} \cdot \sigma^2. \quad (3)$$

Hence, $\frac{\bar{M} - \bar{m}}{\sqrt{\frac{N-n}{N \cdot n}} \cdot \sigma}$ is a probability variable of $N(0;1)$ distribution.

Now, from the table of the distribution function of the standard normal distribution, it can be determined that x_p to a given $0 < p < 1$ number, for which:

$$P\left(\left|\frac{\bar{M} - \bar{m}}{\sqrt{\frac{N-n}{N \cdot n}} \cdot \sigma}\right| > x_p\right) = p. \quad (4)$$

If the absolute value of the above probability variable of $N(0;1)$ distribution is higher than x_p then it is said that $\bar{M}$ and $\bar{m}$ differ significantly. The Null-hypothesis, according to which there is no difference between $\bar{M}$ and $\bar{m}$, can be realised not more than with the critical p probability.

Being supported by this theoretical basis, significance of the difference between the average of an optional share sample of a given time series and that of the whole sample can therefore be revealed.

Similarity between the two-sample t-test and this new test is obvious. Both tests can only be applied to data series with a normal distribution. Both check the hypothesis of whether or not expected values of two probability variables can be considered equal. The essential difference is that the Makra-test can be applied to non-independent data series, while the two-sample t-test requires independence of the two normally distributed data series.

4. Application of the new method to the anomaly wind speed time series

From means of daily average wind speed data, daily anomalies wind speeds were prepared, as follows. Means of daily average wind speed values were divided with those of monthly average wind speed values for the given month. With this procedure seasonalities or periodicities of the data series were to filtered out. Then $\log_{10}$-values of

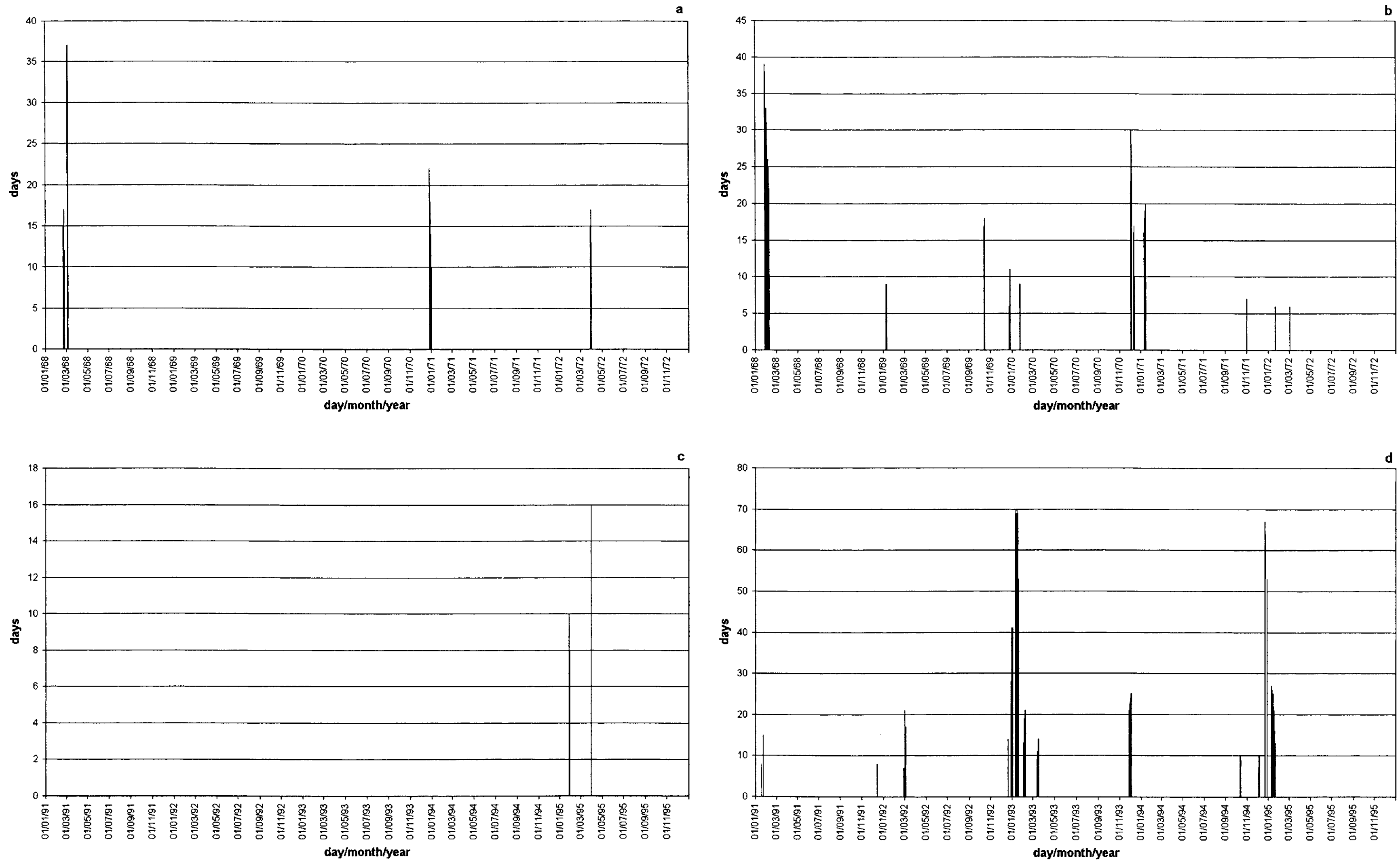


Fig. 5. Duration of relative wind speed (in days), Debrecen; **a** significantly higher (1968–72), **b** significantly lower (1968–72), **c** significantly higher (1991–95), **d** significantly lower (1991–95) than the average, (significance level: 1%)

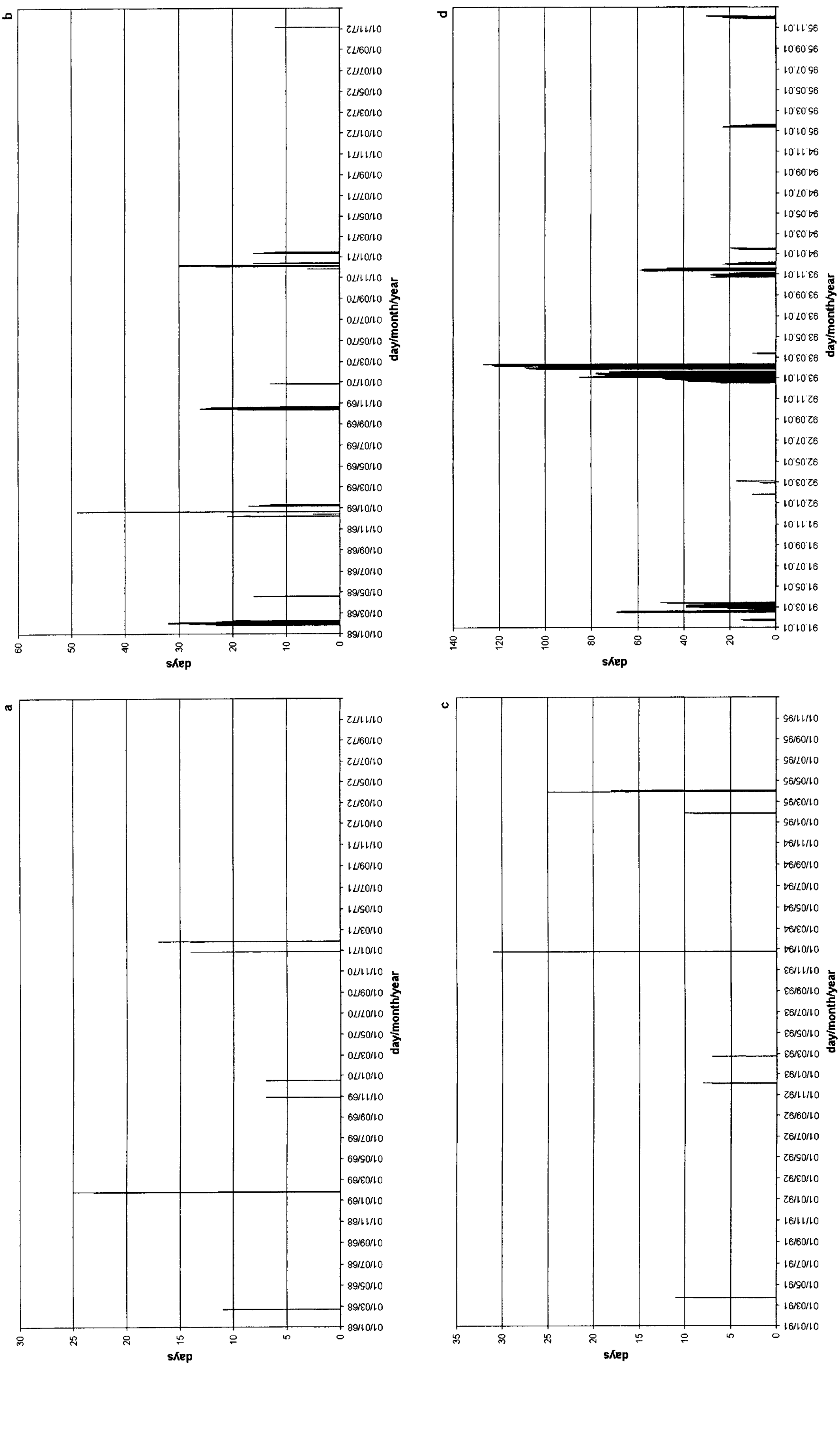


Fig. 6. Duration of relative wind speed (in days), Békéscsaba; **a** significantly higher (1968–72), **b** significantly lower (1968–72), **c** significantly higher (1991–95), **d** significantly lower (1991–95) than the average, (significance level: 1%)

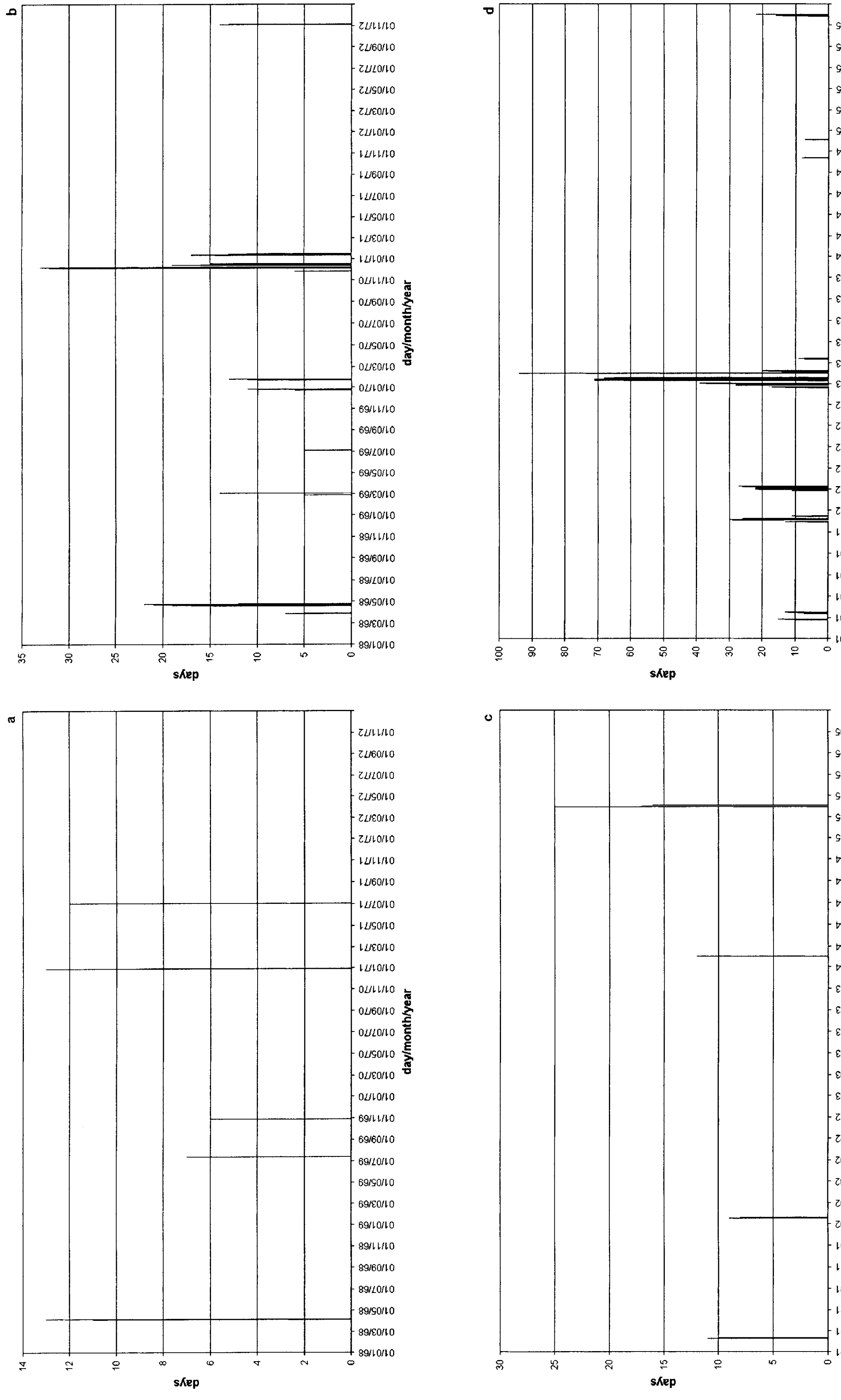


Fig. 7. Duration of relative wind speed (in days), Szeged; **a** significantly higher (1968–72), **b** significantly lower (1968–72), **c** significantly higher (1991–95), **d** significantly lower (1991–95) than the averege, (significance level: 1%)

the resultant data series were counted, normality of which was checked using the χ^2-test. According to this test, the distribution of the resultant data series is normal. Consequently, the Makra-test can be applied to these transformed data series.

Using the Makra-test, it is examined whether or not a given average of n number of elements (where $n = 3, 4, \ldots, N-1$; N is the total number of elements of the given data set; n and N are the number of days), formed of daily relative wind speed values from Debrecen, Szeged and Békéscsaba, respectively, is significantly higher or lower than that of the total data set. Averages of daily relative wind speed values, namely those of n number of elements (n number of days), were made by one step (one day) slipping in case of given n and given data set, while carrying out the test. Significance tests were carried out for each average with element number $n \leq N-1$, and, were realised at $p = 0.01$ probability level.

By this means, considering the utilisation of wind energy, periods given in days, which are significantly more effective or significantly less effective than the average, can be determined (Figs. 5–7). On Figs. 5–7, it can be established that the number of significant periods lower than the average, is definitely higher in both five-year periods, compared to the number higher than average. On the other hand, relative wind speed is significantly lower than the average in January–February 1993 at all three stations, while at Békéscsaba only in November 1993. Characteristic periods lower than the average are much more frequent between 1991–95 than between 1968–72 (Figs. 5b, 6b, 7b and Figs. 5d, 6d, 7d).

5. Conclusion

Our main results, considering the two data sets examined (1968–72, 1991–95), are as follows. The statistical structure of the wind field over the Great Hungarian Plain has changed. This appears, on the one hand, as a decrease in the daily average wind speed. On the other hand, the summer period in the annual cycle changes considerably, whereby the absolute minima moves to the first third of August. At Debrecen, the tertiary maximum in June softens to a plateau; while at the other two stations the summer plateau becomes less definite. The number of periods with significant decrease of daily relative wind speeds are definitely more frequent, their duration is longer, and they show synchrony in both five-year periods which is opposite to periods with characteristic increase. Furthermore, for considering the utilisation of wind energy, the number of periods, given in days, which are significantly less effective than the average, is considerably higher between 1991–95 than between 1968–72.

In conclusion, the summer wind field over the Great Hungarian Plain, according to results obtained for Europe, has changed. However, change in the wind field over Europe in winter, owing to the basin character of the Great Hungarian Plain, can not be shown here clearly.

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