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BURA (BORA) AND BURIN AT SPLIT

Bura i burin u Splitu

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Abstract — In this work, the ten-year hourly values of the main meteorological elements of the Split-Marjan meteorological station for the months of January and July were analysed in order to ascertain the main features of the katabatic winds *burin* and *bura* at that location. Using the method of separating the wind speed subgroups belonging to the *burin* and *bura,* it was possible to determine the main statistical characteristics of these winds and also their duration and the time of onset. At the beginning of the *bura,* the temperature falls on average by one degree Celsius and the relative humidity by approximately 15%. The derived pseudopotential temperature, corrected for its daily interhourly changes, was found especially suitable for the determination of both the *burin* and *bura.* At the onset of the *bura,* this temperature drops approximately by two (January) and four (July) degrees Celsius. The average daily courses of the examined elements during the *burin* and *bura* show distinctive patterns that are significantly different from the average course during the two representative months. The daily course of the average wind speed values during the *bura* in January shows a maximal value of nearly 11 ms^{-1} at noon and a minimum of 8 ms^{-1} at midnight. In July, however, the greatest average speed of the *bura,* nearly 9 ms^{-1}, is achieved just before sunrise and the minimum of approximately 6 ms^{-1} in the early evening hours. In the last part of the article, the results of an analysis of the connection of weather types with the occurrence of *burin* and *bura* are presented. The rate of occurrence of the "clear" and "dark" *bura* in both January and July is seven to three. In January, during the *burin* there is only a very small probability of precipitation in the form of short, light rain or snow while during the *bura* the same types of precipitation may occur with a probability of 30%. In July the occurrence of slight rain during the *burin* or *bura* is extremely small.

Key words: bura (bora), burin, climatic characteristics, Split.

Sažetak — U ovom radu prikazani su rezultati analize desetgodišnjih podataka satnih vrijednosti glavnih meteoroloških elemenata za mjesece siječanj i srpanj postaje Split -Marjan a u cilju određivanja osnovnih značajki katabatičkih vjetrova *burina* i *bure* na toj lokaciji. Korištenjem metode razdvajanja satnih vrijednosti srednje brzine vjetra na podgrupe, koje pripadaju *burinu* odnosno *buri,* određene su glavne statističke značajke tih vjetrova kao i njihovo trajanje te vrijeme početka. Nastupom *bure* temperatura zraka padne u prosjeku za jedan stupanj Celzija, relativna vlaga za približno 15 %. Nađeno je da je pseudopotencijalna temperatura, korigirana za dnevni hod, osobito podesna za određivanje *burina* i *bure*. Početkom puhanja *bure* ova temperatura se smanji u prosjeku za dva stupnja u siječnju odnosno za četiri stupnja u srpnju. Srednji dnevni hodovi ispitanih elemenata tijekom *burina* i *bure* pokazuju oblike koji se značajno razlikuju od prosječnog hoda tijekom dvaju promatranih mjeseci. Dnevni hod srednjih vrijednosti brzine vjetra za puhanja *bure* postiže u siječnju najveću vrijednost od skoro 11 ms^{-1} u podne te minimum od 8 ms^{-1} u ponoć. U srpnju, *bura* pak postiže u prosjeku najveću brzinu od blizu 9 ms^{-1} tik pred izlazak Sunca a minimum od približno 6 ms^{-1} u ranim večernjim satima. U zadnjem dijelu rada prikazani su rezultati analize povezanosti vremenskih tipova sa pojavom *burina* i *bure*. U oba promatrana mjeseca odnos pojavljivanja "jasne" odnosno "tamne" bure u ispitanim slučajevima je sedam prema tri. Tijekom puhanja *burina* postoji vrlo mala vjerojatnost pojave kratkotrajne slabe oborine bilo u obliku kiše ili snijega, dok je tijekom puhanja *bure* takva vjerojatnost oko 30%. Tijekom srpnja mogućnost pojave bilo kakve oborine tijekom puhanja promatranih vjetrova je izvanredno mala.

Ključne riječi: burin, bura, klimatske značajke, Split.

1. INTRODUCTION

On the eastern side of the Adriatic Sea there are several characteristic winds, the best-known being the *bura*[1], *jugo*[2], *sea breeze, land breeze, maestro* and *etesian winds*. The *bura*, a catabatic and often very strong wind of destructive force, has been investigated in detail from both the theoretical and synoptic aspects (Smith, 1985; Jurčec et al., 1991, 1994), climatological aspects (Lukšić, 1972, 1975, 1989; Poje, 1981), while the persistence of characteristic winds on the Adriatic was analysed by Poje (1990,1992). The *bura* has also been studied in detail during the ALPEX period with the help of an enlarged network of surface and upper air stations. General reviews of the bura have been presented in papers by Penzar B. (1976), Makjanić B. (1976), Šegota T. (1988) and Watanabe (1976).

Earlier I examined the possibility of the application of different distribution functions to groups of anemograph wind speed data from a large number of meteorological stations in Croatia. This analysis indicates that when estimating wind energy at the locations examined one should, in most cases, take into account multiple compound distributions that overlap each other. In this way the estimation of wind energy could be improved.

Using commercial statistical PC programs for the process of group separation, we have found that in most cases the groups of NE quadrant wind speed data from the Adriatic stations can be divided into two (rarely three) subgroups. Furthermore, in the ten-year data from the Split-Marjan station distinct differences in basic meteorological elements, have been found pertaining to these subgroups. Thus, we can get a more detailed insight of the *bura* characteristics and of the *burin* as a form of weak or moderate *bura*. In this paper, we shall describe some of the basic climatological features of these winds and also outline their connection with weather types.

2. THE DATA

In this paper, we shall analyse the hourly values of temperature, humidity, pressure and wind from the Split-Marjan meteorological station for the period 1977—1986. The data cover the months of January and July, which are representative of winter and summer. Considering that this station had no night observations of cloudiness and weather phenomena we have taken these data from the meteorological station at the Split-Sućurac airport, situated on the northern edge of the Kaštela bay, approximately 11 km in WNW of the station Split-Marjan.

The hourly wind data from the mechanical anemograph R. FUESS at the Split-Marjan station are average wind speed and predominant wind direction data (the amount of missing data are negligible small: ≈ 0.26% for January and 0.22% for July). The values of all the other meteorological elements studied stand for the values at the end of every hour. For the ten-year period, the weather types for the larger Split area have been determined according to Poje's method (1965). Additionally, for all the periods with *bura* and *burin* the predominant wind direction and mean wind speed at the 850 hPa level above this area have been determined on the basis of the published upper-air charts of *Europäischer Wetterbericht* at 00 UTC. (Radiosounding in Split was operative only in the period 1956—1963 and could not be used in this study).

For the periods of *bura* and *burin*, precipitation data have also been taken from the airport station at Split-Sućurac. In our opinion, the differences in intensity of precipitation, weather phenomena and cloudiness between the two stations considered are sufficiently small to be neglected for our purposes.

3. ANALYSIS OF WIND DATA

Our statement that nearly all stations on the eastern Adriatic coast have wind speed data groups composed of two or more subgroups necessarily imposed us a conclusion that at least two different winds of the same predominant direction exist in the area.

At the station Split-Marjan the NNE and NE wind directions show the highest frequency of all directions (Tab. 1). Having in mind that these particular two wind directions represent the *bura* at Split, we have taken the average wind speed data of these wind directions (taken jointly in classes of 1 ms^{-1}) and have analysed them for every month in the period 1977—1986. In this way, we got two subgroups of wind speed data, called here *burin* and *bura*, with the following properties (Tab. 2):

[1] *Bura* is the Croatian name for the catabatic mainly NE wind, generally known as *Bora*.

[2] *Jugo* is the Croatian name for the SE wind in the Adriatic generally know in the Mediterranean as *scirocco*.

Table 1. The wind direction relative frequencies (in %), Split-Marjan, 1966—1980.

Tablica 1. Relativne čestine smjerova vjetra (u %), Split-Marjan, 1966—1980.

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Jan.	4.3	22.1	17.9	13.5	5.9	13.3	4.1	3.6	1.7	2.6	0.6	1.2	1.2	2.7	1.7	3.5
July	3.8	16.2	10.4	6.4	2.4	6.4	3.9	4.2	4.2	13.8	9.0	6.1	1.9	4.0	2.5	4.6
Year	3.0	19.1	11.7	8.4	3.7	12.9	5.4	4.8	2.9	9.6	4.6	3.4	1.4	3.4	2.1	3.3

Table 2. The basic statistical values of wind speed (ms^{-1}) subgroups for NNE and NE wind directions, Split-Marjan, 1977—1986.

Tablica 2. Osnovne statističke vrijednosti podgrupa brzine vjetra (ms^{-1}) za smjerove vjetra NNE i NE, Split-Marjan, 1977—1986.

	burin			bura		
Month	Min.	Mod.	Max.	Min.	Mod.	Max.
Jan.	0.5	3.9	11.0	6.0	6.9	24.0
Feb.	0.5	2.3	7.0	2.5	6.1	20.5
March	0.5	2.6	8.0	3.4	7.5	20.0[1]
April	0.5	3.1	6.2	3.0	6.1	15.0
May	0.5	2.0	8.0	2.5	6.1	15.0
June	0.5	2.1	7.5	3.0	5.6	15.0
July	0.5	2.2	6.5	2.5	5.4	13.0
Aug.	0.5	2.5	8.0	3.0	6.1	15.5
Sept.	0.5	2.3	8.5	3.0	6.7	17.5
Oct.	0.5	2.6	8.5	3.0	6.9	16.5
Nov.	0.5	3.0	10.5	6.0	8.2	17.5
Dec.	0.5	2.6	7.5	3.5	6.0	22.5
			[1]III.	13.5	15.3	23.5

At this station, two subgroups of wind speed data for the NNE and NE wind directions may be discerned throughout the year and in March even three. For every group, the maximum and minimum values as modus are stated. The *burin* subgroups in some months penetrate deep into the subgroups of *bura* and the same is valid also for the *bura* subgroups.

3.1. The criteria for the bura and burin

In order to separate the pronounced periods of these winds, only blowing periods of at least three-hour duration have been considered. Further, it has been defined that blowing from NNE or NE will be considered continuous even when the wind blows from some other direction for the most of one hour. The term ***burin*** refers to a period of predominantly weak winds, with speeds under 5 ms^{-1}. The beginning of the ***bura*** has been defined as that hour in the set of wind speed data (direction NNE or NE) when the wind speed suddenly increases to at least 5 ms^{-1} and then develops, attaining a value of at least 8 ms^{-1}. The cases of occurrence of ***bura after burin*** (so-called ***"bura2"***) and the cases of ***burin after bura*** (so-called ***"burin2"***) have been also separated. The subgroup *burin2* has been separated in those cases when a decrease in wind speed under 4-5 ms^{-1} is clearly visible in the set of data and the subgroup *bura2* in those cases when a sharp increase in wind speed over 5 ms^{-1} occurs. The number of cases of *burin2* and *bura2* in winter and summer is comparatively small.

To illustrate the possibility of separation of wind speed groups into *burin* and *bura* subgroups the cases of *burin2* and *bura2* are included into the subgroups of *burin* and *bura* respectively. The Figure 1. depicts the measured frequencies of the *burin* and *bura* subgroups for the month of July, the corresponding Weibull's theoretical distributions of the same subgroups as well as the total measured frequencies of NNE and NE winds. By joining the two theoretical distribution frequencies a high degree of fitting with the total measured frequency has been achieved (r=0.999437, with (χ^2=0.4538298). Noticeable differences from the theoretical distribution frequencies for the *bura* are visible in the region of around 4.0 ms^{-1}, but these do not exceed 2 %. A corresponding high degree of fitting of theoretical and empirical distributions has been achieved for the month of January.

4. THE BASIC CHARACTERISTICS OF THE BURIN AND BURA

4.1. The beginning, duration and termination

It is well known that in the area of Split, in the warmer part of the year, besides the *bura* and *burin*, a *land breeze* (in Croatian called *kopnenjak*) also appears, blowing most frequently from the same direction. We did not try to separate the *burin* from this *land breeze* and consequently all winds from the NNE and NE directions are considered as *burin* or *bura*. To my knowledge, up to now, nobody has tried to define separately the characteristics of the *bura, burin* and *land breeze*. In her description of the Split climate, B. Penzar (1976) mentioned the nocturnal burin: *"In the warmer part of the year, with sunny weather, two (weather) types similar to the first one occur: with one of these the nocturnal burin is strengthened and lasts longer"*. The same author writes, with Makjanić (1978), that *"In summer nights, the wind of coastal and mountain-side circulation may be transformed into weak bura, which abates in the morning"*. Šegota (1988) refers to this form of weak *bura* as *burin,* and according to him the *burin* is often the initial or final phase of *bura,* and is of the same genetic origin as the *bura.* He also points out that it would be better to call the nocturnal wind in summer *land breeze.* Makjanić (1976) points out that during the summer, in the evening, a land breeze begins to blow towards the sea, the so called *burin,* which lasts till the morning. In his investigation of wind persistence in Croatia Poje (1992) found that the mean duration of NNE winds with speeds greater than 3 or 5 ms^{-1} is 8 hours, and that for wind speeds greater than 8 ms^{-1} the mean duration is 6.2 hours.

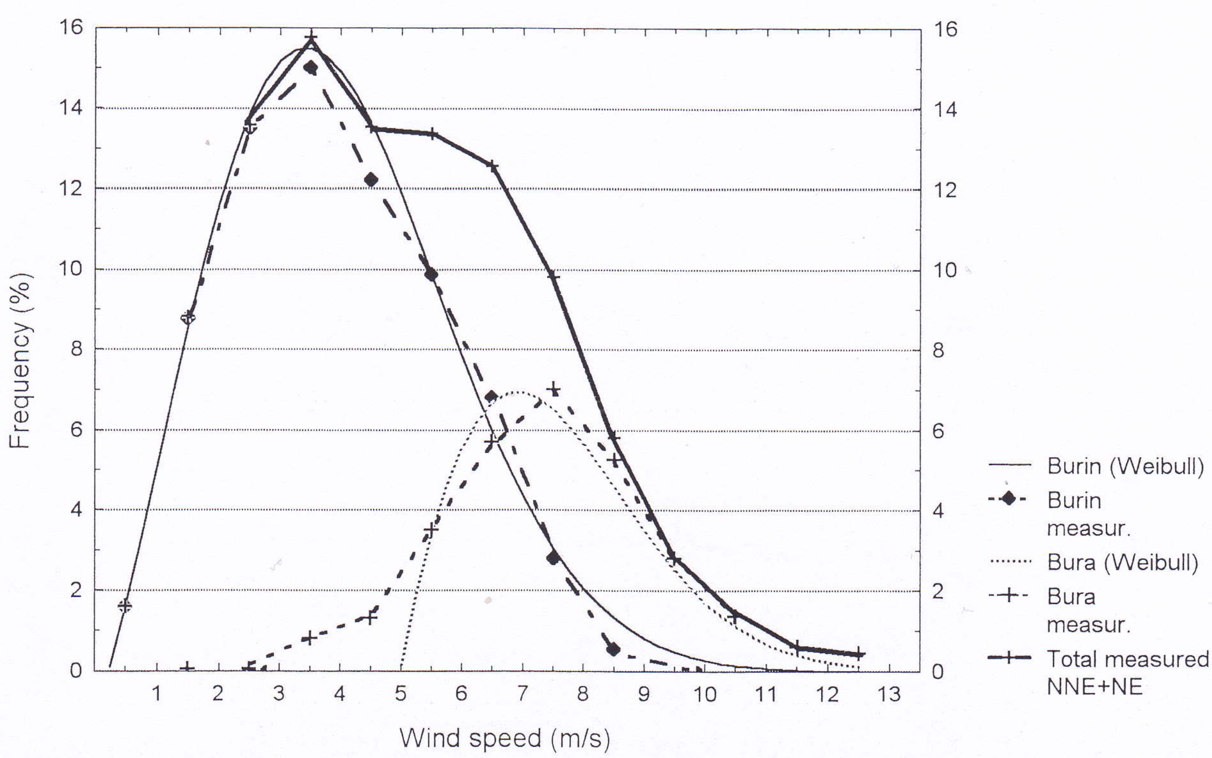

Figure 1. Theoretical and empirical distributions of *burin* and *bura* winds at Split-Marjan, July, 1977—1986.

Slika 1. Teoretske i empirijske razdiobe čestina vjetrova *burina* i *bure,* Split-Marjan, srpanj, 1977—1986.

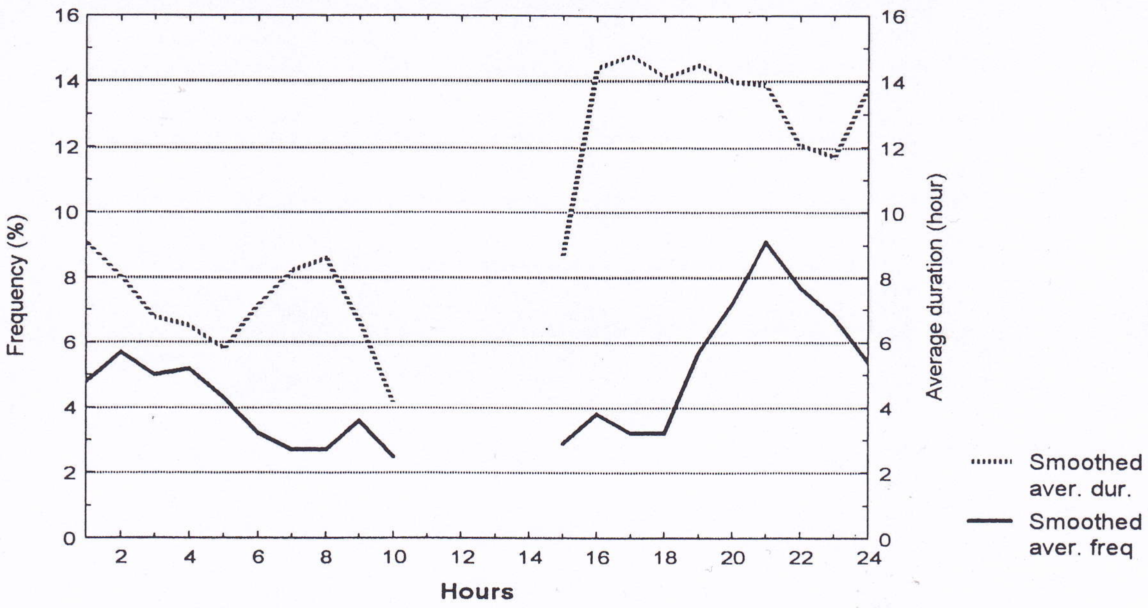

Figure 2. The smoothed average duration (in hours) and the frequency (in %) of the onset of *burin* in January, Split-Marjan, 1977—1986.

Slika 2. Izglađeno prosječno trajanje (u satima) i čestina (u %) početka puhanja *burina*, Split-Marjan, siječanj, 1977—1986.

On the basis of the above criteria we could determine the duration of the *burin* and the frequency of the hour in the day at which the *burin* started to blow. The average frequency of *burin* occurrence in January is 6.4 and in July 5.2. Figure 2. shows that, in January, the *burin* starts most often in the late evening hours (9 p.m.) and that it hardly ever occurs in the period between 10 a.m and 2 p.m. If the *burin* starts to blow at 3 p.m. it is most probable that it will last only 9 hours. However, if the

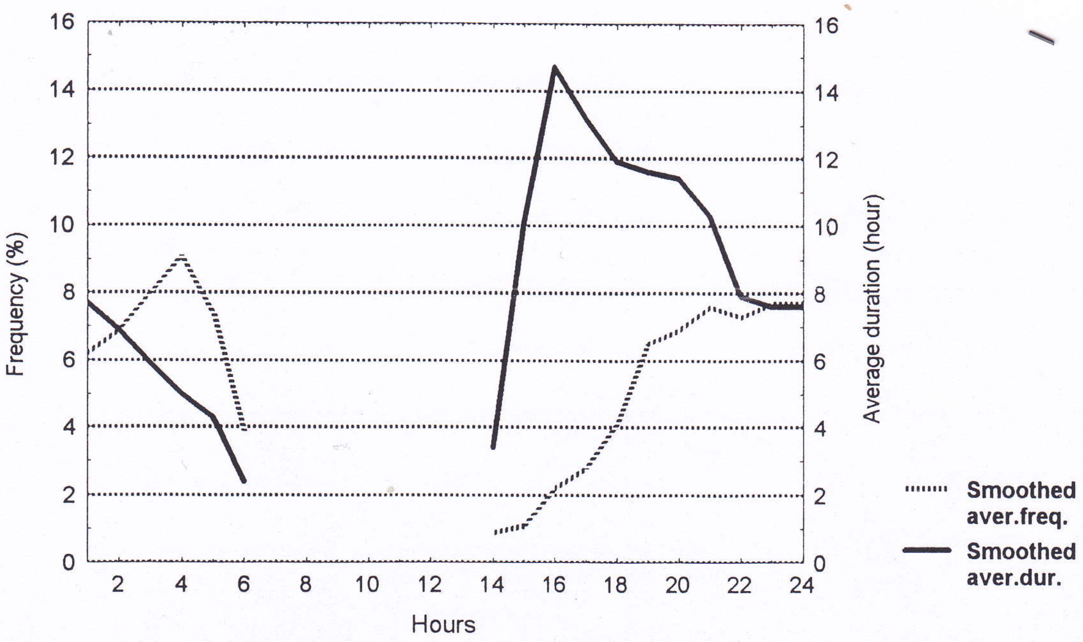

Figure 3. As Figure 2, but for July.

Slika 3. isto kao i na slici 2., no za mjesec srpanj.

Table 3. The probability of the *burin* and *bura* duration (in %), Split-Marjan, 1977—1986.

Tablica 3. Vjerojatnost (u %) trajanja *burina* i *bure*, Split-Marjan, 1977—1986.

	January		July		January		July	
Duration (hours)	*Burin*	*Burin2*	*Burin*	*Burin2*	*Bura*	*Bura2*	*Bura*	*Bura2*
3-6	39.7	33.3	51.3	50.0	13.0	3.9	21.7	20.0
7-12	30.1	22.2	30.5	30.0	26.1	19.2	21.8	20.0
13-24	23.0	33.3	16.9	20.0	34.8	38.4	21.8	40.0
> 24	4.3	11.1	1.3	1.4	26.1	38.5	34.8	20.0
Max. dur.	57	38	40	14	67	66	46	38
Mean dur.	10.5	12.1	8.1	8.4	20.8	23.8	14.0	17.4

burin starts only one or two hours later, then it is most probable that it will last until 6 a. m.

The same characteristics of the *burin* for July are shown in Figure 3. In that month it is most probable for the *burin* to occur between 9 p.m. and 4 a.m. with the most frequent appearance around 4 a.m. Further information on the duration of the *burin* and *bura* can be found in Table 3. Although in exceptional cases the duration of the *burin* may be up to 40 hours, its duration is on average only half of the duration of the *bura* in January.

4.2. Air temperature

After the average daily courses of the basic meteorological elements - air temperature, humidity, pressure and wind speed - for selected months have been determined, it was possible to compare them with the corresponding courses of these elements during the occurence of the *burin* and *bura*.

It should be noted that the negative temperature deviations of the *burin* from the mean daily course are in the range of 1- 2 degrees C with the highest

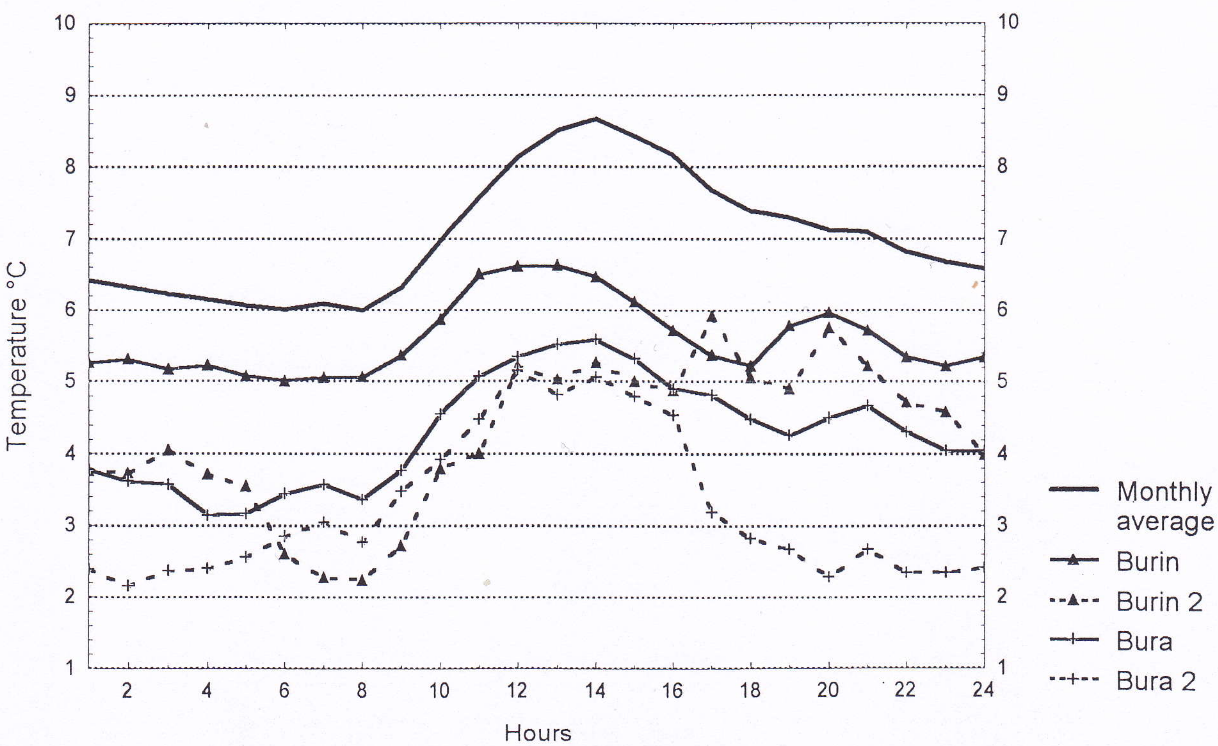

Figure 4. The daily course of air temperature during the *burin* and *bura*, Split-Marjan, January, 1977—1986.

Slika 4. Dnevni hod temperature zraka za *burina* i *bure*, Split-Marjan, siječanj, 1977—1986.

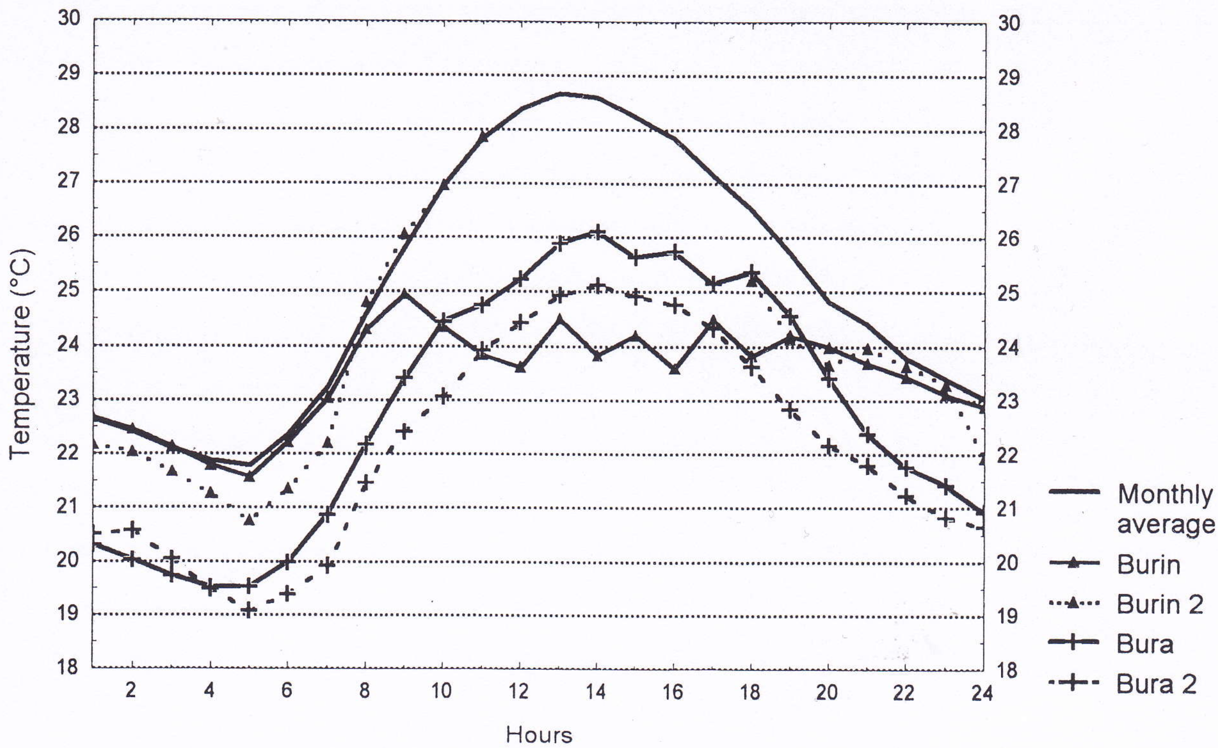

Figure 5. Same as for Figure 4, only for July.

Slika 5. Isto kao za sliku 4. no za srpanj.

values in the afternoon hours and that those of the *bura* may exceed 3 degree C.

Due to stronger air warming in July the temperature deviations during the *bura* or *burin* (Fig. 5.) are significantly different from those in January: when the *burin* blows in the period between 10 p.m. and 8 a.m. there is generally no temperature decrease while in the other, warmer, part of the day the negative deviation may attain almost 3 degrees. The temperature deviation during the *bura* is generally somewhat lower than 2 degrees Celsius. A survey of selected statistical values of air temperature for the *burin* and *bura* is given in Table 4. Significant differences exist in all the presented mean values compared to the average monthly values at the significant level of at least 0.05.

Table 5. provides a more detailed view of the temperature changes during the onset of the *burin* and *bura*. The left part of the table includes the changes within the first hour of the onset of the *burin* and *bura* and the right part shows the maximal temperature changes that took place during the whole period of blowing. At the onset of the *burin* the average air temperature drops are mainly quite

Table 4. The basic characteristics of mean air temperature for the *burin* and *bura*, Split-Marjan, 1977—1986.

Tablica 4. Osnovne značajke srednje temperature zraka za *burina* i *bure*, Split-Marjan, 1977—1986.

	January					July				
	Mon. mean	*Burin*	*Burin2*	*Bura*	*Bura2*	Mon. mean	*Burin*	*Burin2*	*Bura*	*Bura2*
t	7.02	5.60	4.24	4.29	3.23	25.08	23.44	23.83	22.84	22.14
σ_t	0.871	0.528	0.215	0.759	1.021	2.422	0.923	2.474	2.365	1.999
Max.	8.66	6.62	5.92	5.58	5.16	28.65	24.94	29.90	26.09	25.11
Min.	5.99	5.01	2.24	3.14	2.15	21.78	21.57	20.76	19.51	19.08

Table 5. Interhourly average changes in air temperature of *burin* and *bura* Split-Marjan, 1977—1986.

Tablica 5. Srednje međusatne promjene temperature zraka za *burina* i *bure,* Split-Marjan, 1977—1986.

	Changes at the first hour of blowing								Maximal changes during the blowing							
	Burin		*Burin2*		*Bura*		*Bura2*		*Burin*		*Burin2*		*Bura*		*Bura2*	
Mont.	I	VII	I	VII	I	VII	I	VII	I	VII	I	VII	I	VII	I	VII
n	146	153	26	10	23	22	24	10	140	152	18	9	23	25	25	10
Mean	-0.2	-0.4	-0.1	-0.1	-1.0	-1.3	-0.4	-0.2	-1.0	-1.5	-0.8	-0.8	-3.4	-4.4	-3.3	-2.3
Max. ↓	-3.2	-6.7	-1.9	-0.8	-5.7	-6.5	-2.1	-1.5	-6.6	-8.8	-6.7	-4.7	-28.1	-8.5	-9.3	-7.8
Max. ↑	1.3	1.2	1.8	0.5	0.7	1.8	1.0	1.9	4.5	6.2	4.9	1.8	5.2	2.5	2.1	3.4

small while in the case of *bura* they are about one degree C. The greatest measured temperature decrease with the onset of the *bura* was about 6 degrees. If the whole period of the *burin* is considered, then the mean temperature decrease is about one degree, while in the case of the *bura* it reaches three to four degrees C, and in extreme cases even 28 degrees! In situations with clear sky, due to the radiation of the sun, the blowing of *burin* and *bura* may also cause a temperature increase but this hardly ever attains several degrees C.

4.3. Relative humidity

The analysis of relative humidity during the *burin* and *bura* revealed that with the onset of these winds an inflow of dryer air actually sets in. Due to the weaker warming of the soil surface in January, the average negative deviations of relative humidity during the *burin* are only about 5% and those of the *bura* between 13 and 20% (Fig. 6.).

In July the relative humidity shows a very pronounced daily course during a *bura* occurrence with a minimum at 1 p.m. As opposite to a *bura* situation when the average negative deviations of relative humidity are in the range of 10 to 13% (Fig. 7), during the *burin* the average values between 10 a.m. and 6 p.m. are greater than the mean daily values for about 10%.

More information on the behaviour of relative humidity are provided in Table 6 which reveals that only during the *burin* there are no significant differences in relation to the average monthly values. The greatest decrease in relative humidity can be expected during the occurrence of *bura* and *bura2*.

4.4. Pseudopotential temperature

The calculation of the pseudopotential temperature for all data has made it possible to better explain the changes during the onset and duration of the *burin* and *bura* than it was possible using only air temperature data. The basic expressions for this characteristic are:

$$\Theta_p = T_p\left(\frac{1000}{p}\right)^{\frac{k-1}{k}}; \quad \frac{k-1}{k} = 0.286; \quad T_p = T + \Delta T_p, \quad \Delta T_p = 2.5‰$$

In order to eliminate the influence of the daily course of air temperature and other meteorological elements on Θ_p, the corresponding value of the

Table 6. The average values of relative humidity during the *burin* and *bura,* Split-Marjan, 1977—1986.

Tablica 6. Srednje vrijednosti relativne vlage za *burina* i *bure,* Split-Marjan, 1977—1986.

Month	January					July				
	Mean	*Burin*	*Burin2*	*Bura*	*Bura2*	Mean	*Burin*	*Burin2*	*Bura*	*Bura2*
U	59.9	54.8	37.6	44.0	36.8	48.8	48.4	42.3	38.2	39.0
σ_U	0.864	1.316	1.328	2.891	1.362	5.681	3.406	4.153	4.012	4.570
Max.↓	60.8	58.4	40.2	49.1	38.8	56.1	53.3	46.7	43.3	46.8
Max.↑	57.7	52.7	34.9	39.9	34.0	40.4	42.0	34.00	31.2	32.5

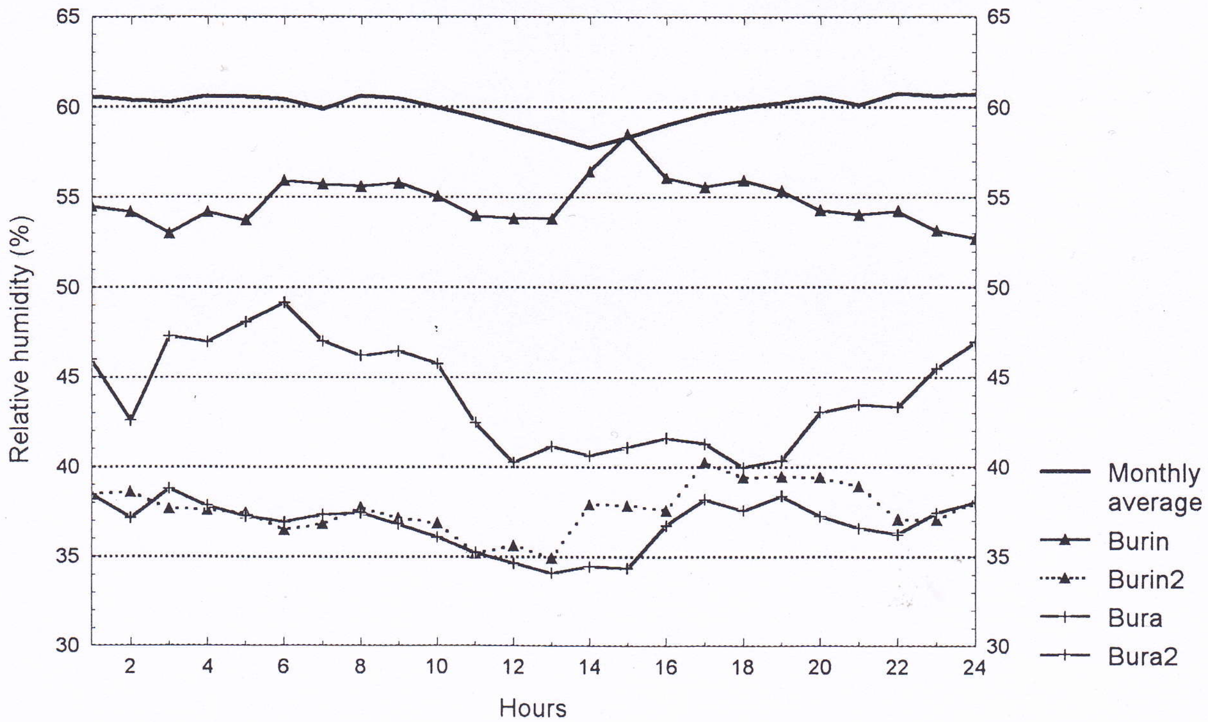

Figure 6. The daily course of average relative humidity during the *burin* and *bura,* Split-Marjan, January, 1977—1986.

Slika 6. Dnevni hod srednje relativne vlage za *burina* i *bure,* Split-Marjan, siječanj, 1977—1986.

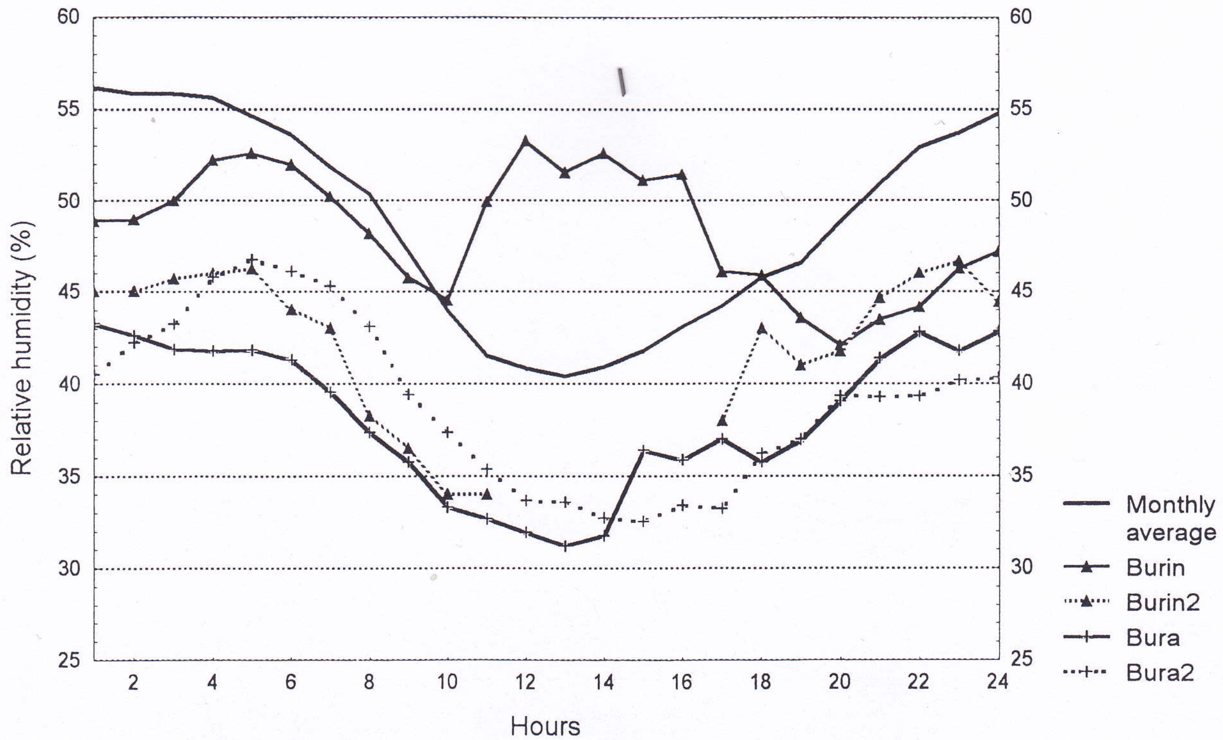

Figure 7. As for Figure 6, only for July.

Slika 7. Isto kao slika 6. no za srpanj.

hourly change of Θ_p at the onset of the *burin* or *bura* or, later, during the period of blowing, when the greatest change of Θ_p occurred, is subtracted from the value of the pseudopotential temperature at the beginning or somewhere during the period of blowing. The interhourly changes of Θ_p were in the range of -0.6 to 0.8 °C for January and between -0.2 and 2.5 °C for July. The Figure 8. depicts the Θ_p changes in July; these changes, as well as those in January, are numerically presented in Table 7. Except for the *burin* the deviations of other wind types in January are nearly 50 % greater than the deviations in temperature. The appropriateness of Θ_p as an indicator of the onset of the *burin* and *bura* is remarkably noticeable in July (Fig. 8) when the difference between Θ_p and air temperature in monthly mean hourly values is nearly tenfold greater than in January. During the *bura* the average value of Θ_p is in average 9.7 degrees C smaller than the monthly average, and nearly eleven degrees lower during *bura2*.

The basic characteristics of Θ_p at the onset of the *burin* and *bura* are shown in Table 8. When the *bura* begins to blow the average drop of Θ_p is 2.4 degrees C in January, and 4.3 degrees C in July. The case of 31 January 1983 should be pointed out, when, with the onset of the *bura* at 9 a.m., the Θ_p suddenly decreased from 24.8 to 13.7 degrees C, the air temperature from 8.2 to 2.5 degrees C and the 3.1 ms^{-1} wind from WNW veered to NNE increasing to a speed of 13.1 ms^{-1}. Another case was the one on 14 July 1983 when, with the onset of the *burin* at 10 p.m., the Θ_p dropped by 10.5 degrees C in one hour, the relative humidity from 75 to 50 % and the 1.7 ms^{-1} wind with no change in wind speed backed from ENE to NNE. These cases demonstrate that there are good reason to use Θ_p instead of air temperature for the determination of the onset of *burin* and *bura*.

4.5. Wind speed

An important feature of the *burin* and *bura* is wind speed, whose basic characteristics are presented in Table 9. The mean monthly wind speeds and scalar values for all the periods were calculated. The values of the *burin* average wind speeds are nearly the same in both the months considered. On the other hand, the mean wind speeds for the *burin* and *bura* are significantly different even at a

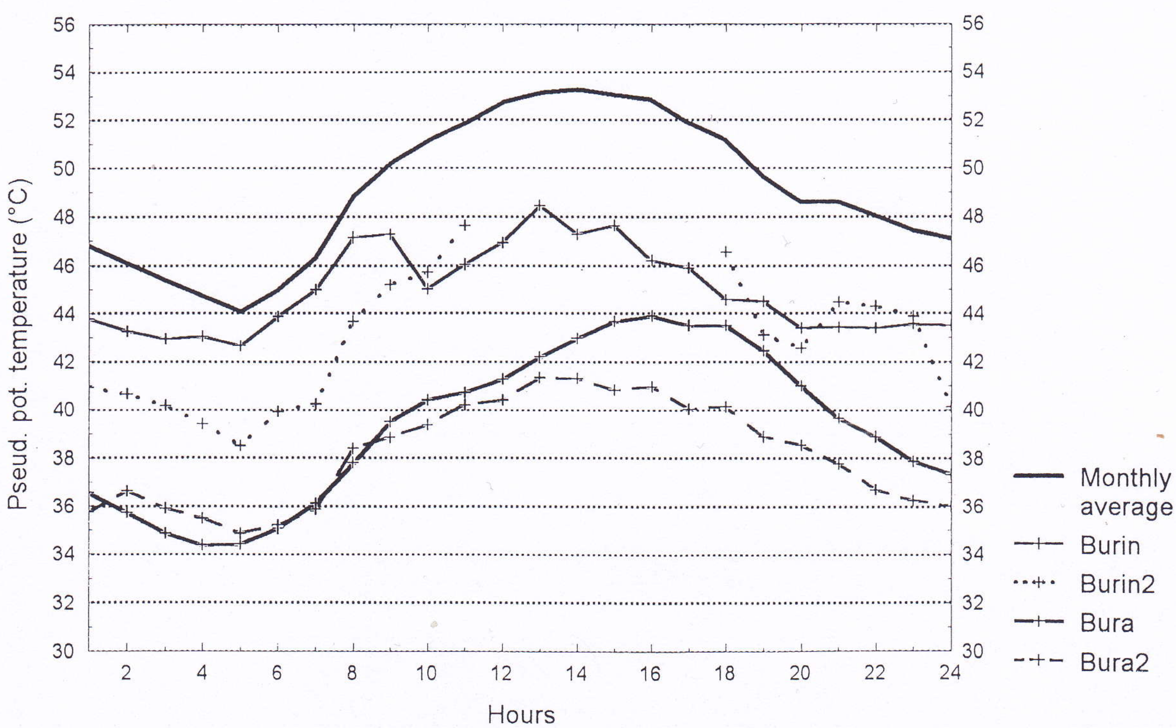

Figure 8. Daily course of the pseudopotential temperature Θ_p of *burin* and *bura* in July, Split-Marjan, 1977—1986.

Slika 8. Dnevni hod pseudopotencijalne temperature Θ_p za puhanja *burina* i *bure,* Split- Marjan, srpanj, 1977—1986.

Table 7. The average hourly reduced values of Θ_p (except the monthly means) in deg. Celsius during the *burin* and *bura*, Split-Marjan, 1977—1986.

Tablica 7. Srednje reducirane satne vrijednosti Θ_p (osim mjesečnih srednjaka) u stupnjevima Celsiusa za puhanja *burina* i *bure*, Split-Marjan, 1977—1986.

	January					July				
Hour	Month. mean	*Burin*	*Burin2*	*Bura*	*Bura2*	Month. mean	*Burin*	*Burin2*	*Bura*	*Bura2*
1	13.27	13.1	8.56	9.73	6.92	46.78	43.78	40.93	36.55	35.75
2	13.09	13.12	8.53	9.07	6.46	46.08	43.25	40.64	35.72	36.63
3	12.94	12.71	8.88	9.62	6.95	45.34	42.92	40.16	34.86	35.88
4	12.92	13.03	8.42	8.95	6.90	44.70	43.04	39.40	34.36	35.49
5	12.82	12.64	8.18	9.16	7.01	44.10	42.64	38.50	34.40	34.87
6	12.68	12.83	6.87	9.64	7.32	44.97	43.86	39.91	35.06	35.19
7	12.68	12.84	6.49	9.52	7.61	46.31	44.97	40.22	36.12	35.87
8	12.74	12.84	6.56	9.09	7.21	48.84	47.12	43.65	37.8	38.40
9	13.15	13.31	7.13	9.64	8.08	50.17	47.26	45.18	39.50	38.83
10	13.91	13.96	8.50	10.54	8.56	51.12	45.02	45.71	40.40	39.37
11	14.64	14.72	8.52	10.87	9.21	51.83	46.00	47.62	40.73	40.21
12	15.27	14.94	10.14	10.95	**10.01**	52.69	46.92		41.28	40.39
13	15.62	14.91	9.61	11.32	9.49	53.11	**48.43**		42.19	**41.33**
14	**15.73**	**15.18**	10.23	**11.36**	9.88	**53.24**	47.26		42.97	41.29
15	15.54	14.97	9.93	11.10	9.53	53.01	47.61		43.65	40.81
16	15.34	14.17	9.78	10.64	9.59	52.83	46.20		**43.89**	40.95
17	14.79	13.56	**11.60**	10.61	7.93	51.84	45.88	**54.88**	43.49	40.03
18	14.43	13.37	10.39	9.94	7.32	51.15	44.57	46.52	43.49	40.11
19	14.35	14.17	10.22	9.68	7.23	49.62	44.49	43.11	42.44	38.88
20	14.19	14.28	11.40	10.54	6.60	48.57	43.39	42.56	40,98	38.54
21	14.05	13.80	10.58	10.84	7.04	48.59	43.43	44.46	39.64	37.77
22	13.58	13.16	9.69	10.26	6.58	48.00	43.37	44.28	38.88	36.70
23	13.64	12.84	9.49	10.11	6.75	47.42	43.55	43.87	37.87	36.25
24	13.53	12.96	8.82	10.29	6.91	47.08	43.48	40.13	37.33	36.00
Mean	13.96	13.64	9.11	10.14	7.80	49.06	44.93	43.24	39.32	38.15

Table 8. The changes of Θ_p at the onset and during the blowing of the *burin* and *bura*, Split- Marjan, 1977—1986.

Tablica 8. Promjene Θ_p početkom i tijekom puhanja *burina* i *bure*, Split-Marjan, 1977—1986.

	Changes during the first hour of blowing								Greatest changes during the blowing							
	Burin		*Burin2*		*Bura*		*Bura2*		*Burin*		*Burin2*		*Bura*		*Bura2*	
Month	I	VII	I	VII	I	VII	I	VII	I	VII	I	VII	I	VII	I	VII
n	146	153	26	10	23	22	24	10	143	152	19	9	23	25	25	10
Mean	-0.4	-1.3	0.2	0.8	-2.4	-4.3	-1.1	-1.8	-1.8	-2.1	-1.0	0.1	-7.3	-7.6	-5.1	-3.8
Max.↓	-4.2	-10.5	-5.6	-3.3	11.5	-16.7	-4.6	-3.1	-16.8	-11.9	-6.3	-6.7	25.5	22.3	13.4	18.0
Max.↑	2.4	6.3	1.6	3.4	0.5	2.1	0.3	-0.3	9.9	5.2	4.4	5.7	4.0	2.2	1.1	0.9

Table 9. The average wind speeds (ms^{-1}) during blowing of *burin* and *bura,* Split-Marjan, 1977—1986.

Tablica 9. Srednje brzine vjetra (ms^{-1}) za puhanja *burina* i *bure,* Split-Marjan, 1977—1986.

Month	January					July				
	Mean	*Burin*	*Burin2*	*Bura*	*Bura2*	Mean	*Burin*	*Burin2*	*Bura*	*Burin2*
v	5.2	3.4	4.3	8.8	9.2	3.4	3.4	4.6	7.5	7.2
σ_v	0.164	1.226	0.878	2.473	2.164	0.358	1.412	0.914	0.783	0.770
Max.	5.5	6.6	6.5	16.6	10.4	4.2	6.4	6.0	9.1	8.5
Min.	5.0	1.0	2.9	5.7	8.8	2.9	0.9	3.2	6.2	5.8

level of significance of 0.001. It should be noticed that in extreme cases, as on 31 January 1983, the *bura* lasted 7 hours and reached a mean hourly speed of 23.8 ms^{-1}. At the onset of this *bura* period the air temperature increased from 2.6 to 4.3 degrees C, the wind speed from 3.1 to 13.1 ms^{-1}, while the Θ_p fell from 24.8 to 13.7 degree C and the relative humidity from 87 to 51 %.

In January during the blowing of *burin* and *burin2,* the average wind speeds are weaker than the mean wind speed, except in the period between 2 and 5 p.m. (Fig. 9). The daily course of the *bura* wind speeds is quite pronounced in January with a minimum at midnight and a maximum of nearly 11 ms^{-1} at noon. A similar pattern of the daily course holds also for the absolute maximal average hourly wind speeds of the *bura,* which were in the range between 13.1 and 23.5 ms^{-1}.

The wind conditions in July differ significantly from those in January (Fig. 10): the course of the average wind speed shows a maximum of 4.3 ms^{-1} between 2 and 4 p.m. and a minimum of 3 ms^{-1} at 9 a.m. The average wind speeds for the *burin* are mostly greater by one or two ms^{-1} than the average wind speeds for most part of the day. The values for the *bura* in July show a distinctive maximum of

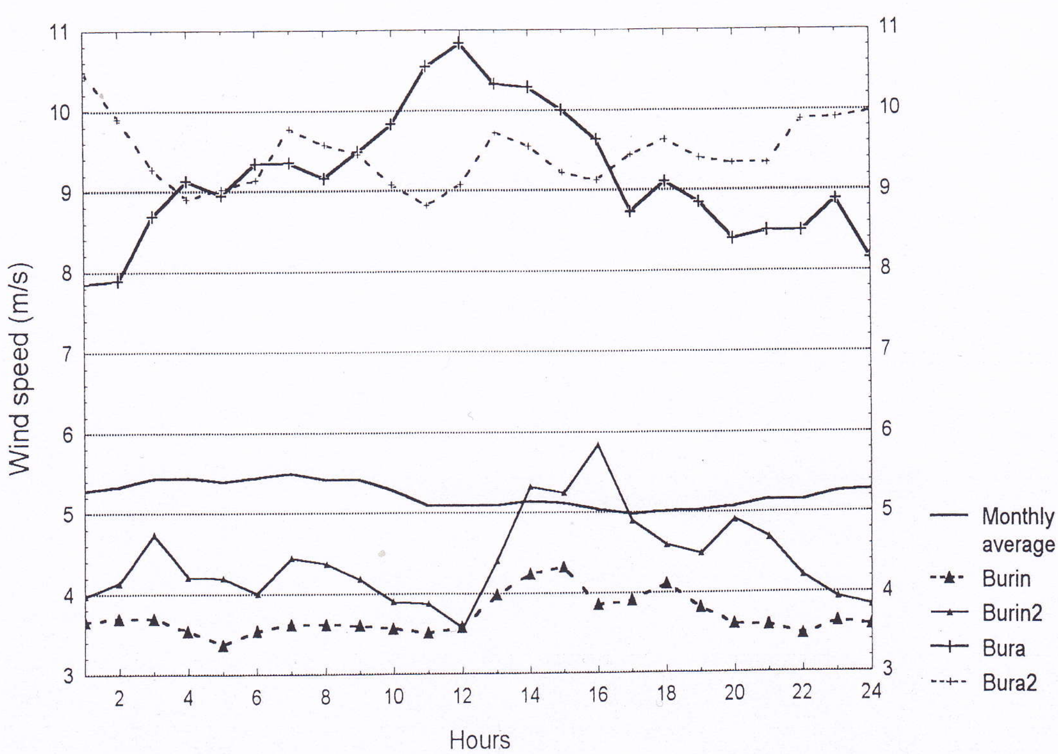

Figure 9. The daily course of wind speed during the *burin* and *bura,* Split-Marjan, January, 1977—1986.

Slika 9. Dnevni hod brzine vjetra za *burina* i *bure,* Split-Marjan, siječanj, 1977—1986.

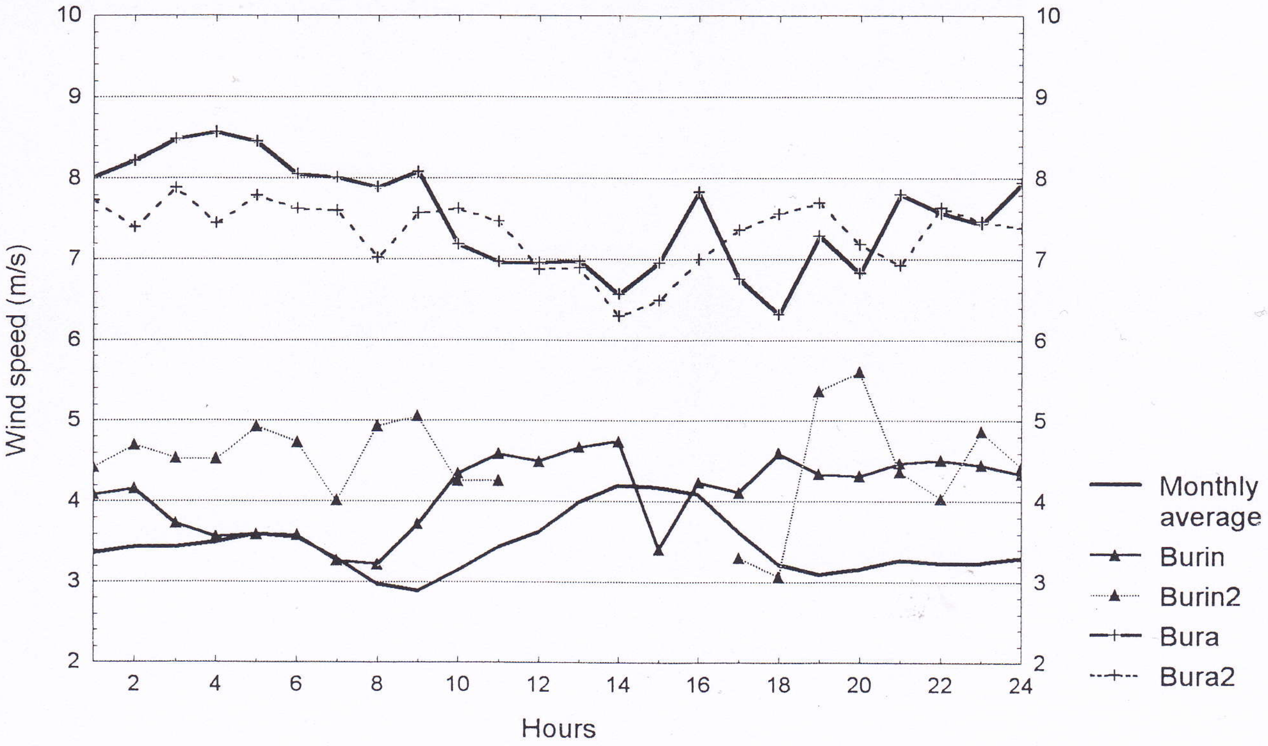

Figure 10. Same as for Figure 9, only for July.

Slika 10. Isto kao za sliku 9, no za srpanj.

8.4 ms^{-1} at 4 a.m. and a minimum of 6.3 ms^{-1} at 6 p.m. Large variations in average wind speeds in the second part of the day could depend on the relatively small number of *bura* periods (less than 20).

4.6. Air pressure

Although the discussion of the connection of the *burin* and *bura* with air pressure (see Chap. 5.) includes the spatial distribution of air pressure during these winds, the average daily course of air pressure in these periods should also be analysed. In Figure 11, in addition to the ordinary sinusoidal course of air pressure average values in January, the corresponding curves are shown for the *burin* and *bura*.

The shapes of the curves for the *burin* and *bura* for the first part of the day have opposite deviations from the mean curve: for the *burin* the values are ***higher*** by 3 to 4 hPa and for the *bura* they are than the mean values by 1 to 4 hPa ***lower***. This indicates that the *burin* is *mainly* connected with high pressure distribution situations and the *bura* with the presence of cyclones at the Mediterranean or the Adriatic. During *burin2*, the air pressure is constantly higher than the mean air pressure during the day.

In July, during the *burin* and *bura* (Fig. 12), the mean air pressure curves follow the mean air pressure curve for the greater part of the day but are twice smaller in magnitude than in January. Let us point out only the maximum of 1002.5 hPa in the *bura* curve at 10 a.m. and its minimum of 999.3 hPa at 4 p.m. A general review of the statistical characteristics of air pressure for different types of *bura* may be seen in Table 10.

4.7. Cloudiness

It is well known that the frequency distribution of cloudiness at certain place can not be properly described by usual statistical parameters due to its specific "U" form. In this paper, the state of cloudiness during the blowing of the winds considered is therefore defined by comparing the cloudiness state during the whole period of the *burin* or *bura* occurrence with the cloudiness of the hour just before the onset of these winds. The following 8 cate-

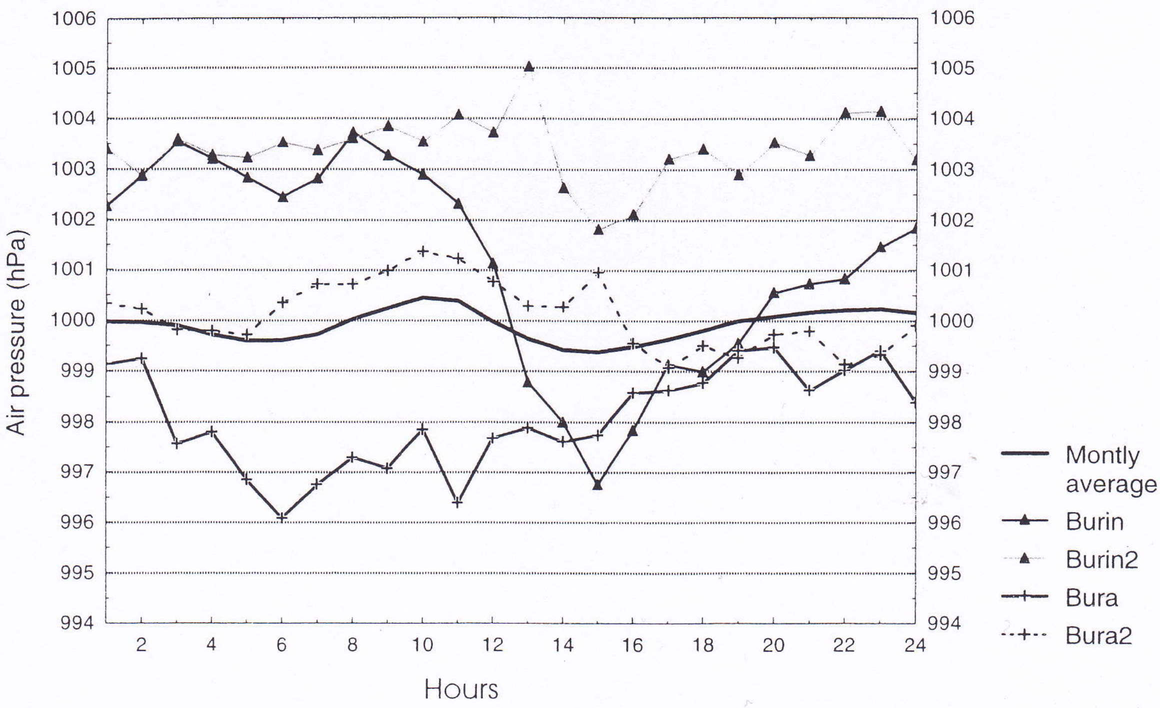

Figure 11. The average daily course of air pressure during the *burin* and *bura*, Split-Marjan, January, 1977—1986.

Slika 11. Srednji dnevni hod tlaka zraka za *burina* i *bure*, Split-Marjan, siječanj, 1977—1986.

gories have been defined:

- V - clear during the whole period
- N - complete overcast set in
- O - cloudy weather prevailed
- TR - complete clearing up set in
- MO - little cloudiness prevailed
- DR - partly clearing up set in
- DN - partly overcast set in, e.g. development of typical daily cloudiness
- PO - predominantly overcast

The data from Table 11 validate the usual opinion that small cloudiness or clear sky prevails at the onset of the *burin* or *bura*. This is particularly noticeable in July when, at the onset of the *burin* or *bura*, in 60% of all cases a clearing-up occurs or clear sky dominates. In January, nearly every fifth onset of the *burin* or *bura* is accompanied by cloudy weather, while in July this applies only to every seventh onset. More information on cloudiness changes can be obtained by combining the groups characterised in general by clearing-up or mostly clear weather and the groups that include overcast or predominantly cloudy weather (Tab. 12.).

In **January**, the *burin* brings about mostly overcast sky in nearly one third of all cases, *burin2* most probably a total or partial clearing-up of the sky. The *bura*, however, causes a clearing-up in 7 out of 10 cases and the *"dark bura"* occurs in less than 30 % of all cases. In **July**, we may expect that all the types of analysed winds will bring a clearing-up or that in the period of their blowing a clear sky will prevail. In that month the *"dark bura"* (overcast sky) occurs in 29 % of all situations. The data including *burin2* and *bura2* should be taken with caution due to the small number of investigated cases.

It is also appropriate to consider the average values of some meteorological elements during the *burin* or *bura* and their average changes at the on-

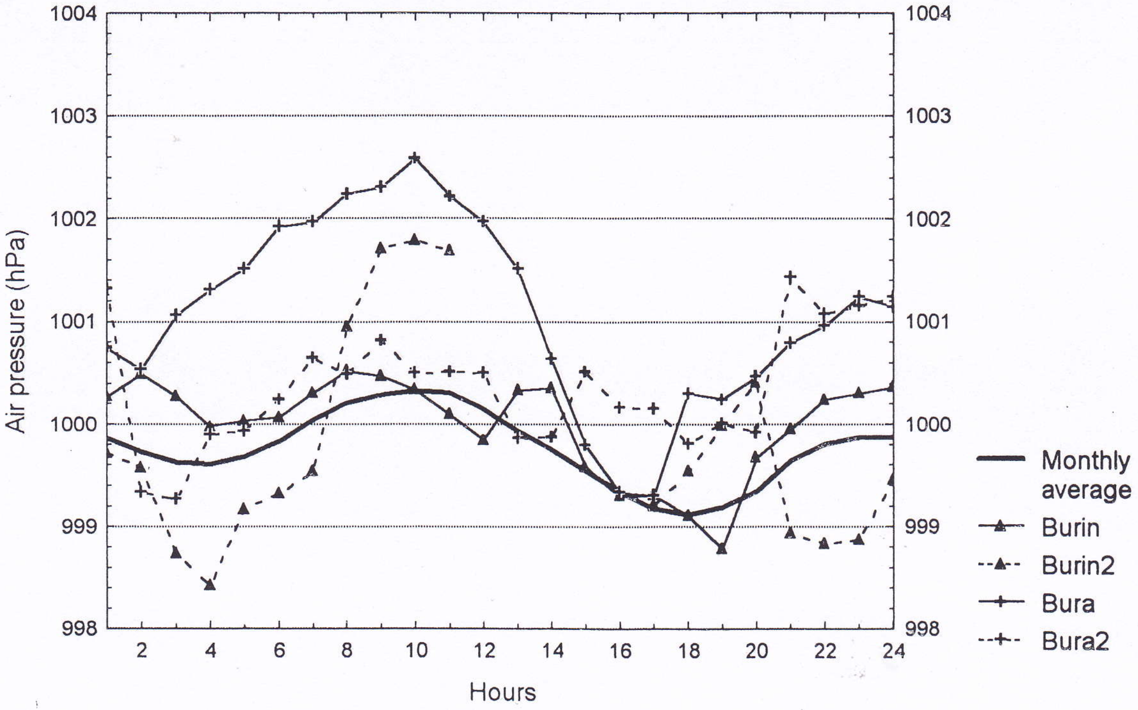

Figure 12. Same as Figure 11 only for July.

Slika 12. Isto kao za sliku 11. no za srpanj.

Table 10. The average values of air pressure (hPa) during *burin* and *bura*, Split-Marjan, 1977—1986.

Tablica 10. Srednje vrijednosti tlaka zraka (hPa) za *burina* i *bure*, Split-Marjan, 1977—1986.

Month	January					July				
	Mean	*Burin*	*Burin2*	*Bura*	*Bura2*	Mean	*Burin*	*Burin2*	*Bura*	*Bura2*
p	999.90	1001.15	1003.38	998.05	1000.11	999.76	1000.00	1001.79	1001.09	1000.36
σ_p	0.303	2.035	0.670	0.998	0.667	0.357	0.474	1.047	0.920	0.597
Max.	1000.4	1003.7	1005.0	999.4	1001.4	1000.3	1000.5	1001.8	1002.6	1001.4
Min.	999.4	996.7	1001.8	996.1	999.1	999.1	998.8	998.4	999.3	999.3

set of these winds. For this analysis that one hour was selected at which in relation to the hour before the beginning of the blowing, the greatest change of reduced pseudopotential temperature occurred (Tab. 13). This was the case during a lasting blowing of the *burin* or *bura*, even several days after the onset of these winds and also in situations when a transformation of the air mass flowing towards Split was in progress or when the daily warming of soil was very pronounced.

Except for *burin2*, there is only a small difference in the average values of the selected meteorological elements during the *burin* and *bura* on "clear" or "cloudy" sky situations, which indicates that near the surface these winds have practically the same characteristics. At approx. 1.5 km, the average wind speeds during the *bura* are significantly

Table 11. The cloudiness changes during the onset of the *burin* and *bura*, Split-Marjan, 1977—1986.

Tablica 11. Promjene naoblake početkom puhanja *burina* i *bure*, Split-Marjan, 1977—1986.

Month	January		July	
	n	%	n	%
V	65	29.0	79	39.7
N	23	10.3	7	3.5
O	42	18.8	27	13.6
TR	30	13.4	28	14.1
MO	14	6.3	10	5.0
DR	21	9.4	12	6.0
DN	14	7.1	14	7.0
PO	13	5.8	22	11.1

Table 12. Frequency (in %) of grouped cloudiness changes at the onset of the *burin* resp. *bura*, Split-Marjan, 1977—1986.

Tablica 12. Čestina (u %) grupiranih promjena naoblake početkom puhanja *burina* i *bure*, Split-Marjan, 1977—1986.

Month	January				July			
	Burin	*Burin2*	*Bura*	*Bura2*	*Burin*	*Burin2*	*Bura*	*Bura2*
V+TR+MO+DR	38.3	76.9	70.8	88.4	66.0	66.7	70.8	40.0
N+O+D+N+PO	61.7	23.1	29.2	11.6	34.0	33.3	29.2	60.0

stronger on "clear" than on "cloudy" days. The difference in Θ_p changes between *burin* and *bura* and the "clear" and "cloudy" situations are also marked in winter and summer. All these changes are negative with the exception of *burin2*, which, generally in "cloudy" situations, may bring an increase in Θ_p values due to longer periods of insolation.

The connection of the surface and upper air flow during the *burin* and *bura* has been analysed at the 850 hPa surface. As outlined earlier, in January and July the surface winds at Split-Marjan are mainly from the NE octant. Figure 13 shows that in both months the predominant winds at approx. 1.5 km altitude are from the N quadrant: in January these winds account for 48% and in July for 71% of all winds. During the blowing of the *burin* with a "clear" sky the upper winds in 40% of cases are from the N quadrant, while during *bura* these upper winds account for 47% of all winds. "Cloudy" weather during the blowing of the *burin* occurs with only 18% of the upper winds from the N quadrant, and with 45% winds from the S quadrant. In the case of *bura* in similar weather situations the

Table 13. The average values of some meteorological elements during the blowing of the *burin* or *bura* and their average changes, Split-Marjan, 1977—1986. (v_{sr} - the average wind speed in ms^{-1} during the period of blowing, Δt - the average of the greatest temperature changes, ΔRV - the average of the greatest relative humidity changes, $\Delta\Theta_p$ - the average of the greatest pseudopotential temperature changes, v_{850} - the average wind speed ms^{-1} during the period of blowing at 850 hPa; V = V+TR+DR+MO, O = O+N+DN+PO)

Tablica 13. Srednje vrijednosti nekih meteoroloških elemenata za puhanja *burina* i *bure* te njihove prosječne promjene, Split-Marjan, 1977—1986 (v_{sr} - srednja brzina vjetra u ms^{-1} u tijeku puhanja, Δt - srednjak najvećih promjena temperature, ΔRV - srednjak najvećih promjena relativne vlage, $\Delta\Theta_p$ - srednjak najvećih promjena pseudopotencijalne temperature, v_{850} - srednjak brzine vjetra u ms^{-1} na 850 hPa, V = V+TR+DR+MO, O = O+N+DN+PO)

Month		January				July			
		Burin	*Burin2*	*Bura*	*Bura2*	*Burin*	*Burin2*	*Bura*	*Bura2*
V	v_{sr}	3.4	4.2	9.2	8.9	3.4	4.9	7.4	6.8
O	v_{sr}	3.3	4.4	8.0	11.7	3.6	4.0	7.7	7.4
V	Δt	-1.1	-1.0	-3.7	-3.4	-1.5	-1.0	-4.7	-2.4
O	Δt	-0.8	1.8	-2.7	-2.6	-1.5	-0.5	-4.5	-2.3
V	ΔRV	-9	-2	-25	-15	-5	-2	-13	-11
O	ΔRV	-1	-1	-19	-16	-3	2	-5	-10
V	$\Delta\Theta_p$	-2.4	-1.0	-7.4	-4.8	-2.1	-0.8	-8.8	-7.1
O	$\Delta\Theta_p$	-1.2	1.1	-6.7	-6.8	-2.1	1.7	-5.7	-1.6
V	v_{850}	13.1	18.0	18.5	19.1	11.6	16.7	16.4	17.5
O	v_{850}	14.0	20.0	15.0	18.3	12.4	10.0	13.6	11.7

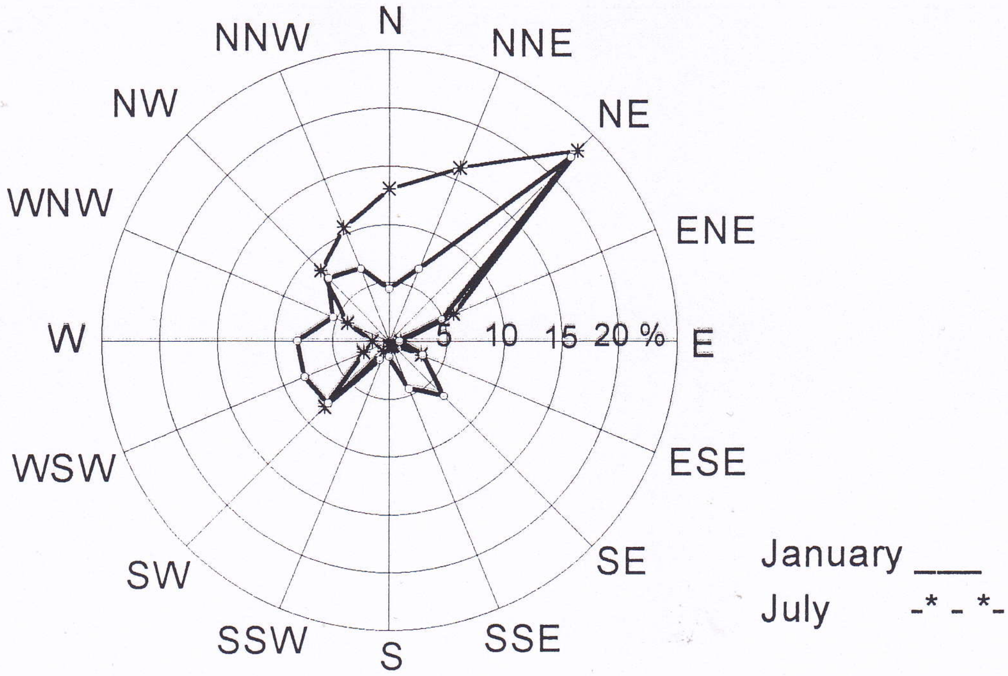

Figure 13. The wind rose at 850 hPa during the *burin* and *bura*, Split-Marjan, January and July, 1977—1986.

Slika 13. Ruža vjetra na plohi 850 hPa za *burina* i *bure*, Split-Marjan, siječanj i srpanj, 1977—1986.

upper winds from the N and S quadrant appear in nearly same amount of 45%.

In July the upper air flow is characterised mainly by winds from the N quadrant: in the case of "clear" sky, the *burin* is accompanied by these winds in 60%, and the *bura*, *bura2*, and *burin2* in 94-100% of all cases. Periods of "cloudy" weather occur with winds from the N quadrant in 48% of all cases during the *burin* and during all other types of *bura* at nearly seven out of ten cases.

5. THE CORRELATION OF THE BURIN AND BURA WITH WEATHER TYPES

The weather type classification based on different forms of surface pressure fields in a larger area around the Split-Marjan station enabled us to ascertain the connection of these types with the occurrence of the *burin* and *bura*. The weather types include: cyclone *(N)*, anticyclone *(V)*, high pressure ridge *(g)*, baric trough *(DOL)*, nongradient baric field (cyclonic B_c and anticyclonic B_a), bridge of high pressure *(mv)* and types which are characterised by a predominant surface flow from 8 main wind direction *(N, NE, E, etc.)*. The sectors of cyclones and anticyclones (eastern, southern, etc.) and their centres (N_c, V_c), are defined when they appear in the area of the southern Adriatic or nearby.

We assume that Table 14 is self-explanatory and go over to the results of the analysis of the state of the sky and weather types during the *burin* and *bura*. In January with **"clear"** sky and *burin* anticyclonic weather types (V, g, B_a) appear in 52% and cyclonic types in 23% of all cases. In July, a predominantly "clear" sky with *burin* is most probably present with type B_a (55%), and g (8%). In January the situation with bura and "clear" sky is somewhat different: the group of anticyclonic types V and g occur with the same frequency as the group of cyclonic types N and DOL (41%). In the same combination of the state of the sky and *bura* the weather types NE, E and SE occur in 18% of all situations. In July, the occurrence of the *bura* with "clear" sky is most probable with anticyclonic weather types: V, g - 67%, B_a - 22%. The appearance of *bura2* may occur only with type g (75%) and type DOL (25%).

As expected, during **"cloudy"** sky the weather types in January are more cyclonic: for the *burin* these are N and DOL (at 20%), V (12%), g (13%) and B_c (14%). In July the occurrence of *burin* is most probable with types B_a (37%), g (19%) and

Table 14. Frequency of weather types (in %) during the *burin* and *bura*, Split-Marjan, 1977—1986.

Tablica 14. Čestina (u %) tipova vremena za puhanja *burina* i *bure*, Split-Marjan, 1977—1986.

	burin		*burin2*		*bura*		*bura2*	
Month	I	VII	I	VII	I	VII	I	VII
N	19.0	3.3	23.1	11.1	34.8	4.0	34.6	-
DOL	16.9	7.2	19.2	-	17.4	4.0	15.4	10.0
N, NE, E	3.5	1.3	12.9	-	13.1	-	15.4	-
SW, W, NW	6.3	-	-	-	-	-	-	-
V	17.6	8.4	30.8	22.2	13.1	28.0	11.5	10.0
mv, g	14.1	17.6	7.7	44.4	4.4	36.0	19.2	50.0
Ba	12.7	49.0	-	22.2	4.4	16.0	3.9	30.0
Bc	3.5	11.1	-	-	4.4	8.0	-	-

B_c (17%). In January, the blowing of *bura* in "cloudy" weather situations may be expected with an equal probability of 14% with the following types: *N, DOL, g, NE, SE* and B_a. In July, the blowing of *bura* and cloudy sky occur most probably with the type *g* (29%) and, with a frequency of 14% with types B_a, B_c, *V, DOL, mv*.

The possibility of occurrence of some kind of ***precipitation*** during the *burin* is quite small: in *January*, during the *burin*, slight rain or snow may happen only for a short period with a probability of 8.2% and with cyclonic types. During the *bura*, some slight rain or snow may occur with cyclonic types but the probability for such cases is much higher - 30%. In *July*, there is an extremely low probability of slight, short rain during the *burin* or *bura*. During the whole ten-year period, only one case with such precipitation occurred with B_c type and *burin* and another case with *DOL* and *bura2*.

6. CONCLUSION

The analysis of the occurrence of the *burin* and *bura* at the Split-Marjan station has revealed that one could, on the basis of wind speed criteria, separate the periods of blowing of these winds, which by their characteristics differ in significant measure not only from their average hourly and monthly means but also mutually. The basic characteristics of the *burin* and *bura* respectively, have been determined for the two representative months of winter and summer. We menaged to show that using the pseudopotential temperature, reduced for the daily course, the changes and the beginning of the blowing of the *burin* and *bura* may be effectively ascertained. An examination of the average daily courses of the four main meteorological elements during the blowing of these winds revealed characteristic deviations of the monthly means for different types of *burin* and *bura* and thus the identification of the particular *bura* wind type could be made. A simple classification of cloudiness changes during the onset of these winds in connection with weather types was also carried out.

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