Statistical Analysis of Severe Adriatic Bora

Statistička analiza olujne bure na Jadranu

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Abstract

This paper presents the results of a statistical analysis of severe bora occurrence at two locations, Split and Dubrovnik, in mid-Adriatic. A situation with severe bora is defined as a period with wind, the direction of which is continuously between 360° and 90°, with a mean hourly speed ≥ 17.0 ms^{-1} during at least one hour. In the 30-year period of observation (1958–1987) 116 situations with severe bora were registered in Split. This is four times less than in Senj, on the northern Adriatic. In Dubrovnik, severe bora is not so frequent. It is shown that severe bora with maximum gusts ≥ 40.0 ms^{-1} appears along the entire Adriatic coast, but its duration and frequency decrease from north to south.

Key words: severe and strong bora, Split and Dubrovnik, statistical analysis of wind

Sažetak

U radu je prikazana statistička analiza pojave olujne bure za dvije lokacije, Split i Dubrovnik, na srednjem Jadranu. Situacija s olujnom burom definirana je kao period u kojem vjetar, iz smjerova od 360°–90° uz srednju satnu brzinu vjetra ≥ 17.0 ms^{-1}, traje barem 1 sat. U 30-godišnjem periodu (1958–1987) u Splitu je zabilježeno 116 situacija s olujnom burom. To je četiri puta manje nego u Senju na sjevernom Jadranu (Bajić, 1989). U Dubrovniku bura nije tako česta pojava. Pokazano je da se olujna bura s maksimalnim udarima ≥ 40.0 ms^{-1} javlja duž cijele jadranske obale, ali trajanje i učestalost olujne bure se smanjuje od sjevera prema jugu.

Ključne riječi: olujna i jaka bura, Split i Dubrovnik, statistička analiza vjetra

1. Introduction

Many authors have analysed the Adriatic bora from various points of view, mainly along the northern Adriatic coast and especially in Senj. The climatological and statistical analysis of the northern Adriatic wind field indicates that bora is the most frequent local wind (Makjanić, 1966; Lukšić, 1975; Yoshino, 1976).

It is known that there are many other places along the Adriatic coast where the relief allows strong channeling effects. However, there are no wind measurements at such locations and available data do not allow final conclusions.

A detailed statistical study of severe bora in Senj, during a 30-year period, was

done by Bajić (1989). It showed that bora duration and strenght strongly depend on the locality. On the northern Adriatic the location with the most frequent and the longest duration of severe bora is Senj. The Senj region belongs to the lowest mountains area in the Dinaric Alps (Fig. 1). The lowest pass in the region (Vratnik Pass) rises close to Senj. However, the mountain range upstream of the Senj bora belongs not only to a fairly low-lying region of the Dinaric Alps, but also to a region where the mountain barrier is the narrowest. Because of that, violent bora occurs in this region and the strong channeling effects are responsible for the Senj bora longevity and strenght.
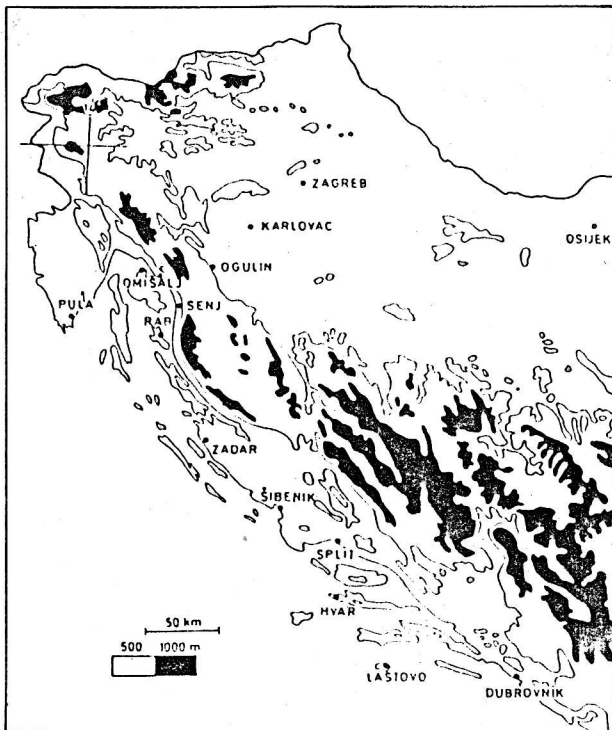

Fig. 1. Topography of the western part of Yugoslavia
Sl. 1. Topografija zapadnog dijela Jugoslavije

The basic characteristics of the wind regime on the northern and mid-Adriatic were described by Penzar (1977) and Makjanić (1978). Makjanić examined first the spatial connection between bora occurrences at the different locations along the Adriatic coast. If bora blows at any of the coastal stations there is a large probability of its occurrence (63 %) in Senj, too. If it blows in Senj, the probability of its occurrence at

some other station is less than 50 %. This means that there are situations with bora only in the Senj region. However, if bora occurs in the mid-Adriatic region (Split) its probability in Senj is 74 % and in Dubrovnik 50 %. If bora blows in Dubrovnik, the probability of bora occurrence at Senj is 72 % and at Split 84 %. It has been shown that the connection of bora occurrence between Split and Dubrovnik is better than between Split and Senj.

Although the existing climatological and statistical analyses of the mid-Adriatic bora have brought about important results, they have still not presented all the severe bora characteristics. The purpose of this paper is to show that the bora wind can be severe and long lasting along the entire Adriatic coast.

The basic statistical analysis was done using the wind data from Split and Dubrovnik on the mid-Adriatic coast and compared to a similar analysis of the northern Adriatic Senj bora (Bajić, 1989).

2. Severe Bora in Split

Makjanić (1978) has shown that the highest probability of bora occurrence, after Senj, is found in the Split region. Therefore, Split data for the 30-year period (1958-1987) were analysed first.

Split is situated in the central part of the Adriatic coast, also near a mountain pass (Klis Pass, Fig. 1), but close to a region where the Dinaric Alps are broader and higher than in the Senj region.

In the following analysis we will consider the frequency and duration of severe bora and the maximum bora speeds. A severe bora situation is defined as a period in which wind direction is from $360° - 90°$ with a mean hourly speed $V_{sred} \geq 17.0$ ms^{-1} during at least one hour.

In the considered 30-year period, 116 situations with severe bora were observed in Split (Tab. 1) which was four times less than in Senj. In 28.5 % of these cases the maximum gusts in Split reached ≥ 35.0 ms^{-1}.

The total number of days with severe

Tab. 1. Statistical review of strong and severe bora in Split for individual years during the period 1958-1987.
Tab. 1. Statistički pregled situacija s jakom i olujnom burom u Splitu po godinama u razdoblju 1958-1987.

YEAR	MVmax	MN	Vm ≥35	35> Vm ≥30	Vs ≥20	20> Vs ≥17	17> Vs ≥10	Vm (ms⁻¹)	DATE	tmax (hours)	DATE	Tmax (hours)	DATE	Nd (%)	Nd1	Nh (%)	Nh1	Nh2	nd (%)	nd1	nh (%)	nh1	nh2
1958	-	-	1	4	4	3	38	35.3	22.02.	8	19-20.02.	36	29-30.04	10	2.7	25	0.3	2.5	46	12.6	363	4.1	7.9
1959	-	-	2	1	4	3	35	38.8	22.02.	15	16-17.01.	40	16-18.01	10	2.7	41	0.5	4.1	39	10.7	332	3.8	8.5
1960	-	VIII-XII	-	-	-	-	23	22.7	25.04.	-	-	15	25-26.05	-	-	-	-	-	22	6.0	117	1.3	5.3
1961	-	XII	1	1	1	3	46	36.5	05.11.	11	22-23.03.	37	07-08.12.	8	2.2	29	0.3	3.6	50	13.7	378	4.3	7.6
1962	I,II	-	1	-	6	2	52	42.2	15.03.	25	14-15.03.	68	14-17.03.	11	3.0	81	0.9	7.4	51	14.0	481	5.5	9.4
1963	-	-	3	2	3	2	30	41.0	21.11.	11	21-23.01.	65	21-23.01.	6	1.9	30	0.3	5.0	38	10.4	375	4.3	9.9
1964	-	-	1	7	1	9	41	36.2	03.01.	4	31.01.	37	08-10.06.	10	2.7	22	0.3	2.2	42	11.5	327	3.7	7.8
1965	VII	-	-	-	2	3	41	27.9	09.02.	8	11.12.	41	08-10.02.	5	1.4	22	0.3	4.4	43	11.8	326	3.7	7.6
1966	XI	-	-	-	-	2	39	27.7	31.12.	3	16-17.03 26.03.	33	21-22.12	3	0.8	6	0.1	2.0	35	9.6	296	3.4	8.5
1967	II,VII	-	1	6	3	3	42	40.4	14.03.	21	14-15.03.	40	13-15.03	8	2.2	44	0.5	5.5	52	14.3	361	4.1	6.9
1968	-	-	2	3	3	5	38	42.0	08.01.	9	08.01.	27	17-18.02.	9	2.5	32	0.4	3.6	43	11.8	334	3.8	7.8
1969	III,X,XII	-	1	-	1	3	47	39.9	02.12.	3	02.12.	35	01-02.01.	4	1.1	14	0.2	3.5	46	12.6	383	4.4	8.3
1970	I-III V,VI	-	-	3	2	2	44	31.6	09.02. 19.03.	5	19.02.	25	15-16.04.	5	1.4	11	0.1	2.2	51	14.0	300	3.4	5.9
1971	XI,XII	-	1	4	1	5	40	37.3	09.12.	11	20.11. 09.12.	29	08-10.12.	8	2.2	37	0.4	4.6	57	15.6	446	5.1	7.8
1972	I,X	-	-	2	-	1	22	34.1	25.11.	3	25.11.	21	03-04.10.	2	0.6	5	0.1	2.5	29	7.9	162	1.8	5.6
1973	IV,XI	I	2	2	1	3	38	35.5	04.04.	3	04.04.	33	24-25.10.	4	1.1	8	0.1	2.0	45	12.3	311	3.6	6.9
1974	XI	-	-	-	-	1	17	29.0	27.10.	5	14.12.	17	17-18.04.	1	0.3	5	0.1	5.0	15	4.1	111	1.3	7.4
1975	IV,VIII	I,II, XI,XII	-	-	-	-	21	26.7	06.06.	-	-	16	21-22.03 04-06.06.	-	-	-	-	-	18	4.9	120	1.4	6.7
1976	XI,XII	I	-	-	-	1	30	24.0	19.11.	1	28.03.	33	18-20.11.	1	0.3	1	0.01	1.0	22	6.0	150	1.7	6.8
1977	-	-	-	2	-	1	12	33.0	02.12.	3	02.03.12.	25	02-03.12.	3	0.8	4	0.1	1.3	14	3.8	101	1.2	7.2
1978	-	IX	1	-	-	1	41	36.6	05.01.	4	05.01.	19	27-28.10.	1	0.3	4	0.1	4.0	33	9.0	218	2.5	6.6
1979	-	XII	2	-	2	1	17	37.9	31.12.	8	31.12.	23	02.01.	3	0.8	20	0.2	6.7	19	5.2	124	1.4	6.5
1980	-	XII	1	1	1	2	30	36.0	22.12.	6	02-03.01.	26	07-08.12.	4	1.1	12	0.1	3.0	33	9.0	224	2.6	6.8
1981	-	I	4	6	4	3	39	38.0	08.01.	8	07-09.01.	42	07-09.01.	8	2.2	24	0.3	3.0	42	11.5	332	3.8	7.9
1982	-	V	2	3	1	3	30	39.4	01.02.	5	02-03.03.	16	06.03.	6	1.6	10	0.1	1.7	29	8.0	165	1.9	5.7
1983	-	-	2	5	3	3	40	45.0	31.01.	11	27.12.	48	01-03.12.	6	1.6	32	0.4	5.3	41	11.2	344	3.9	8.4
1984	-	VII	2	5	1	1	29	37.6	09.02.	10	09-10.02.	22	09-10.02.	3	0.8	11	0.1	3.7	25	6.8	213	2.4	8.5
1985	-	-	-	1	-	-	27	30.0	04.02.	-	-	10	15-16.02.	-	-	-	-	-	23	13.2	121	1.4	5.3
1986	X,XI	-	-	2	-	2	28	34.0	12.02.	1	12.02. 25.12.	26	03-04.11	2	0.6	2	0.02	1.0	25	7.1	157	1.8	6.3
1987	-	-	3	7	2	2	57	43.2	21.11.	4	03.03. 11.10./21.11.	22	21.11.	6	1.6	16	0.2	2.7	55	14.8	302	3.5	5.5
Total	27	17	33	67	46	70	1033	45.0	31.01. 1983.	25	14-15.03. 1967.	68	14-17.03. 1962.	147		548			1083		7969		
Annual mean	0.9	0.6	1.1	2.2	1.5	2.3	34.5							4.9	1.3	18.3	0.2	3.7	36.1	9.9	265.6	3.0	7.4

Tab. 2. Statistical review of strong and severe bora in Split for individual months during the period 1958-1987.
Tab. 2. Statistički pregled situacija s jakom i olujnom burom u Splitu po mjesecima u razdoblju 1958-1987.

MONTH	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
MN (MV_{max})	3(3)	1(3)	1(2)	(2)	1(1)	(1)	3(2)	1(1)	2	1(3)	2(6)	5(3)	17(27)
$V_{max} \geq 35$	13	15	4	1	–	–	–	–	–	–	3	7	33
$35 > V_{max} \geq 30$	12	11	12	2	1	–	–	–	4	5	10	10	67
$V_{sred} \geq 20$	15	10	4	3	–	–	–	–	1	1	3	9	46
$20 > V_{sred} \geq 17$	15	11	9	5	3	1	–	–	4	8	5	14	70
$17 > V_{sred} \geq 10$	130	137	144	109	47	38	40	29	73	80	100	106	1033
SEVERE BORA													
N_d	32	27	27	9	3	1	–	–	5	8	9	26	147
N_{d_1}(%)	3.4	3.2	2.9	1.0	0.3	0.1	–	–	0.5	0.9	1.0	2.8	1.3
N_{d_2}	1.2	0.9	0.9	0.3	0.1	0.03	–	–	0.2	0.3	0.3	1.0	
N_h	156	78	96	23	7	2	–	–	11	15	38	122	548
N_{h_1}(%)	0.7	0.4	0.4	0.1	0.03	0.01	–	–	0.1	0.1	0.2	0.6	0.2
N_{h_2}	4.9	2.9	3.6	2.6	2.3	2.0	–	–	2.2	1.9	4.2	4.7	
t_{max} (hours)	23	10	25	10	4	2	–	–	3	4	11	11	25
date	29-31.01. 1962.	09-10.02. 1984.	14-15.03. 1962.	20-21.04. 1959.	15.05. 1968.	09.06. 1964.	–	–	01.09. 1971.	11.10. 1987.	20.11. 1971.	27.12. 1983.	14-15.03. 1962.
STRONG BORA													
n_d	160	158	138	90	50	36	37	26	69	90	100	129	1083
n_{d_1} (%)	17.2	18.7	14.8	10.0	5.4	4.0	4.0	2.8	7.7	9.7	11.1	13.9	9.9
n_{d_2}	5.9	5.5	4.6	3.0	1.7	1.2	1.3	0.9	2.5	3.1	3.6	5.2	
n_{h_1} (%)	1323	1233	1059	680	259	269	155	110	446	575	678	1182	7969
n_{h_2}	5.9	6.1	4.7	3.2	1.2	1.3	0.7	0.5	2.1	2.6	3.1	5.3	3.0
n_{h_2}	8.3	7.8	7.7	7.6	5.2	7.5	4.2	4.2	6.5	6.4	6.8	9.2	
T_{max} (hours)	65	51	68	36	26	37	9	10	14	33	33	48	65
date	21-23.01. 1963.	26-28.02. 1963.	14-17.03. 1962.	29-30.04. 1958.	14-15.05. 1968.	08-10.06. 1964.	19-20.07. 1971.	04.08. 1958.	03-04.09. 1958.	24-25.10. 1973.	18-20.11. 1976.	01-03.12 1983.	21-23.01. 1963.
V_{max}(m/s)	45.0	39.4	42.2	35.5	31.0	28.5	26.2	29.7	30.0	33.3	43.2	43.9	45.0
date	31.01. 1983.	01.02. 1982.	15.03. 1962.	04.04. 1973.	16.05. 1964.	30.06. 1964. 09.06. 1986.	21.07. 1963.	27.08. 1985.	09.09. 1977.	16.10. 1958.	21.11. 1987.	27.12. 1983.	31.01. 1983.

bora, N_d, was 147 (1.3 % of all days) and with strong bora (10.0 ms^{-1} V < 17.0 ms^{-1}) 1083 days (36.1 %). Severe bora occurred on the average for 18 hours (compared to

SEVERE BORA

STRONG BORA

SEVERE AND STRONG BORA

DURATION OF SEVERE BORA
SPLIT 1958-1987

DURATION OF STRONG BORA
SPLIT 1958-1987

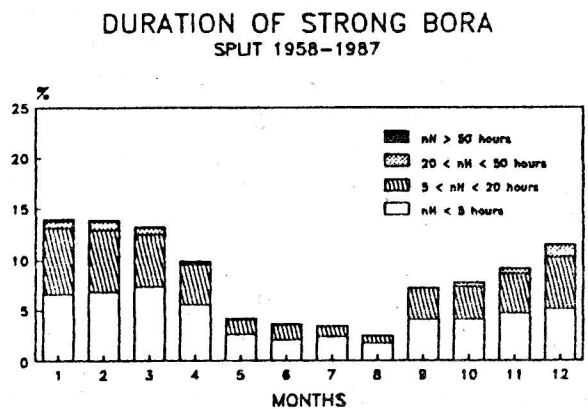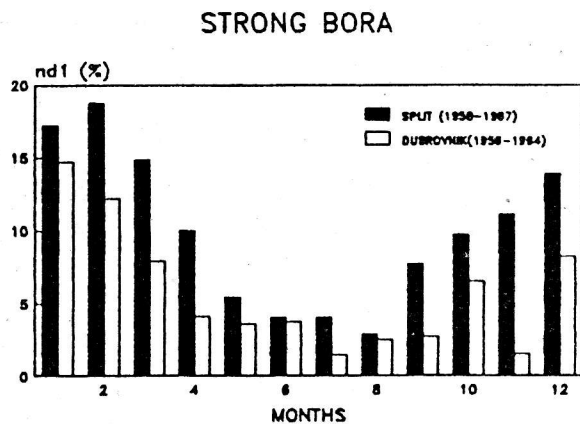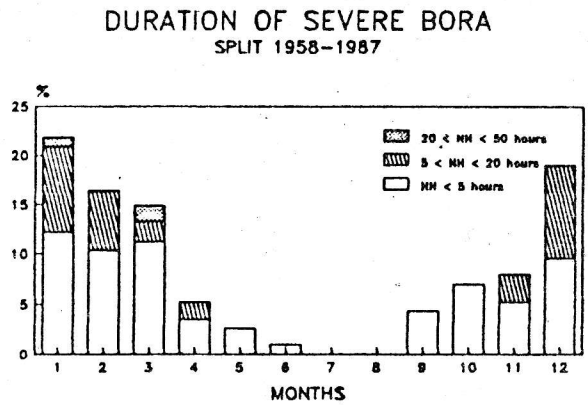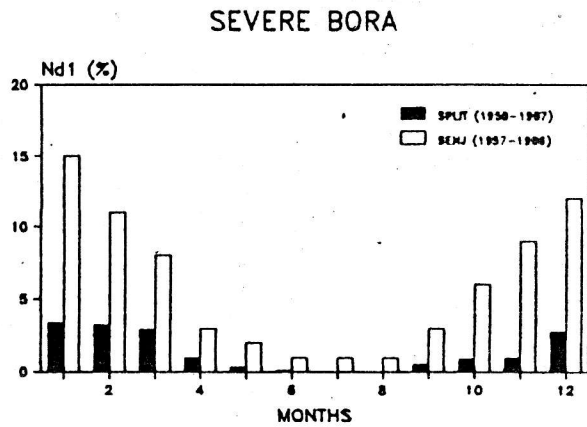## DURATION OF STRONG BORA
DUBROVNIK 1956-1964
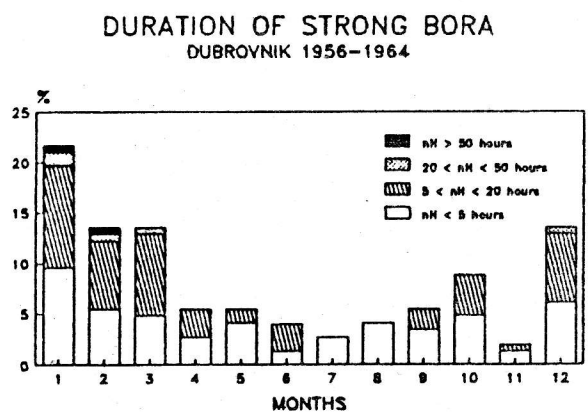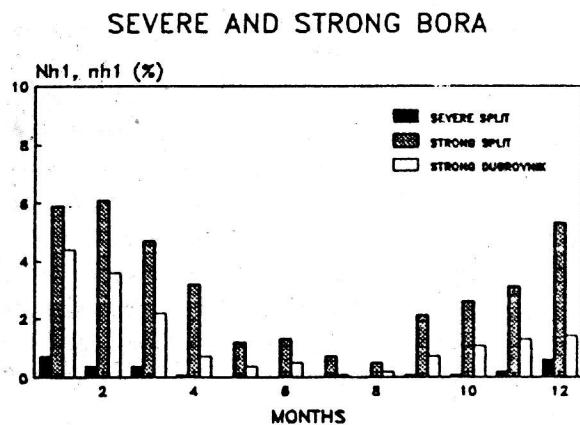
Fig. 2. The annual courses of relative frequency of days (N_{d1}, n_{d1}) and hours (N_{h1}, n_{h1}) with severe or strong bora for Senj (1957-1986), Split (1958-1987) and Dubrovnik (1956-1964)

Sl. 2. Godišnji hodovi relativne čestine dana (N_{d1}, n_{d1}) i sati (N_{h1}, n_{h1}) s olujnom, odnosno jakom burom u Senju (1957-1986), Splitu (1958-1987) i Dubrovniku (1956-1964).

Fig. 3. The annual courses of relative frequency of severe or strong bora situations of particular duration (N_H, n_H) in hours for Split (1958-1987) and Dubrovnik (1956-1964)

Sl. 3. Godišnji hodovi reletivne čestine situacija s olujnom odnosno jakom burom određenog trajanja (N_H, n_H) u satima za Split (1958-1987) i Dubrovnik (1956-1964).

Tab. 3. Relative frequency of severe bora duration and strong bora duration in Split during the period 1958–1987.
Tab. 3. Relativna čestina trajanja olujne bure i jake bure u Splitu za razdoblje 1958–1987.

DURATION (hours)	RELATIVE FREQUENCY OF SEVERE BORA (%)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
<05	12.1	10.3	11.2	3.5	2.6	1.0	–	–	4.3	6.9	5.2	9.5	66.6
05–10	6.1	6.1	1.0	1.7	–	–	–	–	–	–	1.7	7.8	24.3
11–15	2.6	–	1.0	–	–	–	–	–	–	–	1.0	1.7	6.2
16–20	–	–	–	–	–	–	–	–	–	–	–	–	–
21–25	1.0	–	1.7	–	–	–	–	–	–	–	–	–	2.5
TOTAL	21.8	16.4	14.9	5.2	2.6	1.0	–	–	4.3	6.9	7.9	19	100

DURATION (hours)	RELATIVE FREQUENCY OF STRONG BORA (%)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
<05	6.6	6.8	7.3	5.5	2.6	2.1	2.4	1.7	4.1	4.1	4.7	5.1	53.0
05–10	4.6	4.3	4.0	3.1	1.1	0.9	1.0	0.6	2.1	2.6	3.0	2.8	30.1
11–20	1.9	1.8	1.2	1.0	0.4	0.5	–	0.2	1.0	0.6	0.9	2.4	12.1
21–30	0.4	0.6	0.4	0.2	0.1	–	–	–	–	0.4	0.4	0.7	2.8
31–40	0.1	0.2	0.2	0.1	–	0.1	–	–	–	0.1	0.1	0.4	1.3
41–50	0.2	0.1	–	–	–	–	–	–	–	–	–	0.1	0.4
51–60	–	0.1	–	–	–	–	–	–	–	–	–	–	0.1
61–70	0.2	–	0.1	–	–	–	–	–	–	–	–	–	0.3
TOTAL	14.0	13.9	13.2	9.9	4.2	3.6	3.4	2.5	7.2	7.8	9.1	11.5	100.0

140 hours in Senj) and strong bora for 266 hours annually. The average number of hours with severe bora in one day, N_{h2}, was 3.7 hours as opposed to 7 hours in Senj.

A statistical analysis of particular months (Tab. 2 and Fig. 2) presents the greatest relative frequencies of severe bora days, N_{d1}, being 3.4 % in January and 3.2 % in February. Severe bora appeared with almost the same frequency in March (2.9 %) and December (2.8 %). During the summer months strong bora was not observed in Split. The maximum relative frequency of strong bora days, n_{d1}, was in February (18.7 %). The courses of N_{d1} and n_{d1} are in accordance with similar courses of hours with severe and strong bora.

The next bora characteristic is its duration. Althought it is well known that bora lasting up to several days is not un-usual, the bora duration problem must be discussed in terms of wind speed and particular locality.

Distributions of severe and strong bora durations show the exponential decrease in number of cases with increasing duration (Tab. 3). In 67 % of severe bora situations (in comparison with 43 % in Senj) and 53 % of strong bora situations, the duration (N_H, n_H) was less than 5 hours. January is the month with the greatest N_H and n_H, 21.8 % and 14.0 % rsp., of all hours with severe or strong bora (Fig. 3).

The longest severe bora duration of 25 hours was recorded on 14–15 March 1962 (Tab. 4–7). On that occasion the highest mean hourly wind speed of 29.2 ms⁻¹ reached the maximum value in the 30-year period. The absolute maximum speed of bora gusts (45.0 ms⁻¹) was registered on 31 January

Tab. 4. Severe bora situations in Split with a duration of more than 10 hours.

Tab. 4. Situacije s olujnom burom u Splitu s trajanjem većim od 10 sati.

SITUATION	t (hours)	T (hours)	V_{max} (ms^{-1})	V_{sred} (ms^{-1})
14–15. 03. 1962.	25	68	42.2	29.2
29–31. 01. 1962.	23	62	–	23.1
14–15. 03. 1967.	21	40	40.4	23.6
16–17. 01. 1959.	15	40	38.4	24.2
22–23. 03. 1961.	11	24	32.0	23.1
21–23. 01. 1963.	11	65	36.4	21.9
20. 11. 1971.	11	20	31.4	18.3
27. 12. 1983.	11	13	43.9	23.8
24. 01. 1963.	10	11	36.0	23.9
20–21. 04. 1959.	10	20	28.4	21.2
09–10. 02. 1984.	10	22	37.6	20.1

Tab. 5. Strong bora situations in Split with a duration of more than 40 hours

Tab. 5. Situacije s jakom burom u Splitu s trajanjem većim od 40 sati.

SITUATION	T (hours)	t (hours)	V_{max} (ms^{-1})	V_{sred} (ms^{-1})
14–17.03.1962.	68	25	42.2	29.2
21–23.01.1963.	65	11	36.4	21.9
29–31.01.1962.	62	23	–	23.1
26–28.02.1963.	51	2	31.2	17.8
01–03.12.1983.	48	8	37.4	19.4
07–09.01.1971.	42	8	38.0	20.1
08–10.02.1965.	41	6	27.9	18.6
16–18.01.1959.	40	15	38.4	24.2
13–15.03.1967.	40	21	23.6	14.3

1983, when severe bora lasted only 3 hours. In 7 out of 116 severe bora situations in Split maximum gusts were 40.0 ms^{-1} compared to 11 out of 434 such cases in Senj. Their longevity was over 10 hours in 11 situations. In 18 cases the number of hours with severe bora in Senj was greater than 50. Thus, the essential difference between these two locations is not in the intensity of maximum wind speed but in the frequency and persistence of severe bora. It is most

Tab. 6. Severe bora situations in Split with maximum bora gust ≥ 40.0 ms^{-1}.

Tab. 6. Situacije s olujnom burom u Splitu s maksimalnim udarom vjetra ≥ 40.0 ms^{-1}.

SITUATIONS	V_{max} (ms^{-1})	Date	V_{sred} (ms^{-1})	t (hours)	T (horus)
31.01.1983.	45.0	31.01.	23.8	3	5
27.12.1983.	43.9	27.12.	23.8	11	13
21.11.1987.	43.2	21.11.	24.7	4	22
14–17.03.1962.	42.2	15.03.	29.2	25	68
08.01.1968.	42.0	08.01.	27.2	8	20
21.11.1963.	41.0	21.11.	23.3	6	8
13–15.03.1967.	40.4	14.03.	23.6	21	40

Tab. 7. Severe bora situations in Split a with maximum mean bora velocity ≥ 23.0 ms^{-1}.

Tab. 7. Situacije s olujnom burom u Splitu s maksimalnom srednjom satnom brzinom vjetra ≥ 23.0 ms^{-1}.

SITUATIONS	V_{sred} (ms^{-1})	Date	V_{max} (ms^{-1})	t (hours)	T (horus)
14–17.03.1962.	29.2	15.03.	42.2	29	68
08.01.1968.	27.2	08.01.	42.0	8	20
31.12.1979– 01.01.1980.	24.9	31.12.	37.9	8	9
21.11.1987.	24.7	21.11.	43.2	4	22
28–29.04.1958.	24.2	29.04.	34.0	5	10
16–18.01.1959.	24.2	16–17.01.	38.4	15	40
08–10.12.1971.	24.0	09.12.	37.3	11	29
23–24.01.1963.	23.9	24.01.	36.0	10	11
31.01.1983.	23.8	31.01.	45.0	3	5
13–15.03.1967.	23.6	14.03.	40.4	21	40
21.11.1963.	23.3	21.11.	41.0	6	8
01.02.12.1969.	23.3	02.12.	39.9	9	31
22–23.03.1961.	23.1	22.03.	32.0	11	24
29–31.01.1962.	23.1	29.01.	–	23	62

frequent in the cold season and its duration in Split is not as long as in Senj.

3. Severe Bora in Dubrovnik

The mean hourly wind data in Dubrovnik for the 1956–1964 period were also

Tab. 8. Statistical review of strong bora situations in Dubrovnik for individual years (above) and individual months (below) during the period 1956–1964.

Tab. 8. Statistički pregled situacija s jakom burom u Dubrovniku po godinama (gore) i mjesecima (dolje) u razdoblju 1956–1964.

YEAR	SITUATIONS WITH $V_{max} \geq 35$	$35 > V_{max} \geq 25$	$V_{sred} \geq 20$	$20 > V_{sred} \geq 17$	$17 > V_{sred} \geq 10$ (ms⁻¹)	n_d	n_{d_1} (%)	n_h	n_{h_1} (%)	n_{h_2}	V_{max} (ms⁻¹)	date	T_{max} (hours)	date
1956	–	7	–	1	22	29	7.9	187	2.1	6.5	31.5	03.02.	53	02–05.02.
1957	1	5	1	–	10	20	5.5	156	1.8	7.8	45.0	01.12.	36	30.11–01.12.
1958	–	3	–	–	13	18	4.9	74	0.8	4.4	30.9	19.04.	12	19.10.
1959	–	6	–	–	14	19	5.2	102	1.2	4.9	32.7	17.01.	22	17–18.01.
1960	–	1	–	–	11	16	4.4	57	0.7	3.6	29.8	05.01.	12	04–05.01.
1961	–	5	–	–	19	24	6.6	86	1.0	3.6	30.3	18.01.	18	22–23.03.
1962	1	10	–	2	19	25	6.9	158	1.8	6.3	35.0	02.12.	38	14–16.03.
1963	1	10	–	1	18	21	6.3	183	2.1	8.7	38.4	21.11.	67	21–24.01.
1964	1	9	–	–	18	26	7.1	78	0.9	3.0	35.1	03.12.	11	20–21.02. 21–22.09.
Total	4	56	1	4	144	198		1081			45.0	01.12.1957.	67	21–24.01.1963.
Mean	0.4	6.2	0.1	0.4	16.0	22.0	6.0	120.2	1.2	5.5				

MONTH	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
$V_{max} \geq 35$	1	–	–	–	–	–	–	–	–	–	1	2	4
$35 > V_{max} \geq 25$	20	10	6	1	–	2	1	–	3	3	–	10	56
$V_{sred} \geq 20$	–	–	–	–	–	–	–	–	–	–	–	1	1
$20 > V_{sred} \geq 17$	–	2	1	–	–	–	–	–	–	–	–	1	4
$17 > V_{sred} \geq 10$	29	22	17	7	8	5	4	6	9	13	2	22	144
n_d	41	31	22	11	10	10	4	7	17	18	4	23	198
n_{d_1} (%)	14.7	12.2	7.9	4.1	3.6	3.7	1.4	2.5	2.7	6.5	1.5	8.2	6.2
n_{d_2}	4.6	3.4	2.4	1.2	1.1	1.1	0.4	0.8	1.9	2.0	0.4	2.6	
n_h	297	217	146	46	27	32	5	12	48	75	84	92	1081
n_{h_1} (%)	4.4	3.6	2.2	0.7	0.4	0.5	0.1	0.2	0.7	1.1	1.3	1.4	1.9
n_{h_2}	7.2	7.0	6.6	4.2	2.7	3.2	1.3	1.7	2.8	4.2	21.0	4.0	
T_{max} (hours)	67	53	38	14	7	11	2	4	11	13	12	18	67
date	21–24.01. 1963.	02–05.02. 1956.	14–16.03. 1962.	15–16.04. 1957.	15–16.05. 1964.	27.06. 1957.	01.07. 1964.	20.08.60. 30–31.08.61.	21–22.09. 1964.	08–09.10. 1956.	21.11. 1963.	20–21.12. 1962.	21–24.01. 1963.
V_{max} (ms⁻¹)	33.3	32.0	33.0	30.9	23.4	24.0	25.0	22.5	30.5	26.5	38.4	45.0	45.0
date	29.01. 1957.	17.02. 1959.	15.03. 1962.	19.04. 1958.	16.05. 1964.	22.06. 1956.	01.07. 1964.	20.08. 1960.	22.09. 1964.	11.10. 1963.	21.11. 1963.	01.12. 1957.	01.12. 1957.

Tab. 9. Relative frequency of strong bora duration in Dubrovnik during the period 1956-1964.
Tab. 9. Relativna čestina trajanja jake bure u Dubrovniku za razdoblje 1956-1964.

DURATION (hours)				RELATIVE FREQUENCY OF STRONG BORA (%)									
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
<5	9.5	5.4	4.8	2.7	4.1	1.3	2.7	4.1	3.4	4.8	1.3	6.1	50.2
5-10	5.4	4.8	6.8	2.0	1.3	2.0	–	–	2.0	2.0	–	3.4	29.7
11-20	4.8	2.0	1.3	0.7	–	0.7	–	–	–	2.0	0.7	3.4	15.6
21-30	1.3	0.7	–	–	–	–	–	–	–	–	–	–	2.0
31-40	–	–	0.7	–	–	–	–	–	–	–	–	0.7	1.4
41-50	–	–	–	–	–	–	–	–	–	–	–	–	–
51-60	–	0.7	–	–	–	–	–	–	–	–	–	–	0.7
61-70	0.7	–	–	–	–	–	–	–	–	–	–	–	0.7
TOTAL	21.7	13.6	13.6	5.4	5.4	4.0	2.7	4.1	5.4	8.8	2.0	13.6	100.0

Tab. 10. Strong bora situatins in Dubrovnik with a duration of more than 25 hours.
Tab. 10. Situacije s jakom burom u Dubrovniku s trajanjem većim od 25 sati.

SITUATION	T (hours)	t (hours)	V_{max} (ms^{-1})	V_{sred} (ms^{-1})
21-24.01. 1963.	67	–	30.0	15.3
02-04.02. 1956.	53	1	31.5	18.0
14-16.03. 1962.	38	1	33.0	17.5
30.11-01.12. 1957.	36	11	45.0	20.2

Tab. 11. Strong bora situations in Dubrovnik with maximum bora gust $\geq$ 35.0 ms^{-1}.
Tab. 11. Situacije s jakom burom u Dubrovniku s maksimalnim udarom vjetra $\geq$ 35.0 ms^{-1}.

SITUATION	V_{max} (ms^{-1})	Date	V_{sred} (ms^{-1})	t (hours)	T (hours)
30.11-01.12. 1957.	45.0	01.12.	20.2	11	36
21.11. 1963.	38.4	21.11	18.3	2	12
03.01. 1964.	35.1	03.01.	16.7	1	3
02.12. 1962.	35.0	02.12.	15.0	–	9

Tab. 12. Strong bora situations in Dubrovnik with a maximum mean bora velocity $\geq$ 17.0 ms^{-1}.
Tab. 12. Situacije s jakom burom u Dubrovniku s maksimalnom srednjom satnom brzinom vjetra $\geq$ 17.0 ms^{-1}.

SITUATION	V_{sred} (ms^{-1})	Date	V_{max} (ms^{-1})	t (hours)	T (hours)
30.11-01.12. 1957.	20.2	01.12.	45.0	11	36
14.12.1962.	18.6	14.02.	34.4	1	3
21.11.1963.	18.3	21.11.	38.4	2	12
03.02.1956.	18.0	03.02.	31.5	1	53
15.03.1962.	17.5	15.03.	33.0	1	38

analysed. In Dubrovnik only 4 such situations were observed in the period considered, compared to 41 situations in Split for the 1958-1964 period. Since severe bora in Dubrovnik is rare, statistical analysis covered only strong bora cases. These results could not be compared directly to the Split results because of the different periods of wind measurements.

The total number of days with strong bora in Dubrovnik for the 9-year period was 198 (6 % of all days), and strong bora occurred on the average for 120 hours in one year (Tab. 8). Its occurrence is extended to all seasons with the greatest relative frequency of n_{d1} and n_{h1} in January (14.7 % and 4.4 %, respectively, Fig. 3). In 50.2 % of 144 cases strong bora duration was shorter than 5 hours, and it decreased exponentially with an increase in the number of hours (Tab. 9). The longest duration of strong bora (67 hours) was observed on 21-24 January

1963 (Tab. 10–12). The absolute maximum of gust reached 45.0 ms⁻¹ on 1 December 1957. In 4 cases gusts in Dubrovnik were ≥ 35.0 ms⁻¹, and bora duration was longer than 25 hours.

This statistical analysis shows that the intensity of maximum bora gusts at the Dubrovnik location is similar to Split. However, severe bora in Dubrovnik is a very rare phenomenon with a duration of only a few hours.

4. Summary and Conclusion

The statistical analysis of severe bora in Split (1958–1987) and Dubrovnik (1956–1964) showed its frequency and persistence in mid–Adriatic. These results were compared with a similar analysis of the northern Adriatic Senj bora (Bajić, 1989). In the period considered the total number of days with severe bora in Split was four times less than in Senj, confirming Senj specific characteristics in respect to severe bora frequency. In spite of a shorter period of wind measurement in Dubrovnik, it can be concluded that severe bora at this location was rare. Although severe bora frequency and duration in Senj and in mid–Adriatic region were not similar, the absolute maximum of bora gusts was almost the same. The absolute maximum of bora gusts was 48.0 ms⁻¹ in Senj and 45.0 ms⁻¹ in Split and Dubrovnik during brief periods of severe bora.

On both northern and mid–Adriatic severe bora occurred most frequently during the winter season. Severe bora in Split never lasted several days. The average duration of severe bora situations was 4.7 hours in Split as opposed to 12.3 hours in Senj. The longest duration of severe bora exceeded 25 hours in Split and 128 hours in Senj. The strong bora characteristics obtained for two locations considered in mid–Adriatic did not show such differences. The situations of strong bora had approximately equal duration in Split and Dubrovnik (7.7 and 7.5 hours, respectively). The maximum duration of strong bora was 68 hours in Split and 67 hours in Dubrovnik.

Thus, severe bora with gusts greater than 40.0 ms⁻¹ appears along the entire Adriatic coast, but its persistence and frequency decrease from north to south. These results, therefore, comfirm a previous statement (Bajić, 1989) that bora duration and strenght strongly depend on the locality and particularly that the well-known Senj bora is not representative of the broader Adriatic area.

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List of symbols

MV_{max} – month with no data on maximum bora gust

MN – month with no wind data

t_{max} – maximum number of hours with mean bora velocity ≥ 17.0 ms⁻¹ during one severe bora situation

T_{max} – maximum number of hours with 10.0 ms⁻¹ ≤ V_{sred} < 17.0 ms⁻¹ during one strong bora situation

t – number of hours with mean bora velocity ≥ 17.0 ms⁻¹

T – number of hours with 10.0 ms⁻¹ ≤ V_{sred} < 17.0 ms⁻¹

V_{max} – maximum bora gust (ms⁻¹)

V_{sred} – maximum mean hourly velocity during strong or severe bora situations (ms^{-1})

N_d, n_d – number of days with severe (strong) bora for at least one hour

N_{d1}, n_{d1} – relative frequency of severe (strong) bora days (%)

N_{d2}, n_{d2} – mean number of days with severe (strong) bora in a particular month

N_h, n_h – number of hours with severe (strong) bora

N_{h1}, n_{h1} – relative frequency of hours with severe (strong) bora (%)

N_{h2}, n_{h2} – mean number of hours with severe (strong) bora during one severe (strong) bora day

N_H, n_H – relative frequency of severe (strong) bora situations of particular duration in hours

Kratak sadržaj

Iako je poznato da je na pojedinim lokacijama duž jadranske obale česta pojava bure, problem učestalosti potrebno je analizirati u odnosu na njezinu brzinu i specifičnost lokacije. Stoga je za područje Splita (1958-1987) i Dubrovnika (1956-1964) napravljena detaljna statistička analiza olujne ($V_{sred} \geq 17.0$ ms^{-1}) i jake bure (10.0 ms^{-1} $\leq V_{sred} < 17.0$ ms^{-1}) i uspoređena sa sličnim rezultatima u Senju (Bajić, 1989).

U 30-godišnjem razdoblju ukupni broj dana s olujnom burom u Splitu bio je četiri puta manji nego u Senju. Premda je u Dubrovniku postojao kraći niz mjerenja vjetra, može se zaključiti da je na toj lokaciji bura vrlo rijetka pojava i traje svega nekoliko sati. Kao i na sjevernom Jadranu olujna bura na srednjem Jadranu je najčešća u zimskim mjesecima. U Splitu njezino prosječno trajanje je 4.7 sati, za razliku od 12.3 sata u Senju. Situacije s jakom burom u prosjeku približno jednako traju u Splitu i Dubrovniku (7.7 sati i 7.5 sati, redom). Najdulje trajanje olujne bure u Splitu iznosilo je 25 sati u usporedbi s 128 sati u Senju. Jaka bura je u Splitu najdulje puhala 68 sati dok u Dubrovniku 67 sati. Prema tome, na srednjem Jadranu se ne pojavljuje olujna bura u trajanju od nekoliko dana kao što je to slučaj u Senju. Međutim, važno je istaknuti da najčešća i najdulja olujna senjska bura nije reprezentativna za šire područje Jadrana nego je uvjetovana lokalnim efektima.

Iako se čestina i perzistencija olujne bure u Senju i na srednjem Jadranu razlikuju, apsolutni maksimalni udari vjetra su gotovo jednaki. U Senju je registrirano 48.0 ms^{-1}, a u Splitu i Dubrovniku 45.0 ms^{-1}. Stoga se olujna bura s maksimalnim udarima većim od 40.0 ms^{-1} može pojaviti duž cijele jadranske obale. Međutim, njezina učestalost i trajanje se smanjuje od sjevera prema jugu kao i udaljavajući se od Dinarida na što je ukazala analiza olujne bure u Omišlju i Puli (Bajić, 1989).

U meteorološkoj praksi poznato je da postoje i druge lokacije gdje reljef dozvoljava izražene kanalne efekte i olujnu buru. Budući da se na tim mjestima ne obavljaju mjerenja vjetra, raspoloživi podaci o polju vjetra na Jadranu ne omogućuju konačne zaključke.

Lista simbola

MV_{max} – mjeseci s nedostajućim podacama maksimalnih udara vjetra

MN – mjeseci s nedostajućim podacima vjetra

t_{max} – maksimalni broj sati sa srednjom satnom brzinom vjetra ≥ 17.0 ms^{-1} u jednoj situaciji s olujnom burom

T_{max} – maksimalni broj sati sa 10.0 ms^{-1} $\leq V_{sred} < 17.0$ ms^{-1} u jednoj situaciji s jakom burom

t – broj sati sa srednjom satnom brzinom vjetra ≥ 17.0 ms^{-1}

T – broj sati sa 10.0 ms^{-1} $\leq V_{sred} < 17.0$ ms^{-1}

V_{max} – maksimalni udar vjetra (ms^{-1})

V_{sred} – maksimalna srednja satna brzina u situaciji s jakom ili olujnom burom (ms^{-1})

N_d, n_d – broj dana s olujnom (jakom) burom u barem jednom satu

N_{d1}, n_{d1} – relativna čestina dana s olujnom (jakom) burom (%)

N_{d2}, n_{d2} – srednji broj dana s olujnom (jakom) burom u pojedinom mjesecu

N_h, n_h – broj sati s olujnom (jakom) burom.

N_{h1}, n_{h1} – relativna čestina sati s olujnom (jakom) burom (%)

N_{h2}, n_{h2} – srednji broj sati s olujnom (jakom) burom u dana s olujnom (jakom) burom

N_H, n_H – relativna čestina situacija s olujnom (jakom) burom određenog trajanja u satima