

SEVERE BORA ON THE NORTHERN ADRIATIC PART I: STATISTICAL ANALYSIS

OLUJNA BURA NA SJEVERNOM JADRANU DIO I: STATISTIČKA ANALIZA

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Abstract: The results of statistical analysis of severe bora (wind N-E direction and mean hourly wind velocity ≥ 17.0 m/s) occurrence at three locations on the northern Adriatic (Senj, Omišalj and Pula) are presented.

Concerning the representativeness of Senj it is shown that Senj's bora is not representative for a broader area in the northern Adriatic.

In the 30-year period of observation (1957-1986) 434 cases with severe bora were registered in Senj. On the other locations severe bora was not so frequent. Long severe bora usually occurs only during the winter season. The wind velocity is more uniform in situations with the longer lasting bora.

Its basic characteristic of long bora duration is shown to be valid mainly for bora in the cold season particularly in Senj.

Although the great majority of cases the strongest bora occurs in Senj, there are situations with maximum bora gusts greater at other localities.

Key words: severe bora wind, the northern Adriatic, statistical analysis

Sažetak: U radu su prikazani rezultati statističke analize olujne bure (vjetar N-E smjera i srednje satne brzine ≥ 17.0 m/s) na tri lokacije na sjevernom Jadranu (Senj, Omišalj i Pula).

Pokazano je da pojava olujne bure u Senju i njene karakteristike nisu reprezentativni za šire područje sjevernog Jadrana.

U 30-godišnjem razdoblju (1957-1986) u Senju je bilo zabilježeno 434 situacije s olujnom burom. Ova pojava nije bila tako česta na drugim promatranim lokacijama. Analiza je potvrdila da se olujna bura velikog trajanja uglavnom opaža u zimskim mjesecima, te da je brzina vjetra u situacijama s dugotrajnom burom uniformnija.

Pokazano je da se tvrdnja da je veliko trajanje bura njena osnovna karakteristika odnosi uglavnom na buru u hladno doba godine i to naročito na području Senja.

Uprkos činjenici da je velika većina slučajeva s olujnom burom zabilježena u Senju, pokazano je da postoje situacije u kojima su veće maksimalne brzine vjetra registrirane na nekoj drugoj lokaciji.

Ključne riječi: olujna bura, sjeverni Jadran, statistička analiza

1. Introduction

There have been many studies and descriptions of wind regime and bora wind characteristics on the northern Adriatic since the last century. The most comprehensive review of the bora problem is found in the book »Local wind bora« edited by Yoshino (1976). The climatological and statistical aspects of bora given in this book concern

mainly the bora occurrence at the three locations which are the most famous places with extraordinarily strong bora (Trieste, Ajdovščina and Senj). Main attention will be given here to the results of Senj's bora analysis.

One among the earliest and the most detailed descriptions of the climatological characteristics of bora in Senj was done by Makjanić (1966). His analysis was based on the data collected in the three observation times daily

in the period 1948-1963 with the wind speed data from the period 1956-1963. He showed that bora blew in 52.6% of all cases and that the annual march of the bora wind frequency has one marked minimum in June and two maxima in October and January.

Lukšić (1975) analysed a considerably longer series of hourly wind speed and direction data in Senj (1955-1973). He showed that the probability of bora occurrences in Senj was 18 % for the weak bora (mean hourly wind velocity 5.5 – 10,7 m/s); 16% for the strong bora (mean hourly velocity 10.8 – 17,0 m/s) and only 2% for the severe bora (mean hourly velocity > 17.0 m/s). The greatest probability for the severe bora was in winter. The relative frequency of severe bora was the greatest in January (48 %) and the least in June (23 %). The bora duration was the greatest also in winter. The mean bora duration for the whole year was 13.8 hours, and the greatest duration was in December (21.7 hours).

The existed climatological and statistical analysis of bora occurrence gave very important results. However, the severe bora characteristics seem to remain insufficiently known. The question is also: How representative is Senj's bora for the broader northern Adriatic region?

The aim of this paper is to present the results of statistical analysis of severe bora occurrence in Senj and to compare them with the results of similar analysis on the other locations (Pula and Omišalj) in the northern Adriatic.

2. Severe bora in Senj

The occurrence of severe bora wind is of special interest in meteorological practice. Therefore in our analysis a basic statistical review of severe bora will be presented for Senj, Omišalj (Rijeka – airport) and Pula (1) (Pula – airport) (Fig.1).

The meteorological station on the northern Adriatic with the longest period of registered wind data is Senj. Thus, we will begin with the analysis of Senj's data for the 30

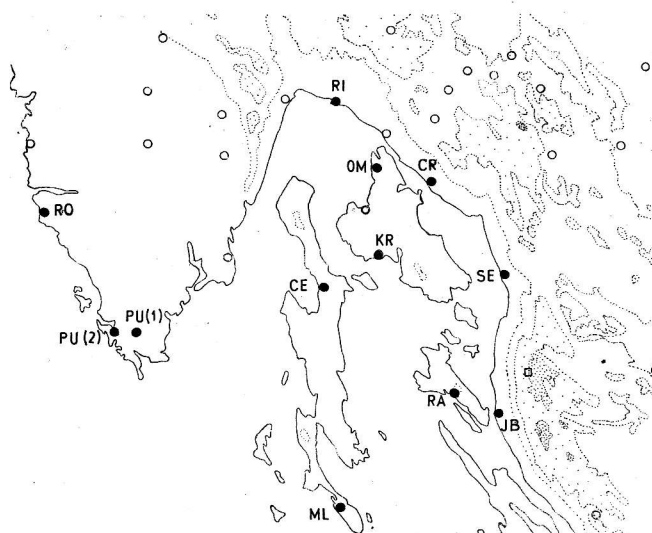


Fig. 1. The northern Adriatic area with meteorological stations.

Slika 1. Područje sjevernog Jadrana s položajem meteoroloških stanica.

– year period 1957-1986. In that period 434 situations with severe bora has been observed in Senj (Table 1). A situation with severe bora is defined as a period with wind which direction is continuously between 360° and 90° and with the mean hourly velocity ≥ 17.0 m/s in at least one hour. In 10 % of such situations maximum hourly bora gusts in Senj was ≥ 35.0 m/s. The total number of days with at least one hour with severe bora was 605 (20.5 % of all days). The average number of hours with severe bora in one day was 7 hours.

A similar statistical review for particular months (Table 2 and Fig.2) shows that January and December are the months with the greatest relative frequency of severe bora days (further N_{d1}) with 15 % and 12 % of all days respectively. The smallest N_{d1} was noticed in June and August (0.2 %). This annual march of severe bora frequency is in agreement with the results given by Makjanić (1957).

The mean number of days with severe bora for a particular month (N_{d2} on Fig.2) has a similar annual march as N_{d1} . The relative frequency of hours with severe bora (N_{h1} on Fig.2) was the greatest in December (5.9 %) and the least in the summer months (0.1 %). The mean N_{h1} for the whole year was 1.7 %, which is almost the same frequency (2 %) as presented by Lukšić (1975), considering the period 1955-1973. At least one hour with mean hourly velocity ≥ 17.0 m/s was registered in 5 % of all days in the cold season (October – March). In other seasons that number was < 3%.

However, the duration of one severe bora situation (N_{h2} on Fig.2) is during a six month, almost the same (4-5 hours). The month with the greatest number of hours with severe bora in one day (11.4 hours) is December.

The severe bora distribution in relation to its duration (N_H on Fig.2) shows that in 43.4 % of severe bora situations the number of hours with severe bora (N_H) is less than 5. Only in 18.9% of situations (observed mainly in January and December) the N_H is greater than 20 hours.

From Table 3. we can see that the number of hours with severe bora is greater than 50 in 18 situations. This number exceeds 100 in two situations: 8–14 December 1968 (128 hours) and 17–22 January 1963 (124 hours) (see the paper by Jurčec in this Volume). However, in these situations hourly maximum bora gusts do not reach velocities greater than 36.0 m/s. In contrast, in 11 situations with maximum bora gusts greater than 40.0 m/s (Table 4) the number of hours with severe bora is less than 60. Therefore we can conclude that wind velocities are more uniform in Senj during the longer lasting bora. This is confirmed in Table 5. by relatively small differences between maximum hourly wind velocities and maximum bora gusts in situations with more than 70 hours with severe bora in Senj.

It is interesting to note that the ALPEX year 1982, together with 1984 and 1986, were the years with the smallest number of days with severe bora in the entire 30-year period even at the location of Senj.

3. Severe bora at other locations

In order to find out whether the characteristics of severe bora occurrence in Senj are the same on the broader northern Adriatic area we will analyse hourly wind data

Table 1. Severe bora in Senj – statistical review for the particular years in 1957 – 1986.

year	MN	situations with				N_d	N_{d1} (%)	N_h	N_{h1} (%)	N_{h2}	V_{max} (m/s)	date	t_{max} (hours)	date
		$V_{max} \leq$	$35.0 \text{ m/s} >$	$V_{mean} \geq$	20.0 m/s									
		35.0 m/s	$v_{max} > 30.0$ m/s	20.0 m/s	$> v_{mean} \geq$ 17.0 m/s									
1957.	—	1	4	2	14	24	6.6	159	1.8	6.6	35.0	30. XI	70	16–20. I
1958.	II	3	9	2	11	14	4.2	70	0.9	5.0	43.8	1. III	15	27–28. I
1959.	IX, X	4	8	4	8	16	5.3	146	2.0	9.1	38.0	23. XI	43	11–14. II
1960.	II, III	—	4	3	14	23	7.5	126	1.7	5.5	34.0	12. I	29	12–13. XII
1961.	X, XII	1	3	3	6	16	5.3	143	2.0	8.9	36.6	5. XI	65	12–18. I
1962.	I, VII, XII	3	6	5	13	27	9.9	118	1.8	4.4	36.5	14. IX	23	28–30. XI
1963.	XII	2	12	10	17	40	12.0	408	5.1	10.2	35.7	22. II	124	17–22. I
1964.	I, XII	1	7	8	21	42	13.9	284	3.9	6.8	35.3	25. X	52	1–2. XI
1965.	—	1	3	6	17	27	7.4	177	2.0	6.6	36.8	9. II	50	9–11. II
1966.	VI, VIII	1	10	7	18	32	10.5	244	3.3	7.6	36.0	8. XII	86	5–8. XII
1967.	—	1	5	9	20	37	10.1	257	2.9	6.9	46.2	12. XII	76	28. XI–2. XII
1968.	—	1	8	10	21	39	10.7	365	4.2	9.4	35.5	9. XII	128	8–14. XII
1969.	—	4	9	9	19	45	12.3	449	5.1	10.0	41.2	2. XII	70	19–22. XII
1970.	—	—	6	11	19	32	8.8	238	2.7	7.4	34.0	16. XII	37	15–17. X
1971.	—	2	10	5	14	37	10.1	240	2.7	6.5	35.0	5. X	120	1–14. I
1972.	—	1	10	2	13	25	6.8	164	1.9	6.6	35.2	18. I	50	17–19. I
1973.	—	1	10	—	14	19	5.2	102	1.2	5.4	35.5	26. X	19	2–3. XII
1974.	—	—	4	—	5	8	2.2	23	0.3	2.9	32.0	14. XII	11	14–15. IV
1975.	—	1	3	—	5	8	2.2	68	0.8	8.5	37.0	19. XII	27	19–20. XII
1976.	—	—	5	1	7	11	3.0	69	0.8	6.3	34.8	2. II	39	1–3. II
1977.	—	2	3	3	6	12	3.3	66	0.8	5.5	36.8	30. III	35	10–14. XII
1978.	—	2	5	2	9	16	4.4	87	1.0	5.4	36.6	5. XII	44	4–7. XII
1979.	—	—	5	—	9	14	3.8	55	0.6	3.9	33.9	11. XI	34	18–21. I
1980.	—	1	7	2	10	16	4.4	69	0.8	4.3	37.8	13. I	27	12–13. I
1981.	—	1	3	1	6	8	2.2	22	0.3	2.8	36.6	22. I	11	21–23. I
1982.	I, II	—	1	—	2	2	0.7	4	0.1	2.0	32.5	6. III.	3	24. III
1983.	II	2	2	—	2	4	1.2	25	0.3	6.3	45.0	3. XII	24	2–4. XII
1984.	III	2	2	—	2	2	0.6	12	0.1	6.0	46.7	28. XII	11	13. XI
1985.	—	5	55	—	5	7	1.9	21	0.2	3.0	48.0	9. I	11	8–9. I
1986.	—	2	2	—	2	2	0.5	3	0.1	1.5	46.2	11. XII	2	11. XII
Total	19	45	171	105	329	605	5.8	4214	1.7	7.0	48.0	9. I 185	128	8–14. XII 1968
annual mean	—	1.5	5.7	3.5	11.0	20.2	—	140.5	—	—	—	—	—	—

Legend:

Situation with severe bora – time period with wind direction continuously between N and E and with mean hourly velocity equal to or greater than 17.0 m/s in one hour at least.

MN – month with lack of data

N_d – number of days with severe bora in at least one hour

N_{d1} – relative frequency of severe bora days

N_h – number of hours with severe bora

N_{h1} – relative frequency of hours with severe bora

N_{h2} – mean number of hours with severe bora on the severe bora day

V_{max} – maximum bora gust (m/s)

t_{max} – maximum number of hours with mean hourly velocity ≥ 17.0 m/s at one severe bora station

V_{mean} – maximum mean hourly velocity in the severe bora period (m/s)

for Omišalj and Pula (1).

Since severe bora is here a very rare phenomenon, statistical analysis will be extended to the situations with strong bora (mean hourly wind velocity ≥ 10.0 m/s). For this analysis we will use available wind registration data in Omišalj and Pula (1).

In the 8-year period (1979–1986) only 10 situations with severe bora were observed in Omišalj in respect to 41 cases in the same period in Senj. The strong bora

Tabela 1. Olujna bura u Senju – statistički pregled za razdoblje 1957 – 1986.

Legenda:

situacija s olujnom burom – razdoblje u kojem je smjer vjetera neprekidno N-E i srednja satna brzina veća ili jednaka 17.0 m/s u barem jednom satu.

MN – mjesec s nepotpunim nizom podataka

N_d – broj dana s olujnom burom u barem jednom satu

N_{d1} – relativna čestina dana s olujnom burom

N_h – broj sati s olujnom burom

N_{h1} – relativna čestina sati s olujnom burom

N_{h2} – srednji broj sati s olujnom burom u danu s olujnom burom

V_{max} – maksimalni satni udar bure (m/s)

V_{mean} – maksimalna srednja satna brzina vjetera (m/s)

t_{max} – maksimalni broj sati sa srednjom satnom brzinom ≥ 17.0 m/s

was registered in Omišalj in 108 situations with the maximum number of cases (15) in the months of November, December and January (Table 6 and 7). Besides the considerably smaller relative frequency of strong bora occurrence the bora duration in Omišalj was not as long as in Senj. The mean hourly bora velocity was ≥ 10.0 m/s in Omišalj in more than 50 hours only in one situation (Table 8). Except for one case (29.11–1.12.1980) maximum wind gust ≥ 35.0 m/s was not noticed in the longest

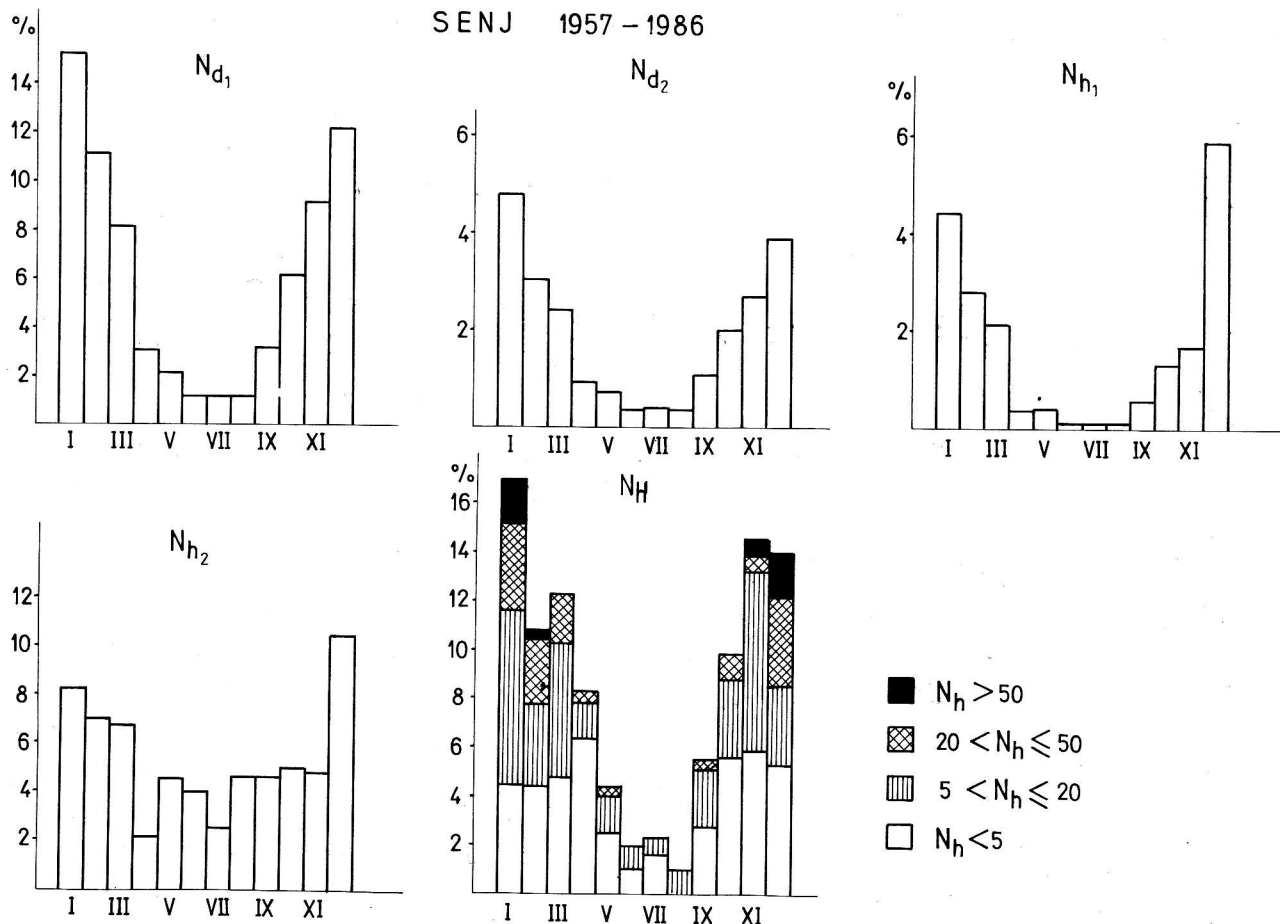


Fig. 2. The annual marches of: N_{d1} (relative frequency of severe bora days); N_{d2} (mean number of days with severe bora for the particular month); N_{h1} (relative frequency of hours with severe bora); N_{h2} (mean number of hours with severe bora in the severe bora day) and N_H (relative frequency of severe bora situations of particular duration N_h in hours).

Slika 2. Godišnji hodovi: N_{d1} (relativna čestina dana s olujnom burom); N_{d2} (srednji broj dana s olujnom burom u pojedinom mjesecu); N_{h1} (relativna čestina sati s olujnom burom); N_{h2} (srednji broj sati s olujnom burom u danu s olujnom burom) i N_H (relativna čestina situacija s olujnom burom određenog trajanja - N_h u satima).

Table 2. Severe bora in Senj - statistical review for the period 1957 - 1986.

Tabela 2. Olujna bura u Senju - statistički pregled po mjesecima za razdoblje 1957 - 1986

month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
MN	3	4	2	—	—	1	1	1	1	2	—	4	11
situations with $v_{max} \geq 35.0$ m/s	9	7	3	—	—	—	—	—	1	4	8	13	45
35.0 m/s > $v_{max} \geq 30.0$ m/s	37	18	19	9	2	—	2	1	9	20	22	32	171
$v_{mean} \geq 20.0$ m/s	26	14	15	3	2	2	1	1	5	8	10	18	105
20.0 m/s > $v_{mean} \geq 17.0$ m/s	52	31	45	29	14	6	7	3	19	32	45	46	329
N_d	129	79	66	27	20	7	11	7	28	54	78	100	605
N_{d1} (%)	15	11	8	3	2	1	1	1	3	6	9	12	6
N_{d2}	4.8	3.0	2.4	0.9	0.7	0.2	0.4	0.2	1.0	1.9	2.6	3.8	21.9
N_h	1069	551	449	59	89	28	29	32	128	268	373	1139	4214
N_{h1} (%)	4.4	2.8	2.1	0.3	0.4	0.1	0.1	0.1	0.6	1.3	1.7	5.9	1.7
N_{h2}	8.3	7.0	6.8	2.2	4.5	4.0	2.6	4.6	4.6	5.0	4.8	11.4	7.0
v_{max} (m/s)	48.0	47.4	43.8	32.5	32.7	28.4	33.2	32.8	36.5	35.5	47.0	46.2	48.0
date	9. I	12. II	1. III	4. IV	18. V	30. VI	18. VII	6. VIII	14. IX	26. X	18. XI	11. XII	9. I
t_{max} (hours)	1985.	1985.	1958.	1973.	1958.	1964.	1958.	1967.	1962.	1973.	1985.	1986.	1985.
	124	52	49	11	28	8	10	13	29	37	52	128	128
date	17-22. I	21-24. II	4-6. III	14-15. IV	13-15. V	15. VI	15-16. VII	6. VIII	17-19. IX	15-17. X	7-10. XI	8-14. XII	8-14. XII
	1963.	1963.	1969.	1974.	1968.	1973.	1970.	1967.	1970.	1970.	1964.	1968.	1968.

Legend:

N_{d2} - mean number of days with severe bora for a particular month

All other symbols have the same meaning as in Table 1.

Legenda:

N_{d2} - srednji broj dana s olujnom burom u pojedinom mjesecu

Ostali simboli imaju isto značenje kao u tabeli 1.

Table 3. Severe bora situations in Senj with more than 50 hours with mean bora velocity ≥ 17.0 m/s in the period 1957 – 1986.

Tabela 3. Situacija s olujnom burom u Senju sa više od 50 sati sa srednjom satnom brzinom ≥ 17.0 m/s u razdoblju 1957 – 1986.

situation	t (hours)	V_{max} (m/s)	V_{mean} (m/s)
8 – 14. XII 1968.	128	35.5	26.3
17 – 22. I 1963.	124	35.1	24.7
21 – 25. XII 1963.	89	36.8	27.0
5 – 8. XII 1966.	86	36.0	25.0
28. XI – 2. XII 1967.	76	32.1	24.6
16 – 20. I 1957.	70	32.7	23.2
19 – 22. XII 1969.	70	36.2	27.1
12 – 18. I 1961.	65	33.4	23.1
11 – 13. XII 1967.	60	46.2	28.9
31. XII – 5. I 1969.	57	34.0	23.5
8 – 11. XII 1969.	56	33.8	21.7
2 – 4. XII 1962.	54	41.1	26.0
30. XI – 2. XII 1969.	53	41.2	28.9
26 – 28. I 1961.	52	31.2	22.8
21 – 24. II 1963.	52	35.7	26.0
7 – 10. XI 1964.	52	33.6	24.2
9 – 11. II 1965.	50	36.8	25.4
17 – 19. I 1972.	50	35.2	20.5

Legend:

t – number of hours with mean bora velocity ≥ 17.0 m/s

V_{max} and V_{mean} – same as in Table 1.

Legenda:

t – broj sati s srednjom brzinom ≥ 17.0 m/s

V_{max} i V_{mean} – imaju isto značenje kao u tabeli 1.

Table 4. Severe bora situations in Senj with maximum bora gust ≥ 40.0 m/s in the period 1957 – 1986.

Legend: V_{max} , V_{mean} , t – same as in Table 3.

Table 4. Situacija s olujnom burom u Senju s maksimalnim satnim udarima vjetra ≥ 40.0 m/s u razdoblju 1957 – 1986. Simboli imaju isto značenje kao u tabeli 3.

situation	V_{max} (m/s)	V_{mean} (m/s)	t (hours)
8 – 9. I 1985.	48.0	18.5	11
15 – 16. I 1985.	48.0	18.1	6
18 – 20. XI 1985.	47.0	17.3	3
13. XI 1984.	46.6	18.9	11
11. XII 1986.	46.2	17.7	2
11 – 15. XII 1967.	46.2	28.9	60
2 – 4. XII 1983.	45.0	19.0	24
1 – 2. III 1958.	43.8	24.0	13
14 – 16. XII 1961.	41.3	21.1	12
30. XI – 2. XII 1969.	41.2	28.9	53
2 – 4. XII 1962.	41.1	26.0	54

bora periods (Table 9). This is in agreement with the earlier statement (obtained for the severe bora in Senj) that the longest bora duration is not accompanied with the greatest bora gusts.

Similar characteristics of strong bora behavior can be also noticed in Pula (1). In the 12-year period of 1975–1986 only 3 situations with severe bora and 124 situations

Table 5. Severe bora situations in Senj with maximum mean hourly velocity ≥ 25.0 m/s in the period 1957 – 1986. (all symbols as in Table 3)

Tabela 5. Situacija s olujnom burom u Senju sa maksimalnom srednjom satnom brzinom vjetra ≥ 25.0 m/s u razdoblju 1957 – 1986. Simboli imaju isto značenje kao u tabeli 3.

situation	V_{mean} (m/s)	V_{max} (m/s)	t (hours)
11 – 13. XII 1967.	28.9	46.2	60
30. XI – 2. XII 1969.	28.9	41.2	53
21 – 28. II 1963.	27.1	33.7	52
19 – 22. XII 1969.	27.1	36.2	70
21 – 25. XII 1963.	27.0	36.8	89
8 – 14. XII 1968.	26.3	35.5	128
2 – 4. XII 1962.	26.0	41.1	54
17 – 22. I 1963.	25.6	30.3	124
9 – 11. II 1965.	25.4	36.8	50
5 – 8. XII 1966.	25.0	36.0	86

with strong bora were registered there (Table 10 and 11). In these Tables we can find considerably smaller average annual number of days with strong bora in Pula (14.8) than in Omišalj (22.1). Only in February the strong bora blows in more than 10 % of all days. However, the number of hours with strong bora in particular situations exceeded 25 only in 8 situations (Table 12).

The specific location of the Pula (1) station (Fig. 1) on the western coast of Istra (a great distance from the mountain barrier) results in smaller relative frequencies of bora occurrence and its lower velocities. The maximum hourly bora gusts reached values greater than 25 m/s only in 6 situations and in neither of them did the bora gust exceed 35 m/s (Table 13).

4. Summary and conclusion

Severe bora frequency

Statistical analysis of wind field in the northern Adriatic indicates that bora is the most frequent local wind. The location with the greatest frequency of severe bora wind is Senj (Makjanić, 1978; B. Penzar, 1977). In the 30-year period (1957–1986) 434 cases of severe bora were registered in Senj (the relative frequency of severe bora days was 6 % of all days). At the other locations in the northern Adriatic with available wind data severe bora is not so frequent. In an 8-year period (1979–1986) only 10 cases with severe bora were observed in Omišalj in respect to 41 cases in Senj for the same period. In Pula this number was even smaller. In a 12-year period (1975–1986) only 3 cases with severe bora were registered in Pula.

The severe bora duration

Although it is well known that bora lasting up to several days is not unusual, the bora duration problem must be discussed in terms of wind speed and particular locality.

In a 30-year period the number of hours with severe

Table 6. Strong bora in Omišalj – statistical review for the particular years in the period 1979 – 1986.

year	MN	situations with				n_d	n_{d1} (%)	n_h	n_{h1} (%)	n_{h2}	v_{max} (m/s)	date	T_{max} (hours)	date
		$v_{max} \leq 35.0$ m/s	35.0 m/s > $v_{max} \geq 25.0$ m/s	$v_{mean} \geq 17.0$ m/s	17.0 m/s > $v_{mean} \geq 10.0$ m/s									
1979.	—	3	5	3	16	27	7.4	165	1.9	6.1	36.0	11. XI	35	10–12. XI
1980.	—	4	5	—	20	29	7.9	277	3.2	9.6	36.0	30. XI	59	29. XI–1. XII
1981.	—	3	7	2	12	23	6.3	146	1.7	6.3	36.0	14. I	40	16–19. IV
1982.	XII	1	7	1	12	22	6.6	151	1.9	6.9	35.0	5. III	44	5–7. III
1983.	—	—	7	—	17	21	5.8	88	1.0	4.2	34.0	7. XII	22	7–8. XII
1984.	IX, X	—	6	1	5	13	4.3	131	1.8	10.1	34.7	31. XII	49	29–31. XII
1985.	—	—	12	2	14	24	6.6	127	1.4	5.3	34.3	17. IV	31	5–7. I
1986.	I	—	8	1	12	18	5.4	105	1.3	5.8	34.0	3. XI	21	27–28. XI
Total	4	11	57	10	108	177	6.3	1190	1.8	—	36.0	30. XI 1980.	59	29. XI–1. XII 1980.
annual mean	—	1.4	7.1	1.3	13.5	22.1	—	148.8	—	—	—	—	—	—

Legend:

strong bora situation – time period with wind direction continuously between N and E and with mean hourly velocity equal to or greater than 10.0 m/s

MN – month with lack of data

n_d – number of days with strong bora in at least one hour

n_{d1} – relative frequency of strong bora days

n_h – number of hours with strong bora

n_{h1} – relative frequency of hours with strong bora

n_{h2} – mean number of hours with strong bora in the strong bora day

v_{max} – maximum bora gust (m/s)

v_{mean} – maximum mean hourly velocity in the strong bora period (m/s)

T_{max} – maximum number of hours with mean hourly velocity ≥ 10.0 m/s in one strong bora situation

Table 6. Jaka bura u Omišlju – statistički pregled za razdoblje 1979 – 1986.

Legenda:

situacija s jakom burom – razdoblje u kojem je smjer vjetra neprekidno N-E i srednja satna brzina ≥ 10.0 m/s u barem jednom satu.

MN – mjeseci s nepotpunim nizom podataka

n_d – broj dana s jakom burom

n_{d1} – relativna čestina dana s jakom burom

n_h – broj sati s jakom burom

n_{h1} – relativna čestina sati s jakom burom

n_{h2} – srednji broj sati s jakom burom u danu s jakom burom

v_{max} – maksimalni satni udar bure (m/s)

v_{mean} – maksimalna srednja satna brzina vjetra (m/s)

T_{max} – maksimalni broj sati sa srednjom satnom brzinom vjetra ≥ 10.0 m/s u jednoj situaciji s jakom burom.

Table 7. Strong bora in Omišalj – statistical review for the period 1979 – 1986

situations with	month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
		MN	1	—	—	—	—	—	—	—	—	1	1	—
$v_{max} \geq 35.0$ m/s		4	—	1	—	—	—	—	—	—	—	2	4	11
35.0 m/s > $v_{max} \geq 25.0$ m/s		6	5	5	7	3	4	1	2	1	7	11	5	57
$v_{mean} \geq 17.0$ m/s		3	—	2	1	—	—	—	—	—	—	3	1	10
17.0 m/s > $v_{mean} \geq 10.0$ m/s		15	11	13	7	5	7	4	4	4	8	15	15	108
n_d		29	18	21	16	8	9	4	4	4	11	25	28	177
n_{d1} (%)		13.4	8.0	8.5	6.7	3.2	3.8	1.6	1.6	1.9	5.1	10.4	12.9	6.3
n_{d2}		3.6	2.3	2.6	2.0	1.0	1.1	0.5	0.5	0.5	1.4	3.1	3.5	22.1
n_h		188	68	144	143	60	38	6	14	11	70	252	196	1190
n_{h1} (%)		3.6	1.3	2.4	2.5	1.0	0.7	0.1	0.2	0.2	1.3	4.4	3.8	1.8
n_{h2}		6.7	3.8	6.9	8.9	7.5	4.2	1.5	3.5	2.8	6.4	10.1	7.0	6.7
v_{max} (m/s)		36.0	34.3	35.0	34.3	30.3	33.5	27.5	27.0	27.5	34.0	36.0	35.0	36.0
date		13. I	15. II	5. III	17. IV	16. V	18. VI	29. VII	27. VIII	19. IX	22. X	11. XI	31. XII	13. I 1981.
T_{max} (hours)		31	19	44	40	36	18	2	6	5	15	35	49	59
date		5-7. I	24-26. II	5-7. III	16-19. IV	15-16. V	18. VI	22. VII	22. VIII	4. IX	18. X	10-11. XI	29-31. XII	30. XI 1985.
		1985.	1986.	1982.	1981.	1980.	1981.	1979.	1982.	1981.	1983.	1979.	1984.	1980.

Legend:

n_{d2} – mean number of days with strong bora for a particular month

All other symbols have the same meaning as in Table 6.

Legenda:

n_{d2} – srednji broj dana s jakom burom u pojedinom mjesecu.

Svi ostali simboli imaju isto značenje kao u tabeli 6.

Tabela 7. Jaka bura u Omišlju – statistički pregled po mjesecima za razdoblje 1979 – 1986.

Table 8. Strong bora situations in Omišalj with 25 or more hours with mean bora velocity ≥ 10.0 m/s in the period 1979 – 1986.

Legend:

T – number of hours with mean hourly velocity ≥ 10.0 m/s v_{max} and v_{mean} – same as in Table 6.**Tabela 8. Situacije s jakom burom u Omišlju sa 25 ili više sati sa srednjom satnom brzinom ≥ 10.0 m/s u razdoblju 1979 – 1986.**

Legenda:

T – broj sati sa srednjom satnom brzinom vjetra ≥ 10.0 m/s v_{max} i v_{mean} imaju isto značenje kao u tabeli 6.

situation	T (hours)	v_{mean} (m/s)	v_{max} (m/s)
29. XI – 1. XII 1980.	59	36.0	16.2
29 – 31. XII 1984.	49	34.7	15.4
5 – 7. III 1982.	40	35.0	19.1
16 – 19. IV 1984.	40	27.8	12.7
8 – 10. III 1984.	40	34.0	14.7
15 – 16. V 1980.	36	30.3	14.8
10 – 12. XI 1979.	35	36.0	17.1
21 – 22. XI 1979.	33	29.2	12.0
5 – 7. I 1981.	31	34.0	14.2
26 – 28. XII 1980.	30	35.0	14.4
11 – 12. I 1980.	29	32.9	15.1
13 – 15. IV 1982.	28	30.3	16.0
20 – 21. IV 1980.	27	27.7	14.2

bora in Senj was greater than 50 hours in 18 cases (all registered in the winter season). This number exceeds 100 hours in two situations (December 1986 and January 1963). Besides the considerably smaller relative frequencies of strong bora occurrence in Omišalj and Pula, the bora duration there was not as long as in Senj. The bora velocity in Omišalj was ≥ 10 m/s in more than 40 hours only in two situations, and in Pula only in one situation. Thus, the statement that the long bora duration is its basic characteristic is mainly valid for bora in the

Table 10. Strong bora in Pula (1) – statistical review for a particular year in the period 1975 – 1986. Symbols have the same meaning as in Table 6.

year	MN	situations with				n_d	n_{dl} (%)	n_h	n_{h1} (%)	n_{h2}	v_{max} (m/s)	date	T_{max} (hours)	date
		$v_{max} \leq 35.0$ m/s	$35.0 < v_{max} \leq 25.0$ m/s	$v_{mean} \geq 17.0$ m/s	$17.0 < v_{mean} \leq 10.0$ m/s									
1975.	—	—	—	—	12	18	4.9	135	1.5	7.5	22.1	26. II	41	20 – 22. II
1976.	—	—	—	—	16	24	6.6	92	1.1	3.8	20.6	9. IV	14	8 – 10. IV
1977.	—	—	—	1	10	13	3.6	81	0.9	6.2	20.1	26. XI	31	29 – 30. III
1978.	—	—	—	—	7	10	2.7	100	1.1	10.0	20.1	15. IV	35	28 – 29. XI
1979.	—	—	1	1	9	13	3.6	63	0.7	4.8	25.1	11. XI	16	10 – 11. XI
1980.	XII	—	1	—	12	15	4.5	112	1.4	7.5	25.7	21. IV	25	20 – 21. IV
1981.	—	—	—	—	11	14	3.8	87	1.0	6.2	21.1	17. IV	26	16 – 17. IV
1982.	III, IX, XII	—	—	—	6	9	3.3	52	0.8	5.8	23.2	14. IV	21	14 – 15. IV
1983.	—	1	—	1	9	13	3.6	87	1.0	6.7	35.0	2. XII	35	1 – 3. XII
1984.	—	—	1	—	13	18	4.9	93	1.1	5.2	27.8	31. XII	19	9 – 10. V
1985.	—	—	2	—	10	15	4.1	97	1.1	6.5	26.5	23. X	29	18. XI
1986.	I	—	—	—	9	15	4.5	84	1.0	5.6	23.7	4. XI	21	10 – 12. II
Total					124	177	4.2	1083	1.1	6.1	35.0	2. XII	41	20 – 22. II
												1983		1975
annual mean	—	0.1	0.4	0.3	10.3	14.8	—	90.3						

Table 9. Strong bora situations in Omišalj with maximum bora gust ≥ 35.0 m/s in the period 1979 – 1986. (symbols – same as in Table 6)**Tabela 9. Situacije s jakom burom u Omišlju s maksimalnim satnim udarom vjetra ≥ 35.0 m/s u razdoblju 1979 – 1986. Svi simboli imaju isto značenje kao u tabeli 6.**

situation	v_{max} (m/s)	v_{mean} (m/s)	T (hours)
10 – 12. XI 1979.	36.0	17.1	35
29. XI – 1. XII 1980.	36.0	16.2	59
13 – 14. I 1981.	36.0	18.0	12
1 – 2. I 1979.	35.0	18.6	17
31. XII 1979.	35.0	17.4	9
4. XII 1980.	35.0	13.4	10
7 – 8. XII 1980.	35.0	16.1	15
26. – 28. XII 1980.	35.0	14.4	30
8 – 9. I 1981.	35.0	15.8	12
20 – 21. I 1981.	35.0	17.6	14
5 – 7. III 1982	35.0	19.1	44

cold season particularly in Senj. However, this does not concern the frontal bora which is very brief in all seasons (see Jurčec in this Volume).

The preferred period of bora occurrence

Long severe bora usually occurs only during the winter season from the end of November to the end of February. Forty three percent of all severe bora situations in Senj in a 30-year period 41 % of all strong bora situations in Omišalj and 34 % in Pula were registered in winter (December – February).

During the period of 1957-1986 in March and April 21% of cases of severe bora in Senj were registered. However, although the cases in the ALPEX SOP (March and April 1982) did not concern severe bora speed it is believed that they were sufficiently representative and

Tabela 10. Jaka bura u Puli (1) – statistički pregled za razdoblje 1975 – 1986. Svi simboli imaju isto značenje kao u tabeli 6.

Table 11. Strong bora in Pula (1) – statistical review for the particular month in the period 1975 – 1986. Symbols have the same meaning as in Table 6.

month		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
situations with	MN	1	—	1	—	—	—	—	—	—	—	1	2	5
	$v_{max} \geq 35.0$ m/s	—	—	—	—	—	—	—	—	—	—	—	1	1
	35.0 m/s $> v_{max} \geq 25.0$ m/s	—	—	—	2	—	—	—	—	—	1	1	1	5
	$v_{mean} \geq 17.0$ m/s	1	—	1	—	—	—	—	—	—	—	—	1	3
	17.0 m/s $> v_{mean} \geq 10.0$ m/s	12	24	12	15	3	2	3	4	6	9	15	19	124
	n_d	18	34	20	20	4	4	5	4	7	14	21	26	177
	n_{d1} (%)	5.3	10.1	5.9	5.6	1.1	1.1	1.3	1.1	1.9	3.8	6.4	8.4	4.2
	n_{d2}	1.6	2.8	1.8	1.7	0.3	0.3	0.4	0.3	0.6	1.2	1.8	2.6	14.8
	n_h	87	190	91	162	32	13	21	12	39	108	191	137	1083
	n_{h1} (%)	1.1	2.4	1.1	1.9	0.4	0.2	0.2	0.1	0.5	1.2	2.4	1.8	1.1
	n_{h2}	4.8	5.6	4.6	8.1	8.0	3.3	4.2	3.0	5.6	7.7	9.1	5.3	6.1
	v_{max} (m/s)	24.5	23.2	22.8	25.7	22.6	19.0	20.5	19.0	19.6	26.5	25.1	35.0	35.0
	date	9. I	12. II	3. III	21. IV	3. V	5. VI	23. VII	18. VIII	25. IX	23. X	11. XI	2. XII	2. XII
T_{max} (hours)	1985.	1986.	1984.	1980.	1985.	1976.	1979.	1985.	1983.	1985.	1979.	1983.	1983.	
date	22-23. I	20-22. II	29-30. III	6-7. IV	9-10. V	5-6. VI	21-22. VII	21. VIII	17.11-12. IX	28-29. X	1-3. XI	20-22. XII	1981. 1975. 1977. 1978. 1984. 1976. 1977. 1982. 1977. 1982. 1977. 1975. 1978. 1983. 1975.	

Table 12. Strong bora situations in Pula (1) with 25 or more hours with mean hourly velocity ≥ 10.0 m/s in the period 1975 – 1986. Symbols have the same meaning as in Table 8.

Tabela 12. Situacija s jakom burom u Puli (1) s 25 ili više sati sa srednjom satnom brzinom vjetra ≥ 10.0 m/s u razdoblju 1975 – 1986. Svi simboli imaju isto značenje kao u tabeli 8.

situation	T (hours)	v_{max} (m/s)	v_{mean} (m/s)
20 – 22. II 1975.	41	21.1	14.4
28 – 29. II 1978.	35	17.5	15.1
1 – 3. XII 1983.	35	35.0	18.2
6 – 7. IV 1978.	33	19.4	15.5
29 – 30. III 1977.	31	19.1	17.0
11 – 12. X 1975.	31	21.1	13.6
17 – 18. II 1985.	29	22.6	12.9
16 – 17. IV 1981.	26	21.1	13.6
20 – 21. IV 1980.	25	25.7	16.7

Table 13. Strong bora situations in Pula (1) with maximum bora gust ≥ 25.0 m/s in the period 1975 – 1986. Symbols have the same meaning as in Table 8.

Tabela 13. Situacije s jakom burom u Puli (1) sa maksimalnim satnim udarom vjetra ≥ 25 m/s u razdoblju 1975 – 1986. Svi simboli imaju isto značenje kao u tabeli 8.

situation	v_{max} (m/s)	v_{mean} (m/s)	T (hours)
1 – 3. XII 1985.	35.0	18.2	35
31. XII 1984.	27.8	12.0	11
23 – 24. X 1985.	26.5	14.7	17
20 – 21. IV 1980.	25.7	16.7	25
17 – 19. IV 1985.	25.7	12.3	24
10 – 11. XI 1979.	25.1	16.3	16

Tabela 11. Jaka bura u Puli (1) – statistički pregled po mjesecima za razdoblje 1975 – 1986. Svi simboli imaju isto značenje kao u tabeli 7.

strong for the purpose of studying the basic dynamics of bora phenomenon, and to capture the necessary ingredients for bora occurrence, for comparison with the archived cases.

Maximum bora gusts

The maximum bora gusts were greater than 40.0 m/s in 11 severe bora cases in a 30-year period in Senj. The relatively small difference between maximum mean hourly wind velocity and maximum bora gusts in situations with the greatest severe bora duration in Senj indicate that the wind velocity is more uniform during the longer lasting bora.

In spite of the fact that in the majority of cases the strongest bora occurs in Senj, there are situations with maximum bora gust greater at some other localities (for example 6 March 1982; Bajić, 1988).

Since the analysed bora occurrences are based on different periods at three locations, it was not possible to compare all details concerning the characteristics of strong and severe bora. However, it is still clearly seen that the bora wind duration and strength strongly depend on the locality and that particularly Senj's bora is not representative for the broader northern Adriatic area.

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Kratak sadržaj

Statistička analiza polja vjetra na sjevernom Jadranu ukazala je na buru kao najčešći vjetar. Lokacija s najvećom čestinom pojave bure je Senj. U 30-godišnjem periodu (1957-1986) u Senju je registrirano 434 situacija s olujnom burom (relativna častina dana s olujnom burom iznosila je 6 %). Na drugim lokacijama na sjevernom Jadranu s raspoloživim registracijama smjera i brzine vjetra olujna bura nije tako česta. U 8-godišnjem periodu (1979 – 1986) u Omišlju je zabilježeno svega 10 situacija s olujnom burom u odnosu na 41 situaciju zabilježenu u istom razdoblju u Senju. U Puli ovaj je broj još manji. U 12-godišnjem razdoblju (1975 – 1986) u Puli su registrirane samo tri situacije s olujnom burom.

Iako je poznato da bura koja traje i do nekoliko dana nije neobična pojava, pokazano je da je problem trajanja bure potrebno razmatrati u odnosu na brzinu vjetra, i posebno na specifičnu lokaciju.

U 30-godišnjem razdoblju u Senju je broj sati s olujnom burom u pojedinom slučaju bio veći od 50 u 18 situacija (sve su registrirane zimi). Ovaj broj je prelazio 100 sati

samo u dva slučaja (prosinac 1968 i sliječanj 1963). Osim znatno manje relativne čestine pojave jake bure, u Omišlju i Puli je i trajanje bure manje nego u Senju. Brzina bure je u Omišlju bila ≥ 10.0 m/s u više od 40 sati samo u 2 slučaja, a u Puli u jednom. Prema tome možemo zaključiti da tvrdnja da je veliko trajanje bure njena osnovna karakteristika vrijedi uglavnom u zimsko doba godine i to posebno na lokaciji Senja. Međutim, to se ne odnosi na frontalnu buru koja je kratkotrajna u svim sezonama.

Dugotrajna olujna bura zabilježena je u hladno doba godine (od početka studenog do kraja veljače) na svim promatranim lokacijama. 43 % svih situacija s olujnom burom u Senju, 41 % svih situacija s jakom burom u Omišlju i 45 % takvih situacija u Puli registrirano je zimi.

Maksimalni udari bure su u 30 – godišnjem razdoblju bili u Senju veći od 40.0 m/s u svega 11 situacija. Relativno mala razlika između maksimalnih srednjim satnih brzina i maksimalnih satnih udara vjetra u situacijama s najdugotrajnijom burom ukazala je na to da je brzina vjetra uniformnija za vrijeme bure dugog trajanja.

Budući da je analiza pojave bure bila bazirana na podacima iz tri različite lokacije nije bilo moguće usporediti karakteristike njenog trajanja i jačine u svim detaljima. Međutim, ipak se jasno može uočiti da trajanje bure i njena jačina znatno ovise o lokalitetu na kojem se promatraju, te da senjska bura nije reprezentativna za šire područje sjevernog Jadrana.