SOME CHARACTERISTICS OF BORA AND ITS BEGINNINGS IN SLOVENIA

NEKATERE ZNAČILNOSTI BURJE IN NJENIH ZAČETKOV V SLOVENIJI

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SUMMARY

For the year of ALPEX (1981/82), first the data of the direction and speed of the bora are treated from different aspects for seven stations in the region of bora in Slovenia. Beside the frequency and spreading of the bora in the region, some surface and time distributions, speeds and durations of the bora are presented. Separately, the beginnings of the bora are treated with regard to the changes of wind and its speed-increase, which show large fluctuations. For Portorož air temperature and humidity at the bora beginnings are also discussed and presented.

POVZETEK

Za leto ALPEX-a so bile najprej večstransko preučeni podatki o smeri in hitrosti burje na 7 postajah na območju, kjer v Sloveniji piha burja. Poleg pogostnosti in razširjenosti burje nad območjem so podane razne časovne in prostorske razporeditve, povprečne hitrosti in trajanje burje. Posebej so obdelani začetki burij glede sprememb in naraščanja hitrosti, ki kažejo velike fluktuacije. Za Portorož so ob pričetkih burij preučene tudi spremembe temperature in vlage zraka.

Rezultati kažejo, da ima burja na posameznih postajah nekoliko različne smeri in različne hitrosti, kar je predvsem posledica reliefnih značilnosti kraja vsake postaje. Zato je tudi razširjenost burje nad razmeroma majhnim območjem raznolika in le v 45% primerov piha ob istem času čez vse območje. Fluktuacije raznih značilnosti burje so zelo velike ter je celo letni hod slabo izražen.

Začetki burje, ki niso enolično določljivi, kažejo tudi veliko raznolikost, vendar pa omogočajo oceniti značilno širjenje burje prek območja, ki ga moramo glede tega razdeliti v zahodni in vzhodni del. Glede temperature in relativne vlage nastopi vsaj v polovici primerov najprej zvišanje in nato znižanje obeh količin. Pravo znižanje pa se največkrat pojavi šele 2 do 3 ure po začetku burje.

INTRODUCTION

An enlarged number of observations and measurements in the ALPEX period enable exhaustive investigations of the bora peculiarities in the region of Slovenia. Up to date main climatic considerations of bora (e.g. Band 1951, Petkovšek-Paradiž 1976, Yoshino 1976) have given only some general views about bora in the region; recent theoretical and model investigations (e.g. Paradiž 1957, Petkovšek 1984 and 1987, Smith 1985) however, have no possibility of reliable verification. Therefore further and exhaustive investigations of natural bora conditions in single places and in the region are very important. The special problem is bora's beginning; their investigation has given new views in the essential processes in the bora. By finding them is given a contribution to knowledge about bora, and to extended possibility for its better forecast, which is the purpose of these investigations and presentation.

REGION OF THE BORA IN SLOVENIA

In Slovenia the region of bora wind spreads from the Gulf of Trieste toward the NE to the chain of the mountain ridges (between Trnovski gozd and Snežnik), which are higher than 1000 m MSL. Between Trnovski gozd and Nanos is a col Strmec (800 m), between Hrušica and Javorniki is a col Postojna (500 m). Over both cols the cold air comes from NE first and most easily, so this region of bora is divided into a western and a eastern part. Under Trnovski gozd Vipava valley spreads in the W-E direction having the height of only 100 m MSL; between this valley and the Gulf of Trieste there is a some hundred meters higher plateau Kras, which sinks rather suddenly to the Gulf of Trieste.

In the time of ALPEX (i.e. 1.6.1981-31.5.1982), in the presented bora region there were seven stations with anemographs, although of different types. Some data of these stations are presented in Table 1 and Fig.1. In Table 1 there are also some results of previous investigations (Urbančič 1982), and our treatment of the data of this year enables us to determine the range of the bora direction at single places.

The highest frequency of strong winds and usually appearing first too, we find at the col station Strmec, where the channel effect on the wind gives it direction N or S only. From here, i.e. from the main ridge towards the Gulf of Trieste the frequency of strong winds diminish. In the southern part of the region and at the same distance from the ridge (in Ocizla), however, the frequency is greater, probably due to the lower col at Postojna.

FREQUENCY AND EXTENT OF THE BORA

From the here treated period of ALPEX the mean hourly wind speed data with the following conditions were used:

Table 1: The list of stations in the bora region, their height h (MSL), part or percent of hourly values of wind speed (v) regardless of the direction, the range of bora direction (dd) and approximate number of used data (N).

Tabela 1: Seznam postaj na območju burje, nadmorska višina h, delež urnih vrednosti vetra s hitrostjo v - neglede na smer, območje smeri burje dd in približno število tu obdelanih podatkov (N).

	h (m)	v>5m/s %	v>10m/s %	dd	N
Strmec	960	50	8.4	N - NNE	17.000
Dolga Poljana	180	25	7.2	N - E	19.000
Ajdovščina	110	19	6.7	N - E	49.000
Škrbina	350	13	0.2	NNE - SE	18.000
Šepulje	320	13	0.4	NNE - SE	19.000
Ocizla	440	34	2.6	NNE - SE	19.000
Portorož	92	-	-	N - E	9.000

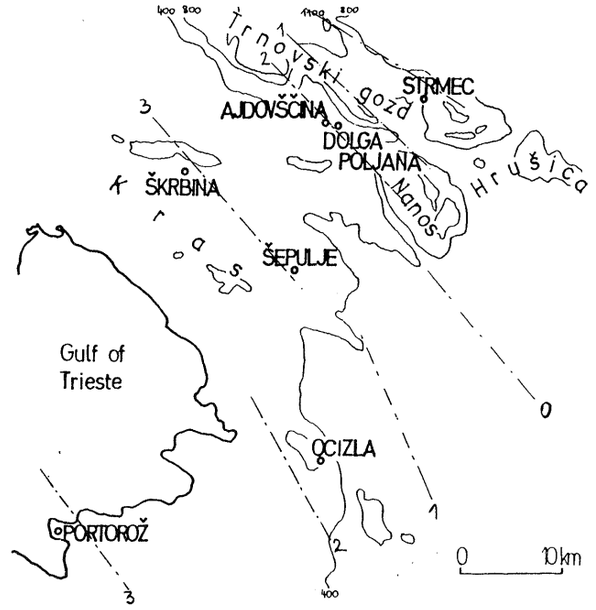

Figure 1: The map of the treated region of the bora in Slovenia with meteorological stations and assesed field of average bora izochrones (in hours).

Slika 1: Zemljevid obravnavanega območja burje v Sloveniji z meteorološkimi postajami in ocenjenim poljem povprečnih izohron širjenja burje (v urah).

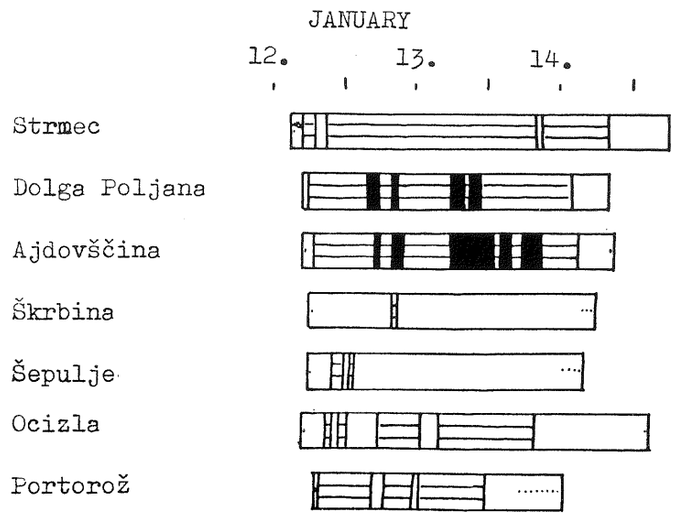

Figure 2: A small part of graphic presentation of time distribution of bora at seven stations; hashed: $10.8 \leq v \leq 17.1 m/s$, black: $v > 17.1 m/s$

Slika 2: Izsek grafičnega prikaza časovnih potekov burij na sedmih postajah; šrafirano: $10.8 \leq v \leq 17.1 m/s$, črno: $v > 17.1 m/s$

- wind direction has to be inside the range of bora direction at the treated station
- the mean hourly wind speed (v) has to be strong enough: v > 3.3 m/s.

The additional condition for the bora is that at least once the speed v > 5.4 m/s. There remains the problem of separation of two consecutive bora cases at the station. Here we suppose that a new bora exists, when after the previous bora there is a wind blowing from a direction that is not in the range of bora at least for 10 hours or if v < 3.3 m/s. The time lag of 10 hours includes the supposition that cold fronts or cold air invasions cannot follow one another in shorter periods.

The mean hourly value that was established for the threshold value of bora is rather small, but as the bora is a very gusty wind, the speed in the gusts can be $v_M > 7$ m/s.

In such a way chosen data have given a graphical presentation of bora cases in the treated period for seven stations altogether what is partly presented in Fig.2. From the complete graph of all the bora cases found at these stations simultaneously, the following overview can be given:

Table 2: The number of bora cases from June 1, 1981 til May 31, 1982 at the meteorological stations and the number of bora cases recorded at least at 4 stations simultaneously

Tabela 2: Število primerov burje za vsak mesec od 1. junija 1981 do 31. maja 1982 na posameznih postajah in število primerov burje, ki pihajo istočasno vsaj na 4 postajah.

	J	J	A	S	O	N	D	J	F	M	A	M	d
Strmec	5	4	6	5	8	5	9	7	4	6	5	5	69
D.Poljana	5	5	7	5	7	6	10	7	6	7	8	6	73
Ajdovščina	5	3	7	5	7	4	9	7	9	7	11	7	81
Škrbina	3	2	5	3	3	2	7	5	6	4	7	5	52
Šepulje	4	4	7	4	5	4	4	6	7	5	11	4	65
Ocizla	7	4	6	5	7	5	9	7	4	9	7	6	76
Portorož	9	3	7	4	7	5	7	6	5	8	11	4	76
4 stations 4 postaje	5	3	7	5	7	4	9	7	8	6	10	6	77
season sezona		15			16			24			22		

number of stations:	7	6	5	4	3	2	1	
število postaj simultaneous boras:	45	10	13	9	8	7	8	(%)
sočasno zabeležene burje								

This means, that in most cases bora was flowing above the whole region; but at one station only, was found no more than in 8 %.

It was decided that only those bora cases will be treated further, which were found at least at half, i.e. at 4 stations simultaneously. In the considered one year period 77 such bora cases can be found (Table 2).

It is obvious, that the fluctuations in the number of bora cases from one month to another are large, and that even an annual course is not very expressive.

The number of boras at Kras (Škrbina, Šepulje) is smaller, because there boras are weaker and may be eliminated by the given criteria. At Strmec the number of hours with bora is very high but the number of bora cases is low because they are of long duration and sometimes joined. The given criteria are not the best of course for all purposes. Sometimes it is obvious that there is one case of bora only, but by the given criteria, two will be counted. Rarely the opposite can be true, and two cases are joined into one.

A special comparison of boras at Ajdovščina and Portorož shows 60 simultaneous cases, in 17 cases bora was blowing at Ajdovščina but not at Portorož, in 13 cases the opposite was true. It may happen due to given criteria, that at one station there are two cases but one at the other. Such a case was taken as bora on both stations; a disagreement in the number of cases and their sum is one

Table 3: A comparison of number of bora cases in regard to their speed and duration at Ajdovščina and Portorož

Tabela 3: Primerjava števila burij glede na jakost in trajanje v Ajdovščini ali v Portorožu

	weak šibka	moderate zmerna	strong močna	sum vsota
short kratko trajajoča	14	4	0	18
middle range srednje trajajoča	15	23	5	43
long range dolgo trajajoča	0	10	6	16
sum vsota	29	37	11	77

of the consequence of these problems. Bora cases found at Ajdovščina but not simultaneously at Portorož were weak, 8 of them were of a shorter duration than 12 hours (3 of them 2 hours only). From the bora cases found at Portorož but not at Ajdovščina, only one was moderate. In 6 cases of bora at Ajdovščina, there was a wind from the bora direction at Portorož also, but not strong enough to be counted as bora.

SPEED AND DURATION OF THE BORA

Bora cases can be divided into groups according to different criteria. In regard to the highest hourly mean wind speed we can define bora as:

weak (šibka)	-	5.4 m/s	<	v	<	10.7 m/s
moderate (zmerna)	-	10.7 m/s	<	v	<	17.1 m/s
strong (močna)	-	once at least		v	>	17.1 m/s

The speed of weak bora corresponds to the numbers of 4 and 5 of the Beaufort scale, the speed of moderate bora corresponds to 6 and 7 Bf, and the speed of strong bora is equal or above 8 Bf. Regarding bora's duration T three classes were formed:

short (kratkotrajna)		T	<	12 hours
middle range	12 <	T	<	48 hours
long range (dolgotr.)		T	>	48 hours

Using these criteria the boras at Ajdovščina and at Portorož were treated, taking in account the values at the station with stronger bora, or of longer duration. In Table 3 these results can be seen.

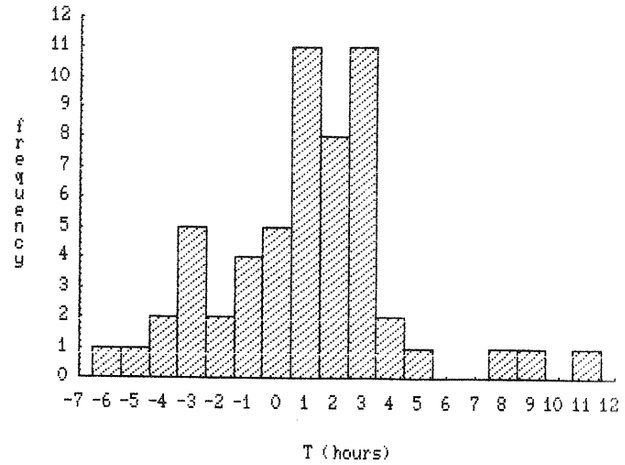

Figure 3: The number of boras with regard to the time differences of bora beginnings at Ajdovščina and Portorož

Slika 3: Število burij glede na časovne razlike začetkov na dveh postajah: Ajdovščina in Portorož

As mentioned already, the number of cases depends on the criteria for bora definition, but the speed also changes continuously and in the gusts can be for a factor of three greater than the mean value.

PECULIARITIES OF THE BORA BEGINNINGS

Especially at the beginning of the bora the wind speed and direction change considerably. Therefore the additional condition for the bora beginning is: until the time of the mean hourly speed of v > 5.4. m/s is reached, there are never two or more successive wind directions other than in the bora range, or wind speeds v < 3.3 m/s. Using these aditional criteria for every bora case, the time of its beginnig was established with an hour accuracy.

Place and time distribution of the beginnings

The time difference of the bora beginnings at two station can be obtained if the beginning at both stations is known. This can not be done if at one of the stations the previous bora is still active, if at one station there are no data of the beginning, or if at one station there is no bora at all.

Table 4: The time differences of the bora beginnings at two stations: the number of cases (the upper triangle) and mean time difference (positive for the station in the upper line - the lower triangle - in hours)

Tabela 4: Časovne razlike med nastopom burje na dveh postajah: število primerjav (zgornji trikotnik) in povprečna časovna razlika (pozitivna za burjo prej na postaji v zg. vrsti - spodnji trikotnik, v urah)

	S	DP	A	ŠK	ŠE	O	P
S		46	47	37	35	47	36
DP	1.52		61	48	42	49	44
A	2.38	0.69		49	47	42	49
ŠK	3.08	1.40	0.51		44	38	46
ŠE	2.89	1.62	0.96	0.27		37	39
O	1.30	0.06	-0.14	-1.34	-2.19		44
P	3.14	2.00	1.02	-0.11	0.13	1.71	

For different pairs of stations graphs were drawn, with the time difference of bora beginnings on abscissa (up to $\pm$ 12 hours), and the number of cases on the ordinate. An example is presented in Fig.3. Thus in 15 cases the bora began in Portorož before Ajdovščina, but these two stations are not in the same part of the region. However, the bora began in Šepulje 10-times and in Škrbina 12-times, one to four hours before than in Ajdovščina. Obviously in these cases the air was not cold enough to reach the bottom of the valley, and has jumped over Ajdovščina.

The average time differences of bora beginnings were calculated also, but here only the differences up to $\pm$ 4 hours were taken into account, because rare high differences spoil the results. Thus for every station the frequencies for 9 hourly values for every mean were taken into account, and the obtained results are presented in Table 4.

A transfer of these data on the map of the bora region has given an approximate picture about a typical propagation of the bora across the treated region - Fig. 1. The figure confirms the above mentioned need for a division of the region in two parts; in the east one, there are two stations only (Ocizla and Portorož) as a col station Postojna unfortunately has no anemograph. Bora was never found at Ajdovščina before it began at the col above it at Strmec. The most frequent opposite time difference is two hours, which is large, regarding the small distance (10 km) between the stations. It means that bora advances much slower than its mean wind speed in the same direction, and warns of unknown processes of its propagation, descent, and internal structure of the flow (e.g. Jurčec 1987, Petkovšek 1988).

For the boras at Ajdovščina and Portorož also the daily distributions of beginnings were drawn. The results are presented in Fig. 4. Obviously they show large fluctuations, and no characteristic daily course can be found.

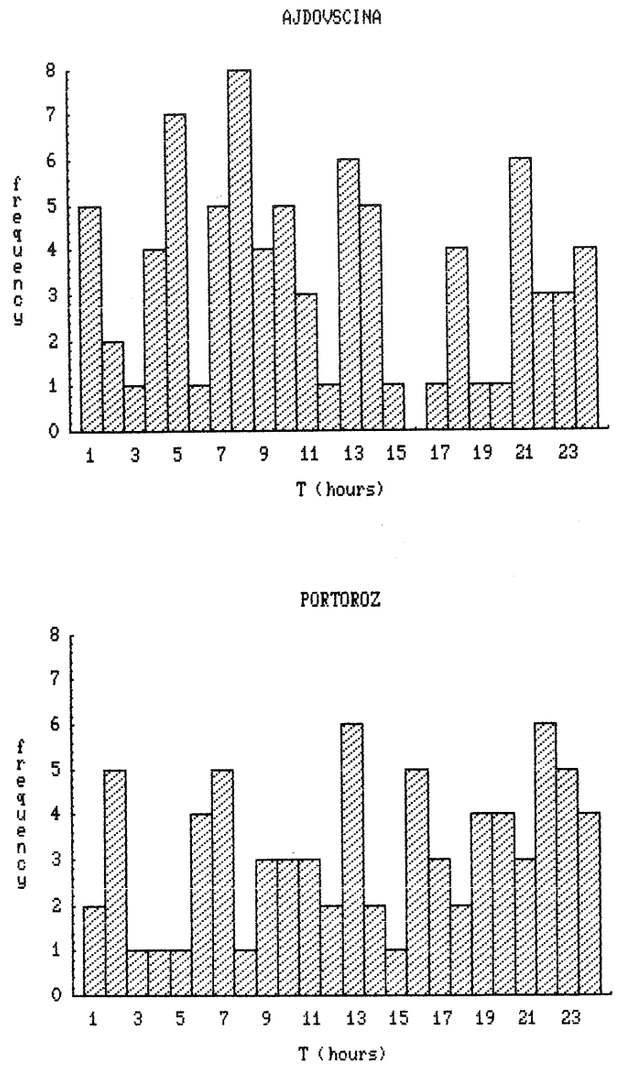

Figure 4: The daily distribution of the bora beginning frequencies for Ajdovščina and Portorož

Slika 4: Število začetkov burij v posameznih urah dneva za Ajdovščino in Portorož

Table 5: The number of bora cases at Ajdovščina and Portorož, regarding different types of speed increase at the beginning

Tabela 5: Število burij v Ajdovščini in Portorožu pri različnih začetnih stopnjah naraščanja hitrosti

	Ajdovščina	Portorož
slow počasi	23	36
moderate srednje	43	24
quick hitro	15	16

Wind changes at the bora beginnings

Let us now consider only a few first hours around the bora beginnings at Adovščina and Portorož. In the first part of these considerations, the mean hourly speeds were considered. In the second part, however, the maximum wind speeds in the gusts using anemograms were treated.

In view of the mean hourly speeds of bora in its first three hours after the beginning, three different manners of wind increase can be distinguished:

slow:	two hours at least			v	<	5.4 m/s
počasen:	najmanj dve uri					
moderate:	two hours at least	5.4 m/s	<	v	<	10.7 m/s
zmeren:	najmanj dve uri					
quick:	once at least			v	>	10.7 m/s
hiter:	vsaj enkrat					

The results of further treatment of these data can be seen in Table 5. In one third of the bora cases only, the beginnings of bora on both stations can be found in the same group; otherwise at Ajdovščina the number with a moderate increase prevails, at Portorož with a slow increase of bora speed at the beginning. The quick increase is more typical for the colder half of the year.

By the investigation of bora speed increase using the maximum wind speed (v_M) i.e. the gusts in anemograms, the period of bora beginning can be divided into three phases:

1. wind before the bora beginning (usually weak)
2. the first gusts can be observed, direction is very changeable
3. direction is fixed in the bora range, the gusts increase

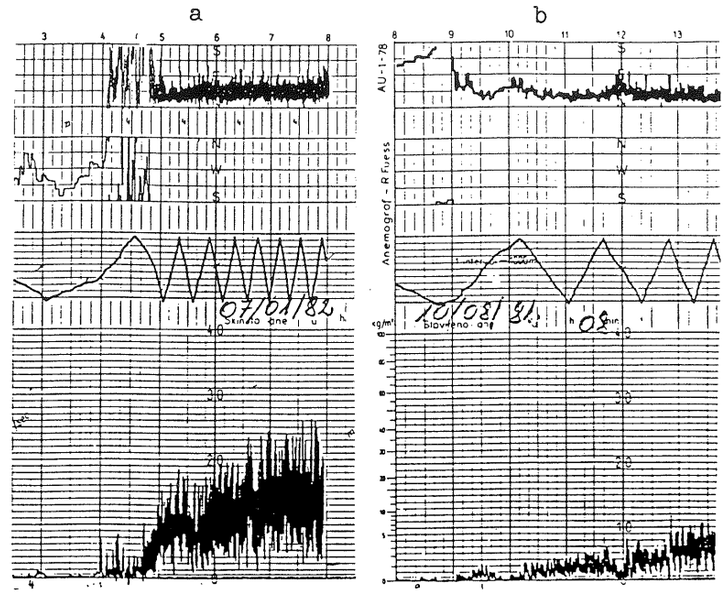

Figure 5: Examples of two different speed increases at bora beginnings in anemograms of Ajdovščina

Slika 5: Primera dveh različnih začetkov burje v Ajdovščini po anemogramih

Examples of these phases can be seen in Fig 5a. At Portorož the second case never can be found, as not shorter than 10-minute wind averages exists. At this station, sometimes before the bora beginning, a strong South wind is observed (v > 10 m/s).

The duration of the second phase can be only a few minutes but also beyond half an hour. When the first gusts are already from the wind direction of the bora range, the second phase may not appear (Fig. 5b).

In the third phase gusts may increase slow or very rapidly, and in a few minutes can excceed the value of $v_M > 20m/s$. There are large fluctuations in the increse of bora's speed of course, and all possibilities cannot be presented briefly, as they depend on macro- and meso-meteorological processes, including local influences of relief characteristics.

The changes of temperature and humidity

In the region of the bora in Slovenia thermohygrograph can be found only at Portorož, where detailed analyses of temperature and relative humidity changes at bora beginnings are possible. The treatment is for the period of ALPEX-SOP (i.e. March, April 1982). In this period 18 bora cases were found.

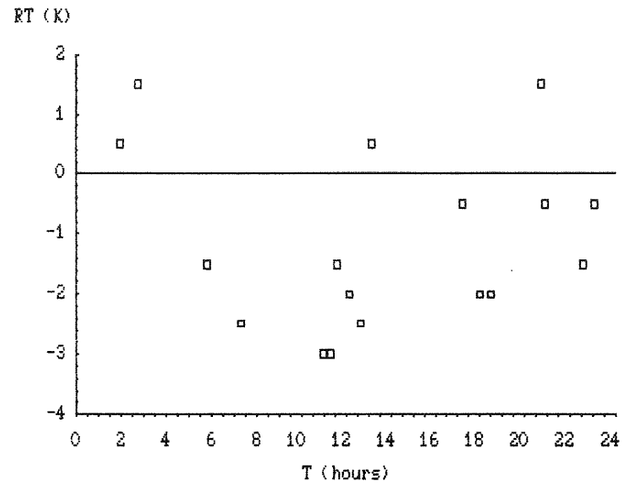

Figure 6: The dependance of the step of maximal cooling (RT) on the daytime of bora beginning

Slika 6: Povezava med stopnjo ohladitve (RT) in dnevnim časom začetka burje

A thorough view on the thermohygrograms shows, that in half of the cases in the surface air for a short time, first an increase of temperature (up to 1.5 K) is evident, and afterward it decreases. At the same time a similar short increase of relative humidity is found even in 60% of cases (up to 30% of relative humidity). This paralell increase of both quantities is probably due to the advection of warm and humid maritime air, which is pushed by the bora at its beginning from the part of the Gulf of Trieste. In Portorož the cases in which at bora beginnins already a temperature and relative humidity fall is found, are minor. Looking at thermohygrograms using theoretical knowledge, the change of air mass into the bora mass occurs, when temperature and relative humidity decrease together. This happens in one third of all cases, already an hour before the bora beginns i.e. before the wind from the bora direction is strong enough to be counted as bora.

In the thermohygrogram a seen and established temperature decrease, a so-called recorded decrease is between 0.5 and 4.0 K in two hours, the recorded decrease of humidity is however 10 to 60%. In thermohygrogram noted changes are of course not the consequence of air mass changes only, but are also due to cloudiness, insolation, precipitations, time of the day, dissipation of inversion etc., which are all only in indirect connection with bora. Therefore changes recorded in the thermohygrogram without further analyses of other influences can not show the differences due to air mass changes at bora beginnings and direct influences of bora.

The bora air mass is doubtless cooler and usually dryer than the proceeding mass but the mentioned influences can be stronger, because at the bora beginning (at

Table 6: An example of temperatures in hours around bora beginning: BD day with bora beginning (23.4.), MSD most similar day, D other similar days, RT the greatest difference in an hour between MSD and BD. No.1. the hour before the bora beginning, 2. at the beginning, 3. to 6. after the beginning. Left columns: recorded temperatures, right columns: to the value at 2.BD arranged temperatures - all . 10^{-1} °C, + the bora beginning, ! precipitations.

Tabela 6: Primer prikaza temperatur po urah okrog začetka burje: BD dan z burjo (23.4.), MSD najbolj podoben dan, D drugi primerjalni dnevi, RT največja temperaturna razlika v kaki uri med MSD in BD. Št. 1 ura pred pričetkom burje, 2. ob pričetku, 3. do 6. ure po pričetku, levi stolpci: absolutna temperatura, desni stolpci: na 2.BD prirejena temperatura - vse . 10^{-1} °C, + začetek burje, ! padavine.

Date /datum No. hour št. ura	23.4. BD	9.3. D	16.3. D	21.3. MSD	1.4. D
1. 12	104	80 101	86 99	100 102	152 111
2. 13 +	105	84 105	92 105	103 105	146 105
3. 14 !	74(103)	98 119	101 114	104 106	154 113
4. 15	101	98 119	98 101	99 101	152 111
5. 16	98	92 113	94 107	96 98	164 123
6. 17	103	88 109	90 103	90 92	160 119

$$\mathrm{RT} = -5.10^{-1}K$$

a cold front) precipitations are also not an exception. To evade the indirect influences, to every day with the bora beginning (BD), the days without bora but with similar temperature distribution up to the hour of bora beginning in BD were found. From these days the day with the most similar weather (MSD) was established using the observation book. In this way established differences in the temperature and relative humidity should be indirectly a consequence of the bora. The influence of precipitations which is usually of a short duration, was eliminated separately. By the comparison of temperature distributions on the day of the bora beginning and on comparison days, the six hours around the bora beginning were treated (No. 1. to 6. in Table 6) i.e.: the first value is at least one hour before the bora beginning, the second at the beginning, and the other four after it. Then the temperatures in the hour No.2. on the comparison days were equated with the value No.2. in BD, and appropriately arranged for all hours after the bora beginning. Afterwards the temperature differences in all the pairs of days were established, and the greatest difference obtained with a half of degree accuracy (RT in Table 6).

In table 6 the appropriate correction of temperature with regard to precipitations can be seen (No.3. (103)) as well. The maximum temperature difference is -0.3 K, but it is due to greater temperature differences in other comparison days rounded to 0.5 K. Similar tables were made for all the 18 bora cases in ALPEX-SOP. Their main characteristics can be found in table 7.

Very interesting is also a connection of RT with the time of the day of its occurence, which is shown in Fig.6. Here can be seen that the biggest temperature decreases are found in boras with the beginnings in the morning hours; temperature increases can be found in the night hours only. The time when the greatest RT is found regarding the hour after the bora beginning, is obtained from the tables like Table 6 for all bora cases. An investigation shows that the greatest frequency of RT is in the second and third hour after the bora beginning (i.e. in No.4 and 5.), because in the last of the treated hours the temperature can already be increasing again.

CONCLUSION

The results of the presented investigation of bora in Slovenia show, that at different stations bora has somewhat different ranges of direction and speeds at the same cases, mainly due to peculiar relif characteristics. Therefore and due to established criteria the spreading of bora over the region is not equal and in 45 % only the bora can be defined over the whole region. Fluctuations of bora characteristics are large and even the yearly course is weakly expressed.

The beginnings of bora, which are not simply determinable, show large variability but yet enable an estimate of a typical propagation of the bora across the region, which has to be for this purpose divided in a western and the eastern part. Regarding the temperature and relative humidity changes at the bora beginnings, at least in half of the observed cases first a short increase and then a decrease of both quantities is seen. Their real decrease however, occurs usually not before 2 to 3 hours after the bora beginning.

Table 7: The main characteristics of temperature and relative humidity changes at bora beginnings in ALPEX-SOP. PP increase and soon a decrease. P decrease from the beginning, MIN the minimum relative humidity after the beginning, RT the maximum temperature difference after the beginning, - no data

Tabela 7: Glavne značilnosti sprememb ob začetkih burij v ALPEX-SOP, PP porast in pad, P pad od začetka, MIN minimalna relativna vlaga po začetku, RT maksimalna temperaturna razlika po začetku, - ni podatka

	BEGINNING ZAČETEK		HUMIDITY VLAŽNOST			TEMPERATURE TEMPERATURA		
No. št.	day dan	hour ura	PP	P	MIN	PP	P	RT
1.	2.3.	11.35	+		42	+		-1,5
2.	4.3.	20.55	-	-	42	-	-	-0,5
3.	11.3.	13.50	-	-	37		+	-
4.	13.3.	7.20	+		38	+		-2,5
5.	14.3.	20.45		+	25		+	+1,5
6.	19.3.	17.15		+	42	+		-0,5
7.	20.3.	12.10	+		40	+		-2,0
8.	29.3.	23.05	-	-	-	-	-	-0,5
9.	3.4.	2.45		+	50	+		+1,5
10.	9.4.	11.00	+		44	+		-3,0
11.	12.4.	2.00	+		45	+		+0,5
12.	17.4.	12.40	+		44		+	-2,5
13.	18.4.	18.30	+		52	+		-2,0
14.	22.4.	11.20	+		48		+	-3,0
15.	23.4.	13.10	+		48		+	-0,5
16.	24.4.	22.35	+		35	+		-1,5
17.	27.4.	18.00		+	34		+	-2,0
18.	30.4.	5.50	+		38	+		-1,5

All in the article presented notes and findings should be also a challenge for new theories and models, that should give a more complete description of this phenomena and would increase the possibility of forecasting, and will enable successful nowcasting of the bora.

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