RASPRAVE 23, Zagreb 1988, str. 93-101

UDK: 551.555.4
Stručni rad

BORA AS KATABATIC WIND

Bura kao katabatički vjetar

VERICA PANDŽIĆ I KREŠO PANDŽIĆ
Hydrometeorological Institute, Zagreb
Primljeno 7. svibnja 1988, u konačnom obliku 20. listopada 1988.

Abstract: A case of strong bora wind, on the eastern Adriatic Coast 5-7 March 1982 (ALPEX SOP - Special Observation Period) is considered. The radiosounding observations at Pula and Zadar in addition to an analysis of the surface wind data and the synoptic situations, make possible an analysis of vertical bora profile. It is concluded that maxima wind speeds occur mostly in the layer from 0.5-2 km with a change of wind direction from NE, prevailing in the boundary layer, to SE at a height of 2 km. This is shown by presentation of katabatic wind components, especially pronounced on 6 March, and characterized by the strongest bora wind during ALPEX SOP.

Key words: bora, ALPEX period, katabatic component

Sažetak: Razmatran je jedan slučaj jake bure na Jadranu koja je trajala od 5-7. ožujka 1982. (ALPEX SOP). Budući da su tada obavljana i radiosondažna mjerenja u Puli i Zadru, pored analize prizemnih podataka o vjetru i sinoptičkih situacija, dan je poseban osvrt na analizu njenog vertikalnog profila. Zaključeno je da se maksimalna brzina vjetra u većini termina javlja između visine 0.5 i 2 km, te promjena smjera vjetra s NE, koji prevladava u pograničnom sloju, na SE oko 2 km visine. To se također vidi iz promatranja vertikalnog profila katabatičke komponente, posebno za 6. ožujka koji je i bio 'najburovitiji' dan u promatranom periodu.

Ključne riječi: bura, ALPEX period, katabatička komponenta

1. INTRODUCTION

Bora wind appears close to the mountain barrier, which sharply separates two thermally different air masses. Bora-like wind also occurs in the Novaja Zemlja (the Soviet Union) in the Carpathian mountains, in the Caucasus and elswhere (Paradiž, 1956).

The first well-konwn paper about the bora was given by Band (1956). He considered courses of some meteorological parameters (temperature, relative humidity, air pressure) at several locations during the bora. A contribution to bora research, especially in Slovenia, was made by Paradiž (1956). He divided the bora into four types: the obstruction bora, obstruction-gradient, gradient-obstruction and gradient one, depending which mechanism is stronger, falling air or pressure gradient. Lukšić (1975) presented a detailed statistics of the bora at the town of Senj. According to his research, temperature and relative humidity decrease during the bora. A detailed presentation of the bora is given by Yoshino (1976). He divided the bora in several types depending on the synoptic situation (e. g. cyclonic and anticyclonic A and B types). Petkovšek (1976) described bora gusts. He used records of special anemographs. The vertical structure of bora was investigated by Poje (1962) and Makjanić (1962). Poje presented vertical profiles of wind speed and direction, temperature and relative humidity for several types of bora, using radiosounding data from Split. Makjanić calculated katabatic components of the bora for four typical cases, using radiosoundings from Split too, and corresponding synoptic maps.

In this paper, a similar procedure is executed as in Makjanić's using radiosounding data for three simultaneous soundings at Pula and Zadar, from ALPEX SOP.

The most detailed presentation of ALPEX bora cases, including analysis of research flight data, are given by Smith (1987) with the modern theoretical view of bora characteristics and its possible relationship with other downslope winds and their dynamics.

2. MECHANISM OF KATABATIC WINDS

Wind is, by definition, a horizontal component of air circulation. The vertical component is considered as secondary because it is an order of magnitude less than horizontal on most parts of the globe. However, in hilly areas, the vertical component can be compared to the horizontal one, and sometimes it is greater than the horizontal. Winds which have relatively high vertical descending components are named katabatic winds. Bora, fühn and downslope winds belong to this group.

In meteorological practice there are regular observations of the horizontal component whereas measurements of vertical component are rare. Therefore, katabatic winds are mainly studied only by theoretical methods as presented in this paper.

Starting with a hydrodynamic theory of atmospheric motions (Ivančičević, 1986), it can be presumed that genesis of the bora is caused by: gradient forces, friction and buoyancy forces. Taking this into consideration, Makjanić (1962) assumed that the horizontal component of the bora wind **B** (observed component) can be approximately expressed as a vector sum of three components: Ekman wind **E**, thermal wind **T** and horizontal katabatic component **K**. This vector equation has the from:

$$\mathbf{B} = \mathbf{E} + \mathbf{T} + \mathbf{K} \tag{1}$$

Ekman wind can be calculated for every height, on the basis of relations

$$u' = V_g\,(1 - e^{-\gamma z} \cos \gamma z) \tag{2}$$

$$v' = V_g\, e^{-\gamma z} \sin \gamma z \tag{3}$$

$$E = u'\, i' + v'\, j' \tag{3a}$$

where wind componets u', v' are in the direction of isobars and normal to them respectively. Quantity V_g is the geostrophic wind, z is the height above ground and

$$\gamma = (f / 2\eta)^{1/2} \tag{4}$$

where f is the Coriolis parameter and η the eddy viscosity coefficient which is about 5 $m^2 s^{-1}$ (Ćurić, 1983). Geostrophic wind can be calculated on the basis of synoptic maps and the relations

$$V_g = -\frac{1}{f\rho}\frac{\Delta p}{\Delta n} \tag{5}$$

$$V_g = -\frac{1}{f}\frac{\Delta \Phi}{\Delta n} \tag{6}$$

where n is the normal direction to the isobars or isohipses, p pressure, Φ the geopotential and $\rho \approx 1$ air density. Further more, the thermal wind can be calculated on the basis of relation

$$\mathbf{T} = \mathbf{V}_{g2} - \mathbf{V}_{g1} \tag{7}$$

where the indices 1 and 2 refer to the neighbouring levels.

Data for B can be obtained by radiosounding observations, and the calculation of the horizontal katabatic component can be performed on the basis of equation

$$\mathbf{K} = \mathbf{B} - (\mathbf{E} + \mathbf{T}) \tag{8}$$

Aside from theoretical importance, the katabatic component could be used for determination of the bora layer height. The level at which K ≈ 0 could be considered as the height of this layer, considering that the horizontal katabatic component is zero at the same level where the vertical speed is zero.

In the next section a practical application of this theory is presented.

3. DATA

During the ALPEX SOP (March and April 1982) the commission gave instructions to operators whether they had to do intensively radiosounding (every three hours) or not, depending on the appearance of bora wind. Consequently, because radiosounding observations were being done at Pula and at Zadar during the period 5-7 March 1982, it was a period of bora (see Figure 1). Although radiosounding was available eight times a day, only one term at 00 GMT is considered here. Thus, three observations were taken into consideration.

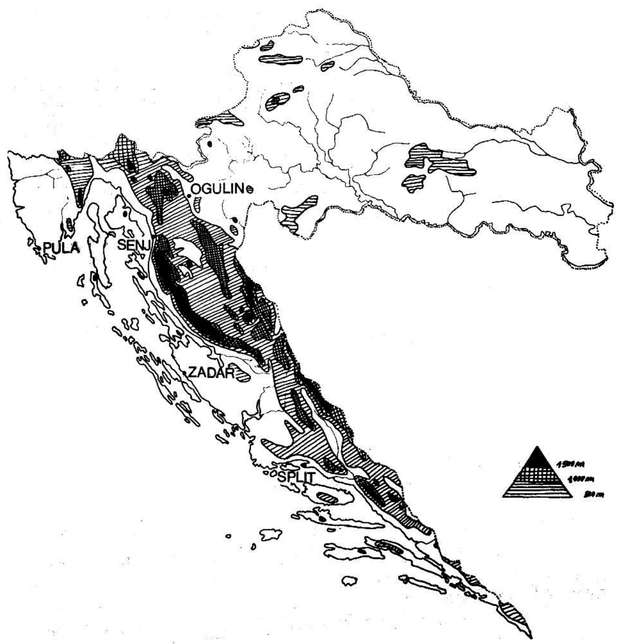


Fig. 1. Map of Croatia

Sl. 1. Geografska karta SR Hrvatske.

Aside from radiosounding data presented in Figures 7 and 8 for Pula and Zadar respectively, the synoptic situations are given in Figures 2,3 and 4 and the course of hourly values of wind speed and directions in Figures 5 and 6 for Ogulin, Senj, Pula, Zadar and Split as well.

4. RESULTS

As already indicated the height up to which the katabatic component is different from zero, can be considered the height up to which an influence of bora exists, as the bora layer. Aside from theory, it is important for the air traffic because the bora is a strong wind with gusts (Petkovšek, 1976).

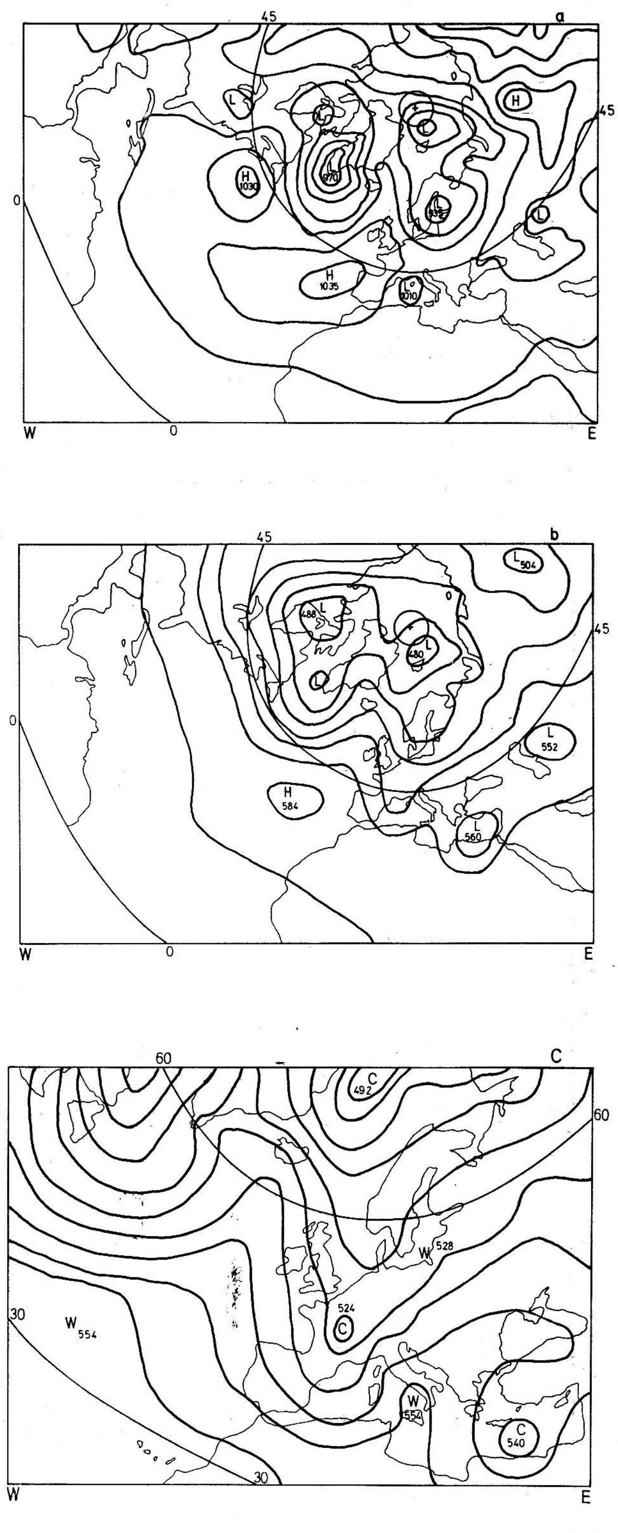


Fig. 2. Synoptic surface map (a), AT 500 mbar (b) and RT 500/1000 mbar (c). All for 5 March 1982 at 0000 GMT. (After Deutscher wetterdienst, 1982).

Sl. 2. Sinoptička prizemna karta (a), AT 500 mbar (b) i RT 500/1000 mbar (c). Sve za 5 ožujka 1982. u 0000 GMT. (prema Deutsch Wetterdienst, 1982).

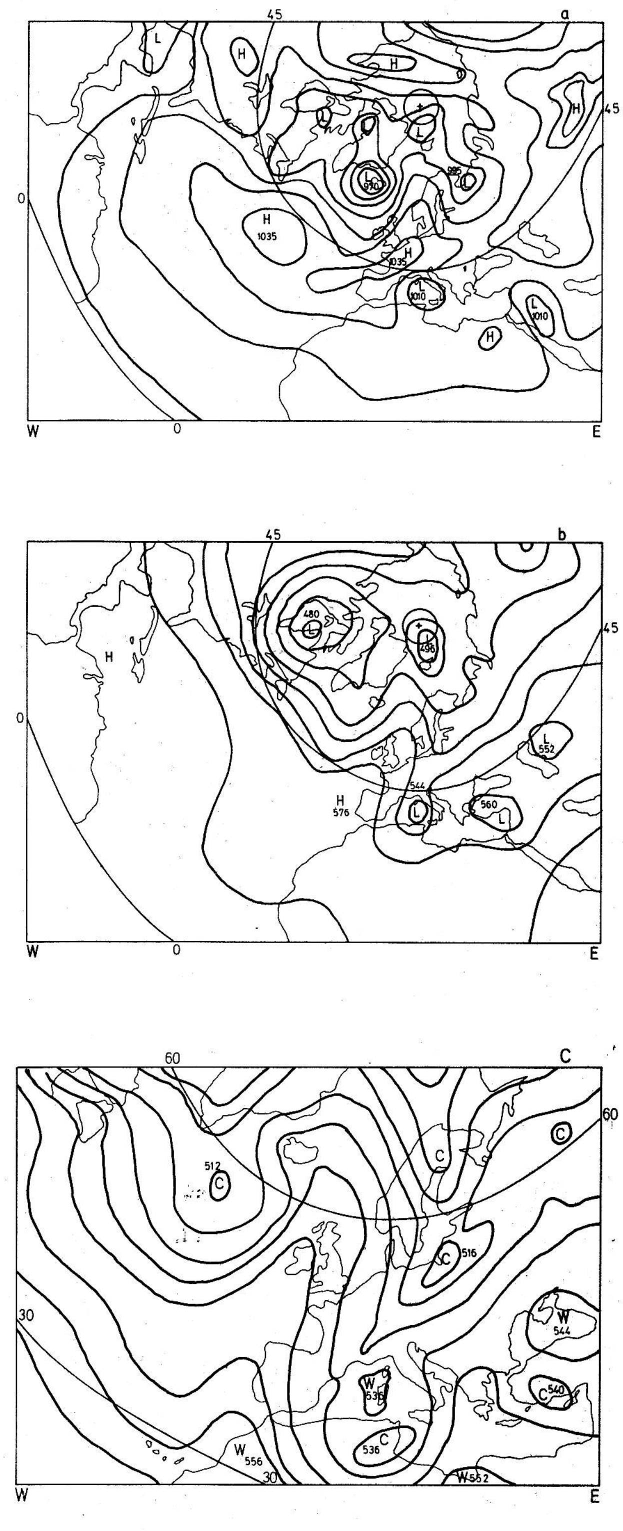


Fig. 3. The same as in Figure 2 except for 6 March 1982.

Sl. 3. Isto kao na slici 2 osim za 6. ožujka 1982.

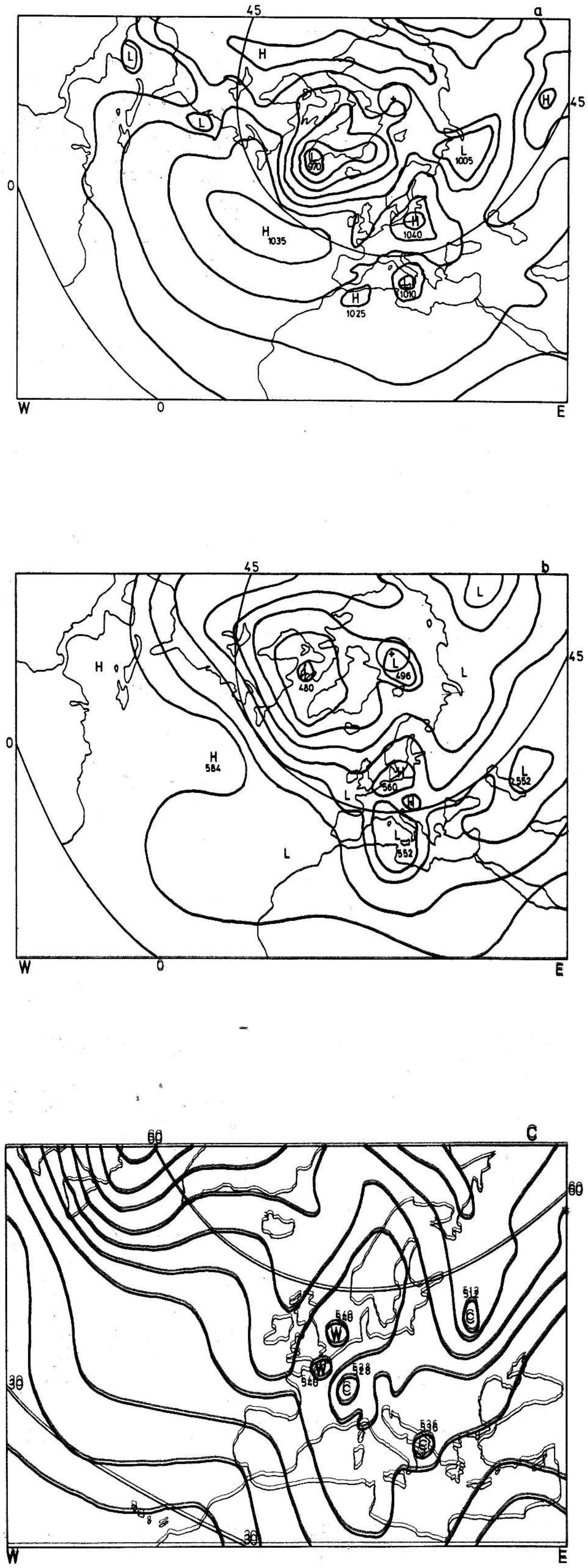


Fig. 4. The same as in Figure 2 except for 7 March 1982.

Sl. 4. Isto kao na slici 2 osim za 7 ožujka 1982.

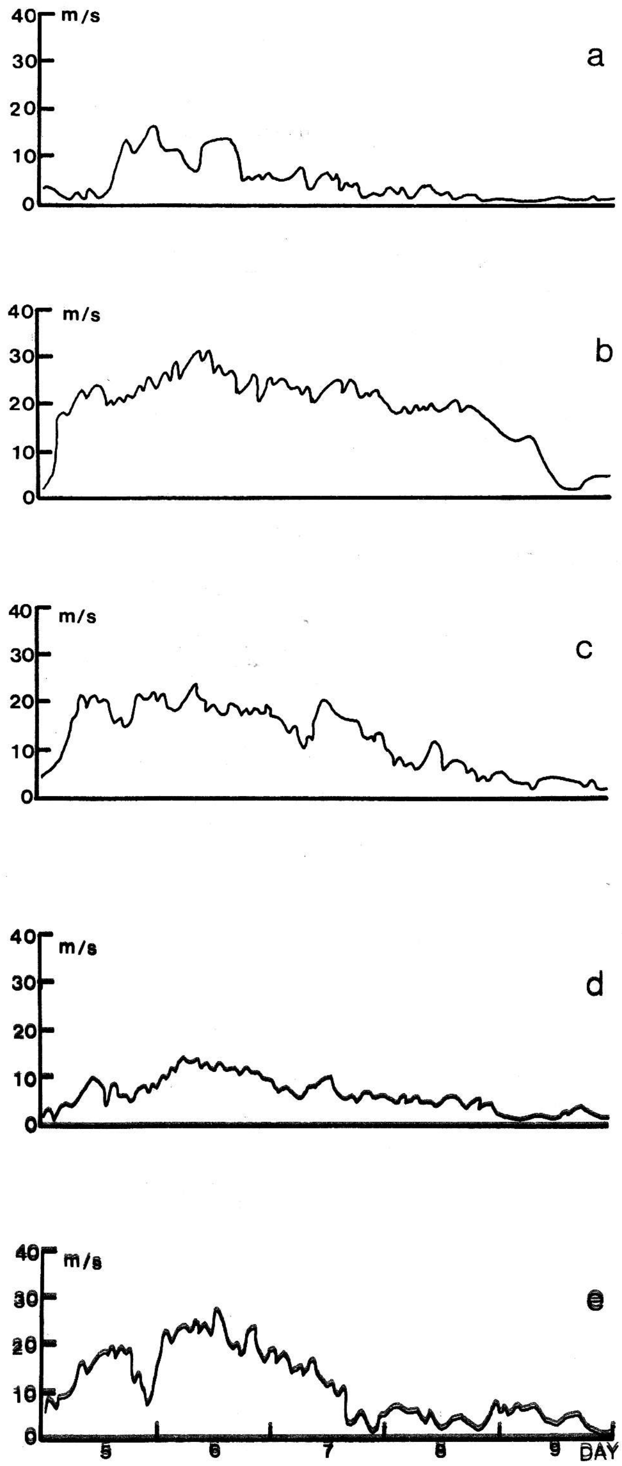


Fig. 5. Daily courses of the maxima hourly gusts of wind (at Zadar ten-minute averages) from 5-9 March 1982 at: a) Ogulin, b) Senj, c) Pula, d) Zadar and e) Split.

Sl. 5. Dnevni hod maksimalnih satnih udara vjetra (za Zadar desetminutni srednjaci) od 5-9. ožujka 1982 u: a) Ogulinu, b) Senju, c) Puli, d) Zadru i e) Splitu

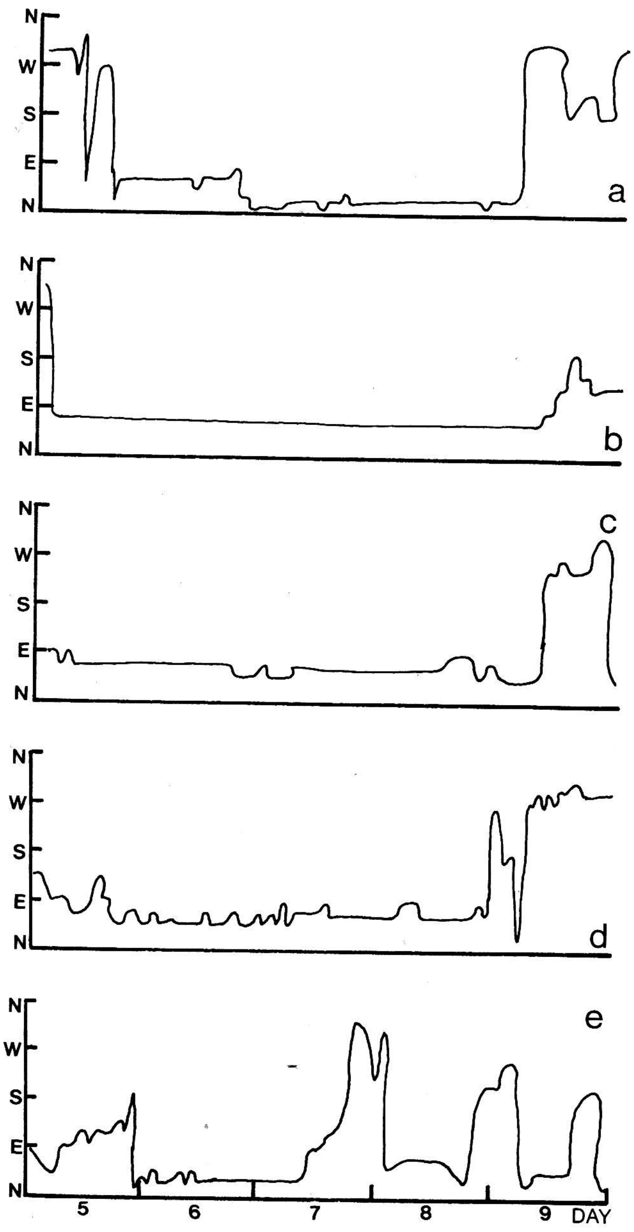


Fig. 6. Daily courses of the wind direction. Other data as in Figure 5.

Sl. 6. Dnevni hodovi smjera vjetra. Ostalo kao na slici 5.

The basic relation from which we start is equation (8). First it is decomposed to components in the zonal and merdional direction. Using maps of AT 700 mbar surfaces and relations (5) and (6), the components of geostrophic wind were calculated. Making use of maps AT 850 mbar, the relation (7) and the presumption that geostrophic wind has the same shear to the ground as from 700-850 mbar, the components of thermal wind were calculated for each 200 m vertically from 0 to 3000 m. The Ekman wind was calculated on the basis of relations (2), (3) and equations for coordinate transformation (orthogonal rotation, Bronštajn and Semendjajev, 1975) which had to be done because of exchange of "Ekman's" coordinate system defined by (3a) with usual zonal-meridional one.

When all components were obtained, their scalar summing was done. On the basis of these results and the Pythagoras theorem, speeds and corresponding directions of the katabatic components were calculated. Computation was performed by microcomputer ZX Spectrum 48 K. Presentation of the results for Pula on 6 March is given in Table 1. The final results of the katabatic components are presented in Figures 9 and 10 for Pula and Zadar respectively. As can be observed from these figures, the results are similar for Pula and Zadar. The direction of the katabatic component varies about the northern one. The speed is the greatest in the boundary layer (in most cases between 200 and 500 m above ground because of surface friction) and at the second term (6 March) that agrees with the preceding ilustrations (Figures 7 and 8). A stronger decreasing of wind speed is emphasized from 1-2 km height, depending on the term. Such a profile is understandable because relatively cold air is accelerated while descending from upper heights toward the ground, the consequence of which is the katabatic component from the considered context (see Paradiž, 1957).

Table 1. A presentation of the calculation of the bora katabatic components for Pula on 6 March 1982 at 0000 GMT.

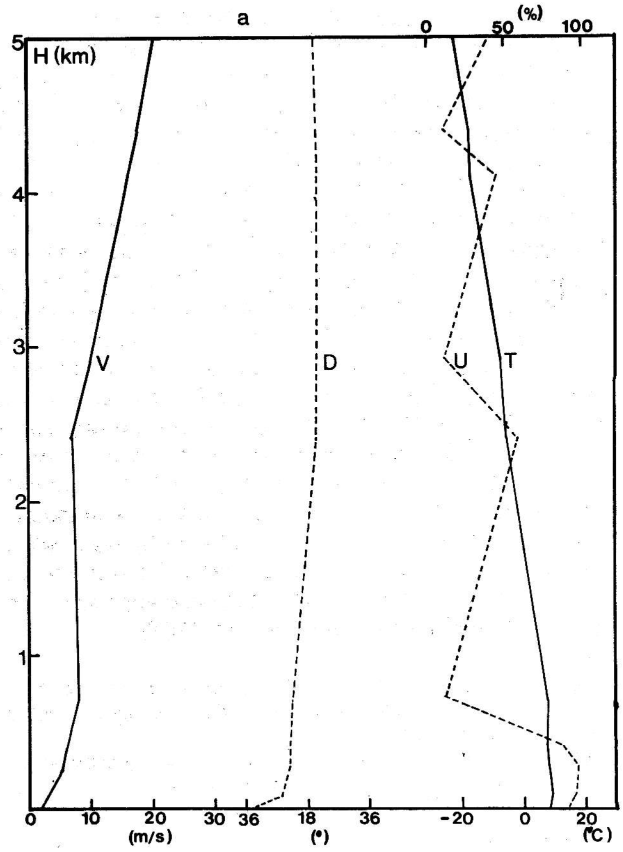
Tab. 1. Prezentacija izračunavanja katabatičke komponente bure za Pulu 6. ožujka 1982. u 00 GMT

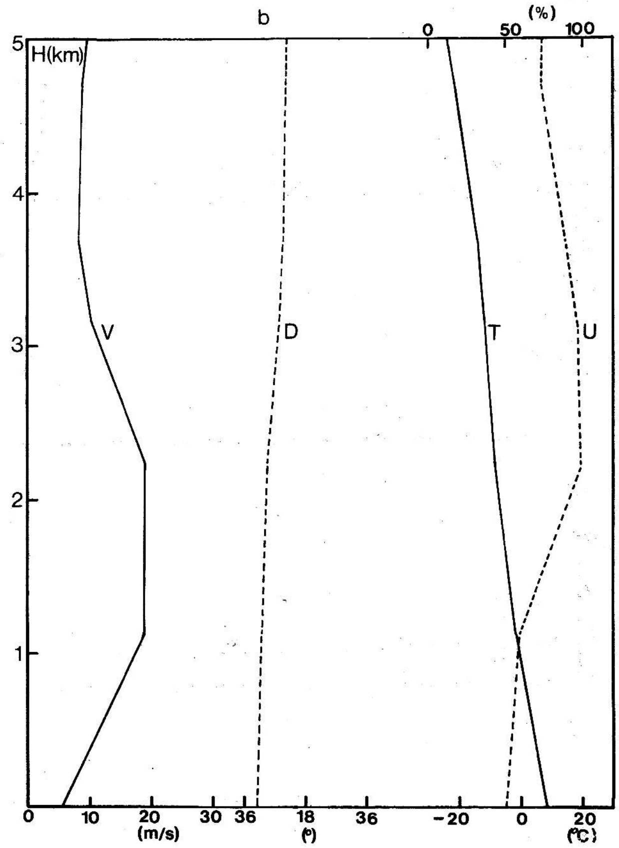
Height (m)	Bx	By	Tx	Ty	Ex	Ey (m/s)	Dir. (°)	K Spead (m/s)
	(m/s)		(m/s)					
100	-9.9	-8.4	-13.3	2.3	-4.1	-2.0	319	11.5
200	-10.7	-9.0	-12.8	2.3	-7.4	-2.5	313	12.9
400	-11.5	-9.6	-11.8	2.1	-11.4	-1.3	312	15.7
600	-13.1	-9.2	-11.0	1.9	-12.6	-0.4	315	15.0
800	-15.6	-9.0	-10.0	-1.8	-12.6	1.2	330	13.9
1000	-16.5	-9.5	-0.2	1.6	-12.3	2.2	339	14.2
1200	-16.5	-9.5	-8.2	1.4	-12.0	2.3	344	13.7
1400	-17.2	-8.0	-7.3	1.3	-11.8	2.2	351	11.6
1600	-17.2	-8.0	-6.4	1.1	-11.8	2.2	335	11.3
1800	-17.8	-6.5	-5.5	1.0	-11.8	2.1	3	9.6
2000	-18.7	-3.3	-4.5	0.8	-11.9	2.1	20	6.6
2200	-18.7	-3.3	-3.6	0.6	-11.8	2.1	28	6.8
2400	-17.9	-1.6	-2.8	0.5	-11.8	2.1	38	5.3
2600	-160	0.0	-1.8	0.3	-11.8	2.1	45	3.3
2800	-13.9	1.2	-0.9	0.2	-11.8	2.1	48	1.6
3000	-10.4	6.0	0.0	0.0	-11.8	2.1	50	1.5

If better results are to be obtained more precise methods must be used for calculating geostrophic and thermal wind (mesomaps), and relation (8) should be substituted with some, if possible, more real connection (see Pielke, 1981). The linear connection between the components in (8) was discussed by Makjanić (1962) too.

5. CONCLUSION

The case of bora wind registered during the ALPEX SOP (5-7 March 1982) excels in its longevity (more than three days), spacious spread (over the greater part of the eastern Adriatic Coast) and strength of the wind. This bora was the most pronounced at Senj, which is in agreement with earlier research of this phenomenon.





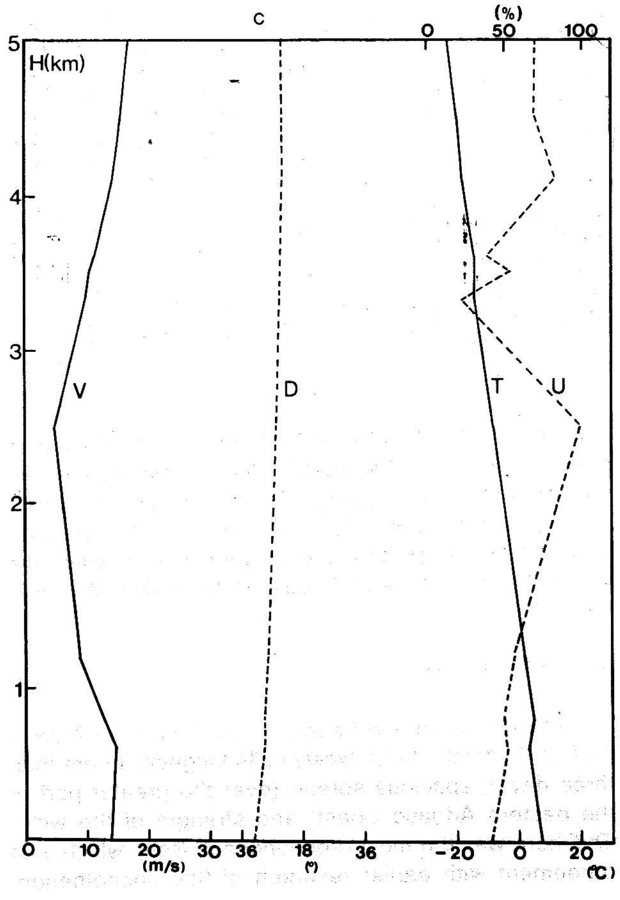


Fig. 7. The vertical profile of: wind speed (V), wind direction (D), temperature (T) and relative humidity (U) at Pula on: a) 5, b) 6 and c) 7 March 1982 at 0000 GMT

Sl. 7. Vertikalni profil brzine vjetra (V), smjera vjetra (D), temperature (T) i relativne vlage (U) u Puli na: a) 5, b) 6 i c) 7. ožujka 1982. u 0000 GMT.

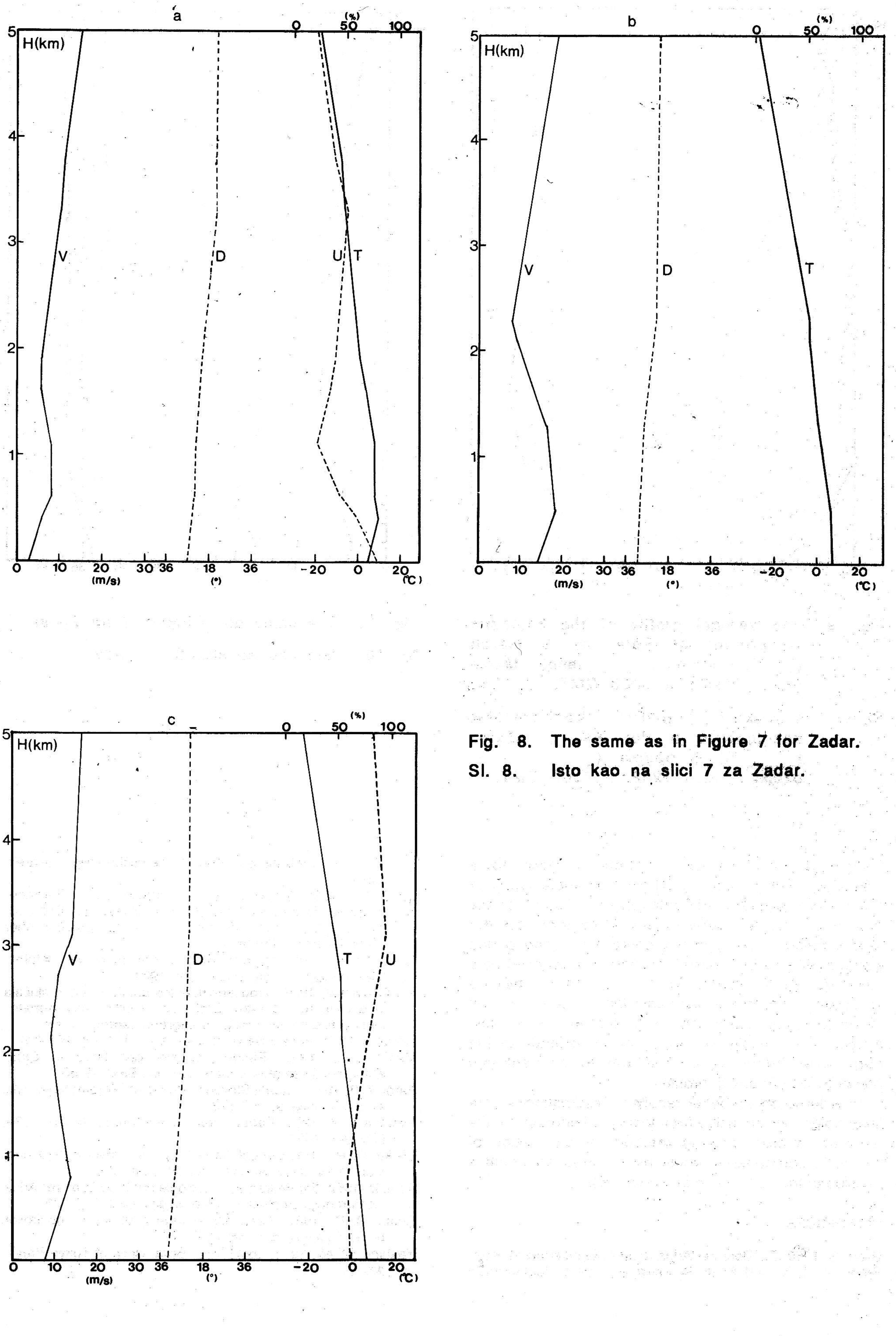


Fig. 8. The same as in Figure 7 for Zadar.

Sl. 8. Isto kao na slici 7 za Zadar.

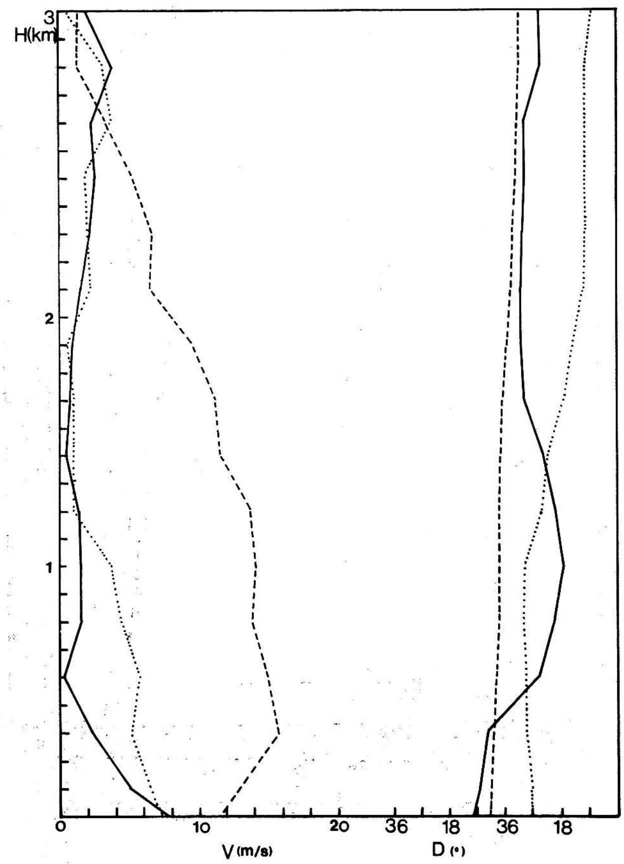


Fig. 9. The vertical profile of the katabatic component at Pula on: 5 March (____), 6 March (_ _ _) and 7 March (.......), 1982 at 0000 GMT.

Sl. 9. Vertikalni profil katabatičke komponente u Puli na: 5. ožujka (______), 6 ožujka (_ _ _) i 7. ožujka (.......) 1982. u 0000 GMT.

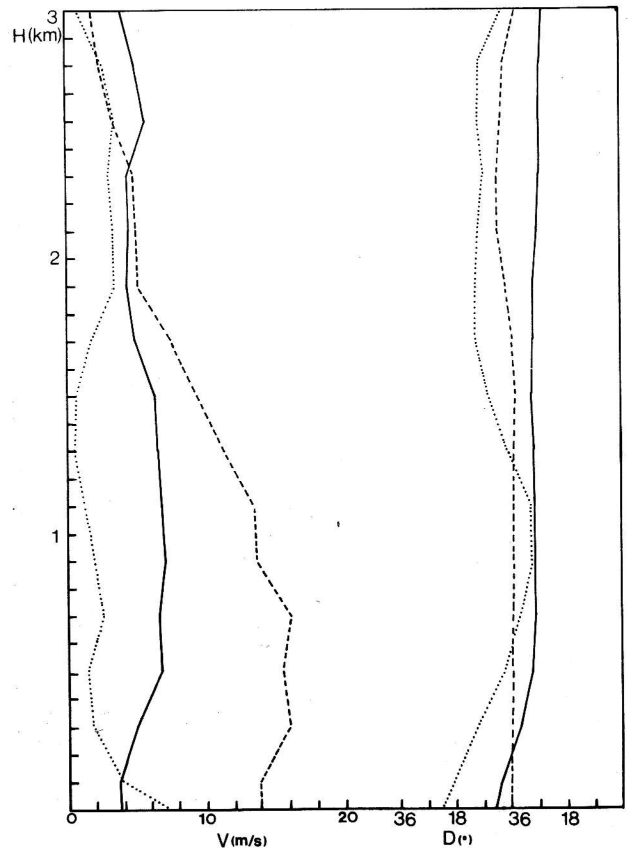


Fig. 10. The same as in Figure 9 for Zadar.

Sl. 10. Isto kao na slici 9 za Zadar.

Consideration of synoptic situations leads to a conclusion that it is a typical bora example because there was a relatively cold anticyclone in Europe on the mainland and a relatively warm cyclone on the Mediterranean. Although the entire mentioned period was named as a bora period, the most pronounced bora occurred on 6 March. That is confirmed by the calculation of bora katabatic component. Consideration of the vertical profile of this component makes possible at least theoretically, a more precise estimate of the bora layer height in comparison to conventional presentation of vertical profiles.

In order to obtain better results for estimation of bora layer height, which, aside from theory is important for the airtraffic, a more precise method for calculation of katabatic components would be required as would a revision of the connection in relation (8).

REFERENCES

Band, G. 1950: Die Bora der Adria (doktorska disertacija), Koln.

Bronštajn, I. N. and K. A. Semendjajev, 1975: Matematički priručnik za inženjere i studente. Tehnička knjiga. Zagreb, 695 str.

Ćurić, M. 1983: Osnovi dinamičke meteorologije. Prirodno-matematički fakultet univerziteta u Beogradu. Beograd. 317. str. Deutscher Wetterdienst, 1982: Europaischer Wetterbericht, Offenbach.

ICAM, 1984: 18 International Conference for Alpine Meteorology, Opatija 25-29. Sep. 1984.

Ivančičević, V. 1986: Trodimenzionalna analiza jednog slučaja jake bure na Jadranu. Dipl. rad, Prirodnoslovno-matematički fakultet sveučilišta u Zagrebu,Zagreb, 43 str.

Lukšić, I. 1975: Bura u Senju, Senjski zbornik, Senj, 467-494.

Makjanić, B. 1962: Einige Aspekte der Bora in Split, Konferencija za alpsku meteorologiju, Bled. 49-55.

Paradiž, B. 1957: Burja v Sloveniji, Deset let hidrometeorološke službe, Ljubljana, 147-172.

Petkovšek, Z. 1976: Periodičnost sunkov burje, Razprave 20, Ljubljana, 67-75.

Pielke, R. A. 1981: Dirnual boundary layer development over sloping terrain. J. Atmos. Sci., 38. 2198-2212.

Poje, D. 1962: Ein Beitrag zur Aerologie der bora über der Adria. Konferencija za alpsku meteorologiju. Bled. 372-383.

Smith, B. B., 1987: Aerial Observations of the Yugoslavian bora. J. Atmos, Sci., 44, 269-297.

Yoshino, M. M., 1976: Local Wind Bora. Univ. of Tokyo Press, 289 str.

REZIME

Uz planinske zapreke, koje oštro dijele dvije temperaturno različite zračne mase, pojavljuje se pojačani vjetar koji nosi naziv bura. Osim na istočnoj obali Jadrana, ona se javlja u području Nove Zemlje, na Uralu, u Norveškoj, na Kavkazu i drugdje (Paradiž, 1957).

Bura je bila predmet istraživanja Banda (1950), Paradiža (1957), Makjanića (1962), Poje (1962), Lukšića (1975), Petkovšeka (1976), Yoshina (1976), Smitha (1987) i drugih.

Ovaj rad, pored kratkog prikaza konvencionalnih podataka za slučaj jake bure koja je trajala od 5-7. ožujka 1982. (ALPEX SOP), bavi se analizom vertikalnog profila njene katabatičke komponente polazeći od teorijskih postavki Makjanića (1962). Rezultati ukazuju na karakterističan hod meteoroloških parametara za vrijeme bure, s maksimalnom brzinom vjetra između 0.5-2 km visine, s relativno dobrom vremensko-prostornom postojanošću smjera vjetra (u prizemlje NE) i temperature zraka. Prikazi konvencionalnih podataka (slike 7 i 8) kao i proračuni katabatičke komponente (slike 9 i 10) ukazuju na to da se visina sloja bure može tražiti na visini između 1-2 km.

Bolji rezultati mogu se očekivat nakon provođenja preciznijih metoda izračunavanja katabatičke komponente i revizije korištenih relacija za njeno izračunavanje.