EPISODE WITH STRONG DOWNSLOPE WIND IN THE SOUTHERN AND CURVATURE CARPATHIANS IN THE PERIOD 5-6 FEBRUARY 2020

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Abstract. Episode with strong downslope wind in the Southern and Curvature Carpathians in the period 5-6 february 2020. The phenomenon that occurred during the blizzard from February 5-6 in the mountains and especially on the southern slopes of the Southern Carpathians, is known in the literature as "strong downslope winds". This phenomenon occurred in a typical blizzard configuration, in which the differentiated advection of temperature led to the formation of a very stable air layer, with thermal inversion approximately between the levels of 850 and 700 hPa; and it also contributed in this layer to the change of wind direction to vertical. Thus, the existence in the same air layer of two factors favorable to the formation of a critical level, created the ideal conditions for generating strong downslope winds.

Keywords: critical level, downslope wind, thermal inversion, isentropic

1. CONCEPTUAL MODEL – DOWNSLOPE WINDS

The undulating movements occur mainly in **a layer of stable air with shearing force**, or **under an inversion**, air moving over a mountain ridge with a speed limit.

In some situations, wind shearing due to changes in wind direction or speed can cause the flow at the intersection of the mountain barrier to be zero or even a reversal of flow (Fig. 1 – left). If this happens when the flow that intersects the mountain barrier near the top of the mountain is sufficient for the development of **mountain waves**, then this level with zero flow is called **the critical level**. Critical levels **do not allow the vertically propagating energy** associated with mountain waves to continue to rise. This energy **is diverted down by the critical layer**, back to the surface. Consequently, critical levels can contribute to the **development and/ or intensification of downslope winds**. A second factor that can prevent the vertical propagation of energy is the presence **of thermal inversion** (Fig. 1 - right), which can act in a similar way to **a critical level**.

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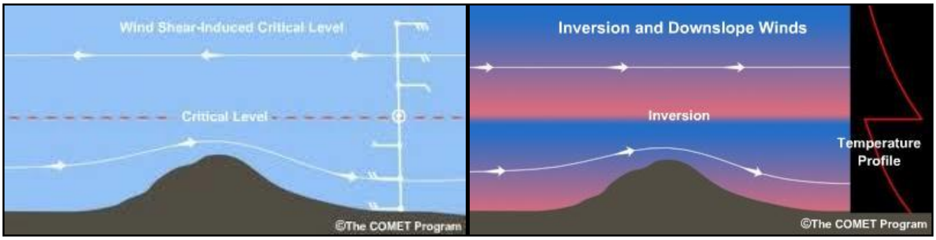

Fig. 1. Critical level above an orographic obstacle - induced by wind shear (left) and thermal inversion (right) Source: COMET modules

This is because a buoyancy oscillation can take place in a stable layer and cannot take place in an unstable layer so that the energy of **a gravitational wave cannot propagate upwards**. In conclusion, the wind speed can be 2-3 times higher than the wind speed from the height of the mountain ridge. This is the case from the night of 5 to 6 February, when at the Sinaia Cotăweather station located at an altitude of 1510 m a wind speed of 60 m/s was recorded, compared to only 41m/s at the upper level of the Bucegi Mountains, respectively at Vf. Omu.

2. THEORETICAL CONSIDERATIONS

The theory put forward by Ficker (1931) is that of the hydraulic jump, which starts from the observation that the slope wind is often associated with an **inversion just above the mountain ridge**. The equation of motion is explained by analogy with the behavior of shallow water. Atmospheric phenomena that occur under an inversion are manifested in the same way as those in "shallow water". In hydraulics it is known that the speed and thickness of the current in a section are closely correlated. The atmosphere provides an analogy to the situation mentioned above. **The inversion is the interface between a cold and a hot air mass**, the density at the top of the flow is not zero, but only slightly reduced by an amount dependent on the temperature difference over the inversion.

Another parameter that explains this phenomenon is the Froude number. Froude's number is similar to **the ratio between kinetic energy (wind speed) and potential energy (stability above the orographic obstacle)**.

The Froude number is dimensionless and indicates whether the kinetic energy is sufficient to cross the mountain (Durran, 1990). Thus, the Froude number suggests whether orographic ascent is possible or not. In this case, the kinetic energy is represented by the wind speed (U) and the potential energy by the Brunt–Väisälä frequency (N) or the mountain height (h).

$$F_r = \frac{U}{Nh}$$

Where N is the Brunt–Väisälä frequency, and h is the height of the mountain.

If $F_r<1$, ie **if the mountain is high and the stratification is stable** (high Brunt–Väisälä frequency), then the air will not be able to climb the mountain and bypass it. **If the mountain is long, the blocking phenomenon will occur with the subsequent splitting of the flow.**

When Froude's number is large ($F_r> 1$), ie either the air is very weakly stable (Brunt–Väisälä frequency is small) or the mountain is small or the speed at which it is approached is high, then the air will rise over the mountain with a very small lateral displacement. If the air passes the mountain, the width of the obstacle comes into play.

3. GENERAL SINOPTIC CONTEXT

On February 5, the southeastern part of Europe and, implicitly, the geographical area of our country was under the influence of a low pressure field at sea level (Fig. 2 left). The rest of the continent was under the influence of an anticyclone, also very intense and extensive as an area, whose center was located just southwest of the British Archipelago.

The evolution was specific to the coupling blizzard configuration, in which the ridge of the anticyclone extended to southeastern Europe, and the cyclone in the Aegean Sea area moved to the northern basin of the Black Sea (Fig. 2 - right).

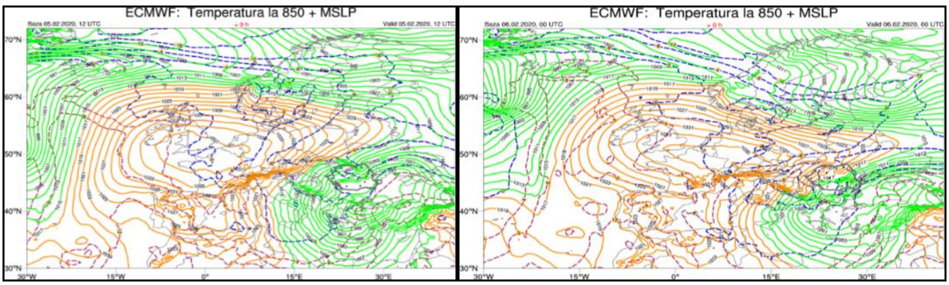

Fig. 2. ECMWF analysis – Sea level pressure on 05 February at 12 UTC (left) and on 06 February 2020 at 00 UTC (right)

In the analyzed area, air flows in accordance with the geopotential structure, from ground level to near 850 hPa (Fig. 3 – left), was from **the north and north-northeast**, respectively perpendicular to the mountain range. At the same time, at the level of 700 hPa (Fig. 3 – right), it was made from **east-**

northeast, and at the level of 500 hPa it was made from the **southeast** (Fig. 3), there being a significant component of flow parallel to the mountain range.

This flow structure ensures **favorable conditions for the existence of the critical level immediately above the level of 800 hPa.**

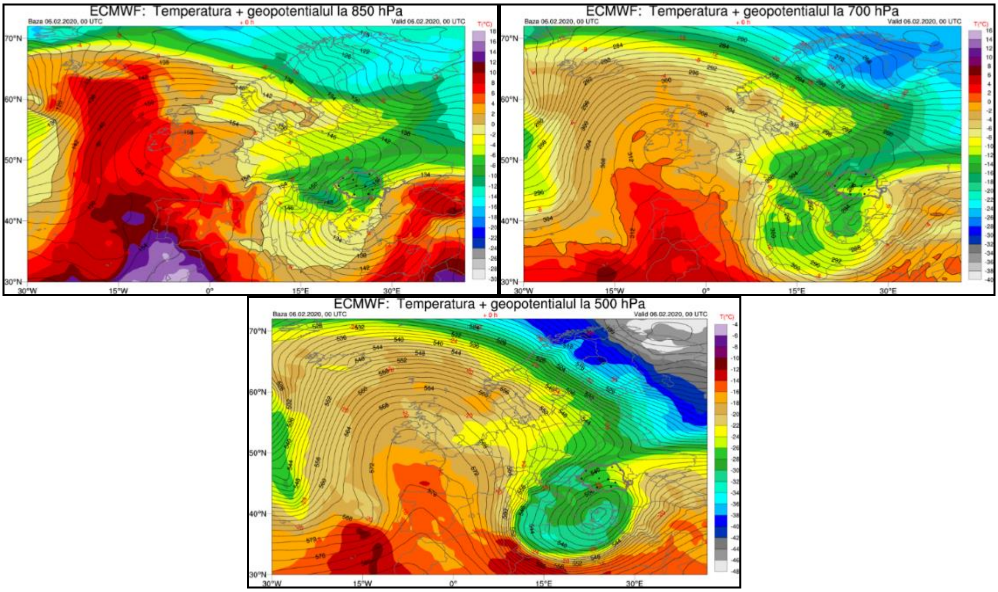

Fig. 3. ECMWF analysis - Geopotential at 925 hPa (right), 850 hPa (left) and 700 hPa (bottom) on February 6, 2020 at 00 UTC

4. MEZOSCALE ANALYSIS – SEA PRESSURE DISTRIBUTION IN ROMANIA

In Romania, during this period (February 5-6, 2020) the baric gradient registered a significant increase of over 24 hPa between the northeastern and southeastern extremities of the country. In the analyzed area, respectively the eastern part of the Southern Carpathians and the Curvature Carpathians, the baric gradient was much more intense (Fig. 4), even compared to the south-eastern regions of the country. This evolution was determined by the presence of the mountain range, which blocked for a while the advection of cold air, and on the other hand, the evolution of the cyclone over the western Black Sea Basin, and determined a stationary, then a slow increase in pressure at soil south of the Southern Carpathians.

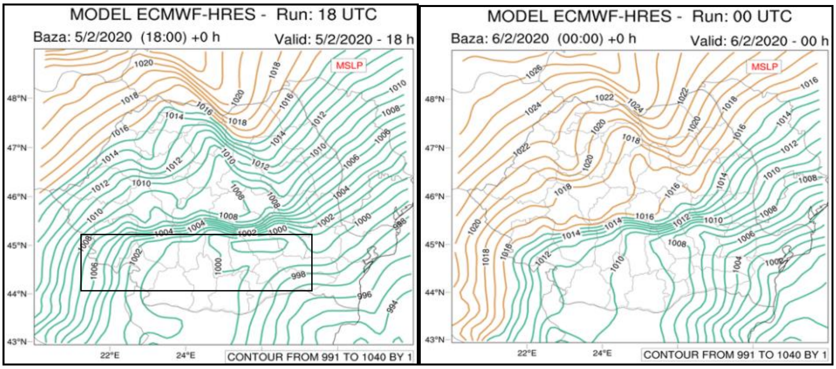

Fig. 4. HRES ECMWF analysis - Ground pressure on05 February 18 UTC (left) and 06 February, 00 UTC (right)

In order to show the increase of the pressure gradient in the analyzed area, the pressure difference between Făgăraș weather station and Câmpina, Curtea de Argeș and Pătârlagele weather stations was shown in the table below (Table 1) between 5 of February, 09 UTC, and 6 of February, 09 UTC.

Table 1. The pressure difference (hPa) between Făgăraș weather station and Câmpina, Curtea de Argeș and Pătârlagele weather stations

Hour (UTC)	**Câmpina**	**Curtea de Argeș**	**Pătârlagele**
9	4.8	4.5	4.7
10	5.6	5.4	6
11	5.8	6	5.7
12	7.2	6.7	6.8
13	7.4	7.8	7.1
14	6.8	7	6.5
15	7.9	8.3	7.3
16	9.5	9	8.6
17	9.6	8.4	9.4
18	8.9	8.2	7.9
19	9.3	9.2	8.4
20	10.8	10	9.5
21	**10.9**	**10.2**	**10.5**
22	9.9	9.4	9.7
23	9.1	8.6	9.4
0	9.7	8.3	9.6
1	9.4	7.9	9
2	9	7.5	8.9
3	8.5	7	8.7
4	7.7	6.9	8.3
5	7.7	6.5	8.1
6	7.8	6.1	8.1
7	8.4	6.2	9
8	8.3	6.1	8.8
9	7.2	5.6	7.8

From the analysis of these data it is found that the largest pressure difference on one side and on the other side of the Southern Carpathians was made at 21 UTC, when it coincided with the registration of maximum speeds in the analyzed area. The high pressure upstream of the mountain barrier and the low pressure downstream of it, offer a possible scenario for the development of winds down the slope.

5. EVENT DESCRIPTION – VERTICAL SECTION ANALYSIS

In order to highlight the vertical structure of the various parameters useful in the analysis of this case, a vertical section (Fig. 5) was drawn up in the north-northwest to south-southeast direction, from southeastern Transylvania, over the Carpathian Mountains chain, to the Romanian Plain.

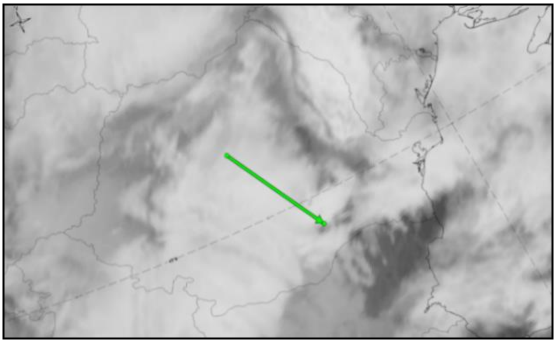

Fig.5. The position of the vertical section

On February 5 at 18 UTC in the vertical sections it can be seen that in the lower layers of the troposphere the advection of cold air was intense (Fig. 6 top left – blue lines). At the same time, in the middle troposphere there is advection of warm air (Fig. 6 upper left – red lines), associated with the occluded atmospheric front.

Differential temperature advection led to the formation of a very stable air layer, **with thermal inversion approximately between the levels of 850 and 700 hPa.** This very stable air layer was another very favorable factor for the existence of **a critical level**, which would favor the **development of strong winds down the slope**. Thus, the existence in the same air layer of two factors favorable to the formation of a critical level, namely **the change of wind direction vertically** and the presence of **an inversion layer**, which acted favorably to create the ideal conditions for generating **strong downslope winds**. Due to the increase in the pressure gradient and the fact that the cold air mass managed to cross the Carpathian Mountains, the wind speed in the lower troposphere reached average speeds of over 25 m/s near the level of 800 hPa (Fig. 6 bottom left - brown lines). **The allure of the isentropes in the sheltered part of the mountains was inclined**, which shows the intensification of the foehn processes. The downward movements of the air are also highlighted by the field of vertical movements that had negative values (Fig.6 lower right - blue dotted lines) in the shelter of the mountains.

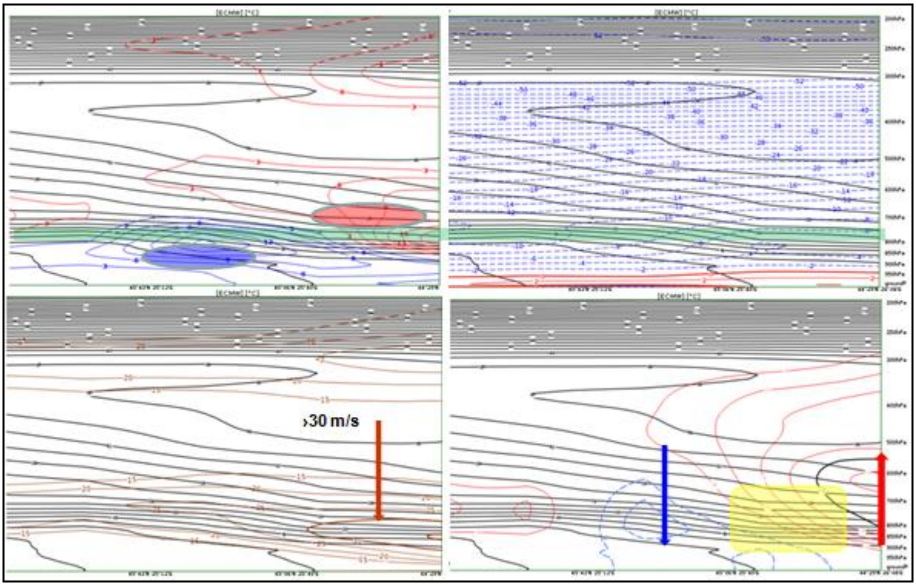

Fig. 6. Vertical sections from February 5 at 18 UTC for potential equivalent temperature (black isentropes, range 2ºC): top left: temperature advection (red: warm advection, blue: cold advection); upper right: air temperature (continuous red isotherms - temperatures greater than or equal to 0ºC; interrupted blue isotherms - temperatures lower than 0ºC, range of 2ºC); lower left: average wind speed (brown isotach, range 5 m/s, only values greater than or equal to 15 m/s); bottom right: vertical speeds (red - ascending; blue – descending.

5.1 Event description - analysis of aerological soundings

The aerialsounding data from Bucharest on February 6 at 00 UTC show the **presence of thermal inversion**, somewhere above the level of 800 hPa (Fig. 7 left) and also above this level is observed **the change of wind direction** from the predominantly north-northeast to predominantly southeast. As a result, the two elements identified in the vertical sections that indicate the presence of **the critical level** are also evident on the aerological sounding in Bucharest. The next sounding, on 12 February at 12 UTC, confirmed the sharp descend on the southern slopes of the Southern Carpathians, the relative humidity in the air layer between the surface and about 750 hPa (2200 m) was generally below 20% (Fig 7 – right).

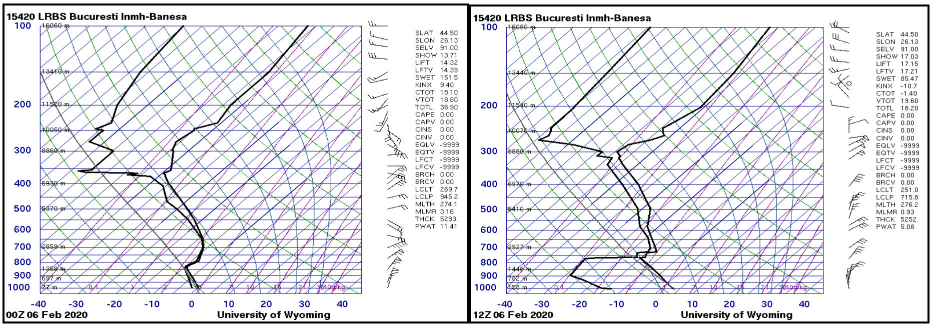

Fig. 7. Air chart, Bucharest, February 6 at 00 UTC (left), February 6 at 12 UTC (right), (Source: University of Wyoming)

5.2 Event description - wind speed analysis

From the analysis of wind gust speeds, the maximum intensity in the analyzed area is reached in the first part of the night of 5/6 February. At 21 UTC it is highlighted the fact that at the **Sinaia Cotă meteorological station (1550 m)** a particularly high wind speed was registered, respectively **60 m/s** (Table 2). This speed was the highest wind gust recorded in our country in the entire range analyzed. The fact that this maximum wind speed was registered at Sinaia Cotă station and not at the upper level of the Bucegi Mountains can only be explained by the amplification of the downward movements the air slope determined by the existence of the **critical level**. This situation can also explain **the maximum speed of 40 m/s** recorded at **the Bisoca meteorological station (850 m)**. These downward movements of the air were fully felt in the sub-Carpathian area where the gust speed reached **22 m/s in Câmpulung,** 17 m/s at Curtea de Argeș, 16 m/s at Câmpina and 18 m/s at Ploiești.

Table 2. Maximum wind gust (m/s) between 5 February at 15 UTC and 6 February at 03UTC

Hour (UTC)	Sinaia	Bisoca	Câmpulung	Curtea de Argeș	Câmpina	Ploiești	București Băneasa
15	20	33	13	7	12	10	10
16	22	34	13	11	12	11	10
17	20	38	17	12	15	15	15
18	22	38	21	5	16	10	16
19	21	37	21	10	14	16	19
20	31	**40**	20	10	**16**	**18**	15
21	**60**	39	20	10	15	13	**9**
22	25	39	**22**	15	13	12	11
23	28	37	17	**17**	15	13	6
0	30	36	13	15	10	13	4
1	36	38	19	10	12	12	5
2	37	36	19	14	12	13	6
3	38	35	14	10	15	10	6

These very high wind speeds recorded at meteorological stations in the sub-Carpathian area, usually sheltered by the Carpathian chain and with a high share of atmospheric calm, can only be explained by **the downward movements** of the air associated with the foehn process and the effect of **their intensification produced by the existence of the critical level**. The forced descent of the air on the southern slopes of the Southern Carpathians is also evident by the extremely low values of relative humidity, at some weather stations, even below 20% (Fig. 9).

A different evolution can be noticed in the central area of Muntenia, respectively at the Bucharest Băneasa weather station, where from gust speeds of 19 m/s at 19 UTC, it reaches only 9 m/s at 21 UTC. This situation is explained by the change of direction from the predominantly northeastern sector to the predominantly northern one, in accordance with the dynamics of the cyclone in the Black Sea Basin, but also with the forced descent on the southern slopes of the Southern Carpathians. This area of weakening the wind intensity captured by the Băneasa meteorological station, can also correspond to the “jump” area described by the conceptual model that describes the strong winds down the slope (Fig. 8).

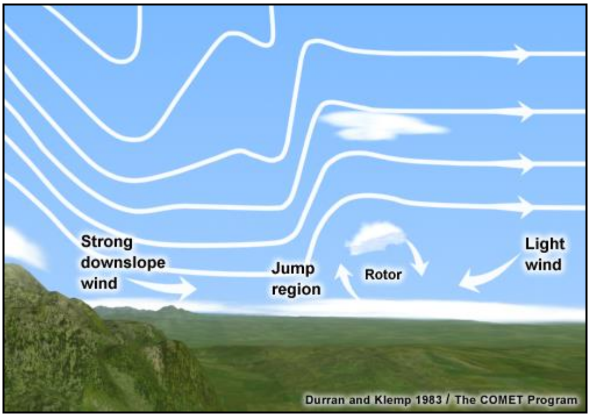

Fig. 8. Conceptual model describing strong winds down the slope(downslope wind) Source: COMET Module

In fact, as observed in the vertical sections in the central part of the Romanian Plain, there were positive vertical movements (ascention). As a result, the low wind speed or the development of a convergence zone, to which the ascent is added, could explain the distribution of precipitation in the form of snow in the southern part of the country, with a clear delimitation of the area where the snow layer exceeded 30 cm (Fig. 9 left).

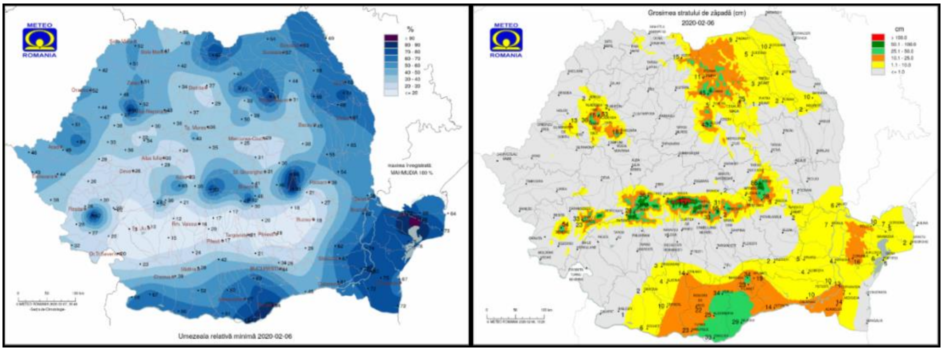

Fig. 9. Maximum relative humidity (left) and snow cover map (right) for the interval 5 February at 08 UTC - 06 February at 08 UTC

CONCLUSIONS

As a result of these phenomena, according to the Romsilva National Forests Authority, 98,000 hectares of forests under its administration were affected by the strong wind intensifications. Of these, a total of 1,058 hectares were knocked down en masse. The largest fallings were registered in the forests managed by the Mureș Forestry Department, with an area of 12,590 hectares, followed by the Prahova Forestry Department, with an area of 10,165 hectares.

The Sinaia ski area was also affected, where the gondola support pillars and cables were severely damaged. "The worst situation was registered at the Carp Gondola – altitude 2000, where wind gusts of over 200 km/h tore off one of the garage walls and several panels of the training station. On the line of the Sinaia Gondola (Elevation 1000 - Elevation 1400) between pillars 4 and 5, three large trees fell over the cables”. – news.ro

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