FOEHN OVER THE EASTERN CARPATHIANS, CHARACTERISED BY A WESTERN CIRCULATION OF ANTICYCLONIC SHADE. CASE STUDY, 4–6 FEBRUARY, 2011

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This paper explores the characteristics of an air mass crossing a mountain obstacle oriented perpendicularly to the air circulation direction, inducing foehn effects on its lee side. After a brief presentation of the general concepts from the specialist literature concerning the occurrence of foehn, this analysis focuses on the particular situation of February 4–6 2011, characterised by a western circulation of anticyclonic nuance, which the northern massifs of the Eastern Carpathians were subjected to, triggering foehn effects in Moldavia. The behaviour of the main meteorological characteristic of the air mass crossing the orographic barrier was interpreted on the grounds of the vertical profiles obtained with the Non-Hydrostatic Mesoscale Model (NMM) numerical model. Thus, the vertical distribution of relative moisture, cloudiness and air temperature, as well as the wind vertical profile on both sides of the mountain obstacle were analysed. Using the data from *in situ* observations over the interval of concern and the diagnostic maps plotted at the National Meteorological Administration (NMA), the differences found in the temperature and precipitation distribution between the windward and leeward sides of the mountain obstacle were highlighted.

1. INTRODUCTION

According to the specialist literature (Bogdan 1993), typical foehn processes occur when a moist air mass moves perpendicularly to a mountain chain. When impacting the windward slopes, the air-mass takes a forced upward motion gradually cooling through adiabatic relaxation, at a thermal variation rate of 1ºC/100 m (the dry adiabatic gradient), until the condensation level is reached. Enhanced cloudiness thus occurs through the orographically-forced aloft and precipitation as rain falls implicitly more intense with height, a process developed with the release of latent heat of condensation. Above the condensation level, the cooling of the saturated air mass with a relative moisture of 100% is at the rate of 0.6ºC/100 m the moist adiabatic gradient (the rain turning to snow if temperature decreases to negative values).

After the mountain crest is escalated, the air driven in a downward motion along the windward side, warming through adiabatic compression, reaches its base at a higher temperature than at the beginning of its ascent (4 … 6ºC or more, dependent on the mountain obstacle height).

The adiabatic compression process leads to a fast decrease of air moisture and of precipitation, which stops under the mountain crest (N. Ion-Bordei 1988).

It must be underlined that, in the sector where the downward air flow impacts the sheltered mountain sides, a counter-foehn phenomenon might occur from the air flowing direction, which exerts more enhanced deflation compared to the rest of the area. This phenomenon may explain the wind intensification in foothill areas, causing even tree uprooting in the forest areas, due to wind channelling along the valleys, and foehn effects induced by the mountainous obstacle.

The foehn effects depend on the moisture content of the air mass (usually high), the circulation intensity in the mountainsides (intense upward motions), the altitude of the mountain chain (the higher the chain the more intense the foehn processes, e.g. the Swiss Alps, 3,500 – 4,000 m a.s.l.), the season

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(in winter and in spring, at high wind speeds, with more contrasting warming and drying processes compared to the norm, induced by the air masses, the effects can be more intense).

At the same time, it must also be taken into account that for the air to warm along the lee side, condensation is not compulsory on the windward side, because the air that "comes crashing" downwards over the mountain crest warms up through adiabatic compression and thus becomes drier (Ciobanu 1998). This explains how the air from the upper level becomes a potential foehn source. However, the specialist literature (Bilwiller 1899, cited by Irimescu 2009) points out that there is no significant difference between the foehn and the warm air "crashed down" from anticyclones within vertical downward motions specific to these forms of pressure relief.

Foehn events are actually intense winds settled suddenly, accompanied by temperature increase, potable moisture decrease and sometimes cloudiness vanishing, all those due mainly to the adiabatic warming during the descent on the lee side of the mountain, summed up to the supplementary warming ensured by the release of the latent heat of condensation on the windward side, right above the mountain. Also, the presence of a thermal inversion at the level of the mountain summits seems to be a typical occurrence, preceding the start of a foehn event and the formation of a cavitation depression on the windward side, right under the crest, which enhances the downward motion and the intensity of the flow specific to the atmospheric fluid (N. Ion-Bordei 1988).

The situation of 4–6 February, 2011 was analysed aiming at illustrating the way in which the orography of Romania induces significant foehn effects in the eastern and / or south-eastern lowland areas under the influence of the westerly and north-westerly circulations. This situation occurred under the circumstances of high pressure circulation towards the west-north-west, roughly oriented perpendicularly to the Carpathian range.

2. CASE STUDY, FEBRUARY 4–6, 2011

At the beginning of February 2011, the structure of the ground level pressure field over the European continent highlighted a vast low-pressure area of Icelandic origin, active over the whole northern half of Europe. The ridge of the Azores High dominated the continent's southern half as far east as the longitude of Romania. In this synoptic context, on February 3 (Fig. 1a), the inflow of oceanic air mass was greater over western and central-southern Europe, but Romania was still under the influence of the very cold continental-polar air, which was dominating Eastern Europe. This synoptic conditions were favourable for inducing higher temperatures in the inner Carpathian areas and for a more severe thermal regime in Moldavia. The presence and massiveness of the Eastern Carpathians favoured the occurrence of notable foehn effects with the advance of the Azores ridge. The air temperature distribution in the ridge determined in the boundary layer proved to be completely different, as will be seen further.

Gradually, with the advance of the Azores High, the ocean air mass constituting the mentioned pressure system (warmer than the continental one in the cold season of the year), moved eastwards, aligning in a longitude profile at the western border of Romania (Fig. 1b). The warmer oceanic air is illustrated in green-yellowish and red nuances. The relatively homogeneous air mass, resulted from the mixing of the pre-existing polar air and the recently advected oceanic one, over Romania is rendered in a shade of blue (Fig. 1b).

The analysis of the relative topography of the 1,000–500 hPa layer (representing the lower and median troposphere respectively, up to 5,000 m high) on the map depicting the structure of the thermal field in this layer (the air temperature distribution along the tropospheric column), showed that the thermal regime was more moderate also in the outer Carpathian areas, situated right below the mountain (Fig. 1c). As a matter of fact, because the Eastern Carpathians stand perpendicular to the advance of the Azores ridge, the area was still free of the influence of the warm oceanic air. Therefore, the pre-existing mass of cold air was still persisting. The only explanation remains that the foehn effects are responsible for the warming observed on the windward side of the mountain.

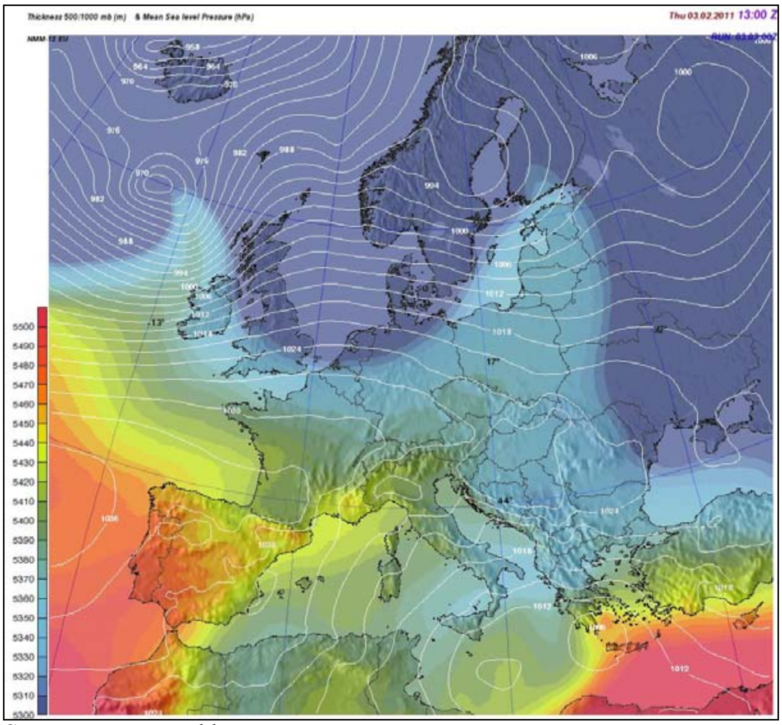

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Fig. 1a – Map with ground-level pressure (white isolines) and relative topography rendering the temperature distribution in the lower and median troposphere (colour waves) in the 1,000–500 hPa layer, February 3, 2011, 13:00 UTC.

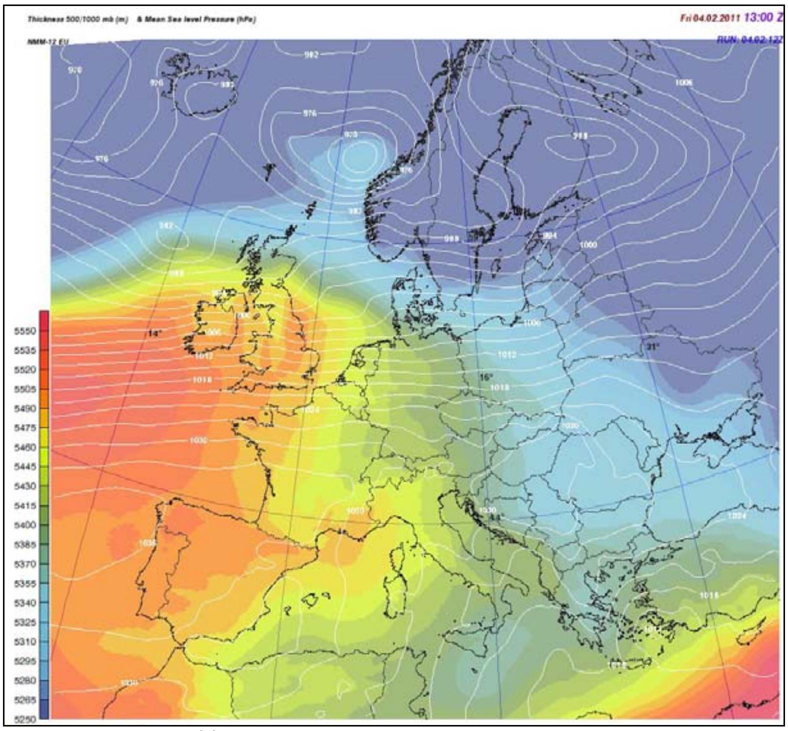

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Fig. 1b – Map with ground-level pressure (white isolines) and relative topography rendering the temperature distribution in the lower and median troposphere (colour waves) in the 1,000–500 hPa layer, February 4, 2011, 13:00 UTC.

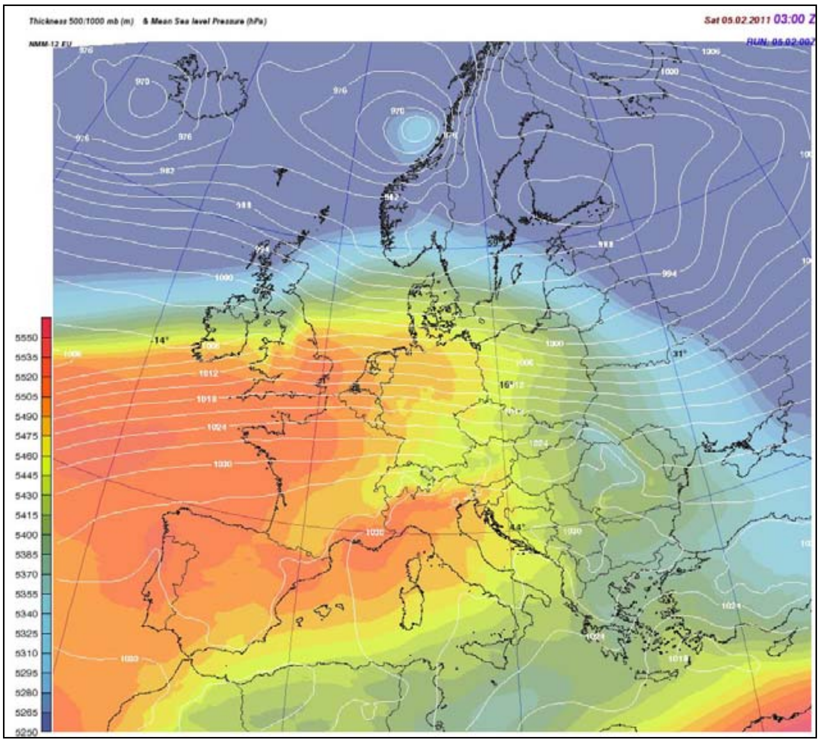

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Fig. 1c – Map with ground-level pressure (white isolines) and relative topography rendering the temperature distribution in the lower and median troposphere (colour waves) in the 1,000–500 hPa, February 5, 2011, 03:00 UTC.

In the upper air structure, a zonal air circulation pattern was observed, depicted by a west-north-west to east-south-east bending of isohypses in the geopotential field at the standard level of 500 hPa (5000 m.a.s.l.), favouring a quasi-perpendicular orientation of the air flow with respect to the (orographic) obstacle, with a meridian disposition (Fig. 2).

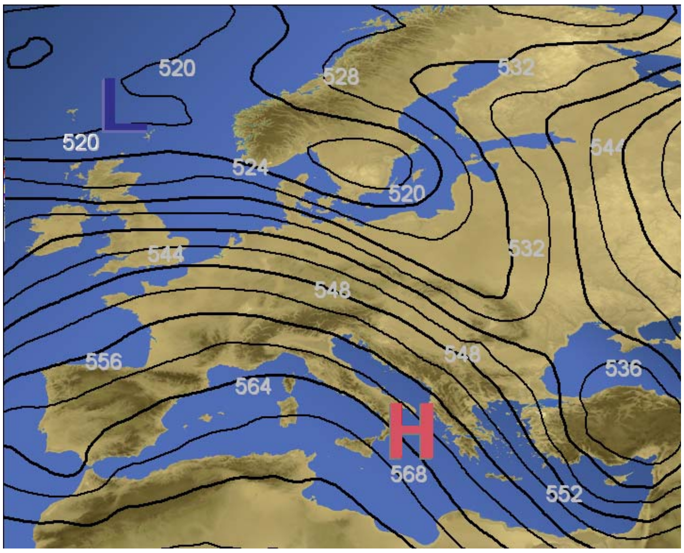

Fig. 2 – Geopotential isohypses at the level of 500 hPa, highlighting the prevailingly western air circulation, February 4, 2011, 00:00 UTC (Bulletin of National Meteorological Administration – NMA).

It can be emphasised that the higher temperatures observed in Moldavia were explained by the thermal advection, but also by the foehn processes occurred over the Eastern Carpathians, as the analysis of the Non-Hydrostatic Mesoscale Model (NMM), developed at the National Centers for Environmental Prediction (NCEP), within the U.S. National Oceanic and Atmospheric Administration (NOAA) showed, using vertical sections, rendering the vertical distribution of the relative moisture, cloudiness and air temperature, and the vertical wind profile on both sides of the mountain massifs in the northern part of the Eastern Carpathians (Figs. 3 a, b, c).

The analysis of the cross-section through the ***relative moisture field*** above the northern part of the Eastern Carpathians, along the parallel of 47º43' N, indicates the presence of an area with a significant moisture content on the slope facing the wind and on the crest (Fig. 3a), as well as high-precipitable potential one (relative moisture > 96%, rendered in nuances of intense red and mauve), where the air is saturated. On the leeside, as a result of the foehn-development process, the relative moisture was found to be considerably decreased (< 50% in green and blue) and the downwards flow growing progressively drier.

The cross-section through the ***cloud cover field*** (Fig. 3b) shows a 100% cloud cover on the windward side of the mountain and in the vicinity of its ridge line, and a significantly decrease of cloudiness to less than 10%, on the lee side accompanied by largely clear sky conditions as the adiabatic compression process involving the down slope wind enhanced.

The characteristic ***windward – intensification*** is accurately illustrated in Figure 3c, showing lower speeds (6–10 m/s) of the air flowing upslope, and higher speeds of >28...30m/s, right under the mountain crest on the lee side of the mountain, where the foehn effects are developing.

The transverse ***distribution of the air temperature*** over the mountain chain is also eloquent for highlighting the foehn effects on the eastern flank of the Eastern Carpathians (Fig. 3 d). The ***differences*** between the variation rate of air temperature between the windward and leeward sides is about ***10ºC*** (according to the thermal adiabatic gradient – moist and dry, respectively).

All the vertical sections, using the outputs of the NMM model, are eloquently illustrating the main theoretical elements of the foehn phenomenon.

The temperature observation data from the weather stations located on the western and eastern sides of the Eastern Carpathians, ***show large differences between the thermal regime in Transylvania***, where the temperature minima were -8...-7ºC ***and that in Moldavia,*** where minima were obviously higher, -2... +1ºC (Figs. 4 a and b).

The diminished snow layer in Moldavia also contributed to the occurrence of high air temperatures as the nocturnal radiation was far less intense than in Transylvania. Moreover, air temperature values were recorded under significantly lower cloudiness on the eastern side of the mountain obstacle, a compensating event, strengthening the conclusion that the temperature differences may be attributed mainly to the foehn effects over the Eastern Carpathians.

The air temperature distribution on the morning of February 5, as provided by the *in situ* measurements, is confided with the results of the analysis of the NMM model, whose representation for the 2-m air temperature field also suggests values visibly higher in Moldavia than those recorded in other regions of Romania (Fig. 5).

The comparison of snow cover depth maps of February 4 and 6 respectively, indicate a significant reduction of snow cover (and even a total melting) in the foothill areas experiencing the warm and dry foehn wind (Figs. 6 a, b).

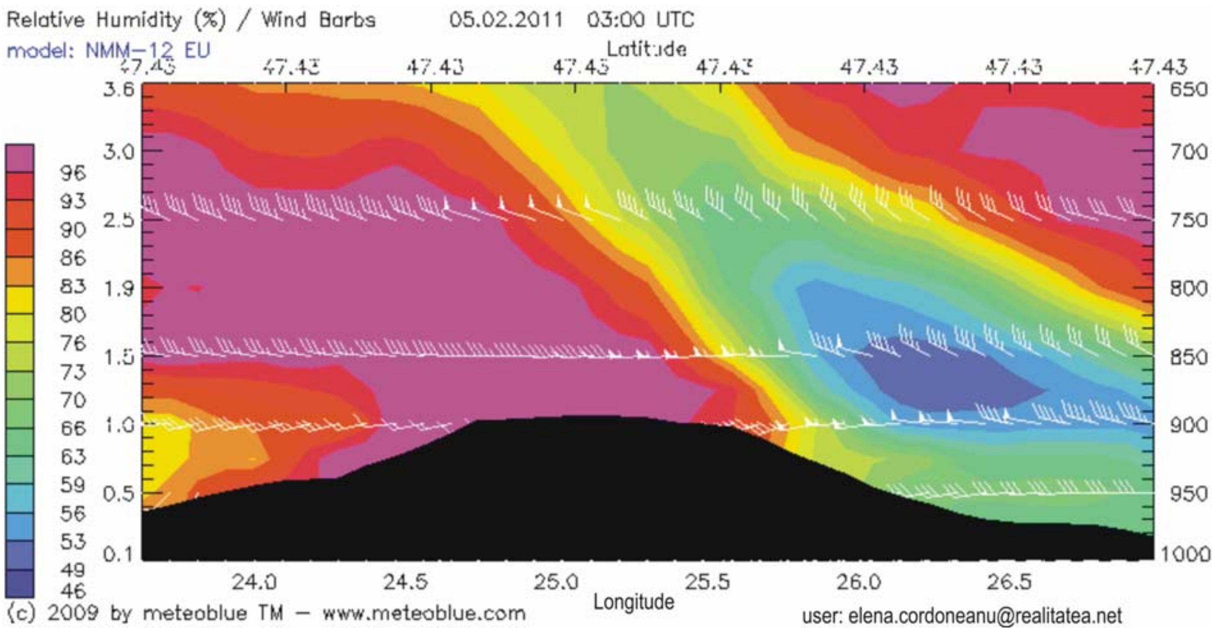

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Fig. 3a – Vertical section in the relative moisture field crossing the Eastern Carpathians, February 5, 2011, 03:00 UTC.

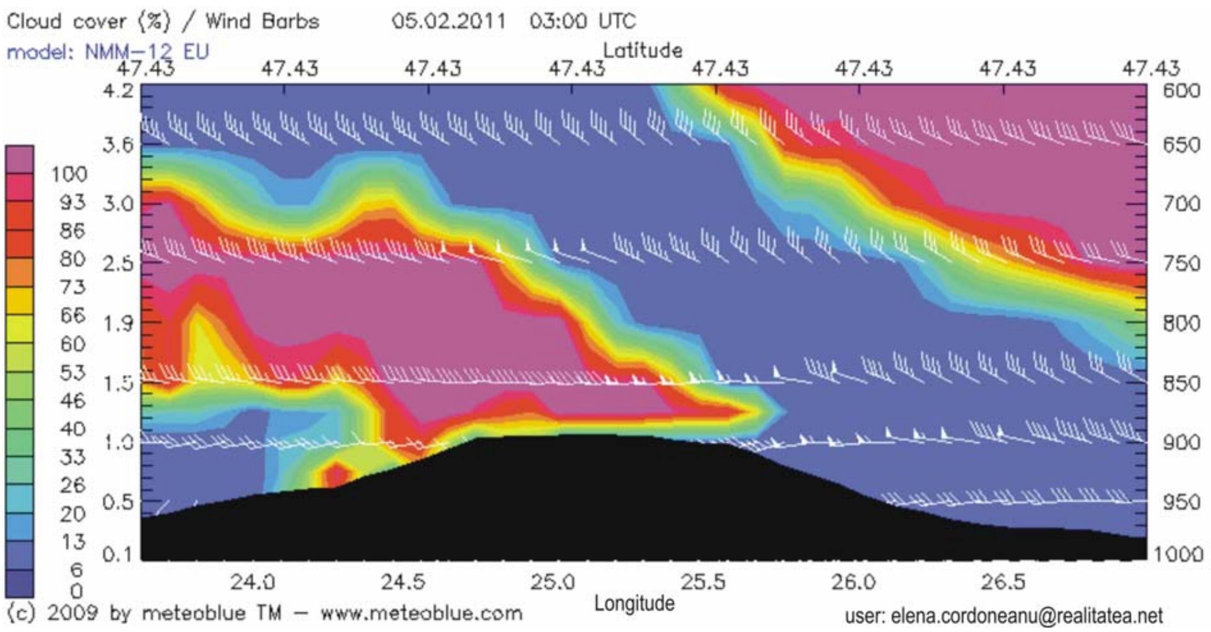

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Fig. 3b – Vertical section in the cloud cover field crossing the Eastern Carpathians, February 5, 2011, 03:00 UTC.

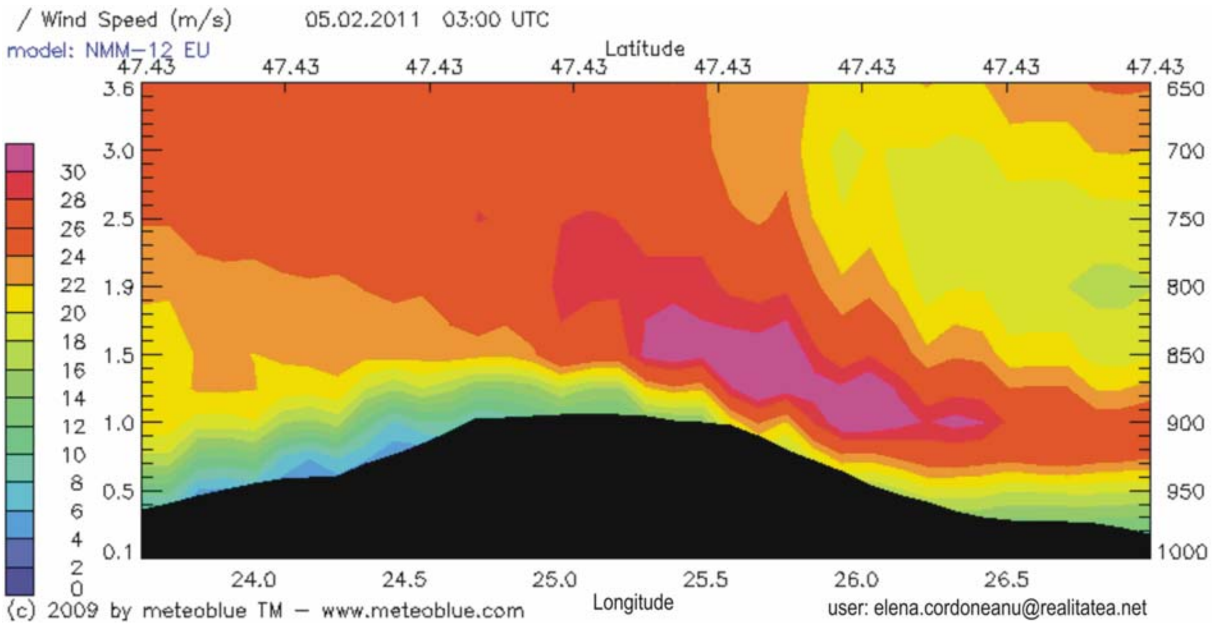

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Fig. 3 c – Vertical section in the wind field crossing the Eastern Carpathians, February 5, 2011, 03:00 UTC.

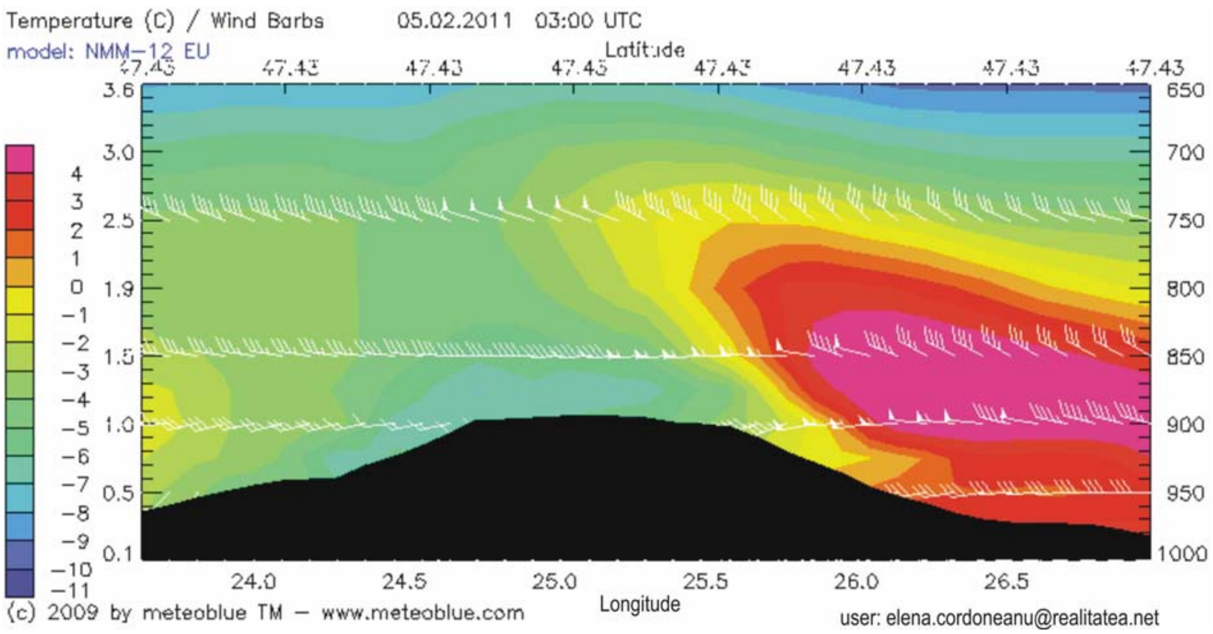

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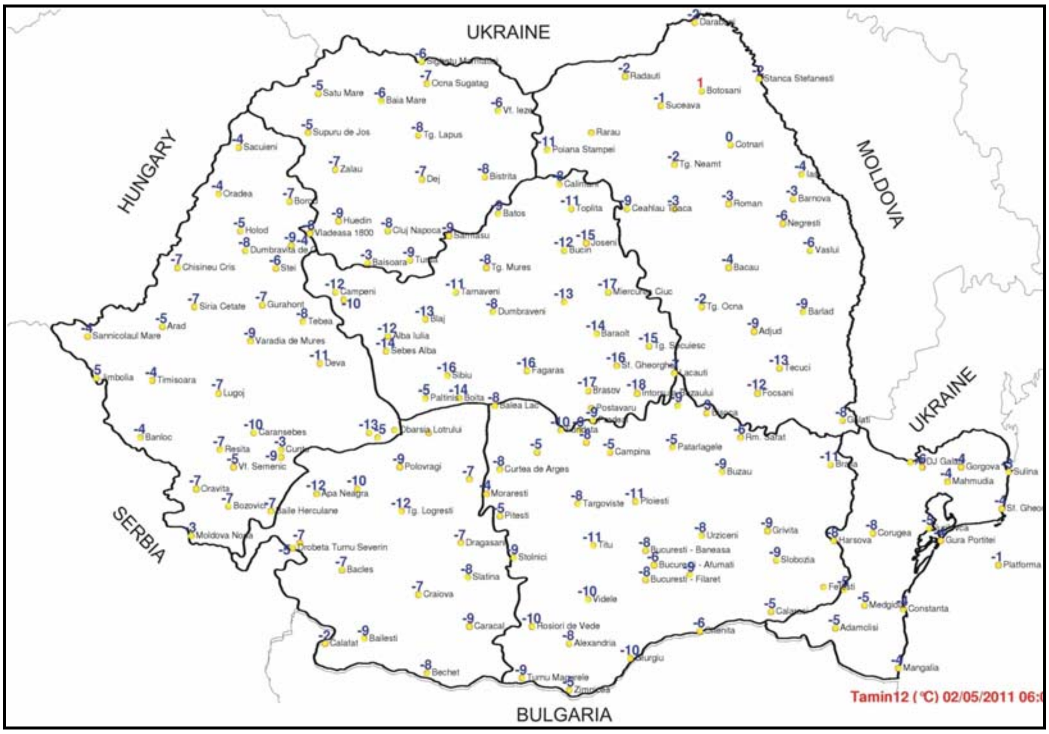
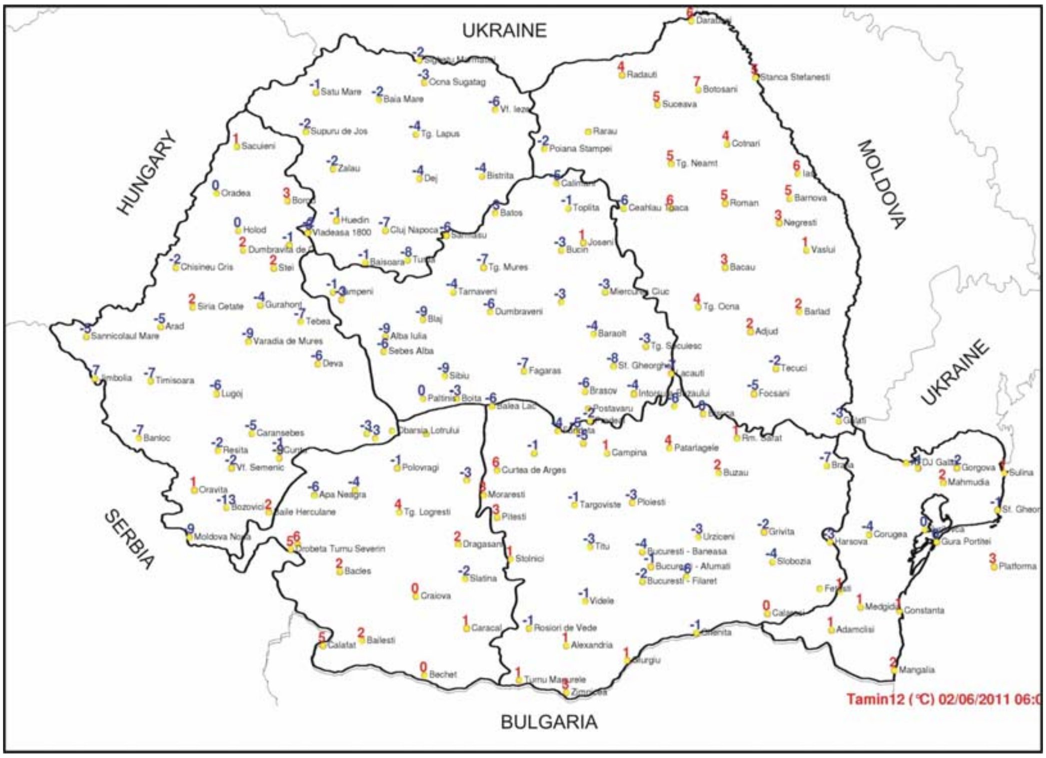
Fig. 3 d – Vertical section in the air temperature field crossing the Eastern Carpathians, February 5, 2011, 03:00 UTC.



a)



b)

Fig. 4 – Map of minimum temperatures recorded
on February 5 (a) and 6 (b), 2011 (NMA).

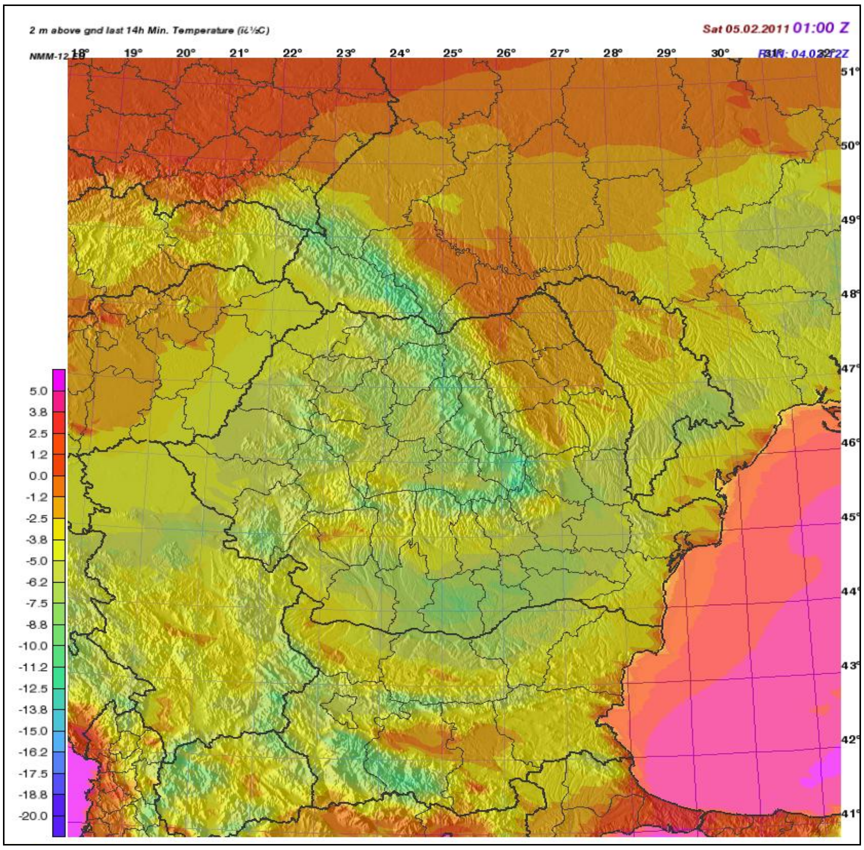


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Fig. 5 – Map of air temperature at 2 m above ground, on February 5, 2011, 01:00 UTC (NMA).

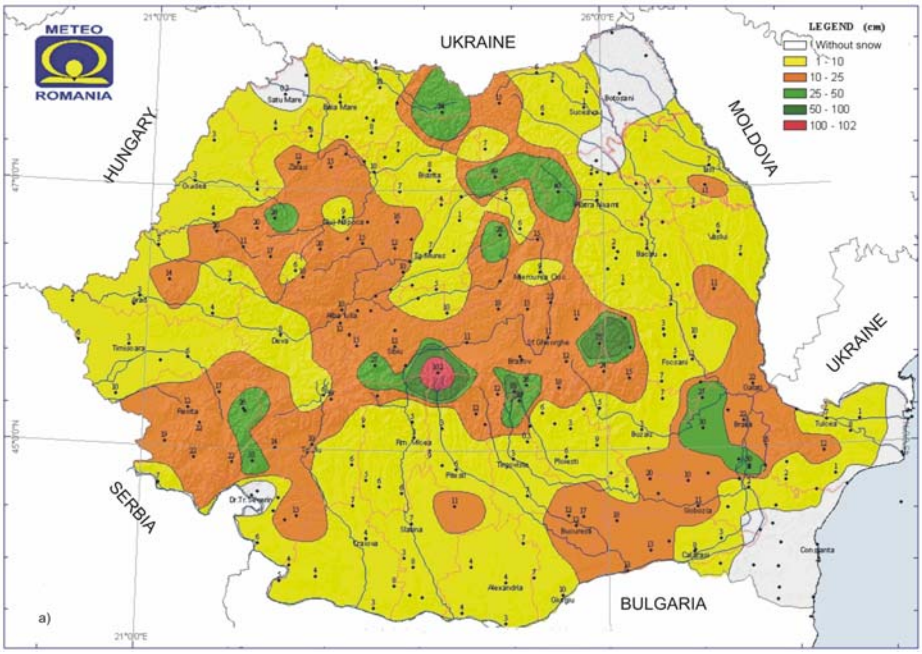

Fig. 6 a) – Snow cover depth, February 4, 2011, 06:00 UTC (NMA).

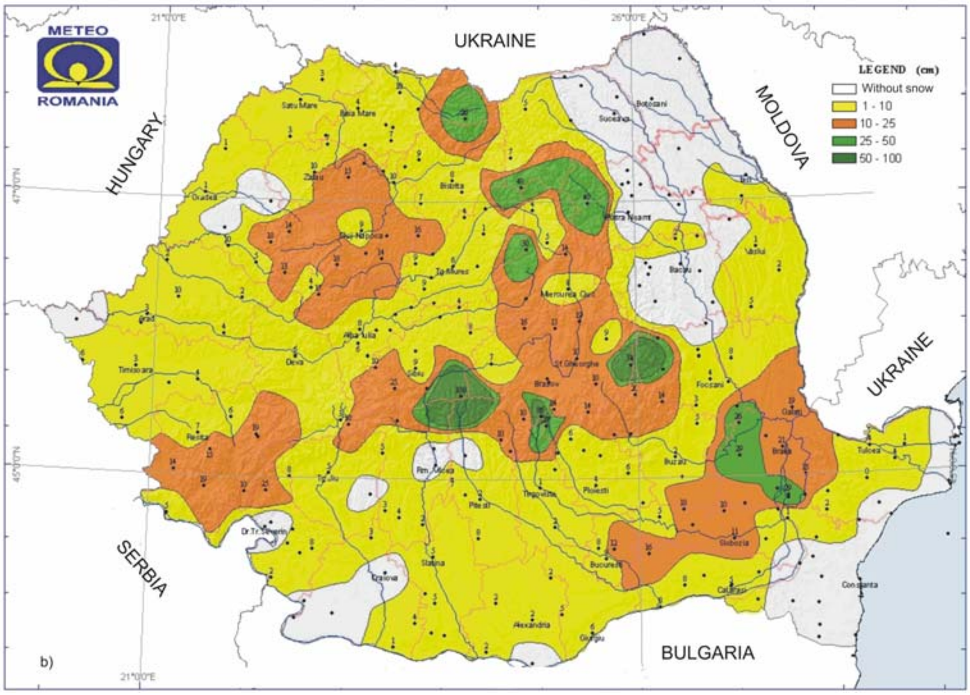

Fig. 6 b) – Snow cover depth, February 6, 2011 (b), 06:00 UTC (NMA).

3. CONCLUSIONS

The analysis of the aero-synoptic configuration over the February 3–6, 2011 interval, as well as the thermobaric configuration generating foehn effects on the eastern flank of the Eastern Carpathians explains why the thermal regime in Moldavia could exhibit specificities, associated with the occurrence of this mesoscale phenomenon in eastern Romania. These specificities consist in a low moisture content of the air mass engaged in downslope motion on the lee side of the Eastern Carpathians, low or absent cloudiness, a remarkable temperature increase, as well as noticeable wind intensification, both on the mountain crest and along the lee side of the mountain.

The diagnoses of the weather course made at Bacău Regional Meteorological Centre for the February 3–6 interval, mention local wind gusts from the north-west in the daytime, then from the west-south-west (reaching 70 km/h or exceeding 100 km/h in the high mountain area) at night, causing wind throw in Suceava and Neamț counties (according to the General Inspectorate for Emergency Situations).

The minima recorded at the weather stations located in Moldavia in the morning of February 5, 2011 ranged from -13ºC at Tecuci to 1ºC at Botoşani, while at most of the weather stations across the country values were below -5ºC. Also, in the same morning, in some areas located at the western mountain foot of the Eastern Carpathians, the air temperature minima were -7ºC at Ocna Şugatag, -8ºC at Târgu Lăpuş and Bistrița and -17ºC at Miercurea Ciuc.

The foehn phenomenon lasted longer, as confirmed by the diagnose for February 7, 2011, as the air minima ranged between -7ºC at Bozovici and Moldova Nouă and +7ºC at Piatra Neamț stations. Comparatively, the value recorded on that same day at Bacău weather station (6.0ºC against 5.0ºC) was the highest in the entire series for that date, representing, therefore, a new daily minimum air temperature record at this site.

In conclusion, the study of the foehn effects on various types of air circulation is very important for the practice of weather forecasting developed by the author, this type of katabatic, warm and dry wind significantly influencing all the meteorological parameters involved in the description of the state of the atmosphere (pressure, temperature, wind speed and direction, moisture, etc.), which is precisely the basic element in the process of weather forecasting.

REFERENCES

Atkinson, B. W. (1981), *Meso-scale atmospheric circulation*, Academic Press, London, 494 p.
Bogdan, Octavia (1993), *Foehnul carpatic*, Analele Universităţii din Oradea, **III,** Oradea, pp. 58–63.
Bogdan, Octavia, Coşconea, Maria (2010), *Riscul doborâturilor de arbori în România (Cauzele),* Risks and Catastrophes, **IX**, *8*,1/2010, Cluj-Napoca.
Bordei-Ion, N. (1979), *Foehnul Carpaţilor de Curbură şi distribuţia precipitaţiilor în Bărăgan,* St. Cercet. Meteor., **1**/1977, MHI, Bucureşti.
Bordei-Ion, N. (1988), *Fenomene meteoclimatice induse de configuraţia Carpaţilor în Câmpia Română,* Edit. Academiei, Bucureşti, 174 p.
Ciobanu, M. (1998), *Studiul efectului de foehn. Aplicaţii în România,* 92 p., teza de doctorat, mss., Facultatea de Fizică, Universitatea din Bucureşti, 100 p.
Ciulache, S. (1985), *Meteorologie şi climatologie*, Facultatea de Geologie-Geografie, Edit. Universităţii din Bucureşti, 471 p.
Durran, D. R., (1990), *Mountain waves and downslope winds. Atmospheric Processes over Complex Terrain* (W. Blumen, Ed.), American Meteorological Society, Boston, pp. 59–81.
Houze, R.A. (1993), *Cloud Dynamics, International Geophysics series*, Vol. **53**, Academic Press, San Diego, California, 573 p.
Irimescu, Anişoara (2009), *Foehnul pe rama sudică a Carpaţilor Meridionali dintre Olt şi Dunăre,* teză de doctorat, mss., Institutul de Geografie, Academia Română, 264 p.
http://www.zamg.ac.at.

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