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THE INFLUENCE OF FOEHN PROCESSES ON RIVER FLOWS FROM EASTERN APUSENI MOUNTAINS

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ABSTRACT

Apuseni Mountains are characterized by a very complex construction of the relief. The main orientation of the peaks is separated in two north – south alignments: Vlădeasa – Bihor - Metaliferi and Gilau – Muntele Mare - Trascău. Because the western circulation is predominant in this sector, on the eastern, sheltered slopes of the Apuseni Mountains foehn processes develop. Due to the relatively modest altitudes, the phenomenon is not very pronounced. Using meteorological radar there could be identified foehn areas or corridors, where cloud formations dissipate. Foehn manifestation presents a temporal differentiation. The maximum frequency is recorded in April - June, and the minimum in winter and September. The existence of foehn processes in Mureș Corridor is reflected in several aspects of the geographical environment, one of which is rivers flow reduction in that area. Analysis of flow distribution in small autochthonous hydrographic basins reveals a clear distinction between the eastern and western slopes. Quantitative differences can be observed not only in the spatial, but also in temporal sense. Comparing the average monthly flow indicates a logical relationship between the foehn frequency and deviation percentage of average average flows on the western and eastern slopes. Moreover, it was possible to assess the altitudinal differentiation of specific flow, which emphasizes the link between foehn processes and flow.

Keywords: orographic barrier, foehn, meteorological radar, air masses, specific flow, altitude steps, flow reduction, deviation

1 INTRODUCTION

Apuseni Mountains represent an orographic barrier in the way of the predominant western air masses. The relief's configuration is very complex (Mihăilescu, 1969), but there can be identified two peaks alignments, orientated north – south: Vlădeasa – Bihor – Metaliferi and Gilău – Muntele Mare – Trascău (Fig.1). The humid air climbs the western slopes of these peaks, descending towards the Mureş Corridor. Because the altitudes are relatively small (few peaks exceed 1500 m), the foehn processes are not very accentuated, but its can be identified using meteorological radars.

From the climatic point of view, the main foehn consequences over the affected areas are temperature's increase and the decrease of rainfall quantities. So, the western slopes of Apuseni Mountains, exposed to humid air masses, receive a higher rainfall quantity than the eastern slopes, situated in "*rain shadow*" (Pandi and Vigh, 2016).

There can be observed, using meteorological radars, a temporal differentiation in foehn manifestation. Foehn's maximum frequency appears in April – June, and the minimum in September and during winter.

In accordance with this phenomenon, also appears a temporal differentiation of river flow (Ujvari, 1972). After comparing the multiannual values of average monthly flow, there can be observed a logical relation between foehn's frequency and the deviation's percentage for specific average discharges between western and eastern slopes. More, there was possible to be made an evaluation of specific flow's altitude differentiation, underlining the links between foehn processes and flow.

2 DATA BASE

For highlighting foehn processes on the eastern slopes of Apuseni Mountains and the surrounding areas, there were used, first, the maps of the Plessey M-42 meteorological radar from Cluj-Napoca Meteorological Stations for the years 1970-1976. Some elements have been taken into account temperature and rainfall data for the periods 1896-1955 and 1961-2000; synoptic maps and aerologic data from Cluj-Napoca Aerologic Observatory for the period 1962-1966: meteorological data, synoptic maps and satellite imagines for the period January, 9-11th, 2015.

The hydrographical basins corresponding to the analysed hydrometric stations cover the mountainous area of Apuseni Mountains' two slopes. The analysis relates to "opposite" hydrographical basins, which enables us to monitor the hydric effect of western air masses' ascending and descending in the studied area. The analysed hydrographical basins are: Crişul Negru – Lower Arieş and Crişul Alb – eastern basins of Trascău Mountains (Fig.1). All rivers have an autochthonous character and their basins are situated between the analysed altitude intervals – 500-1200 m.

The specific multiannual monthly average discharges have been calculated from the monthly discharges for the period 1950 – 1994. The analysed was made for the months June and September, months with foehn's maximum (11.7%) and minimum frequency (3.4%). It was not taken into consideration the winter, with a smaller foehn frequency, because the flow is influenced by winter phenomena.

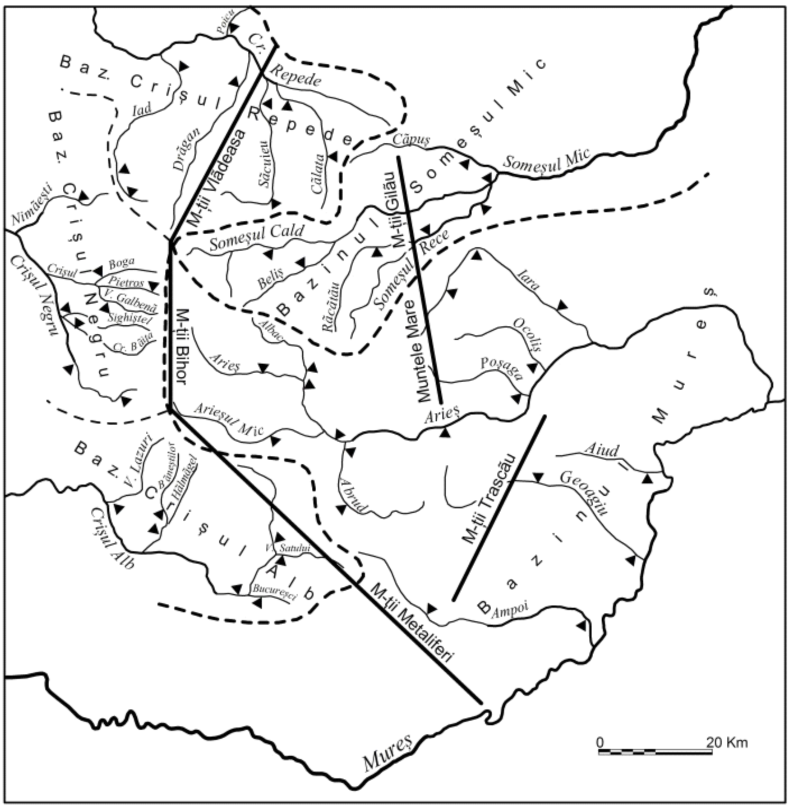

Figure 1. Hydrometric stations and mountain barriers from Apuseni Mountains (lines-mountains, broken lines-watersheds, triangles-hydrometric stations)

3 METHODS

The direct data concerning foehn processes' manifestation are lesser, these events being first mentioned in the geographical literature using analysis and comparison of average values of multiannual temperatures and rainfalls registered on the western slopes, exposed slopes of Apuseni Mountains, respectively on the eastern slopes, in rain shadow. The correct identification of foehn situations was made, first, by identifying the presence of a foehn corridor (lack of cloudy echoes) on the maps from Cluj-Napoca Meteorological Radar for the period 1970-1976. Second, there were made some statistical processing of meteorological and aerologic data, analyses and comparisons of synoptical maps and satellite imagines.

For the analysis of river flow there were made correlations between multiannual monthly average discharges obtained at the hydrometric stations in analyse and the average altitudes of the corresponding hydrographical basins. From the logarithmic functions there were obtained the values of specific average flow for the altitude steps of 100 m and 200 m, according to the basins' level difference. After that, flows have been compared for the same altitude steps in two "opposite" basins. Finally, a comparison was made between the flow deviations in June and September.

4 RESULTS
4.1 Foehn analysis

Foehn is a katabatic local wind, of a short period, warm and dry, determined by a humid air mass' ascending of a mountainous ridge high enough to determine the condensation of the contained water vapours, and it's descending on the sheltered slope (Ciulache, 1987, Bogdan, 1993, cited by Tudose and Moldovan, 2016). Foehn's formation is a complex phenomenon, and the theories about air's descending and it's causes are very diverse. In principle, the explanations include the development of some thermo-dynamic processes associated with other conditions: the existence of thermal inversions over the edge, undulating movements in the medium atmosphere, barric gradient existing between the ridge and the base of the sheltered slopes, the mass difference between dry (heavier) and moist air; the influence of an atmospheric front, especially of a cold one, with a movement direction perpendicular over the orographical obstacle (Tudose and Moldovan, 2016).

The study about foehn apparition in eastern Apuseni Mountains, using the meteorological radar from Cluj-Napoca for the period 1970-1976 (Tilinca and Moldovan, 1984), show a total number of 503 days with foehn processes, with an annual average of 72 days (19.7%). They appeared through the entire year, with the main maximum between April and June (a period with intense cyclone activity at medium latitudes), with the highest values in June – a monthly average of 11.7 cases, with a secondary maximum during October – November. The smallest number of cases appeared during January – February, with the lowest average of 2.7 cases in February. The period with no winter phenomena on rivers presented the lowest number of cases (3.4) in September.

Referring to the wind direction at several levels of reference (Vlădeasa Meteorological Station, 850 hPa, 700 hPa and 500 hPa), the frequency of days with foehn processes was the highest where air circulation was made from directions W, SW and NW. The total percentage for these three directions was 81 % at Vlădeasa (1836 m), 52 % at 850 hPa level (approx. 1500 m) and 700 hPa level (approx. 3000 m), and 49 % to 500 hPa level (approx. 5500 m).

The longest time interval with foehn corridor on the meteorological radar's screen was 4-6 hours (172 cases, respectively 34.1%), followed by 1-3 hours (162 cases, 32.2 %) and the interval of 7-9 hours (102 cases, respectively 20.3 %). The least frequent were cases where the duration of the phenomenon was greater than 15 hours (5 cases, 1.0% respectively).

In terms of the synoptic situation, optimal conditions for the production of foehn processes were related to the existence of a depression thalweg that functions as a cold front, in an old marine - polar air mass (Tilinca at all, 1976), (Table 1).

Table 1. The frequency of foehn processes at the Meteorological Radar from Cluj-Napoca

Anul	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	An
	N %	N %	N %	N %	N %	N %	N %	N %	N %	N %	N %	N %	N %
1970	2 0.4	7 1.4	7 1.4	12 2.4	10 2.0	5 1.0	3 0.6	2 0.4	2 0.4	5 1.0	0 0	0 0	55 11.0
1971	0 0	0 0	5 1.0	6 1.2	5 1.0	13 2.6	8 1.6	1 0.2	4 0.8	3 0.6	7 1.4	4 0.8	56 11.1
1072	1 0.2	4 0.8	5 1.0	13 2.6	14 2.7	10 2.0	5 1.0	7 1.4	6 1.2	2 0.4	11 2.2	1 0.2	79 15.7
1973	4 0.8	2 0.4	2 0.4	6 1.2	8 1.6	14 2.7	10 2.0	1 0.2	3 0.6	11 2.2	13 2.6	6 1.2	80 15.9
1974	1 0.2	6 1.2	3 0.6	14 2.7	19 3.8	24 4.8	9 1.7	11 2.1	2 0.4	5 1.0	1 0.2	5 1.0	100 19.9
1975	2 0.4	0 0	5 1.0	10 2.0	3 0.6	8 1.6	6 1.2	2 0.4	5 1.0	7 1.4	3 0.6	5 1.0	56 11.1
1976	11 2.1	0 0	7 1.4	5 1.0	13 2.6	8 1.6	12 2.4	4 0.8	2 0.4	2 0.4	5 1.0	8 1.6	77 15.3
Tot.	21 4.1	19 3.8	34 6.8	66 13.1	72 14.3	82 16.3	53 10.5	28 5.5	24 4.8	35 7.0	40 8.0	29 5.8	503 100.0
Med.	3.0	2.7	4.9	9.4	10.3	11.7	7.6	4.0	3.4	5.0	5.7	4.1	71.8

4.2. Flow analysis

The hydrographic basins corresponding to the hydrometric stations cover better the difference in altitude (500-1200 m) from the Crişul Negru Basin. In Lower Arieş Basin, the lowest basin is at an average altitude of 900 m. The values of June of the six, respectively five stations, present a good support for logarithmic functions (Fig.2).

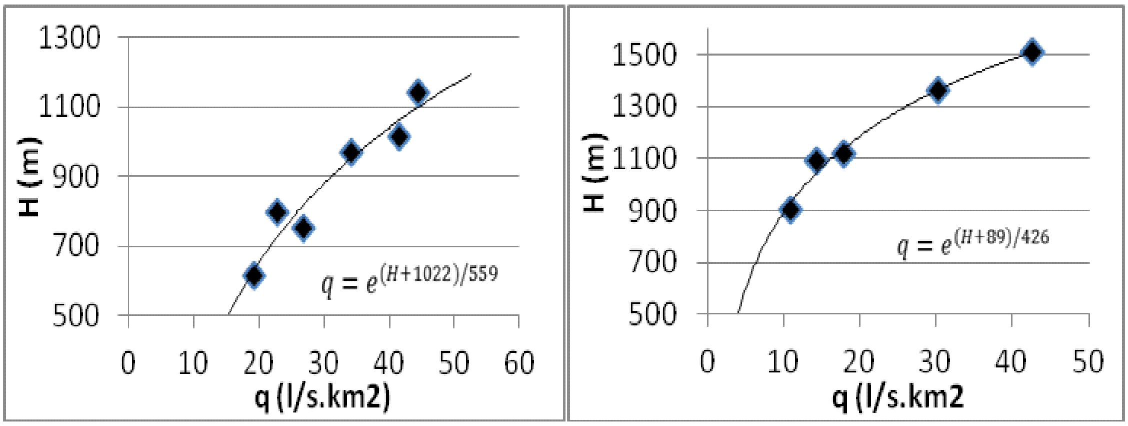

Figure 2. Flow variation in Crişul Negru and Lower Arieş river basins in June

The multiannual specific discharges of June, when feohn has its maximum frequency, present clear differences between the two slopes of the Apuseni Mountains. In west, the range is of 15-53 l/s.km2 and in east presents much lower values (4-20 l/s.km2). Deviations from the eastern slope grow at lower altitudes. It is a normal regularity since foehn effect is accentuated if the air descending is longer. Thus, at 1200 m flow is reduced by just over 60%, but at 500 m the deviation is 74% from the west value (Table 2).

Table 2. Flow deviation by altitude steps in June

	Crişul Negru	Arieşul inf.	
H(m)	q(l/s.km^2)	q(l/s.km^2)	ε (%)
500	15.2	4.0	74
700	21.8	6.4	71
900	31.1	10.2	67
1100	44.5	16.3	63
1200	53.2	20.6	61

In September, the values specific flow control well the logarithmic curve in the lower basin of Arieş River (4 stations), but in Crişul Negru Basin, the stations at high altitudes show different trends. There were taken into consideration both of these stations categories to express a average trend (Fig.3).

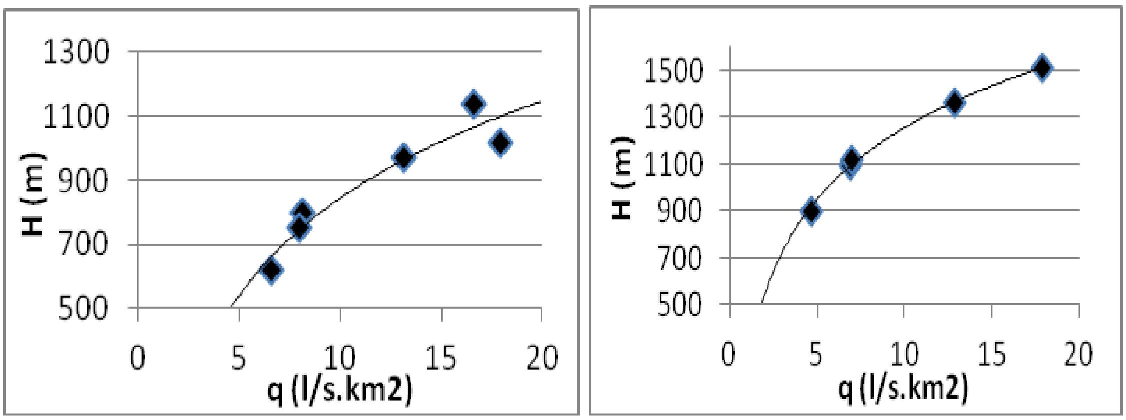

Figure 3. Flow variation in Crişul Negru and Lower Arieş river basins in September

Specific flows differ also in September, when the foehn frequency is low. The deviations have the same value at all altitudes (61%), indicating that the foehn is not the main phenomenon that reduces the flow (Table 3).

Table 3. Flow deviation by altitude steps in September (%)

	Crişul Negru	Arieşul inf.	
H(m)	q(l/s.km^2)	q(l/s.km^2)	ε (%)
500	4.5	1.8	61
700	7.2	2.8	61
900	11.3	4.5	61
1100	17.9	7.0	61
1200	22.5	8.8	61

A second pair of hydrographical basins to be analyzed is Crișul Alb River and Mureș River's tributaries coming from Trascău Mountains. Here, the mountain barrier is not as high and uniform as Bihor Mountains for the previous analysis. Therefore, the foehn's effects are also not so obvious. Western watersheds have average altitudes below 800 m, while the eastern basins barely exceed 900 m. The analyzed difference in altitude covers only 300 m (between 500-800 m). The distribution of points describing logarithmic functions is higher, especially in the area of Trascău Mountains (Fig.4). There were compared the same months with extreme foehn frequencies, June and September.

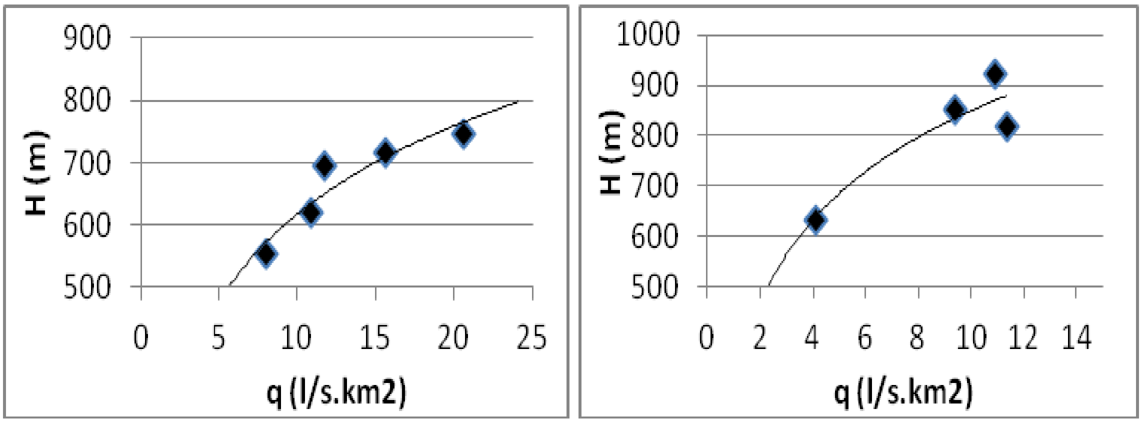

Figure 4. Flow variation in Crişul Alb hydrographical basin and in the river basins from Trascău Mountains in June

In June, the deviations of specific flow between west and east exceed 50 %. The range of variation is narrow, only 8 % (between 59 and 67 %) (Table 4). Note that deviations decrease slightly to the lower altitudes of the Mureş Valley.

Table 4. Flow deviation by altitude steps in June (%)

	Cr.Alb	Trascău	
	q(l/s.km^2)	q(l/s.km^2)	ε(%)
500	5.6	2.3	59
600	9.2	3.5	62
700	15.0	5.3	65
800	24.6	8.1	67

Correlations for September are similar to those for June. The two correlations are stronger, but here the values distribution is higher Trascău Mountains' basins, situated at higher altitudes (Fig.5).

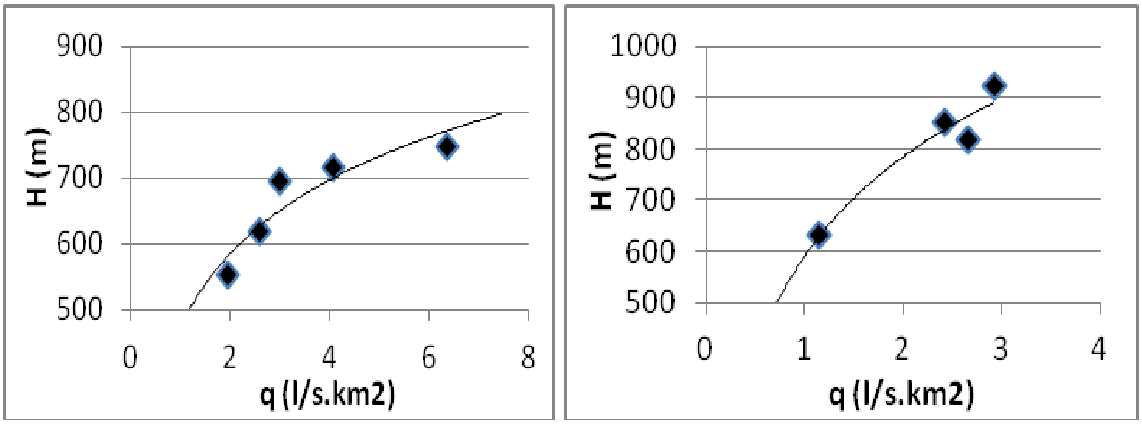

Figure 5. Flow variation in Crişul Alb hydrographical basin and in the river basins from Trascău Mountains in September

The range of variation for flow deviations between west and east is higher. The values are almost double (38–72 %). The same decreasing deviation trend is found toward lower altitudes (Table 5).

Table 5. Flow deviation by altitude steps in September (%)

	Crişul Alb	Trascău	
	q(l/s.km^2)	q(l/s.km^2)	ε (%)
500	1.2	0.7	38
600	2.2	1.0	52
700	4.0	1.5	63
800	7.5	2.1	72

4.3 Monthly deviations' comparison

In both pairs of hydrographic basins is highlighted the foehn's role in decreasing rivers' flow. Flow deviations between the eastern and the western slopes are higher in June, when foehn has a higher frequency. In September, the east-west deviations decrease. At the same time, there can be observed the influence of different mountain barriers.

The flow differentiation June/September between Crişul Negru and Lower Aries is felt below 1100 m. At this altitude, the deviation difference is of 2% (63-61%), but it steeply increases, reaching 13% at 500 m altitude (74-61%). Between Crişul Alb and Trascău river basins the differences east/west are not so obvious. Average deviations in June are higher by 7% compared to September, which indicates foehn's role in flow reduction. Also in this case, due to foehn's effects, deviation difference for June/September significantly increases towards lower altitudes (2% to 700 m, 28% to 500 m). At 800 m, the deviation is less in June than in September (67-72%), probably due to local conditions that reduce the flow.

5 CONCLUSIONS

Foehn processes existence on the eastern, sheltered slope of Apuseni Mountains is indisputable. In this study, it was shown mainly using weather maps from Cluj-Napoca Meteorological Radar. Accordingly, the maximum frequency of foehn situations was recorded in April-June (with peak in June). Minimums are found in winter (with the fewest cases in February) and September. From synoptic point of view, the occurrence of these processes is favored by the presence of a depression thalweg working with a cold front moving in from the west, amid an old marine-polar air masses. The existence of foehn processes in eastern the Apuseni Mountains is reflected primarily in climate (warmer and less wet), but also in other aspects of the geographical environment, one of which is decreasing rivers flow in that area.

Specific flow analysis indicates an accentuated flow decrease in the basins on the eastern slope of the Apuseni Mountains. Although this mountainous area is considered as a region with excess of water resources (Sorocovschi and Pandi, 1995), spatial and temporal differences are obvious. The way specific flow varies in west-east direction, especially flow deviations with altitude indicates a clear influence by foehn. Comparing flow's degree of influence with the frequency of foehn phenomenon underlines this link.

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