THE CLIMATOLOGY OF ATMOSPHERIC FRONTS CROSSING CLUJ-NAPOCA CITY AND THE WEATHER ASSOCIATED

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ABSTRACT. The climatology of atmospheric fronts crossing Cluj-Napoca city and the weather associated. In this paper the evolution of weather patterns by tracking various weather variables change as a result of frontal passages through the area of Cluj-Napoca city was investigated, over a period of 10 years (2001 – 2010). The study is focused on warm and cold fronts, while other types of atmospheric fronts have not been considered for this study. Hourly air temperature, sea level pressure, relative humidity, and wind speed have been analyzed. The main conclusions of the study are: the lowest number of atmospheric fronts charaterizes the summer, and especially the last weeks of summer and the first weeks of the autumn, because of the high frequency of anticyclone regime which is dominant over that period, while the most are specific to spring season; the most intense changes in weather parameters (>10.1°C, >10.1 hPa) are much less frequent compared to the moderate (5.1 - 10.0°C, 5.1 - 10.0 hPa) and small ones (0.0 - 5.0°C, 0.0 - 5.0 hPa); the warm fronts had the highest occurrence frequency between 06:00 and 12:00 UTC and the cold fronts between 18:00 and 00:00 UTC.

Key-words: atmospheric fronts, meteorological variables, synoptic analysis, Cluj-Napoca.

1. INTRODUCTION

Atmospheric fronts and frontal systems are one of the most frequent factors which can influence the weather in the mid-latitudes. These phenomena are often associated with, among other things, precipitation, dramatic changes in temperature, humidity, and changing direction and increasing wind speed (Simmonds et al., 2012). Fronts can also induce extreme events such as heavy rains, sometimes with hail and thunderstorms, property-damaging wind gusts, and disruptive snowfalls. However, not all fronts cause notable weather.

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Another type of impact of the frontal passage is on air quality, by ventilation or transportation of pollutants on long distances (Shahgedanova et al. 1998, Sinclair et al. 2010, Walna et al. 2013). Hence, new information on weather fronts frequency affecting a specific location or what changes in weather patterns they cause is beneficial to forecasters and other domains (Sinclaire, 2013).

Due to the difficulties faced in compiling an objective classification and detection of weather fronts, the number of studies on frontal climatology is quite small. The great majority of frontal climatology studies are based on synoptic analysis charts and focus on small geographic areas (Chiang, 1961, Morgan et al., 1975) or single weather stations (Sinclaire, 2013). But some researchers expended the covered area to continental (Łupikasza, 2016), hemisphere (Simmonds et al., 2012), or global scale (Catto et al., 2012).

The main purpose of this study is to present a climatology of frontal activity focused on Cluj-Napoca city area, Romania. Specific objectives are: to identify the type of changes in meteorological parameters as a results of the weather fronts presence (warm and cold) passage over Cluj-Napoca, over a 10-yr period; to detect the intensity of the fronts based on different intensity classes in weather variables (air temperature, air pressure, relative humidity, and wind speed); to determine the 6h-interval with the highest frequency of weather front occurence over Cluj-Napoca area.

2. DATA AND METHODS

a. *Data used*

For this paper we used data from online databases of different international meteorological organizations. First, for the synoptic analysis, the Europe's synoptic maps at sea level were used for the identification of the frontal passages. Maps from the electronic archive of the British Meteorological Service (Met Office), freely available on the website http://www.weathercharts.org and synoptic maps retrieved from the archive of the Center Meteorological Karlsruhe, Germany (www.wetterzentrale.de) have been used. After that, we continued with the analysis and processing of statistical data on weather variables: air temperature, air pressure, relative humidity and wind speed. Sub-daily precipitation data were not available for this study. The numerical data were obtained from the online database of the Russian Meteorological Service, available online at http://meteo.infospace.ru. We used the weather variables values recorded every 6 hours at the main terms (00, 06, 12 and 18 UTC), at the weather station of Cluj-Napoca.

b. *Methods*

This study was conducted in four phases:

a) The first phase included the analysis of the synoptic maps from the period

2001-2010 in order to identify the days and hourly interval with frontal (warm/cold) passage over Cluj-Napoca city.

b) On the basis of the identified dates, in the second stage, we calculated the differences of weather variables compared to the previous day, the same hour. The differences were calculated for all four variables by subtracting the value of the parameter before the frontal passage from the value recorded post passing. The 24-hours interval for comparison was chosen, in order to remove the influence due to the normal, diurnal evolution of the meteorological parameters.

c) In the next phase, we established three intensity classes for each of the four weather variable fallowed by the calculation of their frequencies for each season. For each weather variable the same number of classes was chosen to facilitate the comparison between changes produced by both warm and the cold fronts.

The changes in air temperature produced by a frontal passage, both warm and cold fronts, were classified in the same three intensity classes. Those classes were:

- increase/decrease between 0.0 °C and 5.0 °C,
- increase/decrease between 5.1 °C and 10.0 °C,
- increase/decrease with more then 10.1 °C.

In the same way as in case of air temperature, the changes produced in the atmospheric pressure, have been classified as:

- increase/decrease between 0.0 hPa and 5.0 hPa,
- increase/decrease between 5.1 hPa and 10.0 hPa,
- increase / decrease with more then 10.1 hPa.

For this paper, because it was intended to study the modifications of relative humidity at the same time of day, on a 24-hour interval, there were recorded both increases and decreases of relative humidity values as well as constant ones. Because it was difficult to establish some definite intensity classes to match the modifications produce by both types of front, we decided to go with:

- „increase”,
- „constant” ,
- „decrease” .

Wind is also one of the weather variable influenced by a front passage. Both direction and wind speed are disrupted following the occurrence and crossing of an area by a meteorological front. In this study, the focus was on speed changes, given that the modifications of direction are predictable. For this, we established three intensity classes:

- „increase”,
- „constant”,
- „decrease”.

d) Of particular interest related to the weather fronts was the time of the day when the they pass over a certain region. In order to simplify the procedure of classification, instead of the time of day, we chose to study intervals. These interval ware chose to cover the period between two main UTC hours measurements, resulting in a total of four intervals: 00:00 - 06:00 UTC, 06:00-12:00 UTC, 12: 00-18:00 UTC, and 18:00-00:00 UTC. We calculated the frequency and performed further analysis of the impact of the two types of fronts for these intervals.

e) All the charts were made by using Microsoft Office Excel 2007.

3. RESULTS AND DISCUSSION

Analysis of the synoptic maps available for the period 2001-2010, allowed identification of 786 weather fronts crossing over Cluj-Napoca city area. Out of them, 390 were warm fronts and 396 cold fronts (both first and second type cold fronts).

Analyzing the number of warm and cold fronts registered per year (fig.1), over the period 2001-2010, no clear distribution pattern was found. It can be noticed a certain periodicity of 2-3 yrs. of the registered frontal passage, but due to the short studied period of time, this conclusion cannot be generalized and expressed as certain.

On average, similar numbers of warm and cold fronts per year were registered: 39 warm fronts and 39.6 cold fronts. Compared to these values, in 2001, the maxim number of frontal passages was registered, as well as the minim value in 2006.

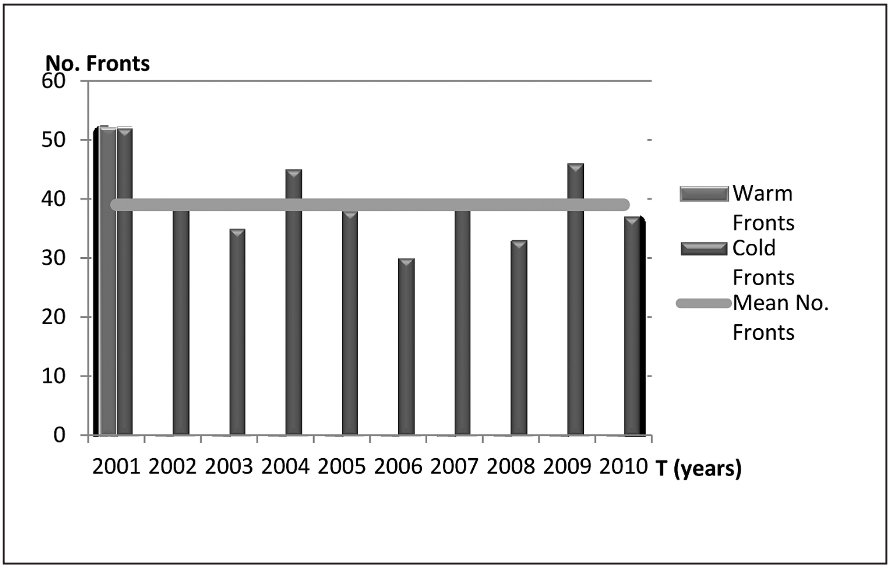

Figure 1. Distribution of warm and cold fronts per year

a) ***Air temperature***

Air temperature is one of the most influenced weather variable by the occurrence of a weather front even though sometimes it is reduced by the pre-existing conditions.

After a detailed analysis of the intensity classes of air temperature values (Table 1), we found that both types of weather fronts produced, in most of the cases, a change in temperature with values ranging from 0.0 °C to 5.0 °C (more than 65% of the warm front and more than 50 % in case of cold front). The hightes frequency, for both warm and cold fronts, is specific to spring, but we should mention that in case of the warm front, the same value was recorded in winter.

The higher intensity fronts (5.1-10.0 °C) are more frequent in winter in case of warm fronts and in winter and autumn in case of cold fronts. The lowest frequency is specific to summer, but it should be emphasized that cold fronts are more than four times more frequent compared to the warm fronts.

In case of the highest intensity (air temperature difference higher than 10.0 °C), only few cases were recorded for each type of fronts.

Table 1. Frequency calculated for each season, for the air temperature changes

Season	Front type	Warm front				Cold front			
	Classes	0.0-5.0°C	5.1-10.0°C	>10.1°C	Total	0.0-5.0°C	5.1-10.0°C	>10.1°C	Total
Spring	No. of cases	73	26	2	**101**	72	31	5	**108**
	%	18.72	6.67	0.51	**25.90**	18.18	7.83	1.26	**27.27**
Summer	No. of cases	66	5	1	**72**	60	22	9	**91**
	%	16.92	1.28	0.26	**18.46**	15.15	5.56	2.27	**22.98**
Autumn	No. of cases	70	25	1	**96**	53	37	5	**95**
	%	17.95	6.41	0.26	**24.62**	13.38	9.34	1.26	**23.99**
Winter	No. of cases	73	45	3	**121**	62	37	3	**102**
	%	18.72	11.54	0.77	**31.03**	15.66	9.34	0.76	**25.76**
Total	No. of cases	**282**	**101**	**7**	**390**	**247**	**127**	**22**	**396**
	%	**72.31**	**25.90**	**1.79**	**100.00**	**62.37**	**32.07**	**5.56**	**100.00**

b) ***Atmospheric pressure***

Atmospheric pressure is another weather variable extremely sensitive to frontal passages. As in case of air temperature, the highest, for both types of front was registered for low intensity class (0.0 - 5.0 hPa) during summer, followed by spring (Table 2). The cold fronts seems to be slightly more intense, in terms of sea level pressure, when considering the frequency of higher intensity classes.

Table 2. Frequency calculated for each season, for the atmospheric pressure changes

Season	Front type	Warm front				Cold front			
	Classes	0.0-5.0 hPa	5.1-10.0hPa	>10.1hPa	Total	0.0-5.0 hPa	5.1-10.0hPa	>10.1hPa	Total
Spring	No. of cases	57	34	10	101	61	37	10	**108**
	%	14.62	8.72	2.56	25.90	15.40	9.34	2.53	**27.27**
Summer	No. of cases	59	13	0	72	69	20	2	**91**
	%	15.13	3.33	0.00	18.46	17.42	5.05	0.51	**22.98**
Autumn	No. of cases	52	34	10	96	49	31	15	**95**
	%	13.33	8.72	2.56	24.62	12.37	7.83	3.79	**23.99**
Winter	No. of cases	53	36	32	121	30	44	28	**102**
	%	13.59	9.23	8.21	31.03	7.58	11.11	7.07	**25.76**
Total	No. of cases	**221**	**117**	**52**	**390**	**209**	**132**	**55**	**396**
	%	**56.67**	**30.00**	**13.33**	**100.00**	**52.78**	**33.33**	**13.89**	**100.00**

c) *Relative humidity*

Relative humidity values depend on the air temperature. Between the two meteorological variables there is a reverse relationship: the relative humidity increases with temperature decrease, and vice versa. Depending on the time of the day when the front pass, relative humidity may decrease, even though its normal daily evolution continuous unaffected. For example, if the front passage happens about noon, when normally, the daily minimum relative humidity is recorded and the warm air mass behind a warm front is poor in water vapors, the values of relative humidity will continue to decline. But when the same type of air mass arrives during the night, when the relative humidity normally increases, its values, may or may not be influenced.

The results showed that the highest frequency of „decrease" class for the warm front, is specific during winter, while for the cold front, the „increase" class record maximum frequency in spring (Table 3).

Table 3. Frequency calculated for each season, for the relative humidity changes

Season	Front type	Warm front				Cold front			
	Classes	increase	constant	decrease	Total	increase	constant	decrease	Total
Spring	No. of cases	43	3	55	**101**	56	3	49	**108**
	%	11.03	0.77	14.10	**25.90**	14.14	0.76	12.37	**27.27**
Summer	No. of cases	24	2	46	**72**	72	3	17	**92**
	%	6.15	0.51	11.79	**18.46**	18.18	0.76	4.29	**23.23**
Autumn	No. of cases	28	9	59	**96**	52	7	36	**95**
	%	7.18	2.31	15.13	**24.62**	13.13	1.77	9.09	**23.99**
Winter	No. of cases	47	9	65	**121**	44	2	55	**101**
	%	12.05	2.31	16.67	**31.03**	11.11	0.51	13.89	**25.51**
Total	No. of cases	**142**	**23**	**225**	**390**	**224**	**15**	**157**	**396**
	%	**36.41**	**5.90**	**57.69**	**100.00**	**56.57**	**3.79**	**39.65**	**100.00**

d) *Wind speed*

Both types of meteorological front had the most impact on the wind speed in the direction of increasing its values. The highest frequency by seasons, was registered, for both front types, by the „increase" class (Table 4). The difference consisted in the maxim number of cases which was registered in the winter for the warm front, and in the spring for the cold front. The "constant speed" class recorded the lowest frequency (less than 28 %) both in case of warm and cold fronts, while "decreasing wind speed" class had similar values for both types of fronts (around 30 %, as an annual overall value).

Table 4. Frequency calculated for each season, for the wind speed changes

Season	Front type	Warm front				Cold front			
	Classes	increase	constant	decrease	Total	increase	constant	decrease	Total
Spring	No. of cases	39	30	32	**101**	53	25	30	**108**
	%	10.00	7.69	8.21	**25.90**	13.38	6.31	7.58	**27.27**
Summer	No. of cases	25	21	26	**72**	39	31	21	**91**
	%	6.41	5.38	6.67	**18.46**	9.85	7.83	5.30	**22.98**
Autumn	No. of cases	37	32	27	**96**	43	21	31	**95**
	%	9.49	8.21	6.92	**24.62**	10.86	5.30	7.83	**23.99**
Winter	No. of cases	62	26	33	**121**	42	26	34	**102**
	%	15.90	6.67	8.46	**31.03**	10.61	6.57	8.59	**25.76**
Total	No. of cases	**163**	**109**	**118**	**390**	**177**	**103**	**116**	**396**
	%	**41.79**	**27.95**	**30.26**	**100.00**	**44.70**	**26.01**	**29.29**	**100.00**

The hourly interval when the weather front passed

It is necessary to know the time of the day when a front, be it warm or cold, passes over a specific region for several reasons. The most important one is related to the daily evolution of the weather variables. In other words, depending on the time of the day when the front crosses, the evolution of the weather may differ. For instance, in case of a warm front, we can have different air temperature evolution depending of the time of the day the front affects a region. Thus, if the front passes between sunrise and noon – afternoon, when the air temperature, normally, rises, the warm air from behind the warm front may increase the temperatures, up to a value higher than would normally register under no front conditions. If the transition would occur in the afternoon, or during the night, the situation is different. Instead of decreasing, the temperature may remain constant around the same values for several hours, or it can increase to a value much higher than the maximum recorded at noon.

Under these circumstances, we chose to calculate the seasonal frequencies for the interval of the day when the fronts crossed Cluj-Napoca city area over the considered period of 10 years. We found out that the most numerous warm front cross the area under study between 06:00 and 12:00 UTC (38.97 %), while in case of cold fronts the "preferred" interval is between 18:00 – 00:00 UTC (43.43 %). In both situations, the highest frequency was recorded in spring (Table 5). The lowest frequency is recorded by warm fronts between 18:00 and 00:00 in summer and spring (less than 2 %), while by the warm fronts between 00:00 and 06:00, especially in spring and autumn (less than 3.5 %).

Table 5. Frequency calculated for each season, for the hourly interval when the weather front passed

Season	Front type	Warm front					Cold front				
	Classes	00:00-6:00 UTC	06:00-12:00 UTC	12:00-18:00 UTC	18:00-00:00 UTC	Total	00:00-06:00 UTC	06:00-12:00 UTC	12:00-18:00 UTC	18:00-00:00 UTC	Total
Spring	No. of cases	19	50	26	6	**101**	10	19	23	57	**109**
	%	4.87	12.82	6.67	1.54	**25.90**	2.53	4.80	5.81	14.39	**27.53**
Summer	No. of cases	3	42	24	3	**72**	17	18	19	36	**90**
	%	0.77	10.77	6.15	0.77	**18.46**	4.29	4.55	4.80	9.09	**22.73**
Autumn	No. of cases	12	33	21	30	**96**	13	11	28	43	**95**
	%	3.08	8.46	5.38	7.69	**24.62**	3.28	2.78	7.07	10.86	**23.99**
Winter	No. of cases	21	27	32	41	**121**	21	16	29	36	**102**
	%	5.38	6.92	8.21	10.51	**31.03**	5.30	4.04	7.32	9.09	**25.76**
Total	**No. of cases**	**55**	**152**	**103**	**80**	**390**	**61**	**64**	**99**	**172**	**396**
	%	**14.10**	**38.97**	**26.41**	**20.51**	**100.00**	**15.40**	**16.16**	**25.00**	**43.43**	**100.00**

Case study: warm front recorded on 04.08.2009

In order to describe the situations which generated the highest day-to-day change in the weather variables, we chosen the warm front from 04.08.2009, which conducted to an increase in the air temperature of 14.8°C.

This specific warm front crossed Cluj-Napoca city on 4th of August, 2009, between 06:00 and 12:00 UTC. The synoptic situation of that day (fig. 2), revealed the conditions over Europe, including Romania, which generated that extreme weather event: intense Icelandic Low affected the northwestern Europe, while the rest of the continent was dominated by cyclone individuals less developed, but powerful enough to create an intense instability across Europe. Anticyclonic cores were also located over France, Germany or northeastern Greece.

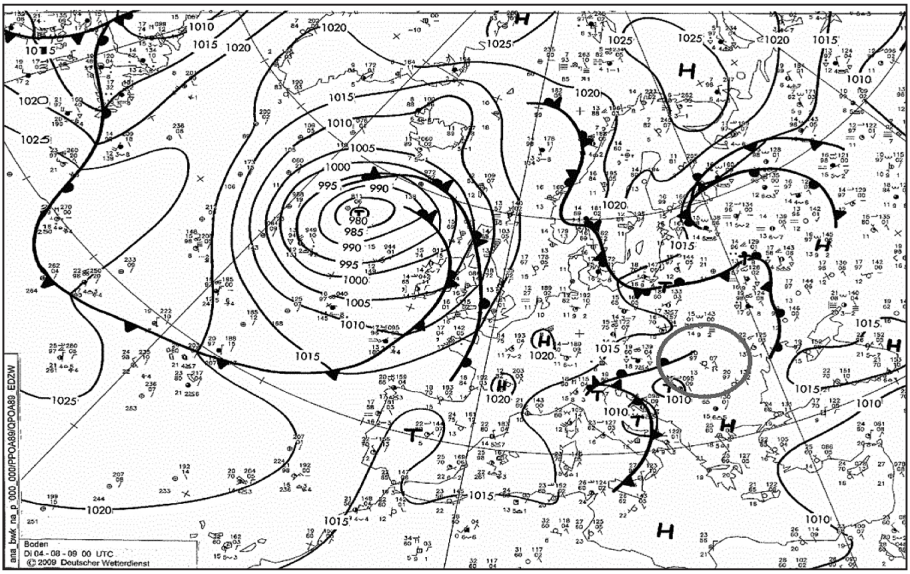

Figure 2. Synoptic map from 08.04.2009, 00:00 UTC
(source: Deutscher Wetterdienst, http://www2.wetter3.de)

Romania was affected by the fronts system of a Mediterranean cyclone, situated over the Po Plain (Northern Italy). The warm front of that low pressure center crossed the area considered in the morning of August, 4.

That day, around 06 UTC, the air temperature began to increase, reaching the maximum value, at 12:00 UTC. With the temperature increase, the sea level pressure began to decrease. The minimum value was recorded after 12:00 UTC, as sea level pressure continued to decrease after the passage of the warm front (fig. 3).

This particular event is part of a longer period of instability characterized by rapid warm and cold fronts of several cyclone individuals. Therefore, one can notice that on August 3, between 06:00 and 12:00 UTC, a sudden drop in temperature and an increase in pressure took place. These changes were due to a cold passage that had disturbed the evolution of the two parameters. Given the low value of the temperature on August 3, may explain why, in addition to the warming due to passage of the warm front, the temperature on August 4, registered that kind of difference compared to the previous day.

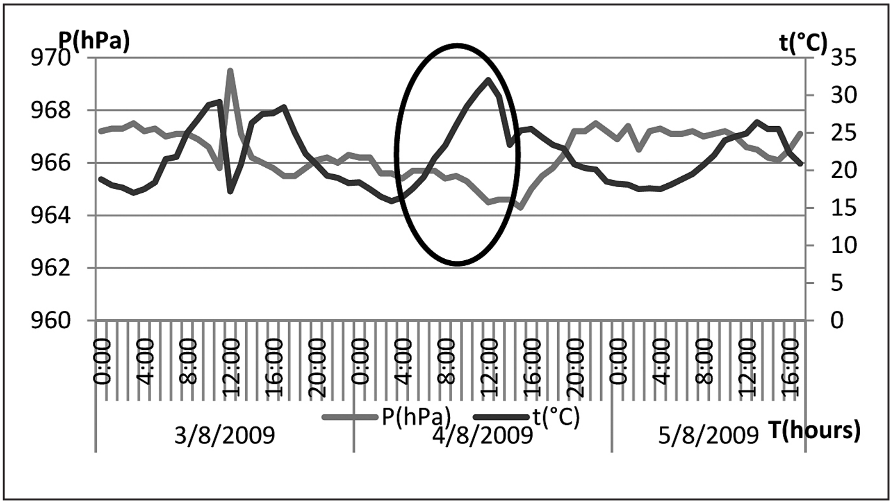

Figure 3. The evolution of air temperature (˚C) and sea level pressure (hPa) over the interval 03-05, August, 2009

Relative humidity (fig. 4) decreased as the temperature values increased. After the front passed, due to evaporation, relative humidity started to rise, but did not reach the values recorded during the previous night. The wind speed increased on August 4, with a peak around 09:00 UTC, and after it decreased.

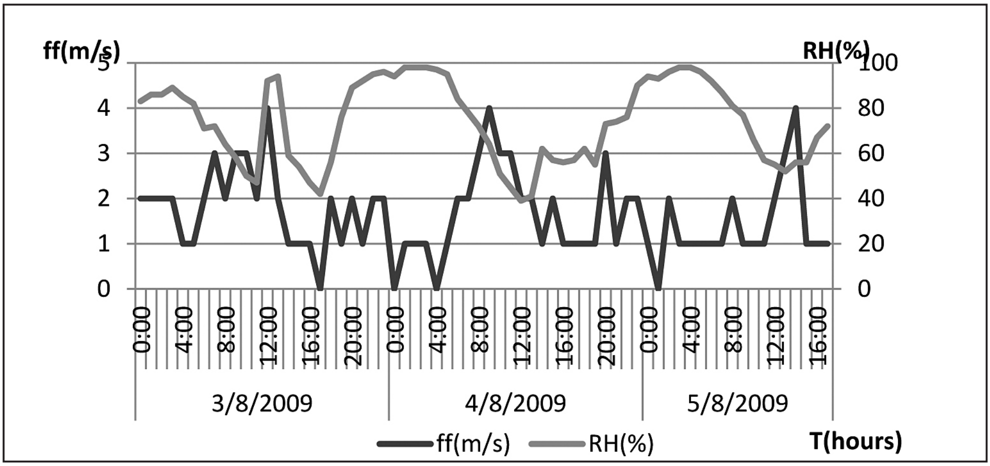

Figure. 4. The evolution of wind speed (m/s) and relative humidity (%) over the interval 03-05, August, 2009

CONCLUSIONS

Considering the hourly interval when the warm frontal passage, we can distingue the next cases about the normal, daily evolution of air temperature: when the warm front crosses the area in the daytime (in the period of normal increase), the temperature will be higher compared to the previous day and depends on the front intensity; when the front crosses in the nighttime, or during the normal decreasing interval of the day (in the afternoon), the normal evolution can be different: the decrease in air temperature, will be replaced by an increase in the air temperature values. The relative humidity has a reverse evolution compared to air temperature. A similar situation is also valid for the cold fronts

The most intense changes (>10.1^{o}C, >10.1 hPa) are much less frequent compared to the moderate (5.1 - 10.0^{o}C, 5.1 - 10.0 hPa) and small ones (0.0 - 5.0^{o}C, 0.0 - 5.0 hPa).

The highest in day-to-day changes over the studied period were:

- an increase of 14.8 ^{o}C on 04.08.2009;
- a decrease of 16.5 ^{o}C on 11.07.2007;
- a decrease of 38.26 hPa on 24.02.2002;
- an increase of 22.8 hPa during 14-15.11.2001

The warm fronts had the highest occurrence frequency between 06:00 and 12:00 UTC and the cold fronts between 18:00 and 00:00 UTC.

During the summer, and especially during the last weeks of summer and the first weeks of the autumn there were the lowest number of weather fronts passages, because of the high frequency of anticyclone regime.

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