THE RISKS ASSOCIATED TO THE HOARFROST PHENOMENON IN THE WEST PLAIN

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Abstract. *Hoarfrost is a hydrometeor which is produced only in the presence of frost and it represents a major risk factor to agriculture especially when it appears early in autumn or late in spring. It is formed by direct condensation of water vapor to ice at temperatures below freezing and occurs when air is brought to its frost point. Hoarfrost produces significant damage in agriculture when overlap with the growing periods of the plants (after 20 March) or when vegetative rest is not installed yet (until 15 October). This paper shows an analysis of the parameters which define the hoarfrost phenomenon in order to highlight the vulnerability of the analyzed area regarding this phenomenon. In a first phase, in order to identify the periods of high vulnerability, we analyzed the frequency of the days with minimum temperature ≤ 0 º C. But the occurrence of temperatures below 0° C is not enough to guarantee the formation of hoarfrost. Additionally, the air must be initially damp enough so that when cooled it reaches saturation, and any additional cooling will cause condensation to occur. We also analyzed the medium annual number of days with hoarfrost and their multiannual variation, the monthly and season variation of the days with hoarfrost, and the medium and extreme dates of hoarfrost production. The analysis of the parameters which define the hoarfrost phenomenon was realized on the basis of the information recorded at the meteorological stations present in the Western Plain. Finally we analyzed some cases in which there was hoarfrost and we described synoptic conditions that favored this phenomenon. The optimal conditions for the occurrence of hoarfrost are anticyclone systems with clear sky and slight wind, high relative humidity and negative air temperatures. When intense weather cooling is predicted, farmers can take various measures against the risks associated with this cooling, respective to early hoarfrost phenomenon in autumn or late hoarfrost in spring.*

Key words*: frost, hoarfrost, frequency of hoarfrost days, vulnerability, risk*

INTRODUCTION

Under clear frosty nights soft ice crystals might form on vegetation or any object that has been chilled below freezing point by radiation cooling. This deposit of ice crystals is known as hoarfrost and may sometimes be so thick that it might look like snow. The interlocking ice crystals become attached to branches of trees, leafs, hedgerows and grass blades and are one of the most prominent features of a typical "winter wonderland" day.

Fig. 1. Hoarfrost deposits on the grass and on the leaves.

When the temperature of items on the ground is below freezing, condensation of water vapor can occur. Similar to the formation of dew, moist air will be cooled when it comes in contact with the cold surfaces. The air will quickly reach the dew point temperature, which, in this case, is below freezing. The water vapor will then convert directly into ice and leave needle-like coatings of hoarfrost on various objects including grass, trees, telephone wires, and more.

Hoarfrost is formed by direct condensation of water vapor to ice at temperatures below freezing and occurs when air is brought to its frost point by cooling. The occurrence of temperatures below 0^{o}C is not enough to guarantee the formation of hoarfrost. Additionally, the air must be initially damp enough so that when cooled it reaches saturation, and any additional cooling will cause condensation to occur.

The hoarfrost phenomenon is part of climate risks of the transition seasons (spring and autumn), whose characteristic is the alternation from positive to negative temperatures. (Octavia Bogdan, 2005).

Hoarfrost can cause extensive damages to crops, plants, and delicate flowers. Hoarfrost produces significant damage in agriculture when overlap with the growing periods of the plants (after 20 March) or when vegetative rest is not installed yet (until 15 October).

MATERIAL AND METHODS

In order to highlight the periods which present a risk of producing hoarfrost, we considered data corresponding to meteorological stations that are representative for the Western Plain: Timişoara, Arad and Oradea. We studied data on the phenomena of frost and hoarfrost for the last 5 years, from 2010 to 2014. For analysis, we used meteorological data from SRPV Timişoara and climatological data based on which we drawn comparative tables and graphs for each weather station. We also used synoptic maps related to the individual cases studied.

RESULTS AND DISCUSSIONS

In terms of number of days with frost (t_{min}< 0^{o}C), as we can see in the Tables 1-3, they are distributed in the period from October to May, except that, during the period studied, only in Arad there was a day with frost in May. The maximum annual number of days with frost was recorded in 2011 for all the weather station studied, with a significant contribution in February, and especially in November, when the number of days with frost was far above average.

Table 1.

The number of days with frost (t_{min}< 0ºC)), monthly and yearly, for Timişoara weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually
2010	21	12	10	0	0	0	0	0	0	4	2	20	69
2011	19	22	13	0	0	0	0	0	0	4	18	15	91
2012	23	26	13	2	0	0	0	0	0	1	2	21	88
2013	17	8	15	0	0	0	0	0	0	2	4	24	70
2014	15	11	5	0	0	0	0	0	0	1	2	11	45
Average for 2010-2014	19	15.8	11.2	0.4	0	0	0	0	0	2.4	5.6	18.2	72.6
Monthly / yearly multiannual average	24.9	19.2	12.9	1.8	0	0	0	0	0.1	2.9	9.8	20.4	92

Table 2.

The number of days with frost (t_{min}< 0ºC), monthly and yearly, for Arad weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually
2010	21	11	11	0	0	0	0	0	0	8	3	20	74
2011	20	23	13	0	1	0	0	0	0	8	20	15	100
2012	22	27	14	2	0	0	0	0	0	1	3	23	92
2013	21	9	15	1	0	0	0	0	0	2	4	24	76
2014	15	10	5	0	0	0	0	0	0	3	3	9	45
Average for 2010-2014	19.8	16	11.6	0.6	0.2	0	0	0	0	4.4	6.6	18.2	77.4
Monthly / yearly multiannual average	29.4	19.5	15	3.2	0.2	0	0	0	0	2.1	8.2	17.2	94.8

Table 3.

The number of days with frost (t_{min}< 0ºC), monthly and yearly, for Oradea weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually
2010	23	13	10	0	0	0	0	0	0	4	3	22	75
2011	18	23	11	1	0	0	0	0	0	6	19	15	93
2012	19	27	14	3	0	0	0	0	0	1	1	20	85
2013	19	12	16	2	0	0	0	0	0	4	3	25	81
2014	13	8	3	0	0	0	0	0	0	4	5	7	40
Average for 2010-2014	18.4	16.6	10.8	1.2	0	0	0	0	0	3.8	6.2	17.8	74.8
Monthly / yearly multiannual average	24.3	20.3	13.6	2.8	0.5	0	0	0	0	1.8	8.5	20.7	92.5

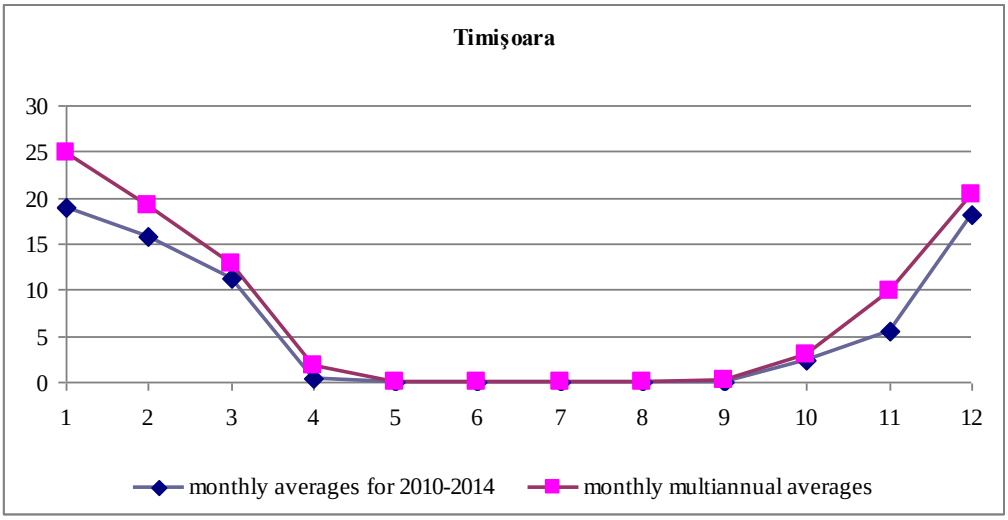

Fig. 2. Comparative Chart: The monthly average number of days with frost - Timişoara weather station

In Figures 2-4, the comparative charts reveals the following: for Timişoara weather station, the monthly number of days with frost is less than the monthly multinnual average throughout the studied period; for Arad weather station is observed an exceeding of the multiannual average for October and December, generated especially by the values more then average in the years 2010, 2011 respectively 2012, 2013; for Oradea weather station, the multiannual average is exceeded only in October which was characterized by a greater number of days with frost than normal in almost all studied years.

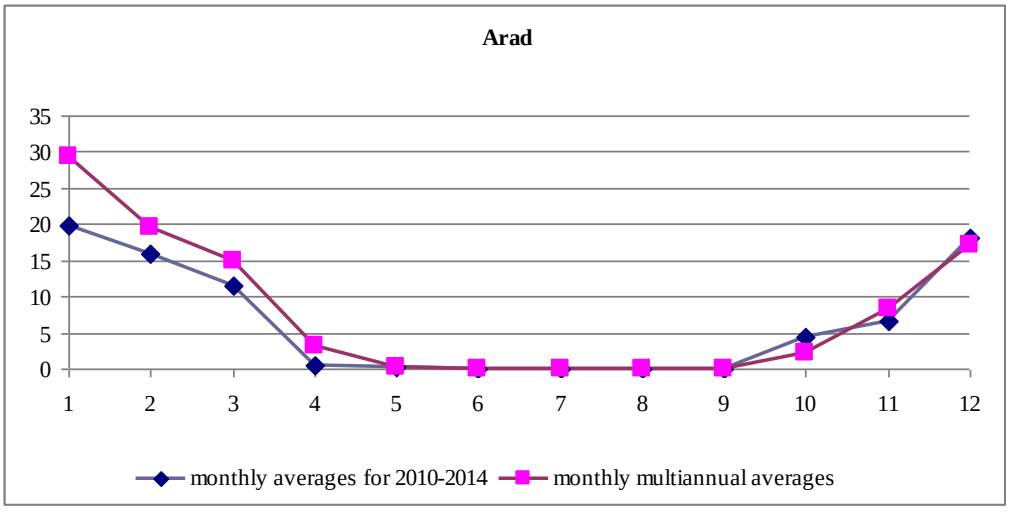

Fig. 3. Comparative Chart: The monthly average number of days with frost – Arad weather station

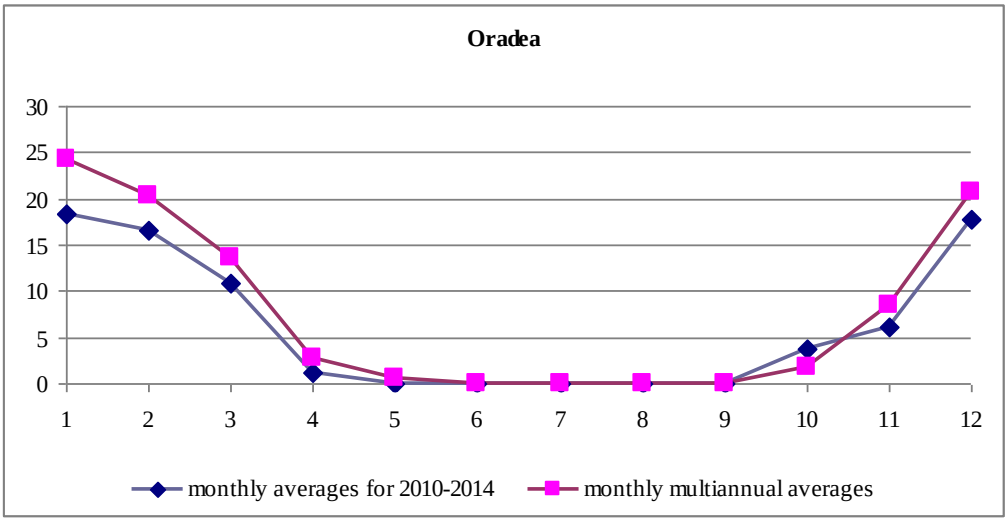

Fig. 4. Comparative Chart: The monthly average number of days with frost – Oradea weather station

Regarding the annual number of days with frost, Table 4 shows there is a negative deviation from its annual average, throughout the period 2010-2014, which can be defined as "softer" than normal. But there is a positive deviation in 2011 in Arad and Oradea.

Table 4.

The annual number of days with frost and average for 2010-2014; deviation compared to multiannual average for Timişoara, Arad and Oradea weather stations

Weather station /Year	**2010** (no. days)	**2011** (no. days)	**2012** (no. days)	**2013** (no. days)	**2014** (no. days)	**Average for 2010-2014** (no. days)	**Multiannual average** (no. days)
Timişoara	69	91	88	70	45	72.6	**92**
Deviation compared to multiannual average	-23	-1	-4	-22	-47	-19.4	
Arad	74	100	92	76	45	77.4	**94.8**
Deviation compared to multiannual average	-20.8	5.2	-2.8	-18.8	-49.8	-17.4	
Oradea	75	93	85	81	40	74.8	**92.5**
Deviation compared to multiannual average	-17.5	0.5	-7.5	-11.5	-52.5	-17.7	

The data in this table are plotted in Figure 5:

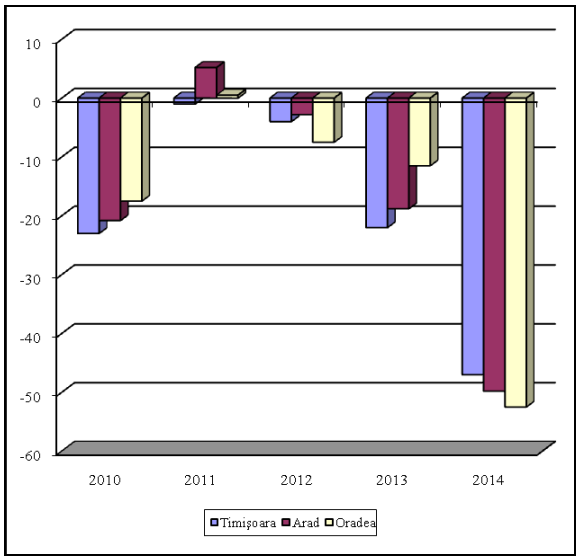

Fig. 5. The annual average deviation (between 2010-2014) compared to the multiannual average of the annual number of days with frost, for Timişoara, Arad şi Oradea weather stations

In Table 5 we can find summarized data of the last frost (spring), data of the first frost (autumn) for the studied period (2010 – 2014), for representative weather stations in the Western Plain (Timişoara, Arad, Oradea), as well as extreme values and their average, according to the latest statistics.

Table 5.

Dates of the last frost occurrence (spring) and occurrence of the first frost (autumn) - extreme values, averages, years 2010 – 2014

	Weather station	**Extreme dates**		**The average date**	**2010**	**2011**	**2012**	**2013**	**2014**
		earliest	**latest**						
Date of last frost	Timişoara	23.III	19.V	09.IV	18.III	25.III	10.IV	29.III	26.III
	Arad	**09.III**	**21.V**	**17.IV**	**17.III**	**06.V**	**10.IV**	**02.IV**	**26.III**
	Oradea	10.III	02.V	10.IV	17.III	14.IV	10.IV	08.IV	14.III
Date of first frost	**Timişoara**	**04.X**	**21.XI**	**24.X**	**22.X**	**17.X**	**31.X**	**04.X**	**28.X**
	Arad	29.IX	30.XI	20.X	09.X	15.X	31.X	04.X	28.X
	Oradea	**04.X**	**29.XI**	**20.X**	**22.X**	**14.X**	**31.X**	**04.X**	**27.X**

The average timeframe without frost, regarded as the difference between the average date of the last frost and the average date of the first frost, varies depending on the advective

and radiative processes that take place throughout the country. Figure 6 highlights the spatial variability of the average annual frost-free interval in our country. As can be seen, in the Western Plain, the frost-free period lasts between 175 and 200 days.

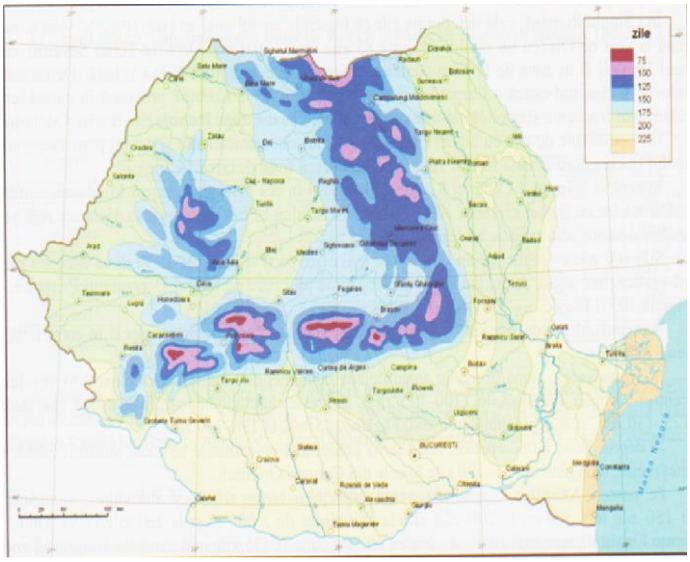

Fig. 6. The average duration of annual frost-free interval (1961-2000)

Data on the hoarfrost occurrence at the studied stations were summarized in tables 6-8.

Table 6.

The number of days with hoarfrost, monthly and yearly, for Timişoara weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually
2010	10	2	6	0	0	0	0	0	0	7	2	4	31
2011	5	7	6	0	0	0	0	0	0	6	15	6	45
2012	12	8	11	1	0	0	0	0	0	2	3	7	44
2013	7	3	7	0	0	0	0	0	0	2	1	16	36
2014	4	7	6	0	0	0	0	0	0	3	4	7	31
Average for 2010-2014	7.6	5.4	7.2	0.2	0	0	0	0	0	4	5	8	37.4
Monthly/yearly average	6	8.7	8.7	3.2	0.4	0	0	0	0.2	4.4	7	9	47.6

It can be seen, for Timişoara weather station, that in all the years taken into account, the annual number of days that have experienced the phenomenon of hoarfrost does not exceed the annual average. This relationship applies to monthly averages for the period 2010-2014 (fig. 7), except for January, which does not present a particular interest in this context. In this regard, noteworthy would be 2012, when there were 12 cases of hoarfrost in spring, and 2011, with 21 days with hoarfrost recorded in the autumn.

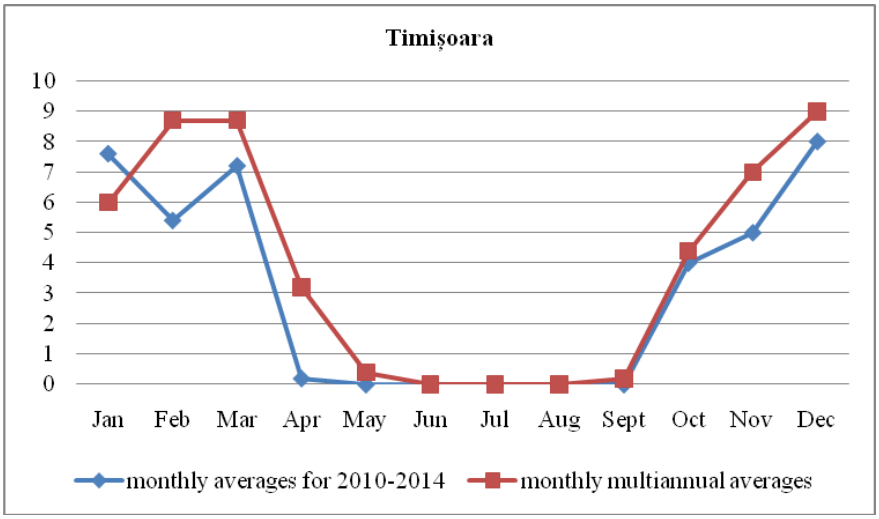

Fig. 7. Comparative Chart: The monthly average number of days with hoarfrost – Timișoara weather station

Table 7.

The number of days with hoarfrost, monthly and yearly, for Arad weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually
2010	6	1	7	0	0	0	0	0	0	9	2	3	28
2011	5	7	8	0	2	0	0	0	0	7	15	8	52
2012	10	10	12	2	0	0	0	0	0	1	2	9	46
2013	8	2	9	1	0	0	0	0	0	3	1	9	33
2014	4	5	4	0	0	0	0	0	0	3	3	10	29
Average for 2010-2014	6.6	5	8	0.6	0.4	0	0	0	0	4.6	4.6	7.8	37.6
Monthly/yearly multiannual average	1.7	3	3.1	1.3	0.3	0	0	0	0.1	2.5	4.4	3.4	19.8

For Arad weather station, the data in Table 7 reveal the following: the annual number of days that have experienced the phenomenon of hoarfrost is almost double compared to the annual average, which may suggest a significant increase in crop damage; a reason for this could be the existence of a number of days with frost well above average in spring, especially those of 2011, when there were 10 days with hoarfrost, of which 2 in May, and 2012, when there were 14 days with hoarfrost, of which 2 in April; but it can be also considered quite important the large number of cases in relation to the multiannual average of hoarfrost in autumn 2011 and 2010. As can be seen in Figure 8, the monthly average number of days with hoarfrost for the studied period, is exceeding the multiannual average in all months except April, most notably in March, with a number of days of almost 3 times higher than normal.

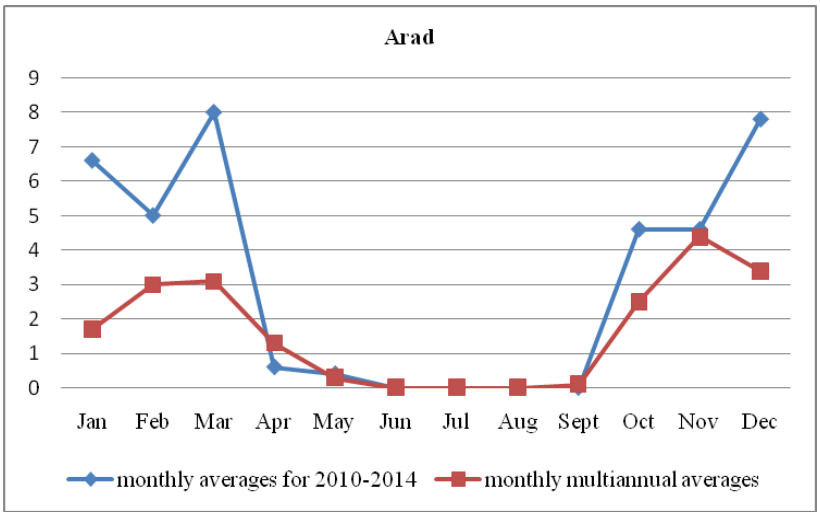

Fig. 8. Comparative Chart: The monthly average number of days with hoarfrost – Arad weather station

Table 8.

The number of days with hoarfrost, monthly and yearly, for Oradea weather station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually
2010	5	0	3	0	0	0	0	0	0	3	3	3	17
2011	3	7	5	1	1	0	0	0	0	7	17	7	48
2012	10	13	9	2	0	0	0	0	0	1	2	9	46
2013	6	4	6	1	0	0	0	0	0	2	1	14	34
2014	4	8	2	0	0	0	0	0	0	4	4	5	27
Average for 2010-2014	5.6	6.4	5	0.8	0.2	0	0	0	0	3.4	5.4	7.6	34.4
Monthly/yearly multiannual average	1.1	2.2	2.6	0.7	0.2	0	0	0	0.1	1.5	3.3	2.7	14.4

Regarding the phenomenon of hoarfrost signaling at the Oradea weather station, the situation is similar to the one in Arad: an annual average much higher than normal (about 2.5 times), and for the years 2011 and 2012 in which there were many cases, there was again hoarfrost appearance in May and April 2011 (one day), and a large number of days in the spring of 2012 (9 days in March, and 2 in April). Also, there were a large number of cases compared to normal in the fall of 2011: 7 days in October and 17 days in November

The comparative graph in Figure 9 also shows the multiannual average exceeding the number of days with hoarfrost in the studied period, except September. Note as March and October, when monthly averages of the survey period were approximately two times higher than normal. These months are important in terms of the risks crops are exposed to.

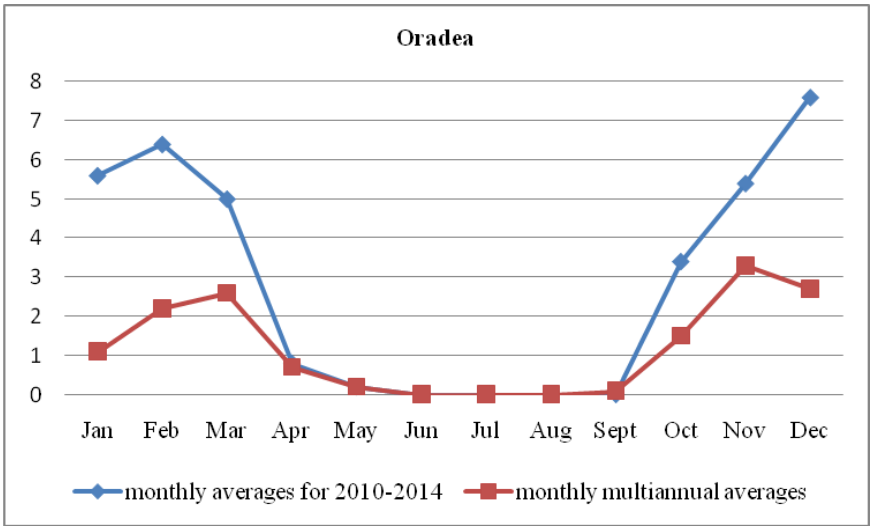

Fig. 9. Comparative Chart: The monthly average number of days with hoarfrost – Oradea weather station

Assessments made on the basis of the tables above, revealed that in the years 2011 and 2012 there was a significant number of days with frost, and hoarfrost respectively (2-3 times higher than normal) and also that these phenomena occurred in periods of risk of damage to crops when they are in different stages of vegetation. Therefore we considered it would be useful to decipher the synoptic context in which the pronounced cooling of the weather occurred, in order to inform those interested in these issues in a most efficient way possible.
For example we considered as important period the one in the latest frost (and hoarfrost) occurrence in the years 2010-2014: between 4 and 7 May 2011.

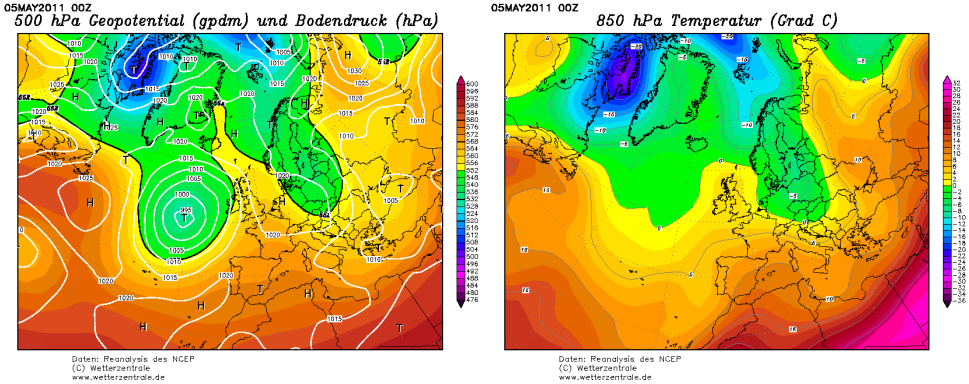

Fig. 10. Geopotential at 500 hPa and sea level pressure in 05.05.2011 h 00 GMT; temperature at 850 hPa in 05.05.2011 h 00 GMT

In the night of 04/05 May 2011, pressure distribution in our country was the result of the following context: the Icelandic Depression was displaced towards south, thereby allowing the intrusion of a mass of warm and humid air above the western European extremity, the

depressionary field that previously affected our country was receding towards north-west, and in the northern and central part of the continent, a high pressure field was causing, in its extension towards south-east, the intrusion of a very cold air mass, of arctic origin up to medium latitude levels. Thus, the north-west of our country was entering, due to a northern circulation supported by the thalweg on the 500 hPa level, a process of pronounced cooling. As it can be observed in Figure 10, the air temperature at the 850 hPa level becomes negative, the thermal gradient of the whole country being approximately 8 ºC.

In Figure 11 we present the baric and thermal context after 24 hours. In the night of 05/06 May, the high atmospheric pressure field that was extended to the Central Basin of the Mediterranean caused the air temperature to drop below 0 ºC above the entire country, at the 850 hPa level and others. The stability of the cold air mass led to an amplified cooling through radiative processes, so that the air temperature became negative, even on ground level.

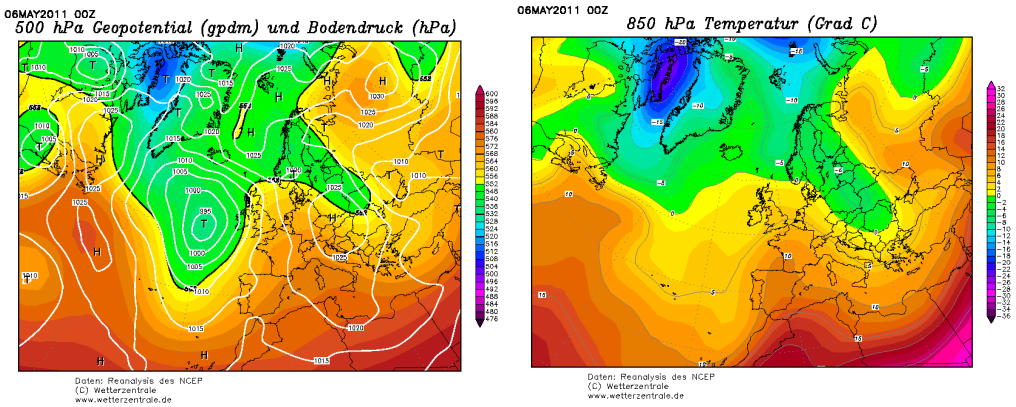

Fig.11. Geopotential at 500 hPa and sea level pressure in 06.05.2011 h 00 GMT; temperature at 850 hPa in 06.05.2011 h 00 GMT

That night, the Arad weather station recorded negative temperatures, and hoarfrost occurrence was locally reported in the western part of the country, including Arad and Oradea.

CONCLUSIONS

The early hoarfrost in autumn causes significant damage to agricultural crops on the fields, the effects being even worse when the plants are hit during the vegetation stage, before the phenological cycle ends. The late hoarfrost in spring causes the most damage to agricultural crops being at the beginning of the vegetation period, not only slowing down plant development and early terminating the growing season, but also causing partial or total death. The most damage occurs in the pomiculture, when the low temperature associated to the hoarfrost phenomenon hits the trees during the vegetation cycle, sometimes destroying all harvest. The vineyards are also affected, especially the early varieties.

According to the present study, for Timişoara, Arad and Oradea weather stations in the Western Plain, for the period 2010 – 2014, the date of the first frost is placed around the multiannual average date of the first frost, while the date of the last frost is placed after the multiannual average date, the biggest difference being 18 days, for Arad, in 2011.

Regarding the number of days with hoarfrost, this was above average in Arad and Oradea, weather stations that are situated in the northern part of the Western Plain, therefore being more exposed in case of Nordic circulations of the atmospheric air.

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