MEDITERRANEAN CYCLONES TRACKS IN EUROPE WITH SPECIAL VIEW OVER ROMANIA (1985-2015)

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Abstract. *Mediterranean cyclones (MCs) affect not only the countries neighboring the Mediterranean basin, but also the weather conditions in regions that are not in direct contact with the Mediterranean basin such as Central, Eastern and South-Eastern Europe, including Romania. They are associated, in general, with extreme weather events. This study considered data over a 30-yr. period (December 1, 1986 – November 30, 2015). For MCs identification and their track tracing, the mean sea level pressure, 500 hPa geopotential heights, 500-1000 hPa relative topography and 850 hPa pseudo-equivalent potential temperature were employed. The European spatial domain was delimited as 30°-60° N latitude and as 20° V - 45 ° E longitude. To select those cyclones influencing the weather in Romania a square-shaped area whose external limits are located about 500 km from the center of Romania was used. For tracing the trajectory, the low-pressure center position at every 6 hours was considered. Frequency of occurence and track density were analyzed considering two temporal approaches: i. for the entire period and for three 10-yr subperiods; ii. the annual and seasonal scale for the entire period. For track density, the anomalies for each 10-yr sub-period and for each season were calculated. The main findings of this study are: the most exposed area to MCs are central and eastern Mediterranean regions, 43.39% of the cyclones generated in the Mediterranean basin crossed the region of Romania; seasonally, the highest occurrence frequency is specific to winter and the lowest to summer; no significant changes in the annual or seasonal occurrence was detected; during the second 10-yr sub-period weak to moderate positive anomalies were detected, whereas during the first and the last ones, positive and negative anomalies were found depending on the season and region; seasonal average position of the MCs tracks revealed the largest shift from one sub-period to another in winter and the smallest in autumn.*

1. INTRODUCTION

The semi-enclosed Mediterranean basin is one of the main cyclogenesis regions in the world (Akhtar et al., 2014, Ragone et al., 2020) with a large number of cyclones different in structure, lifetime and intensity forming every year (Lionello et al., 2016). Mediterranean Cyclones (MCs) are climate determinants for the southern and south-eastern regions of Europe and are one of the most important factors generating severe meteorological and hydrological events in the crossing regions (Jansa et al., 2001a; Lionello et al., 2006). They affect, mainly by producing extreme precipitation or heavy dust transport from Africa towards Europe (Fita and Flaounas, 2018), not only the countries neighboring the Mediterranean basin, but also the weather conditions in regions that are not in direct contact with the Mediterranean basin such as Central, Eastern and South-Eastern Europe.

The important variation in the tracks density (TD), position, frequency, and intensity of the Mediterranean lows determines frequent changes in weather conditions, generating drought, flash floods and persistent floods, wind storm events in the crossed regions (Șorodoc, 1962; Bordei, 1983; Radionović, 1987, Jansa et al., 2001a,b, Nissen, 2010, Nissen et al., 2013, Dobri et al., 2017, Catrina et al., 2018, Gvoždíkováa and Müller, 2021). For this reason, topics like the density, frequency and position of the MCs tracks got the attention of many researchers at European level (Lionello et al, 2006; Ulbrich et al., 2009; Zappa et al, 2013 and 2015; Nissen, 2010; Nissen et al., 2013). Cyclones originated in the Mediterranean Sea basin followed a large variety of tracks, but the most frequent are those towards east and northeast (Radionović, 1987). One of the most recent finding was a north-easterly migration of Atlantic and Mediterranean cyclones track, generally agreed upon as an expected result of climate change in this region (Bonaldo et al., 2020).

Some other studies focused on analyzing the intensity of MCs, such as those describing the statistics of Medicanes in the Western Mediterranean basin based on a set of multidecadal simulations performed with WRF in different model setups (Ragone et al., 2018), or simulating the deepening rate and exploring the role of sea surface heat fluxes for some specific cases of explosive cyclogenesis in the eastern Mediterranean (Kouroutzoglou et al., 2018). It is estimated that in a warming climate, the intensity and duration of the Mediterranean Tropical-Like Cyclones will increase, while their number (occurrence frequency) will remain constant (Dafis et al., 2020).

To detect the occurrence and follow the MCs tracks the information provided by geostationary satellites with high temporal and spatial resolution is very important as it allows the use of infrared brightness temperature to better estimate the presence of convective clouds associated to the MCs. Although some limitations were observed in discriminating convective clouds from high-level clouds the infrared remote-sensing observations is still the most common approach in literature (Dafis et al., 2020).

For the Romanian territory, the depressions originated over the Mediterranean Sea represent an important source of precipitation, mainly for the south, south-east and east of the country as well as a factor generating extreme meteorological events such as heavy rainfall, massive snow and snow storms, long-lasting drought events, and sometimes, upper dust transport. (Șorodoc, 1962; Bordei, 1983; Gogu, 2007, Dobri et al., 2017).

The main aim of this paper is to investigate the low-pressure systems originated over the Mediterranean Sea in terms of their TD and frequency for a 30-yr period (1986-2015) over the Romania's region. The data and methodology used for the identification and tracking of the MCs and the methods used in the study are described in section 2, the results obtained and discussions are presented in section 3 over the considered region. The last section is dedicated to Conclusions.

2. DATA AND METHODES

2.1. Data used

To create the database, the spatial domain for further analysis was delimited as latitude between 30° N and 60° N and as longitude between 20° V and 45 ° E (FIG. 1a). We identified all the low-pressure systems that crossed over the European region over a 30-yr the period, from December 1, 1985 to November 30, 2015. We consider the December 1985 data in order to catch the seasonal features, too. In order to select the MCs influencing the weather in the region of Romania following the trans-Balkan tracks, the average radius of these cyclones was established at 520 km (Gogu, 2007).

This way a square-shaped area whose external limits are located about 500 km from the center of Romania resulted: a cyclone with a radius of 500 km located with the center on one of the 4 sides covers about 50% of the country's territory (Fig. 1b).

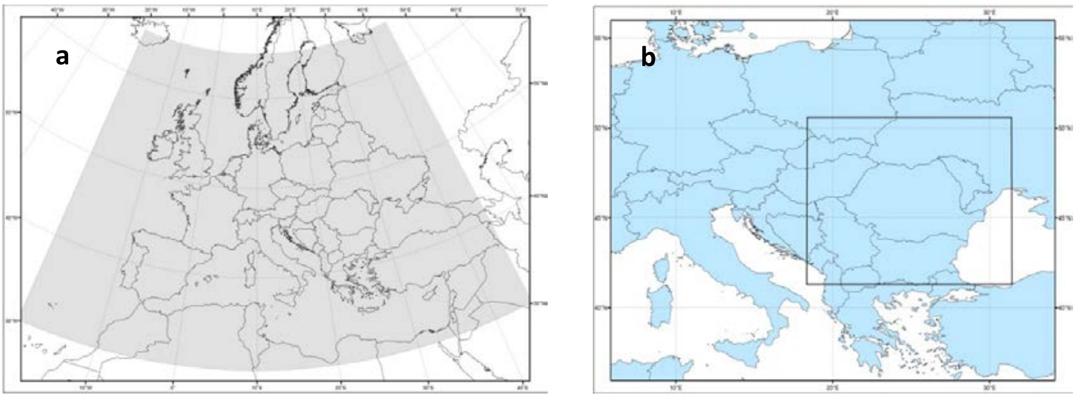

FIG. 1 Study area (a). Romania (b)

For MCs identification and their track tracing, the mean sea level pressure (MSLP), 500 hPa geopotential heights, 500-1000 hPa relative topography and 850 hPa pseudo-equivalent potential temperature were employed. The MSLP field data used in this study were extracted from the re-analysis data set, ERA-interim (Dee et al., 2011) with a spatial resolution of 0.75°×0.75° and a 6-hour temporal resolution, made available by the European Center for Medium-Range Weather Forecast (ECMWF). The other data are available at http://www1.wetter3.de/archiv_gfs_dt.html. (WASA 1998; Alexandersson et al. 2000; Gulev et al 2001; Hoskins and Hodges 2002; Almazroui et al, 2014). The 6-hour temporal resolution has the disadvantage of increasing TD in the case of stationary and quasi-stationary low-pressure systems (Serreze et al, 1997), but it is the optimal time-step to capture cyclogenesis process over the Mediterranean Sea and its neighboring regions. Using the center position for a 12- or 24-hour time step (resolution) would lead to ignore or to later identification of the MCs.

The cyclones developed over the island of Cyprus that did not followed a northward track were excluded from this study because they left the study region after a short time from their occurrence (less than 24 h from their identification).

2.2. Low-pressure systems detection and tracking

Low-pressure systems were identified based on the minimal principle in the MSLP field, surrounded by at least one closed isobar. It was intended that the minimum pressure at the center be less than 1010 hPa. The tracks of the Mediterranean lows were derived from the center position points identified at every 6 hours. All lows detected based on MSLP and confirmed by the mid-troposphere data, including those stationary, were maintained for further analysis. When a cyclone, in its initiating phase developed two centers (two centers-cyclone), we consider the track of the center with the lowest pressure and the longest displacement. If the second center had a life-time longer than 24 hrs, it was registered as a new individual starting from the first closed isobar.

A MC identified based on the previously described method was considered to have the initial position at time t_0, and the next position corresponds to its 6-hr later location, at time t_1. The track of the cyclone is given by all locations corresponding to consecutive time-steps where the low-pressure center was identified during its life-time.

2.3. Analysis of the MCs activity

The activity of the low-pressure systems originated over the Mediterranean Sea was analyzed by their occurrence frequency and by the track density (TD) with a special focus on the second issue.

The occurrence frequency analysis was performed for the entire period (1985-2015), but also for three shorter sub-periods, of 10 years each (1985-1995, 1996-2005, 2006-2015), as well as considering the entire year and the seasonal values.

The analysis considered the MCs occurrence, but also the frequency of the tracks crossing each grid established as described below.

Low-pressure systems track density (New et al., 2013) is the measure of the spatial distribution of a low-pressure center activity (Nissen et al, 2010). For density analysis polynomial interpolation was used, for centroids of each 3° x 3° grid. This method of interpolation was chosen given the homogeneous distribution of points at the level of the studied area. To highlight the evolution of average TD over the considered period, the difference between a specified decade and the average of the three 10-yrs sub-periods (considered as the reference value) was obtained as rasters:

$$M_3 = \frac{(D_1+D_2+D_3)}{3} \tag{1}$$

Where,

M_3 – mean decadal number of cyclone tracks (TD) calculated for annual value or for each season;

D_1 - TD for the period 1986-1995 (1985-1995 for winter season);

D_2 - TD for the period 1996-2005 (1995-2005 for winter season);

D_3 – TD for the period 2006-2015 (2005-2015 for winter season).

Further on, we calculated the anomaly for each sub-period over the entire period:

$$TN_{Dn} = D_n - M_3 \tag{2}$$

Where,

TN_{Dn} – anomaly of the TD for a specified sub-period;

D_n – TD for each subperiod, n=1; 2; 3 as given in equation (1);

M_3 – mean decadal number of cyclone tracks calculated for each season.

The spatial analysis was performed both on an annual and seasonal basis. We have chosen to focus also on the seasonal analysis, first because of seasonal occurrence of the MCs, with a maximum frequency during the cold half of the year and because different TD has been found for each season (winter - DJF, spring - MAM, summer - JJA autumn – SON).

In order to determine the mean position of the MCs' tracks, we used the latitude and longitude coordinates values and for each decade a linear regression function was applied. The resulting coordinates were first converted to points using ESRI ArcGIS v.10.8 software and then converted to lines marking the general trend of cyclones over the analysed (sub-)period. Thus, the mean trajectory (average position of the tracks) of the MCs in the study area were obtained.

2.4. Trend analysis

The trend analysis was performed based on annual and seasonal frequency data. We used Mann-Kendall test to detect de trend, whereas for the magnitude of the trend, Sen's slope method was employed (Mann, 1945; Kendall, 1975, Sen, 1968).

They are commonly and largely used methods for detecting changes in hydro-climatic variables (Zhang et al., 2005; Choi et al., 2009; Croitoru et al., 2012a; Tabari et al., 2012). The significance level was established at α=0.05.

The data were processed by employing XLSTAT software, Premium version.

3. RESULTS

3.1. Frequency of the MCs occurrence

3.1.1. Frequency of MCs occurrence over the entire year

Using the data and methods described above, 779 closed lows-systems have been identified and traced based on MSLP, originating from the Mediterranean Sea basin between December 1, 1985 and November 30, 2015, to which we added 95 cyclones generated over the Atlantic Ocean or in the region of Iceland, but following the Vb track, established by van Bebber (van Bebber, 1891 cited by Messmer et al., 2015). It resulted in a total of 868 tracks. More than 43 % of them ended up influencing the weather in Romania (Table 1).

Table 1. Frequency of the MCs occurrence over the period 1986-2005 and over the 10-yr sub-periods

Decade	Frequency of MCs* occurence	Frequency of MCs crossing Romania	Frequency of MC crossing Romania (%)
1986-1995	272	116	42.64
1996-2005	312	136	43.59
2006-2015	290	127	43.73
Total	**874**	**379**	**43.36**

For the 10-yrs sub-periods, one can see that the most intense cyclonic activity characterized the second sub-period both in terms of general occurrence over the Mediterranean basin and on crossing Romania's territory, whereas the least intense was specific to the first 10-yrs sub-period (Table 1).

As multiannual average, more than 28 cyclones occur each year, but their number varied over the entire period from 15 to 45. Less than half followed tracks crossing our focus region (Tables 1 and 2).

No change was detected for the annual frequency of cyclones occurrence over the Mediterranean Sea or of those crossing Romania (Table 3).

Table 2. Frequency of the MCs occurrence by seasons over the period 1985-2015

Value	Total MCs occurrence									
	Winter		Spring		Summer		Autumn		Annual	
	No	%*	No.	%	No	%	No	%	No	%
Total number	**349**	**39.93**	**261**	**29.86**	**65**	**7.44**	**199**	**22.77**	**874**	**100**
Minimum	4	-	6	-	0	-	3	-	15	-
Average	11.6	39.8	8.7	30.1	2.2	7.3	6.6	22.8	29.1	100
Maximum	19	-	13	-	8	-	14	-	45	-
	MCs crossing Romania									
Total number	**127**	**36.39**	**129**	**49.43**	**39**	**60.0**	**84**	**42.21**	**379**	**43.36**
Minimum	0	-	1	-	0	-	1	-	6	-
Average	4.2	33.3	4.3	34.1	1.3	10.2	2.8	22.3	12.6	100
Maximum	12	-	8	-	5	-	7	-	22	-

*The percentage value for the *Total MCs occurrence* represents the share of the total annual number and for the *MCs crossing Romania* represents the share of the total MCs occurrence for the corresponding season

Table 3. Trend test results for the frequency of the MCs occurrence and those crossing Romanian territory by seasons over the period 1986-2015

Series/ Test	Frequency of MCs occurrence in the Mediterranean Basin			Frequency of MCs crossing Romania		
	Kendall's tau	p-value	Sen's slope	Kendall's tau	p-value	Sen's slope
Winter	0.204	0.131	0.118	0.230	0.092	0.083
Spring	-0.124	0.372	0.000	-0.056	0.699	0.000
Summer	-0.183	0.192	0.000	-0.173	0.228	0.000
Autumn	0.066	0.637	0.000	0.010	0.956	0.000
Annual	0.028	0.844	0.000	0.047	0.733	0.000

3.1.2. Frequency and trends of the MCs occurrence by seasons

a. Winter

As expected, the frequency of cyclones developed over the Mediterranean basin is the highest in winter when 349 individuals were identified (39.93 %), out of which 127, representing 36.39%, passed with their central point over different areas of the focus region. The multiannual average frequency for winter season for the occurrence over the 30-yrs period is more than 11 cases/season, with extreme values ranging from 4 to 19 CMs/season. For the Romanian region a mean value of 4.2 cyclones/season was identified, but their number varied from one year to another from 0 to 12 (Table 2).

The trend analysis indicated a slight increase, yet not statistically significant, in the number of cyclones both in terms of those generated over the Mediterranean Sea and those crossing Romania (Table 3).

b. Spring

In spring, the frequency of cyclones in the Mediterranean basin is much lower than in winter, registering 261 cyclones out of which, 129 cyclones (49.43%) passed through the region of Romania. The mean seasonal occurrence frequency of the MCs is 8.7 whereas 4.3 MCs/season crossed the focus region during spring. Extreme values varied between 6 and 13 for the total number of cyclones generated over the Mediterranean, and between 1 and 8 for those crossing Romania (Table 2).

The trend test did not indicate any change (Table 3).

c. Summer

Summer season was characterized by the lowest number of cyclones (65), much lower compared to the other seasons. The multiannual average was calculated to be 2.2 cyclones/season, ranging from 0 to 8 MCs/season. Weather in Romania, during summer was affected by a total number of 39 cyclones over the entire period (60 % of active MCs in summer), with a multiannual average of 1.3 MCs/season, but from one year to another the seasonal number varies from 0 to 5 (Table 2).

The trend indicates a slight decrease in the number of cyclones (Table 3).

d. Autumn

During the autumn, the number of cyclones generated in the Mediterranean basin increased to 199 cyclones, with a multiannual average of 6.6 cyclones/season, and 84 of them (42% of the total and with a multiannual average of 2.8 MCs/season) influenced the weather conditions in the focus region (Table 2).

For this season the trend detected are slightly different for the two categories discussed in this section: for the total number of low-pressure centers generated in the basin a slight increase was registered, whereas stationarity characterized those crossing the region of Romania (Table 3).

3.2. TD spatial analysis at European scale

The TD spatial analysis followed two approaches: first, we considered the TD spatial distribution at annual and seasonal scale over the entire period, and second, we focused on the entire period and the three 10-yrs sub-periods.

3.2.1. TD analysis over the entire year

Thus, the average distribution of TD is higher over the Mediterranean basin and in the eastern and south-eastern European countries. The most affected regions are the Central Mediterranean basin (the Italian Peninsula, the Tyrrhenian Sea, and the Adriatic Sea) with up to 560 tracks, followed by the Eastern Mediterranean (Greece, the Ionian and Aegean Seas) with an average of 281-350 tracks. A much lower TD (71-140) characterized the south-eastern France, Germany, and Poland, most of Ukraine and Belarus as well as the southwest of the European Russia. In other regions of Europe, especially in western and northern regions of the continent, TD averages between 1 and 70 MCs over the entire period. Throughout the study period, the largest Romania's territory was crossed by 141-210 tracks/sub-period over the southern and central regions, whereas the northern third of the region was characterized by a density of 71-140 tracks (Fig. 2).

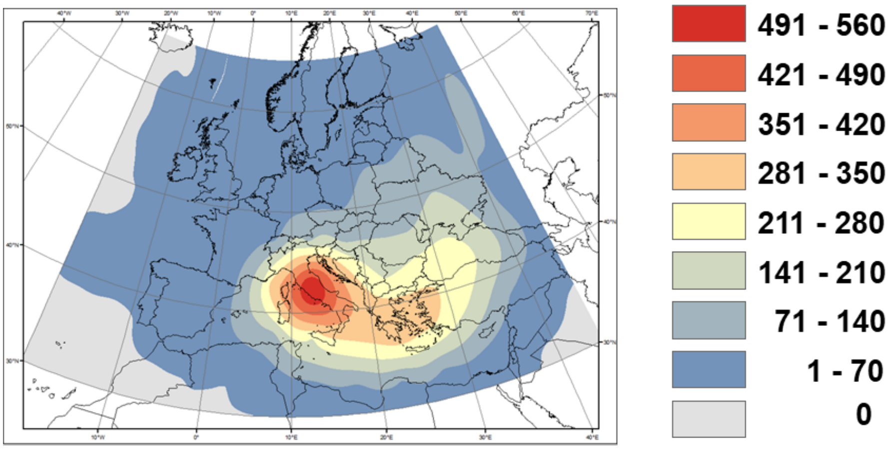

FIG. 2 Spatial distribution of MCs TD over the 30-yr period

Analysis of the MCs TD by 10-yr sub-periods revealed an increase of the frequency from the first sub-period to the next two. However, the highest density characterizes the central Mediterranean and central Italy followed by Eastern Mediterranean region for all three sub-periods.

Romania's territory was affected by 25-50 MCs /sub-period in the northern regions and by 51-75 MCs/sub-period in the southern ones during the first and the last sub-periods, whereas over the second sub-period, the entire country was crossed by 51-75 MCs/sub-period (Fig. 3).

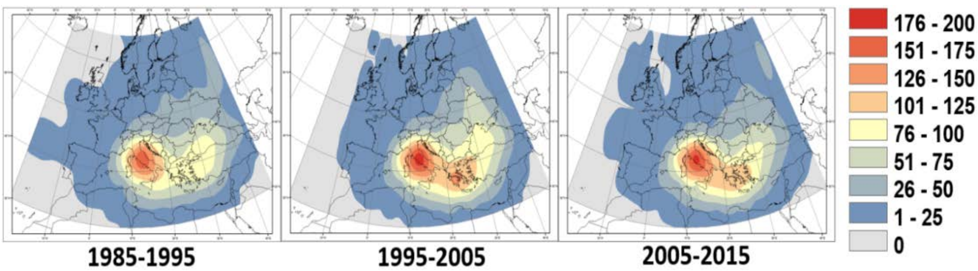

FIG. 3 Spatial distribution of MCs TD over the period 1985-2015 by 10-yrs sub-periods

3.2.2. TD analysis by seasons

The seasonal distribution shows that most tracks were recorded during winter (December, January and February), followed by autumn, spring, and summer.

a. Winter

Among the three sub-periods, the last one was characterized by the most intense cyclonic activity in terms of TD, followed by the second one and by the first one. The highest density over the first sub-period (1985-1995) was identified in the centre of the Italian Peninsula (52-60 tracks/sub-period), followed by Southern Italy and the Ionian Sea (46-51 tracks/sub-period). Beginning with the second sub-period one can notice a decrease in the TD in the Italian Peninsula and an increase in their number in the eastern Mediterranean (southern Greece and Aegean region), where the highest TD was specific during the last sub-period (61-71 tracks/sub-period) (fig. 4). This finding is in agreement with that previously obtained by Zappa et al. (2015).

To better emphasize this feature, we calculated the difference between the TD of each sub-period and the average of the entire 30-yrs period. Results indicated the strongest negative anomaly (-14…-11 tracks/sub-period) during the first 10 years of the study period in the central and Eastern Mediterranean basin (Greece and the Aegean Sea) and the strongest positive one, of 6-14 tracks/sub-period, over the last sub-period in the same region (Fig. 5).

The Romanian region was crossed in winter by 4.2 tracks / season, as an average value. Over the first sub-period (1985-1995), the TD is lower (less than 10 tracks/sub-period in the nordic regions; 10-18 tracks/sub-period in most of the territory and 19-27 tracks/sub-period in the extreme southeast of the country (southern Dobrogea region). Similarly to the situation described for eastern Mediterranean, an increase of the tracks number over Romania was detected over the second decade (10-18 tracks/sub-period over the largest area of the country and 19 - 27 tracks/sub-period in the south and south-east) (Fig. 4).

In terms of anomaly calculated by sub-periods, during the first decade, the negative anomaly of TD is low (2-5 tracks). Over the second sub-period, the TD increases, leading to a low positive anomaly (2-5 tracks) over almost the entire country and to a moderate one, of 6-10 tracks in the extreme north of the country. During the third decade no important changes from the average were found, excepting a narrow region in the south of the country where a low positive anomaly (2-5 tracks) was detected (Fig. 5).

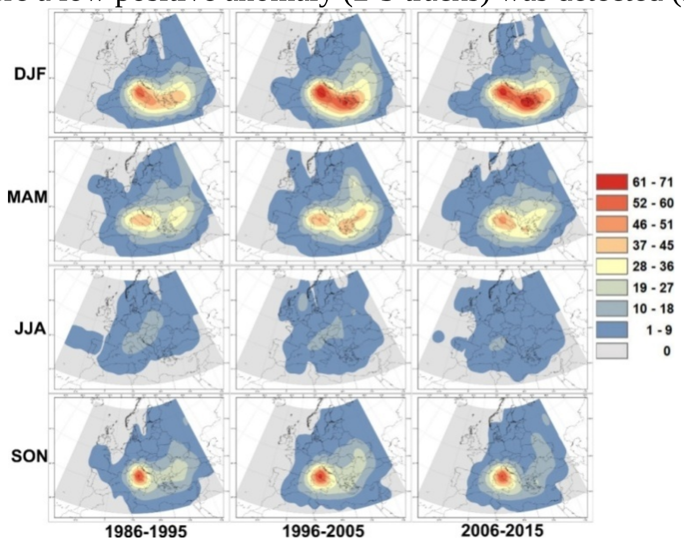

FIG. 4 Seasonal spatial distribution of MCs TD over the 10-yrs sub-periods (for winter season, the period begins for each sub-period in December month of the previous year)

b. Spring

In spring (March, April and May), the average annual number of cyclones generated in the Mediterranean basin over the entire period was 8.2. Over the first sub-period, the most affected region was the central Mediterranean including the Italian Peninsula (37 - 45 tracks). During the second one (1996-2005), the TD increased in the same region to 46-51 tracks, and to 37-45 tracks in the Greek Peninsula, the Aegean Sea, eastern basin of the Mediterranean Sea, the basin of the Marmara Sea, to 28-36 tracks in the central and western regions of the Black Sea, and to 19-27 tracks/sub-period in central and northern Ukraine (Fig. 4).

The anomaly of the TD during the spring revealed that closed lows-systems of Mediterranean origin recorded strong and moderate negative anomalies for the first sub-period (1986-1995) affecting Greece and the Aegean basin (with 14-10 and, respectively 6-9 tracks/decade), whereas Bulgaria, eastern Romania and central Ukraine experienced weak positive anomalies (2-5 tracks/decade) (fig. 5). During the second decade (1996-2005), positive moderate anomalies characterized Greece and the Aegean Sea, the Black Sea basin, the central Anatolian Plateau (6-10 tracks/decade), and strong positive anomalies were detected for central Ukraine, the eastern half of Belarus and western Russia (11-14 tracks / decade) (Fig. 5).

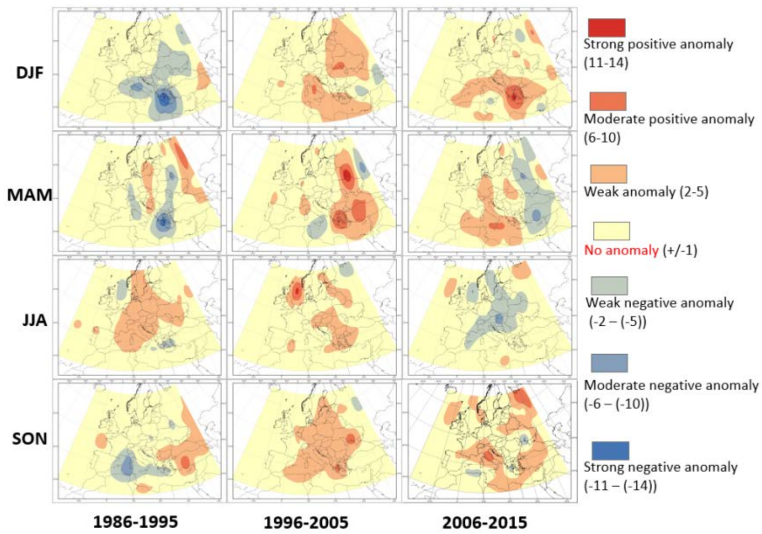

FIG. 5 Seasonal spatial distribution of MCs TD anomaly over the 10-yrs sub-periods (for winter season, the period begins for each sub-period in December month of the previous year)

During the last sub-period (2006-2015), the TD indicated moderate anomalies only over a small area in Italy, whereas weak positive anomalies (2 to 5 tracks/decade) characterized the largest part of the Mediterranean basin, Italy, Greece, Central Europe and more restricted areas in the central and eastern regions of the continent (East of Hungary and Slovakia, South-eastern Poland, western Ukraine). Weak negative anomalies were specific to the eastern Mediterranean Sea, Black Sea, Anatolia Plateau, Ukraine, Eastern Belarus and Western Russia (Fig. 5).

In the focus region, the TD during the spring is comparable to that recorded in winter. During the first two decades (1986-1995 and 1996-2005), the density is 19-27 tracks/decade in the northern half of the country and lower in the northern regions (10-18 tracks/decade). During the last sub-period considered (2006-2015) the number of tracks in the range of 19-27 expanded throughout the entire country (Fig. 4).

In terms of anomalies, during the first 10-yrs period a weak negative anomaly characterized the eastern third of Romania, whereas during the second sub-period, a weak positive anomaly was detected for almost the same region affected by the negative anomaly during the first sub-period. The last 10 years considered for this study indicated a weak positive anomaly in the central and northern regions of Romania (Fig. 5).

c. Summer

Summer season was characterized by the lowest frequency of MCs as indicated by our analysis and by some previous studies (Flocas et al, 2010). The maximum values of TD was in the range of 10-18 for the first two sub-periods in the northern Mediterranean basin, the northern Italian regions, the northern half of the Adriatic Sea, Austria, Hungary, Slovakia, Southeastern Poland and Western Romania. The area characterized by the same frequency considerably decreases from one sub-period to another one for the following ones. The TD did not exceed 9 tracks/sub-periods for the rest of the continent (Fig. 4).

The TD evolution shows a greater number of tracks during the first decade in the Western Mediterranean basin and in the central and eastern regions of the European continent (2 to 5 tracks / decade) (Fig. 5).

In the second decade, the density of the tracks increases in smaller areas in the Central Eastern Mediterranean region (Greece, the Aegean Sea, West Anatolia and Southwest of the Black Sea) and in the eastern and south-eastern regions of the continent (Austria, Hungary, Serbia, Bulgaria and most of Romania with 2 to 5 tracks/sub-period). During the third decade the TD decreases by 2 to 5 tracks/sub-period in the western Mediterranean region, the central, southern and eastern regions of the European continent (Fig. 5).

The Romania’s territory was characterized by no more than 1 MCs/year, as average value. Their number decreased from 12 tracks/decade (over the period 1986-1995) and 14 tracks/decade (during the period 1996-2005), to 4 tracks/decade for the last sub-period (Fig. 4).

In terms of anomaly detected for each sub-period, the first two were characterized by weak positive anomalies, whereas over the last one a weak negative anomaly extended over almost the entire country (Fig. 5).

d. Autumn

In the autumn, the TD of MCs increases compared to that in summer, with the maximum values specific to the Italian Peninsula (more than 46 tracks/sub-period), a region where no significant changes were recorded throughout the study period. Thus, the spatial distribution over the three sub-periods is quite similar. The first one was characterized by 10-18 tracks/sub-period crossing the greatest part of Greece and the Aegean Sea, whilst northern Greece, Bulgaria, north-western Turkey, the Marmara Sea, and the Western Black Sea are impacted by 19-27 cyclones/decade. During the second sub-period, the TD increased in southern Greece and the Aegean Sea to 19-27 tracks/sub-period, and Hungary and Ukraine were crossed by 10-18 MCs. Over the third decade, the TD in the Greek, the Aegean and Western Black Sea regions decreased to less than 20 (10-18 tracks/sub-period) (Fig. 4).

The anomaly analysis of closed-low systems TD over the average value indicated moderate negative values during the first 10-yr sub-period in the Western Mediterranean (6 - 9 tracks/sub-period). Weak negative anomalies were identified for the Sicilian, Ionian and southern regions of Greece (2 - 5 tracks/decade). Weak positive anomalies were detected in Bulgaria, the Marmara Sea, Cyprus and the Black Sea and moderate positive anomalies were identified in central Anatolian Plateau. The second 10-yr sub-period was characterized by weak positive anomalies in Central and Eastern Europe as well as in the western and central Mediterranean Sea.

During the last sub-period, the TD increased in the central and southern regions of the continent, the central region of the Mediterranean Sea, the Adriatic Sea Basin, the Anatolian Plateau, the eastern half of the Black Sea, eastern Poland and Belarus indicating weak positive anomalies (Fig. 5).

The spatial distribution of the annual number of the MCs crossing the Romania's region in the autumn revealed higher values for the first sub-period, and lower for the second and the third ones (Fig. 5).

Regarding temporal anomalies detected in the focus region, a weak positive anomaly characterized the southern Romania during first sub-period, followed by an extension at the entire country level during the second sub-period. No anomalies were detected in the last sub-period considered (Fig. 5).

3.2.3. Analysis of the average position tracks

MCs impacted usually the southern and western regions of Romania. The average position of the tracks over Romania, established for each season is a good indicator of their frequency.

During the winter there is a shift of the mean track position 285 km towards northwest of the country in the second sub-period compared to the first ones, when the mean position crossed the country through its central regions, and then it moves 260 km back to towards south-east in the last sub-period (Fig. 6). This oscillation indicates an increase of track number crossing the focus region on the western side and a decrease of those crossing on the southern edge.

In spring, the average position of the MCs tracks over the first 10-yr sub-period crosses the studied region from southeast to northeast through the center of the country and in the second decade it moves northward with about 119 km and then moves slightly southward again during the last sub-period (Fig. 6).

During the summer the average position of the tracks crossed the extreme north-western Romania. Then, in the second decade, it shifted southward with about 126 km and moved only a few tens of km southward too, during la last sub-period. However, the summer mean position was located over the northwestern half of the country all over the entire period considered (Fig. 6).

In autumn the average position of the MCs tracks crossed the country from south-west towards north-east without significant changes from one sub-period to another (Fig. 6).

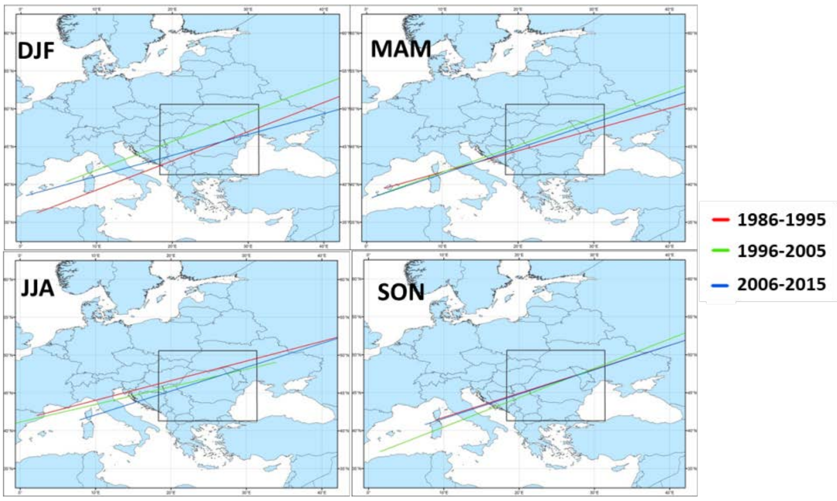

FIG. 6 Seasonal average position of the MCs tracks (for winter season, the period begins for each sub-period in December month of the previous year)

4. DISCUSSIONS AND CONCLUSIONS

Using the horizontal pressure gradient detected based on MSLP, a number of 874 cyclones originated over the Mediterranean were identified between December 1, 1985 to November 30, 2015 and about 43% of them followed a north-east trajectory, which is in agreement with findings obtained by a different approach reported by Radinovic (1987) and Linello et al. (2016).

The track selection for the region of Romania followed the principle of the average radius of the MC, so that the most distant tracks are located 500 km from the center of the country (Gogu, 2007). Thus, 374 cyclones resulted, which is 30% less, compared to the number obtained by Catrina et al. (2019). This difference was generated by the identification method. The MCs tracks inflame the weather in all regions of Europe, but the significant density (more than a tracks/season), occupies a limited area (the Mediterranean basin and the southern and eastern regions of the continent). Some changes were detected in the central Mediterranean basin, where it is worth noting the significant increase in the density of the trails over Greece and the Aegean Sea during the winter. Also, the spatial distribution of the cyclones number for each sub-period indicates a continuous increase in frequency during winter from one sub-period to another in the central and eastern Mediterranean. This finding is in agreement with that reported by Maheras et al (2001) for the period 1958-1997. The increase in TD in the central and eastern regions of the Mediterranean Sea can be attributed to the intensification of the cyclogenesis processes in those regions and to the increase in frequency of tracks towards east-south-east. However, the trend test did not reveal any statistically significant change.

Although in the spring the TD decreases over the central Mediterranean basin, over the non-neighboring countries the TD is comparable to wintertime. A decrease in the number of low-pressure systems during the first and second sub-period and an increase in the third sub-period during the spring was found.

Regarding the region of Romania, a multiannual average of about 12 tracks/yr. was identified, most of them crossing the region during spring and winter, respectively. The minimum frequency was recorded during summer with a multiannual average of 1.3 tracks / season. During the entire period considered, the transition seasons (spring and autumn) were characterized by a constant number of cyclones passing through, whilst in winter, their number slightly increased.

The average seasonal position of the tracks was located in the middle with a south-west towards north-east orientation in relation to the Romanian region with significant shifts northward during winter and spring.

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