NORD ATLANTIC CYCLONES TRACKS IN EUROPE AND THEIR INFLUENCE OVER AMOUNT OF PRECIPITATION RECORDED IN ROMANIA (1985-2015)

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Abstract: *The region of Romania is characterized in terms of continental temperate climate with oceanic influences. Thus, the precipitation regime and the thermal regime in this part of Europe are strongly influenced by the frequency of cyclones whose trajectories cross Europe from west to east coming from the Atlantic Ocean. The present study analyzes the variation of the amount of precipitation in Romania depending on the frequency and variation of the geographical position of the trajectories of the North Atlantic cyclones in the area of the European continent. Using the classic method of identification and tracking, 1189 cyclones were found that crossed Europe north of the Alps in a period of 30 years between December 1, 1985 - November 30, 2015, of which 71% generated precipitation in Romania. Their influence on the amount recorded at meteorological stations in Romania varies between 43% in the northwest of the country to 13% in the southern regions.*

Keywords: *extra-tropical cyclones, North Atlantic, precipitation, Romania.*

1. INTRODUCTION

Extratropical cyclones are complex phenomena whose variability determines both the appearance of daily weather and the appearance of climate for long periods of time. They are also responsible for regulating the temperature, humidity and precipitation in the regions crossed (Varino et al, 2018), and at the same time, they are responsible for some severe manifestations of characteristic phenomena that have negative consequences on communities across the continent, (Browning, 2004), (Pfahl and Wernli, 2012). Precipitations in the European region are generated by extratropical cyclones, convection and orographic convection, (Hawcroft et al., 2012).Central and eastern regions of Europe receive their rainfall from the atmospheric fronts associated with cyclones and North Atlantic basins and from the presence of cyclones of Mediterranean origin. For the central-eastern regions of the European continent, any change in the frequency or position of cyclone trajectories is unmistakably reflected in the wide variation in the amount of precipitation and in important changes in thermal regimes. Studies of extratropical cyclones in the Northern Hemisphere are based on the frequency of cyclogenesis, the frequency of trajectories, the intensity of baric systems, and the density of trajectory types (New et al, 2013). The results obtained in relation to these parameters, oscillate to a large extent depending on the data used and their resolution and depending on the methods of identifying the cyclone and tracking trajectories, (Ulbrich et al, 2009; Wang et al 2006, 2013).

For the North Atlantic region, a vast region where the cyclones that cross Europe originate, negative trends in the frequency of cyclones have been identified over the past century during the winterGulev et al 2001, (1958-1999), Chang and Fu 2002, McCabe, 2001. Positive trends in cyclone intensity were detected by Gulev et al, 2001, Paciorek et al, 2002 and Trigo et al 2006. Numerous studies found significant changes in the position of trajectories in the northern hemisphere Yin, 2005; Chang et al. 2012 and 2013; Zappa et al. 2013, Harvey et al 2020. There has also been an eastward expansion of North Atlantic trajectories across Europe Bengstsson et al 2006, Harvey et al 2020.

This article aims to analyze the variation of the amount of precipitation recorded at meteorological stations in Romania, depending on the frequency of North Atlantic cyclones that crossed Europe from west to east north of the Alps, for a period of 30 years between 1 December 1985 and 30 November 2015.

2. DATA AND METHODS

Data used

In order to compile the data series, it was necessary to inventory the cyclones that crossed the region of Europe in the period 1986-2015. Each cyclone formed at mean sea level was identified and tracked using mean sea pressure (MSLP) and pseudo-potential temperature maps at 850 hPa, available at http://www1.wetter3.de/archiv_gfs_dt.html, (WASA 1998; Alexandersson et al. 2000; Hoskins and Hodges 2002;). Cyclones that formed or crossed the European region were recorded in an area with a western boundary at 20°W, a northern boundary at 65°N, a southern boundary at 30°S, and an eastern boundary at 45°E.

FIG 1 Study area

The data fields provided by the *European Center for Medium-Range Weather Forecast, (ECMWF),* were used to correlate the NACs with the precipitation in the Romanian region through the ERA-Interim program for the same period December 1985-November 2015, (Dee et al, 2011) – surface data were used: wind at 10 meters, temperature and dew point temperature at 2 m, MSLP, lower, medium and upper cloud cover, total coverage, and total precipitation. These data were downloaded using a temporary resolution of 3 hours and a spatial resolution of 0,75°× 0,75°, in a geographical area with a western boundary of 45°V chosen so as to frame the southern border of Greenland, the N limit at 70° S at 30° to fully cover the southern shore of the

Mediterranean Sea and the eastern limit of 45° to cover the eastern Black Sea (Fig. 1). This data was viewed and analyzed using the Integrated data viewer (IDV) program 5.6.

Cyclone identification and tracking

The identification of cyclones on these maps was performed classically, following the minimum value of the pressure surrounded by at least one closed isobar with a maximum value of 1015 hPa, (Hart, 2003; Linello, 2006). The evolution of the cyclone was followed with a time resolution of 6 hours, for at least 24 hours, the threshold needed to filter weak systems. Cyclone tracks were manually plotted using the position of the minimum pressure value at MSLP in ArcGIS 10.8. For each of these trajectories, a temporal characteristic was assigned - the date and time of cyclogenesis identification and a geographical characteristic - the geographical region of origin. The cyclone identified by the method described above with the initial position at time t_0 , after 6 hours is found at the next position at time t_1 , provided that it is at a distance of at least 2° latitudinal from the starting point. When the cyclone developed two centers (bicentric cyclone), the track followed was that of the center that had the lowest pressure and the longest travel. If the second center had a journey of more than 24 hours, it was registered as a new individual from the first closed isobar.

Cyclones classification

Cyclones that crossed Europe from W to E at north of the Alps chain were selected for the database. This includes Atlantic cyclones from the Gulf Stream region, (Rudeva and Gulev, 2011), western and central North Atlantic, eastern Canada and Terra Nova Island – NACs, cyclones from the Icelandic semi-permanent cyclone or formed in the region of Iceland or the SE Greenland, between 60°N and 65°N, and cyclones formed between Iceland and Norway Sea, (Serreze et al, 1997; Serreze, 2007), – ICs, cyclones formed in the Central European region within the Icelandic foothills and Atlantic, (Hofstater, 2016), – TCs and cyclones that intersect the continent from the north along the polar and extrapolar circulations – NCs. This selection excluded the Atlantic and Icelandic cyclones that crossed the continent south of the Alps through the Mediterranean Sea, the cyclone formed in the Mediterranean, the cyclones that after crossing Romania demoted to the Black Sea, and the continental cyclones formed in the hot season in southeastern Europe.

Precipitation data

Precipitation analysis is based on two different data sets. The first set is represented by the daily precipitation recorded between December 1, 1985 and November 30, 2015 at 31 weather stations spread relatively homogeneously on the territory of Romania, (table, 1). The second set consists of the total daily precipitation from the ERA Interim ECMWF, specified above.

Analysis of the NACs activity

Polynomial interpolation was used for the analysis of the spatial distribution, for the centroid of each 3x3 degree grid. This interpolation method was chosen considering the homogeneous distribution of points at the level of the studied area. The evolution of the frequency over time was highlighted by the difference between the decades, the rasters obtained reflecting the spatial evolution of the frequency of the tracks from one decade to another during the study period: D_2 -D_1 , D_3 -D_2 and D_3 -D_1 :

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).

Correlation of cyclone activity with precipitation

The data set taken from the ERA-interim was processed using IDV 5.6 to obtain the presure topography at MSLP, the wind image and the precipitation distribution image. The MSLP pressure was represented as isobars every 5 hPa with the pressure of 1015 hPa as the reference value. For the representation of the wind, the meridian and longitudinal components were used, obtaining a conventional representation in the form of barbs. Precipitation was displayed in mm from a minimum value of 0.1 mm to a maximum value chosen in such a way as to cover the full range of values, with a temporary resolution of 3 hours. The footprint of the precipitations associated with the Atlantic depressions that intersected the region of Romania in a certain time interval was correlated with the corresponding time period from the precipitation data from the meteorological stations. This selection resulted in the amount of precipitation associated with the North Atlantic Low-pressure systems for each of the 31 weather stations.

Table 1 Geographical coordinates of the weather stations.

WEATHER STATION	LATITUDE	LONGITUDE	ALTITUDE
Arad	46°08’	21°21’	117
Bacău	46°35’	26°56’	190
Baia Mare	47°40’	23°3’	216
Bistrita	47°08’	24°3’	366
Botoșani	47°44’	26°39’	161
Brașov	45°42’	25°23’	534
București-Băneasa	44°30’	26°08’	90
Buzău	45°09’	26°49’	96
Călărasi	44°22’	27°21’	19
Caransebeș	45°25’	21°15’	241
Cluj-Napoca	47°46’	23°34’	410
Craiova	44°19’	23°52’	192
Constanța	44°13’	28°38’	12
Deva	45°53’	22°24’	230
Drobeta-Turnul-Severin	44°38’	21°38’	77
Galați	45°29’	28°02’	72
Miercurea Ciuc	46°22’	25°24’	661
Iași	47°10’	27°38’	102
Râmicu-Valcea	45°46’	24°22’	237
Roșiorii de Vede	44°06’	24°59’	102
Ocna Şugatag	47°47’	23°56’	503
Oradea	47°02’	21°54’	136
Sibiu	45°48’	24°09’	443
Sulina	44°13’	28°38’	2
Tg. Mures	46°23’	24°32’	308
Timișoara	45°46’	21°15’	86
Tg.Jiu	45°02’	23°17’	205
Tulcea	45°11’	29°40’	4
Turnu-Magurele	43°45’	24°53	31
Vf.Omu	45°27’	25°27’	2504
Satu Mare	47°48’	21°52’	123

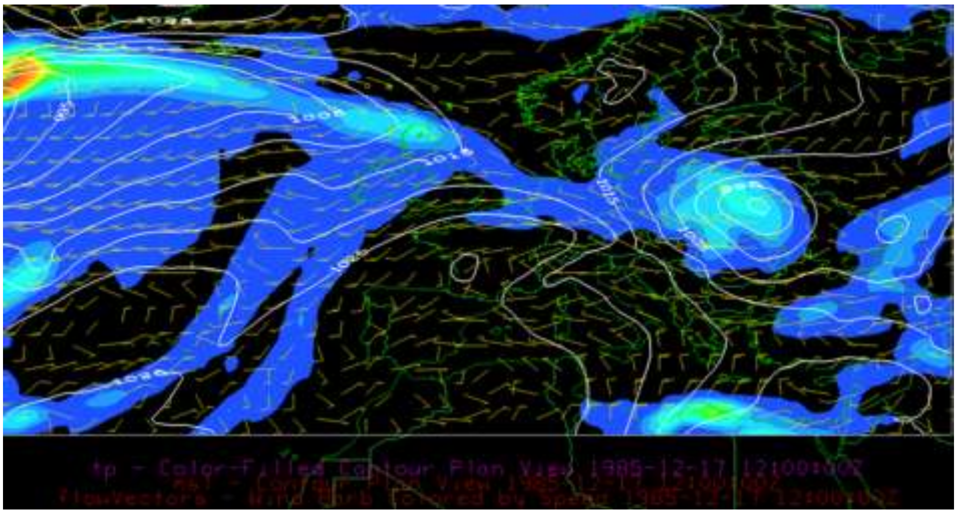

FIG. 2 Image of the cyclone and associated precipitation at 1985.12.17

They were processed in the same way as the spatial distribution of the trajectories in order to highlight the evolution of precipitation over the study period.

The spatial distribution of the meteorological stations taken into account allows the differentiated selection in case the Romanian territory was both under the influence of an Atlantic low-pressure systems and under the influence of a Mediterranean cyclone on the same day. The resulting values were analyzed seasonally and by decade as well as the inventoried cyclones.

3. RESULTS

Between December 1985 and November 2015, 1189 cyclones crossed Europe from V to E north of the Alps, resulting in an average of 39.6 cyclones/year. The spatial distribution of the tracks frequency is maximum in the region of Scotland, North Sea, Scandinavian and Baltic Sea and minimums in the southern regions of the continent. The region of Romania is located in an area where the frequency distribution of tracks is minimal.

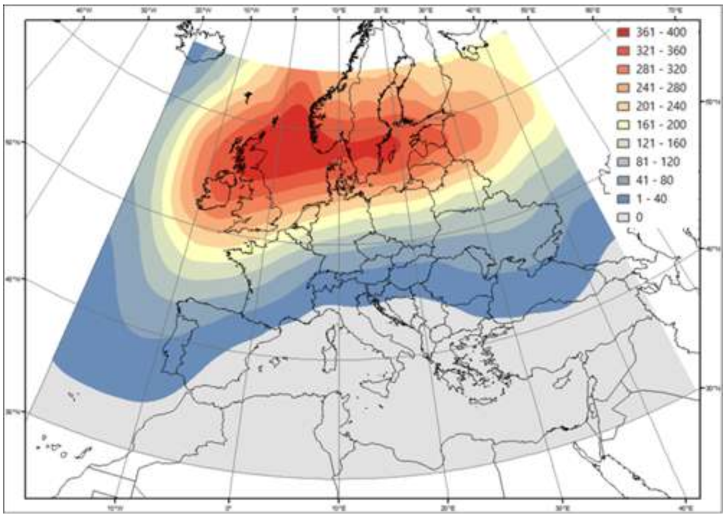

FIG. 3 Distribution of the frequency of the trajectories of extratropical cyclones that cross Europe north of the Alps in the period 1986-2015.

The spatial distribution of the frequency of the trajectories differs from one season to another, its maximum having different positions within the continent.

In winter the classes with the highest frequencies of the trajectories are located in the region of the Baltic Sea, in the spring in the region of Scotland and in summer and autumn in the basin of the North Sea with extension to the Baltic Sea.

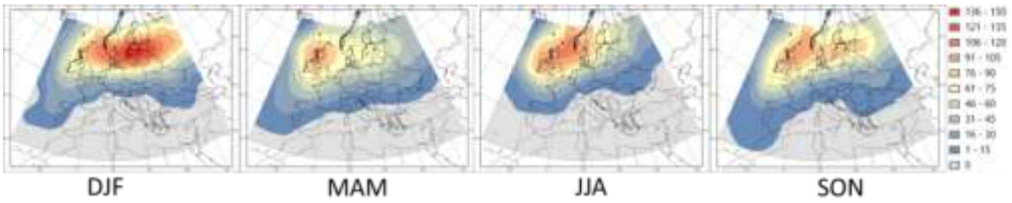

FIG. 4 Spatial distribution of tracks frequency over the seasons.

The spatial distribution of North Atlantic cyclone tracks over the seasons has been divided into 10 classes, with greater agglutination in the North and North Baltic regions. Romania is within the classes with minimum frequencies during the study period, except for the winter of the first decade and during the spring of the second decade when the northern half is within the class of 7 - 12 tracks, (Fig. 5). In the winter of the second decade, there is an expansion to the east of the region with a high frequency of trajectories. In the autumn of the first decade, the spatial distribution of the frequency shows two regions of maximum, the first covering the northern half of the North Sea. and the second the central region of the Baltic Sea. This season, the frequency of tracks decreases, with grades 13-18 and 19-24 retreating north.

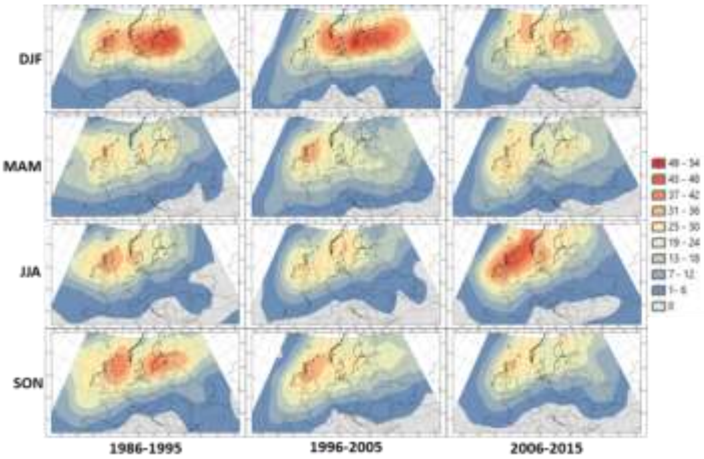

FIG. 5 Distribuția spațială a frecvenței traiectoriilor anotimpual de-a lungul celor trei decade

From one decade to another, a differentiated evolution is observed, depending on the season of the frequency distribution of the cyclone. In winter and summer there are regions where the frequency difference is maximum, while during the transition seasons it reaches only an intermediate class. In winter we find significant changes from 50°N to negative ones occupying an increasingly large area from one decade to another. In the region of Romania, a lower frequency of trajectories was found in the second decade compared to the first and in the third decade compared to the first. In spring, the maximum differences are from 8 to 13 trajectories in both positive and negative directions and the area where these changes take place has extended to the south up to 40°N.

The region of Romania registers a weak increase of the trajectories in the second decade compared to the first and in the third decade compared to the first. In summer, the area where changes are taking place is retreating north of 50°N, with the central southern regions of the continent unchanging except for the western regions where the frequency of trajectories increases in the second decade compared to the first and in the third decade compared to the first. At 50°N in the second decade compared to the first, the zones with negative and positive anomalies alternate meridianally, while at the last two differences the increase of the frequency is manifested in almost the whole region, the maximum being 20 to 25 registered in D_3 -D_2 in North Sea. In autumn, the decrease in trajectory frequencies occupies large areas at all intervals, starting meridianally at D_2 -D_1 and continuing quasi-latitudinally at D_3 -D_2 and D_3 -D_1 .

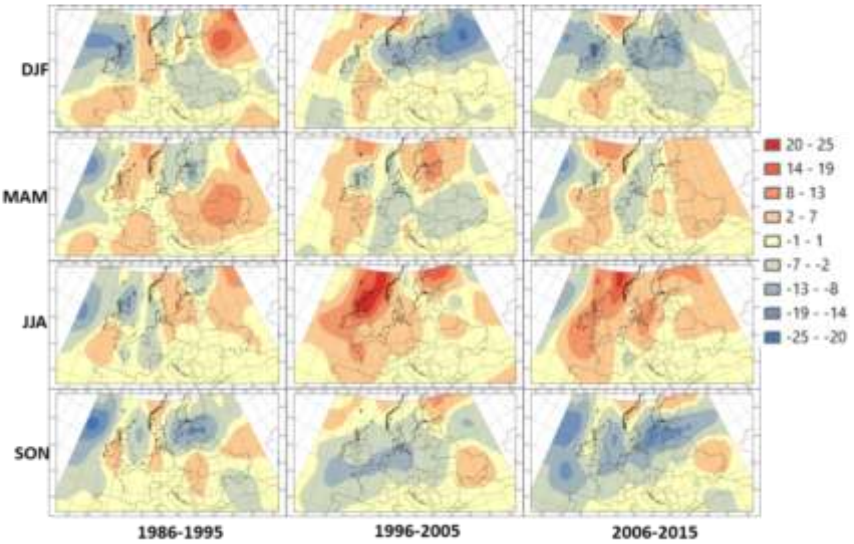

FIG. 5 Seasonal spatial distribution of NACs TD anomaly over the 10-yrs sub-periods

Out of the total of 1189 North Atlantic cyclones that crossed the continent from west to east at MSLP, a number of 847 (71.2%) cyclones generated precipitation that was recorded at weather stations in Romania. The minimum of 48.7% was registered in the autumn of the first decade and the maximum of 93.8% in the summer of the second decade (table, 2).

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

DECADE	ACs	ICs	TCc	NCs	TOTAL	ROMANIA	%
DJF 1986-1995	55	31	21	13	120	80	66,7
DJF 1996-2005	30	51	21	3	105	78	74,3
DJF 2006-2015	28	40	23	3	94	66	70,2
MAM 1986-1995	42	22	25	6	95	66	69,5
MAM 1996-2005	37	27	26	3	93	79	84,9
MAM 2006-2015	37	35	32	1	105	81	77,1
JJA 1986-1995	43	15	26	3	87	58	66,7
JJA 1996-2005	30	29	20	1	80	75	93,8
JJA 2006-2015	51	25	27	0	103	66	64,1
SON 1986-1995	52	30	33	4	119	58	48,7
SON 1996-2005	38	45	17	2	102	80	78,4
SON 2006-2015	27	30	28	1	86	60	69,8
TOTAL	470	380	299	40	1189	847	71,2

North Atlantic cyclones usually travel west to north-northeast and have tracks between 50° and 60°N, resulting in their center usually passing north of Romania. The distribution of precipitation generated by the North Atlantic cyclones on the Romanian territory respects a staggering N - S and V - E but also a staggering generated by relief with the maximum at the northwest and western stations, (Baia-Mare - Cluj-Napoca> 30%) , average at the stations that occupy a central latitude and meridian position, (Arad - Buzău, between 20 and 30%), small, (Tg.-Jiu - Sulina, between 15 and 20%), and minimum, (Turnu-Măgurele - Craiova <15%). The difference between the last two categories is given by the northern depressions which have a general N - S displacement and mainly affect the east of the country. The descending order obtained in the graph below will be maintained for comparison in the decadal-seasonal analysis, (Fig. 7).

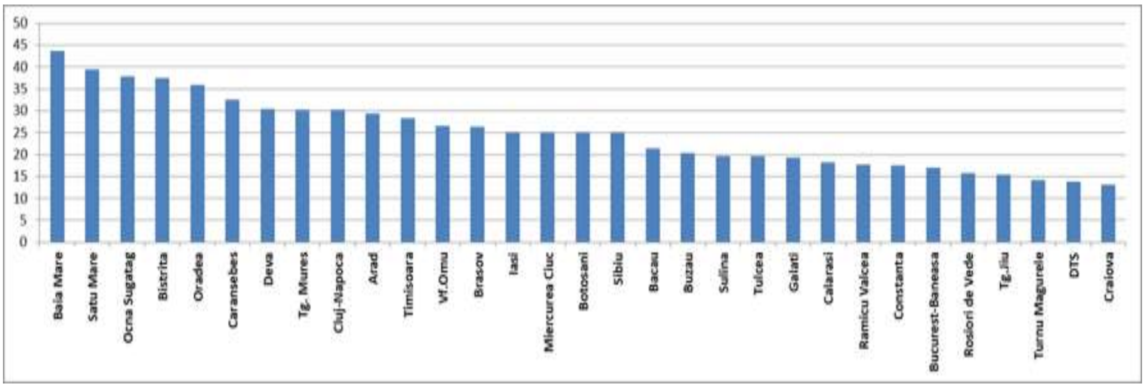

FIG. 7 Distribution of the influence of North Atlantic cyclones on the amount of precipitation in the region of Romania in %.

The greatest influence of NACs on precipitation was recorded in the type of winter at the stations in northwestern Romania, exceeding 50% in Baia-Mare, Ocna Șugatag and Bistrita. The influence of these cyclones on precipitation during spring and summer decreases substantially by a maximum of less than 40% and it is interesting to note that during summer the influence of NACs on precipitation is greater than during spring, (Fig. 7).

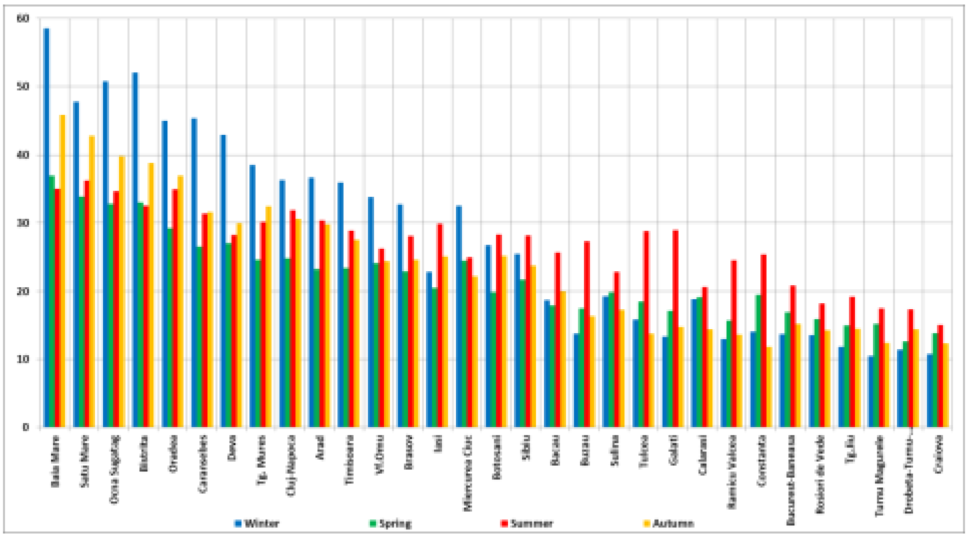

FIG. 8 Distribution of the influence of North Atlantic cyclones on the amount of precipitation in the region of Romania over the seasons in %.

During the three decades, in winter, the number of tracks decreased from one decade to the next both in number on the continent and as an influence on the amount of precipitation in Romania because the amount of precipitation generated by cyclones and the number of days with precipitation. The amount of precipitation generated by cyclones and summed at the stations decreased from 149.1 mm in the first decade to 122.9 mm in the third decade. Between the first and second decade, the number of cyclones decreased by 2 individuals. This small difference is not decisive for the amount of precipitation, which decreases in half of the stations by up to 25% and increased by a maximum of 20% in the other half. The second difference, between the third and second decade, brings a decrease in the number of cyclones with 12 individuals which led to a decrease in the amount of precipitation in 29 of the stations by 4% to 50% except for Omu and Calarasi where the amount of precipitation increased by 45.6% and 47.8%. Between the third and the first decade, the number of trajectories decreases by 14 individuals, resulting in a decrease in precipitation at the vast majority of stations, with the same exceptions persisting (Fig. 8a, b).

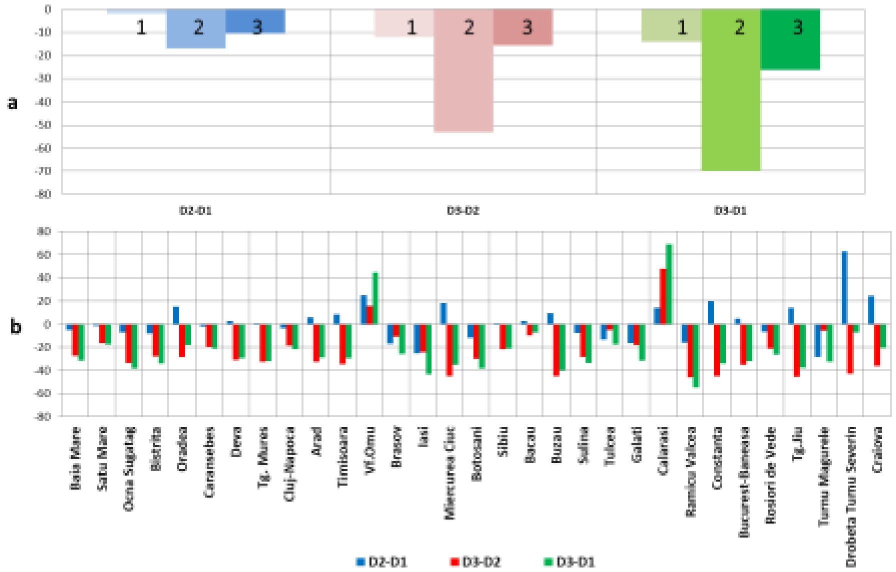

FIG. 8 a). 1 - the difference in the number of track from one decade to another; 2 - the difference in the number of days with precipitation; 3 - the difference in the amount of precipitation/cyclone/Romania; b). Evolution of precipitation generated by cyclones during winter in %.

In the spring, the number of cyclones that affected the amount of rainfall from one decade to another increased. The first difference, (D_2 -D_1), increases the number of cyclones in the number of days with precipitation and the amount of precipitation/cyclone/Romania thus, increasing the amount of precipitation at all stations between 11.8 and 188%, the only exception in this case being Sulina station where the amount of precipitation decreased by 26.5% (fig. 9b). The second difference, (D_3 -D_2), indicates an increase in the number of cyclones by 2 individuals but decreases the number of days with precipitation and the amount of precipitation / cyclone / Ro resulting in a decrease in the amount of pp at almost all stations by 3.8 to 66.8 %.

The third difference, between the third and first decade, brings an increase of 15 individuals in the number of cyclones, the increase in the number of days with precipitation and the amount of precipitation/cyclone /Ro resulting in an increase in precipitation at most stations, with the exception of Sulina Tulcea, Bucharest and Drobeta-Turnu-Severin.

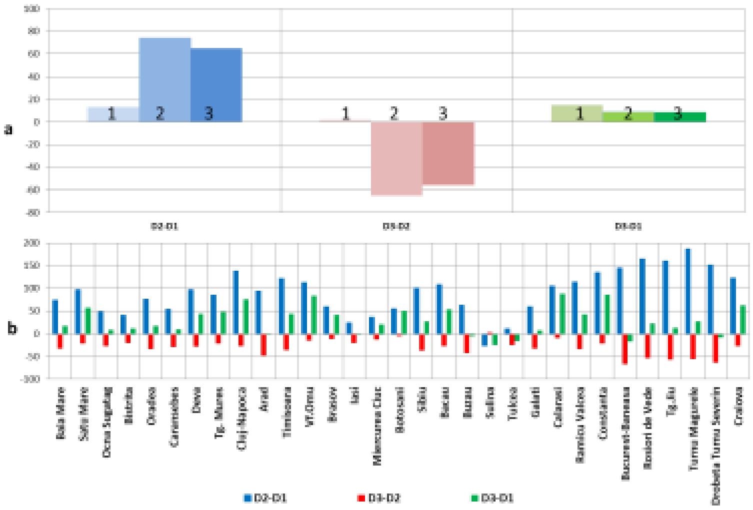

FIG. 9 a). 1 - the difference in the number of track from one decade to another; 2 - the difference in the number of days with precipitation; 3 - the difference in the amount of precipitation/cyclone/Romania; b). Evolution of precipitation generated by cyclones during spring in %.

In the summer, in the case of the first difference, there was an increase in the number of cilones by 17 cyclone, as well as an increase in the amount of precipitation at all stations. From the graph it can be seen that this increase is moderate (below 100%), in the vast majority of stations with just over 100% in two cases and two other cases with spectacular increases of over 200%, in Tulcea, respectively 400% in Constanța. These two anomalies can be attributed to local factors favored by cyclonic passages. The second difference (D3-D2) indicates a decrease of 9 individuals and a decrease in the number of days with precipitation as well as a decrease in cpp / cyclone / Ro resulting in a decrease in precipitation at all stations with values between 4.6% and 58%. The third difference, (D3-D1), indicates an increase by 8 in the number of cyclones, an increase in the number of days by pp but a significant decrease in the cant.pp / cyclone / Ro. Under these conditions, the amount of precipitation decreased in the vast majority of stations by 0.3 to 47%, with the exception of Sulina, Tulcea, Călărași, Constanța and Roșiorii de Vede where the amount of precipitation increased significantly with values between 36.1 and 130, 9%.

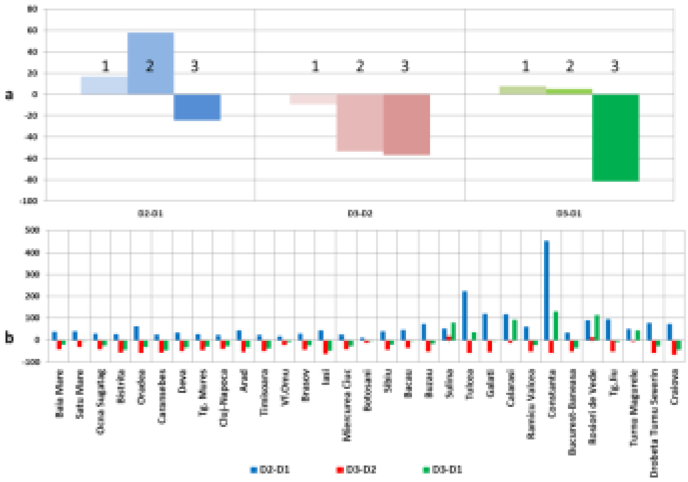

FIG. 10 a). 1 - the difference in the number of track from one decade to another; 2 - the difference in the number of days with precipitation; 3 - the difference in the amount of precipitation/cyclone/Romania; b). Evolution of precipitation generated by cyclones during summer in %.

In autumn, the first difference indicates both the increase in the number of cyclones by (22 cyclones) and the increase in the amount of precipitation at almost all stations with values ranging from 3,6% to 104,8%, except for Constața where rainfall decreased by 7,6 %. The second difference indicates a decrease by 20 in the number of cyclones, a decrease in the number of days by pp but an increase in cant.pp/cyclone/Ro inducing a negative evolution of precipitation in 23 cases with values between 2.8% and 46 ,3%. At the other stations the amount of precipitation increased with values between 15% and 65%. The third difference indicates the increase by 2 of the number of cyclones, the increase of the number of daily precipitation but also the increase of cant.pp / cyclone / Ro this inducing the increase of precipitation at 22 stations by 4 to 147%. In the other 9 cases, the amount of precipitation decreased.

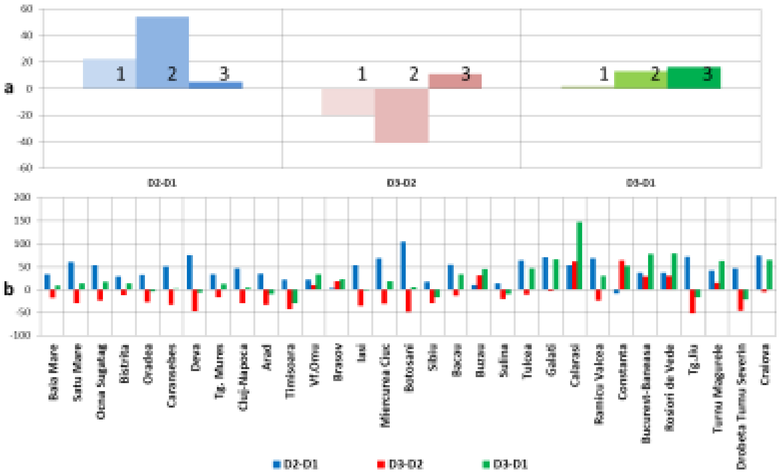

FIG. 10 a). 1 - the difference in the number of track from one decade to another; 2 - the difference in the number of days with precipitation; 3 - the difference in the amount of precipitation/cyclone/Romania; b). Evolution of precipitation generated by cyclones during summer in %.

CONLUSIONS

Using a classical method of identifying cyclones, a number of 1189 Cyclones were identified at MSLP that crossed Europe from V to E at north of the Alps. From the intersection of the footprint of the precipitation on the ground with the amount of precipitation registered at the meteorological stations, it resulted that 71.2% of the NACs that crossed Europe generated precipitation on the Romanian territory. The influence of North Atlantic cyclones on rainfall in Romania varies significantly from northwest to southeast but also from one season to another.

At the level of the continent, it was observed the decrease of the tracks frequency during the winter and the increase of their frequency during the summer, in the period 1986-2015. During the autumn, the frequency of the trajectories that occupy a large part of the studied area was observed to decrease.

The amount of precipitation generated by the North Atlantic cyclones in winter decreased between 1986 and 2015. During the spring it increased significantly in the second decade compared to the first and in the third decade compared to the first. Although the frequency of trajectories increased during the summer in Europe, the amount of precipitation generated by cyclones in Romania decreased significantly from 278.3 mm in the first decade to 196.8 mm in the third decade.

The variations of the precipitation have moderate values at the western stations and extreme at the S and S-E stations - result of some local factors favored by the cyclonic passages.

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