

MEDITERRANEAN CYCLONES AND METEOALARM WARNINGS FOR SOFIA: OCTOBER-APRIL 2010–2019

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Received on October 8, 2025

Presented by K. Stoykova, Corresponding Member of BAS, on December 16, 2025

Abstract

Mediterranean cyclones significantly impact the region, causing severe weather events like heavy rainfall, flooding, and windstorms thus posing risks to densely populated areas. Despite their importance, variability in cyclone tracking methodologies and datasets contributes to differences in reported frequencies. In this work we use Jenkinson–Collison Type (JCT26) objective circulation classification to quantify the role of Mediterranean cyclones for weather warnings issued for the city of Sofia in the period 2010–2019. Four JCT26 circulation types occurred in 50% of days in Sofia; they are South-West (SW – 20%), AntiCyclonic (AC – 15%), Cyclonic (C – 12%), and North (N – 10%). During the winter months, C was associated with the highest number of severe weather warnings namely 33%. Cyclonic directional circulation types have 23% of the warnings while SW and AC have below 5% warnings. Snow, rain, cold, and wind were the most common types of warnings issued during this period. Between 2010 and 2019, monthly averaged snow warnings peak was in January with 11 yellow code warnings. Rain warnings were issued in all winter months, with April having the maximum of nine days with warnings and March the minimum of two days with warnings.

Key words: Mediterranean cyclones, METEOALARM, cold, rain, snow, wind, objective circulation classification

This study is financed by the European Union-NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project No BG-RRP-2.004-0008-C01.
<https://doi.org/10.7546/CRABS.2026.02.07>

Introduction. Understanding Mediterranean cyclones is essential for ensuring the safety of over 200 million inhabitants residing in the European portion of the Mediterranean basin. LIONELLO et al. [1] linked these cyclones to a wide range of weather-induced natural hazards in the region. As noted by FLAOUNAS et al. [2], Mediterranean cyclones frequently have high impacts and are responsible for the majority of extreme precipitation and wind events. Although typically smaller and less intense than mid-latitude Atlantic cyclones, Mediterranean cyclones nonetheless cause significant socioeconomic and environmental impacts across densely populated area [3]. The critical role of the cyclones is well documented. JANSÁ et al. [4] reported that approximately 90% of heavy rainfall events in the western Mediterranean are associated with cyclonic activity. Moreover, cyclones contribute to more than 70% of the annual total precipitation in the region [5,6]. Additionally, PFAHL et al. [7] demonstrated that frontal structures linked to Mediterranean cyclones account for about 40–50% of regional extremes. Flaounas et al. [2] described Mediterranean cyclones as systems characterized by strong circulation, embedded convection, and frontal structures capable of producing a variety of high-impact weather phenomena, including heavy rainfall, flooding, thunderstorms, and windstorms. PETTERSEN [8] recognized the Mediterranean as the most active winter cyclogenetic region in the Northern Hemisphere. Cyclone activity exhibits a pronounced seasonal cycle, with the highest frequency during winter months when cyclone tracks predominantly lie along the northern and central Mediterranean basin. In contrast, summer cyclone tracks are less frequent and tend to occur over North Africa [9]. Winter cyclones originating in the Gulf of Genoa are often deep systems that track southeastward, bringing severe weather to the Alpine region, the Italian Peninsula, the Adriatic Sea, and the central and eastern Mediterranean. This behaviour has been documented by HORVATH et al. [10], ULBRICH et al. [11], and REALE and LIONELLO [12]. Flaounas et al. [2] stated that autumn and spring are transitional periods for cyclogenesis frequency, with to some extent similar characteristics with the climatological spatial variability of winter. Recent climatological analyses have indicated a consistent decline in Mediterranean cyclone occurrences, which is closely linked to an overall decrease in regional precipitation [13]. The relationship between Mediterranean cyclones and severe weather events has long been a foundational element driving international collaborative initiatives aimed at enhancing the practical predictability of the diverse spectrum of these cyclones [2]. Nevertheless, the same study also emphasized that the reported frequency of Mediterranean cyclones varies considerably across different studies. This variability is attributed to differences in cyclone tracking methodologies, the identification criteria applied, and characteristics of the input datasets, including factors such as grid resolution and temporal sampling intervals. The Mediterranean region was pointed out because of the storms resulting in flash floods [14]. According to more recent data from Munich Re [15] the affected Italy, France and Spain had damage and billions of Euros in losses.

BOCHEVA et al. [16] present a study of Mediterranean cyclones and high-impact weather phenomena over Bulgaria in the period 1990–2001. They have established that: 1) 45% of the cyclones cause damage, and 2) about 80% of Mediterranean cyclones passing south of Bulgaria and/or associated with atmospheric blocking phenomena result in damages. Another major advancement in understanding weather patterns is the possibility to define quantitative criteria via objective circulation classification software developed by COST action 733 [17]. Objective circulation classifications have been applied for various regions in Europe. In Bulgaria, STOEV et al. [18] used two objective circulation classifications to study the foehn occurrence in Sofia. They report that most foehn days are linked to south-west, west and northwest circulation types. Importantly, they concluded that the decrease of number of foehn days after 2004 is likely due to decrease of west and northwest circulation types. Using objective circulation classification can help to make quantitative estimation of the weather types leading to warnings in Sofia. Thus the aim of this work is to quantify the link between Mediterranean cyclones and the METEOALARM weather warnings [19] issued for the city of Sofia in the period October–April 2010–2019. Sofia was selected as it is the capital city of Bulgaria, densely populated and a major industrial hub. Thus accurate warnings are of high interest and significance.

Data and methods. This work is based on operational METEOALARM warnings issued by NIMH for Sofia for the period 2010–2019 during the winter season from October to April. Since 2009, Bulgarian NIMH has issued METEOALARM warnings with yellow/moderate for potentially dangerous events and orange/severe for dangerous weather. The red/extreme awareness level was not issued for Sofia for this period. The METEOALARM hazard types selected in this work are: 1) rain, which can lead to flood, landslide, reduced visibility on roads, 2) low temperature which can lead to health risks or affect infrastructure, 3) high wind speeds which can affect outdoor activities, infrastructure and transportation, and 4) snow accumulation or ice formation or freezing rain can affect daily life, outdoor activities and travel. The METEOALARM warnings are combined with Jenkinson–Collison (JCT26) objective circulation classification with 26 subtypes with a numerical threshold for circulation indices by JENKINSON and COLLISON [20]. JCT26 includes: 8 directional types – West (W), South-West (SW), North-West (NW), North (N), North-East (NE), East (E), South-East (SE) and South (S), 8 Anticyclonic directional types – AW, ASW, ANW, AN, ANE, AE, ASE, and AS, 8 Cyclonic directional types – CW, CSW, CNW, CN, CNE, CE, CSE, and CS as well as Cyclonic (C) and AntiCyclonic (AC) types. The types associated with Mediterranean cyclones are as follows: 1) C type with a cyclone centred over the Adriatic Sea, 2) CW with a cyclone centred north of the country, with predominant westerly advection over the Balkan Peninsula, 3) CNW with a cyclone centred over Romania, with predominant northwesterly air mass advection, 4) CN with a cyclone centred over the straits between Europe

and Anatolia, and northerly advection, 5) CNE with a cyclone centred over the southern regions of the Balkan Peninsula and prevailing northeasterly advection, 6) CE with a cyclone centred over the Ionian Sea and easterly advection over the Balkans, 7) CSE with a cyclone centred over the island of Sicily, resulting in predominant southeasterly advection over the Balkan Peninsula, 8) CS with a cyclone centred over the Central Mediterranean and direct southerly advection of air masses over the Balkan Peninsula, and 9) CSW with a cyclone centred over Northern Italy and southwesterly advection over the Balkans. Detailed circulation maps can be found in Stoev et al. [18].

Results. Four JCT26 circulation types happen in 50% of the days in Sofia in the period 2010–2019. As seen in Fig. 1a these types are: SW with 753 days (20%), AC with 565 days (15%), C 425 days (12%) and N 349 days (10%). Altogether 8 cyclonic directional types have 439 days in all months, namely: 1) CNW in 128 days, 2) CNE in 111 days, 3) CW in 80 days, 4) CSW in 76 days, and 5) CS in 44 days. From October to April 2010–2019 winter days in Sofia the most frequent circulation types are: 1) SW in 424 days (22%), 2) AC in 268 days (14%), 3) C in 256 days (13%), and 4) N in 141 days (7%). Altogether cyclonic directional types are in 242 days (12.6%) from October to April, namely CNE (62 days), CNW (53 days), CW (48 days), CSW (47 days) and CS (32 days). Table 1 presents the circulation types and the number of days with warning (third row) during the winter period 2010–2019. The largest number of days with warnings 33% is with Cyclonic type circulation (C) while the days with Cyclonic directional type circulations (CD) are 23%, with South-West circulation (SW) are 5%, and with AntiCyclonic circulation (AC) are 4%. Of all winter days with C type circulation (256), in 33.2% there were severe weather warnings from which 14.5% are rain warnings, 13.7% are snow warnings, 2.3% are wind warnings, 2.3% are cold warnings and only 0.4% are thunder warnings. It is to be noted that up to four different types of warnings can be issued in one day. Of all winter days with Cyclonic Directional types (242), 23% have warnings for either snow, rain,

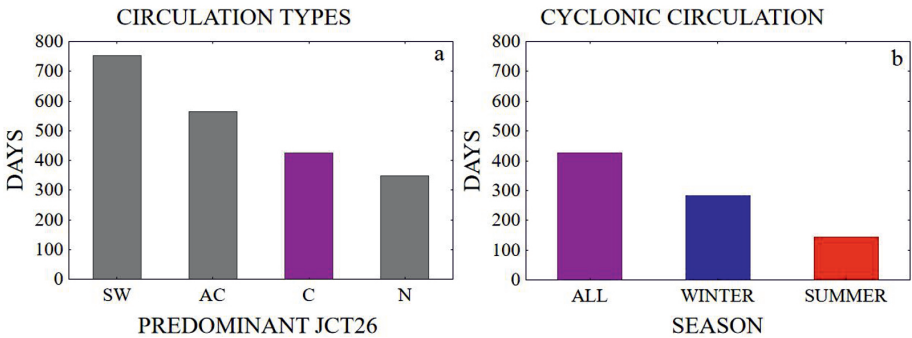


Fig. 1. Number of days in Sofia for the period 2010–2019; a) Four predominant JCT 26 circulation types; b) C circulation type by season

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METEOALARM warnings and JCT26 circulation types for Sofia during winter period of 2010–2019

JCT26 type	C	CD	SW	AC
Winter days	256	242	424	268
Warning winter days	85	56	23	10

cold, wind, ice, thunder, or fog. When divided by subtypes, in 40% of days with CNW circulation in winter there were warnings, which is much above the average for Cyclonic Directional types.

For all months in the period 2010–2019 there are 425 days with C type circulation which are highlighted in purple colour in Fig. 1. In Fig. 1b in blue colour are the days with C type circulation during the cold months, which are 66% (282) of all days. The summer days with C type circulation are in red. This pronounced seasonal asymmetry is consistent with previous climatological studies, which have long established the predominance of cyclonic activity in the Mediterranean during winter.

For cold months from October to April in the period 2010–2019 NIMH issued for Sofia a total of 209 days with warnings from which 187 days with yellow code and 22 days with orange code. The largest number of METEOALARM warnings are for snow (60) followed by rain (58), cold (43), and wind (39). As seen from Fig. 2a the annual snow warnings maximum of 14 days is in 2011/2012 winter season, and the minimum of 2 days is in 2013/2014 winter season. The annual rain warnings maximum is in the 2010/2011 and the 2014/2015 winter season (10 days each), the minimum (3 days) is in the 2012/2013 winter season (Fig. 2b). The annual cold warning maximums of 10 days are in three years, namely 2011/2012, 2015/2016, 2016/2017. In 2012/2013 and 2013/2014 there were no warnings for cold (Fig. 2c). The annual wind warning maximum of 7 days is in the 2017/2018 winter season, the minimum of 1 day is in the 2013/2014 cold months (Fig. 2d). For the period 2010–2019 the monthly snow maximum of 19 days (both yellow and orange code warnings) is in January (Fig. 2e) while the minimum is in April with one day of warning. As seen from Fig. 2f, the monthly rain maximum of 12 days with yellow and orange code warnings is in April and the minimum is in March (4 days). The monthly cold maximum is in January, with 25 days of warnings, with no warnings in October (Fig. 2g). The monthly wind maximum of 10 days (both yellow and orange code warnings) is in December (Fig. 2h) and the minimum is in November (2 days with warning).

Figure 3a presents winter days with C type circulation (256). The annual snow warnings maximum is in 2011/2012 and 2018/2019 winter seasons with 6 days each. The minimum is in 2013/2014 and 2016/2017 winter seasons with 2 days each. The annual rain warning maximum with C type circulation is in

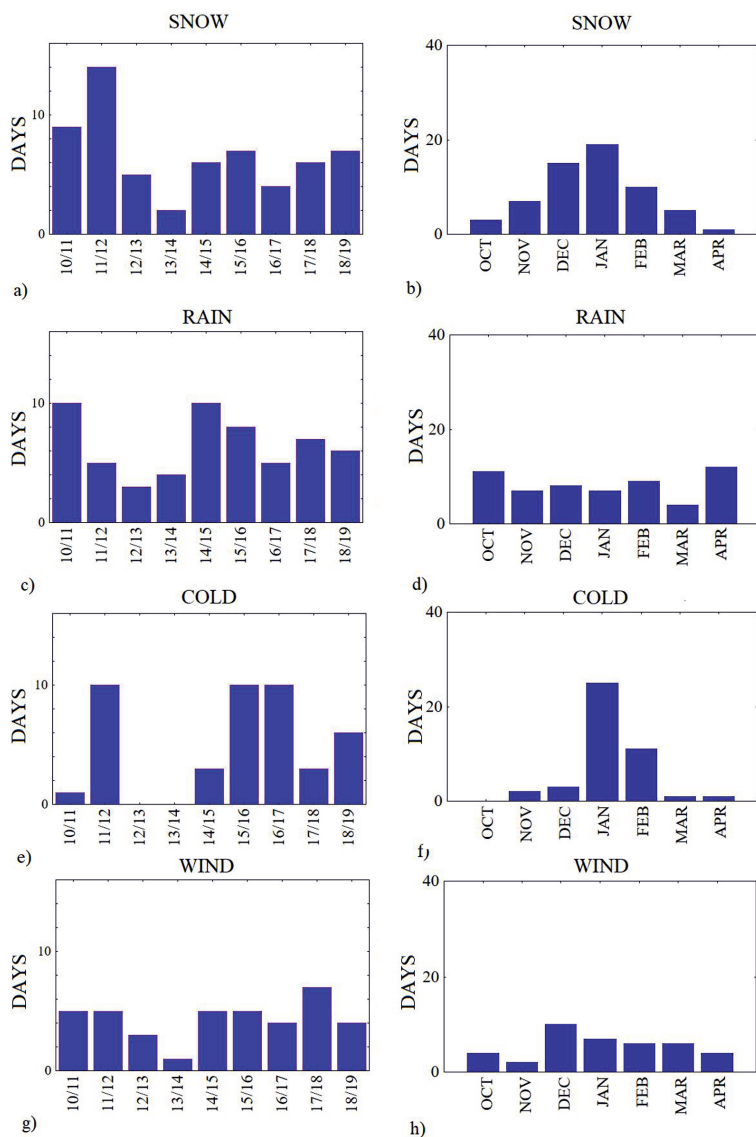


Fig. 2. Yearly (a, c, e, g) and monthly (b, d, f, h) warning statistics from October to April 2010–2019 in Sofia; a) and b) for snow, c) and d) for rain, e) and f) for cold, and g) and h) for wind

the 2014/2015 winter season (6 days), the minimum (2 days) is in the 2012/2013 winter season (Fig. 3b). The annual cold warning maximums with C type circulation is in the 2011/2012 and the 2015/2016 winter seasons (2 days each). There are no cold warnings in more than half of the years in days with C type circulation (Fig. 3c). In 66.7% of the years with C type circulation there were no wind warnings (Fig. 3d). In the 2011/2012, the 2015/2016, and the 2017/2018

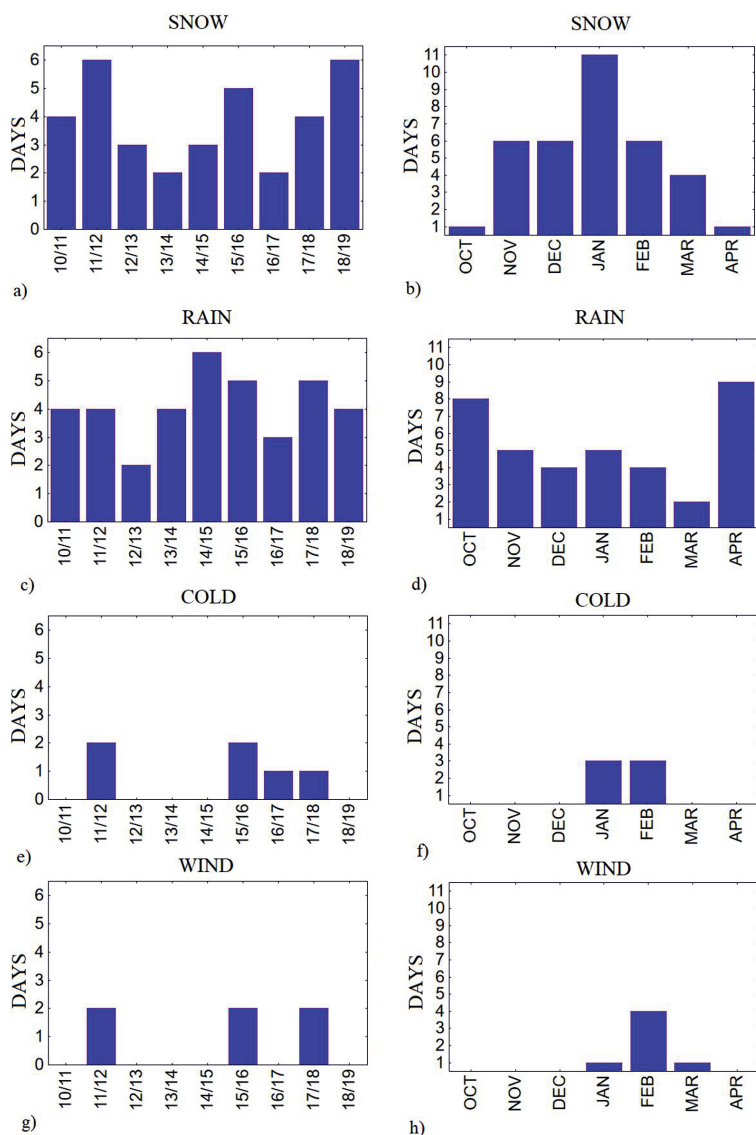


Fig. 3. Yearly and monthly C circulation warning statistics from October to April 2010–2019 in Sofia; a) and b) for snow, c) and d) for rain, e) and f) for cold, and g) and h) for wind

there were wind warnings (2 days each). For the period 2010–2019 in days with C type circulation there is a distinct monthly snow peak in January (Fig. 3e) with 11 days of warnings, all of them with yellow code. In all winter months with C type circulation there is at least one warning. As seen from Fig. 3f, all the winter months with C type circulation have rain warnings. April is with most warnings (9 days) and March with least warnings (2 days). Cold and wind warnings on

days with C type circulation are much less compared to snow and rain warnings. There are 6 days in January and February with warnings for cold (Fig. 3g) and 6 days with warnings for wind (Fig. 3h).

Discussion and conclusions. Mediterranean cyclones have a well known seasonal cycle with the highest frequency during winter months. Thus the period October–April 2010–2019 is the focus of our work. For the 10-year period, NIMH issued a total of 209 days with a METEOALARM weather warning for Sofia, Bulgaria. The monthly snow and cold warning maximums are in January with 19 and 25 days, respectively. It is to be noted that January is the month, defining the winter season in Bulgaria. The largest number of snow and cold warnings was issued in the period October–April 2011/2012. To quantify the impact of Mediterranean cyclones to the weather warnings issued for Sofia we use Jenkinson–Collison (JCT26) objective circulation classification with 26 subtypes (JCT26). Between 2010 and 2019, four JCT26 circulation types (SW, AC, C, and N) accounted for 50% of days in Sofia. During the winter months, 23% of the days were with cyclonic and cyclonic directional circulation types. From the days with cyclonic and cyclonic directional circulation 33% are with weather warnings, primarily for snow and rain. It is to be noted that cyclonic circulation type reflects a low pressure system west of Italy, while the cyclonic directional types essentially represent the trajectory of this cyclone. This is of particular interest as it offers a complex quantitative evaluation of the Mediterranean cyclones and their trajectories across the Mediterranean region before reaching Bulgaria. As follow-up work we will focus on establishing a link between global and local scale by analysing satellite products (air mass RGB composites) and water vapour transport associated with atmospheric rivers.

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