TROPICAL-LIKE CYCLONES IN THE MEDITERRANEAN: IMPACTS AND COMPOSITE DAILY MEANS AND ANOMALIES OF SYNOPTIC CONDITIONS

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ABSTRACT

In the Mediterranean region, a rapidly rotating storm system characterized by gale winds, severe precipitation, and low pressure center, accompanied with a spiral pattern of thunderstorms, is occasionally observed. Thus, these tropical-like cyclones (TLC), known as Medicanes or Mediterranean 'hurricanes', have similar characteristics with hurricanes and a significant research has been done during the last years to investigate their atmospheric characteristics and impacts.

The Laboratory of Climatology and Atmospheric Environment (LACAE), University of Athens, has established a systematic effort since 2009, to document the impact of severe atmospheric phenomena (e.g. medicanes, cyclones, tornadoes, waterspouts), especially over the eastern Mediterranean region. Regarding medicanes, the best way to detect them is a direct visual analysis using satellite images to track and document these extreme phenomena occurred within the Mediterranean. The criteria applied in order to identify medicanes concern the detailed structure, the size and the lifetime of the systems using Meteosat satellite images in the infrared channel. They must have a continuous cloud cover and symmetric shape around a clearly visible cyclone eye. According to the above criteria and the international literature we have focused on 65 cases, which fulfilled the criteria of having a medicane.

The objective of this study is twofold: (i) to illustrate the spatial and temporal distribution of TLC impacts over Mediterranean region and (ii) to present the composite daily means and anomalies of synoptic conditions at the middle and lower isobaric levels of the troposphere and sea level pressure (SLP), as well, during TLC days. The daily composite means and anomalies (with respect to 30 year climatology (1981-2010)) of synoptic conditions were based on the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis data sets. LACAE's data sets concern the period from 1947 to 2014, taken into account all TLC events and their impacts occurred over the western, central and eastern Mediterranean region.

The findings shed light on the impacts of medicanes over coastal areas, including infrastructure damage and casualties due to associated strong winds, heavy rainfall, and in rare instances, tornadoes, indicating the high concern of such extreme atmospheric phenomena should be given by civil protection agencies towards resilience of the society.

Keywords: Tropical-like Cyclones, Medicanes, NCEP-NCAR Reanalysis, Composite Means and Anomalies, Impacts, Mediterranean

1. Introduction

Mediterranean Sea, appears to be a vulnerable area for cyclogenesis (Petterssen, 1956). The specific orographic structures surrounding the Mediterranean, such as Alps, Pyrenees and Atlas mountains may trigger air flow to vortex development. Despite the synoptic formation of cyclones in the Mediterranean, occasionally there are cases when meso-scale extreme low pressure systems appear, having the characteristics of tropical cyclones, as they captured by satellites. Mediterranean Tropical Like Cyclones (TLC) known as Medicanes are accompanied by strong winds, heavy precipitation and thunderstorms, causing occasional severe damages in private property, agriculture and communication networks, or resulting in flooding of populated areas, posing a risk to human life. These meso-scale cyclones, with diameter, usually less than 300 km, have a rounded structure and a warm core, as well as intense low sea level pressure (Businger and Reed, 1989). Their intensity appears much weaker than tropical hurricanes; however, some of them have reached tropical hurricane strengths (Akhtar *et al*., 2014). Emanuel (2005) indicated that their genesis is triggered when an upper-level cutoff low is advected over an area, resulting in air mass lifting and cooling causing convective instability. The cold and humid air under the upper low combined to the warmer sea, favor the development of cyclones with tropical-like characteristics. Overall, there is high scientific concern regarding Mediterranean TLC case studies, focusing on different aspects of their structure and evolution (Pytharoulis *et al*., 1999; 2000; Homar *et al*., 2003; Moscatello *et al*., 2008a; 2008b; Miglietta *et al*., 2011). Recently, Miglietta *et al*., 2014 performed numerical experiments using the WRF model to investigate the model physics in simulating the structure and intensity of a Mediterranean hurricane; however, there is not a general perspective on their properties, lifetime and evolution (Miglietta *et al*., 2013). Generally, the detection of these phenomena is considered to be difficult and includes high resolution meteorological analysis data and dense maritime observations. Besides, there is a number of criteria to identify Medicanes, taking into account the diameter, the symmetry and the eye of the cyclone, as well as the duration of these phenomena. The use of satellite data can be complementary to this method as well (Tous and Romero, 2013).

This study presents an effort to identify the frequency of tropical-like cyclones in the Mediterranean for the period 1947-2014, based on satellite images, literature research and impact studies. Therefore, the classification of the reported impacts has been made and the spatial distribution of these has been visualized via Geographic Information System (GIS). The study is organized as follows: Section 2 presents the methodology used, while the impacts classification along with the daily composite means and anomalies of synoptic characteristics for September with the highest frequency of recorded TLCs, are discussed in Section 3. Finally the summary and conclusions are presented in Section 4.

2. Data and methodology

The Laboratory of Climatology and Atmospheric Environment (LACAE), University of Athens, has established a systematic effort since 2009, to document the impact of severe atmospheric phenomena (e.g. medicanes, cyclones, tornadoes, waterspouts. lightnings), especially over the eastern Mediterranean region. The criteria applied in order to identify medicanes concern the detailed structure, the size and the lifetime of the systems using Meteosat satellite images in the infrared channel. They must have a continuous cloud cover and symmetric shape around a clearly visible cyclone eye. According to the above criteria and the international literature we have focused on 65 cases, which fulfilled the criteria of having a medicane, during the period 1947-2014.

Furthermore, a composite anomaly analysis has been used to determine the daily means and anomalies of synoptic conditions at the middle and lower isobaric levels of the troposphere and sea level pressure (SLP), as well, during TLC days. The daily composite means and anomalies (with respect to 30 year climatology (1981-2010)) of synoptic conditions were based on the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis data sets (Kalnay *et al*., 1996). The spatiotemporal classification of the reported impacts has been visualized via GIS software.

3. Results and discussion

3.1. Seasonal variability and synoptic conditions for TLC

A sample of 65 recorded TLC cases over the Mediterranean during the study period 1947-2014, was used to illustrate the temporal variation of TLCs (Figure 1). September seems to favor the development of TLCs, due to warm waters established during that month, indicating the highest frequency (15 TLCs), followed by October (13 TLCs), December (12 TLCs) and January (8TLCs). During the dry period of the year (April-August), TLCs are diminished, especially in June, due to the poleward shift of the polar front and the incidence of wintertime lows. The relative warmth of the sea during autumn associated with high relative humidity may trigger the development of TLCs, having significant impacts over sea and coastal regions.

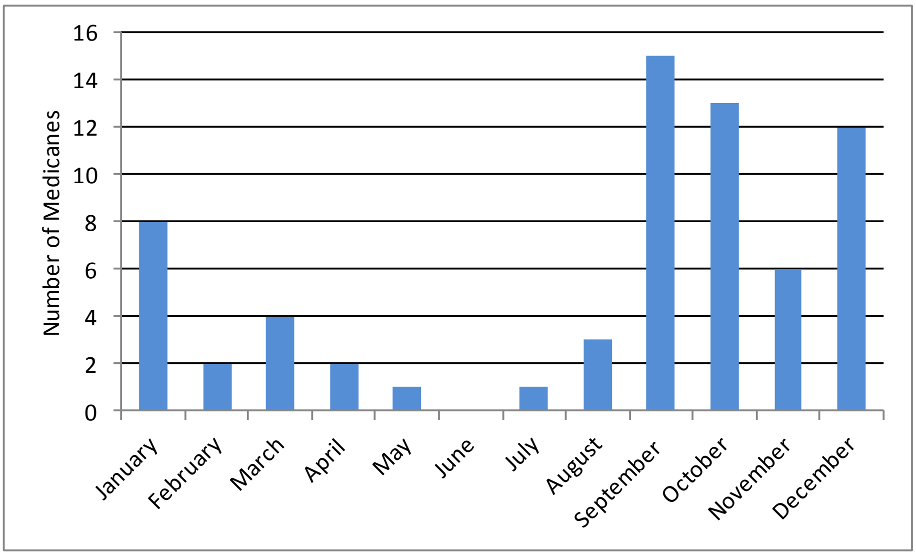
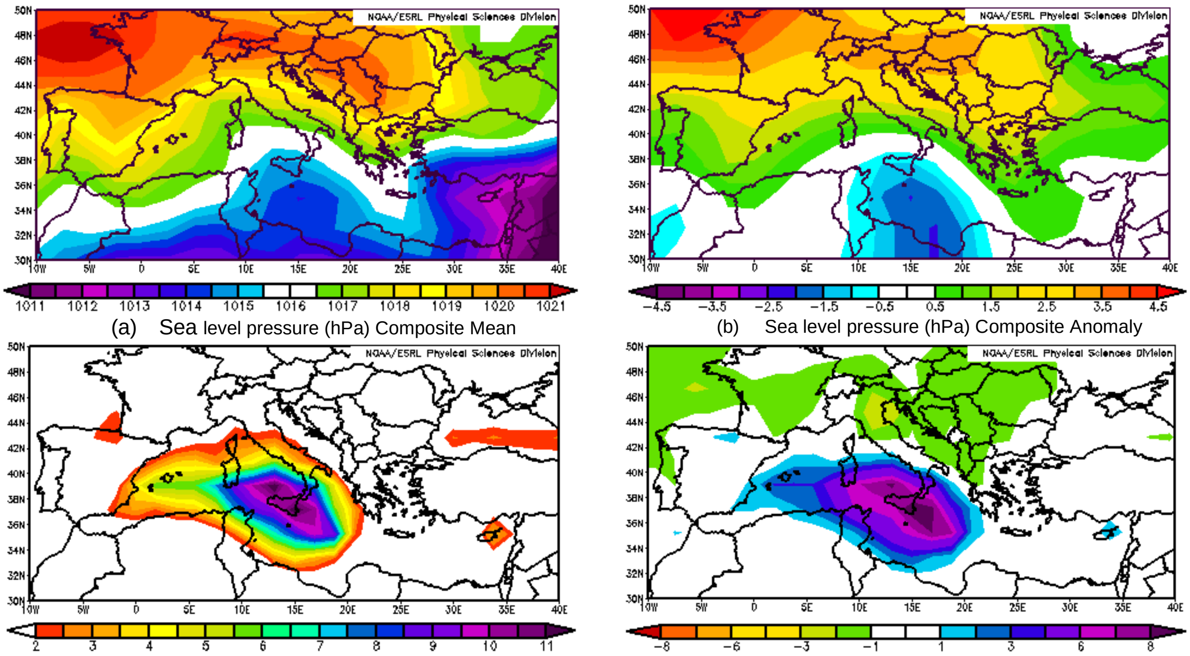


Figure 1: Monthly number of medicanes for the period 1947-2014.

Taking into consideration that TLCs occur mainly during September, we focus only, for brevity sake, on the TLCs synoptic characteristics with respect to that month (Figure 2). More specifically, ensemble means and anomalies for sea level pressure (hPa), surface precipitation rate (mm/day), 500 hPa air temperature (K), lifted index (LI, K) and 500 hpa geopotential heights (m) are presented, based on NCEP/NCAR reanalysis daily composites. Looking at the composite mean sea level pressure (Figure 2a), shallow low pressure pattern (1014 hPa) appears from Sicily to the northern coasts of Africa, indicating also a closed negative anomaly of 2 hPa (Figure 2b). Besides, the composite mean sea surface temperature (not shown) shows warm waters in close distance from the Libya coasts, exceeding 300 K, with a small positive anomaly 0.1 K (not shown).

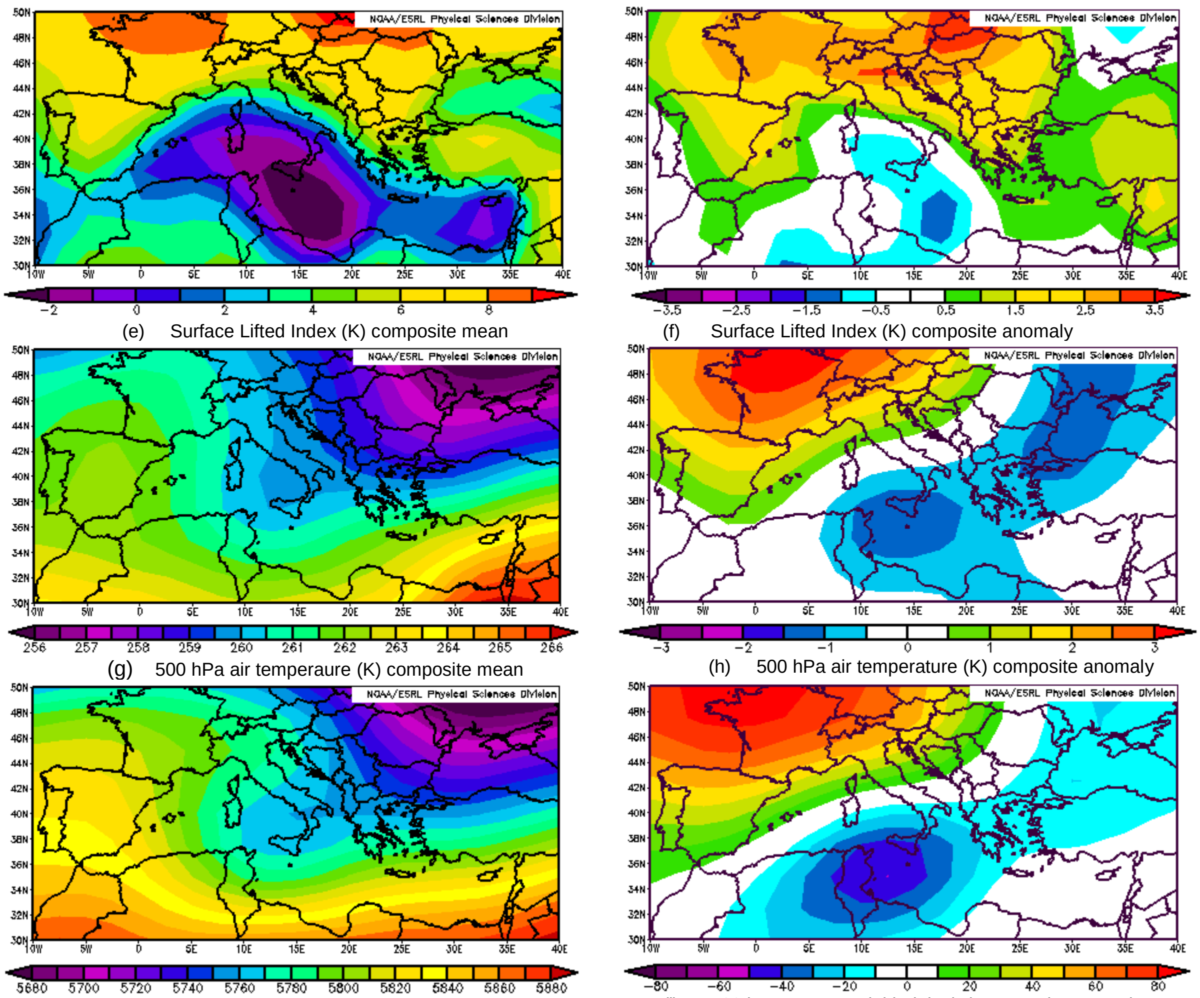


(a) Sea level pressure (hPa) Composite Mean

(b) Sea level pressure (hPa) Composite Anomaly

(c) Surface rain rate (mm/day) composite mean

(d) Surface rain rate (mm/day) composite anomaly



(e) Surface Lifted Index (K) composite mean

(f) Surface Lifted Index (K) composite anomaly

(g) 500 hPa air temperaure (K) composite mean

(h) 500 hPa air temperature (K) composite anomaly

(i) 500 hPa geopotential height (m) composite mean

(j) 500 hPa geopotential height (m) composite anomaly

Figure 2: Daily composite means (left column) and anomalies (1981-2010 Climatology) (right column) of SLP, rain rate, Lifted Index, air temperature and geopotential height at 500 hPa isobaric level for medicane events during September, within 1947-2014 period.

The mean surface rain rate depicts high values (<11 mm/day) over a wider area of Sicily (Figure 2c), with an anomaly of 8 mm/day (Figure 2d). The thermodynamic lifted index shows a negative composite mean of less than -2 K (Figure 2e), over a restricted area southeast of Sicily towards Libya coasts, with a negative anomaly of -1.5 K (Figure 2f). This gives evidence of the unstable conditions prevailed, which are likely ideal for severe thunderstorms. Regarding the middle troposphere, the composite air temperature at 500 hPa isobaric level (Figure 2g) accounts for 260 K south of Sicily towards the northern coasts of Africa, depicting a closed negative anomaly of 2 K (Figure 2h). Further, a trough at 500 hPa isobaric level appears over southern Italy (Figure 2i), with a closed negative anomaly (-50 hPa), extended southwest from Sicily towards the coasts of Tunis and Libya (Figure 2j).

3.2. TLC impacts over mediderranean

The spatial distribution of TLC impacts, based on impacts based on the 65 recorded cases over the Mediterranean during the study period 1947-2014, are depicted in Figure 3. The majority of the recorded impacts concerns favorably specific areas such as the Balearic Islands in the archipelago of Spain in the western Mediterranean Sea, near the eastern coast of the Iberian Peninsula, Sardinia, Sicily and also southern Italy, although there is a large number of casualties regarding the northern coasts of Tunisia, with respect to a flood episode mentioned as "*north African flood*" in September, 1969. Tornadoes associated with significant damages are mainly spotted in the west and central Mediterranean basin, mostly accumulated near the shores of the Balearics and the Aeolian Islands in a volcanic archipelago in the Tyrrhenian Sea north of Sicily

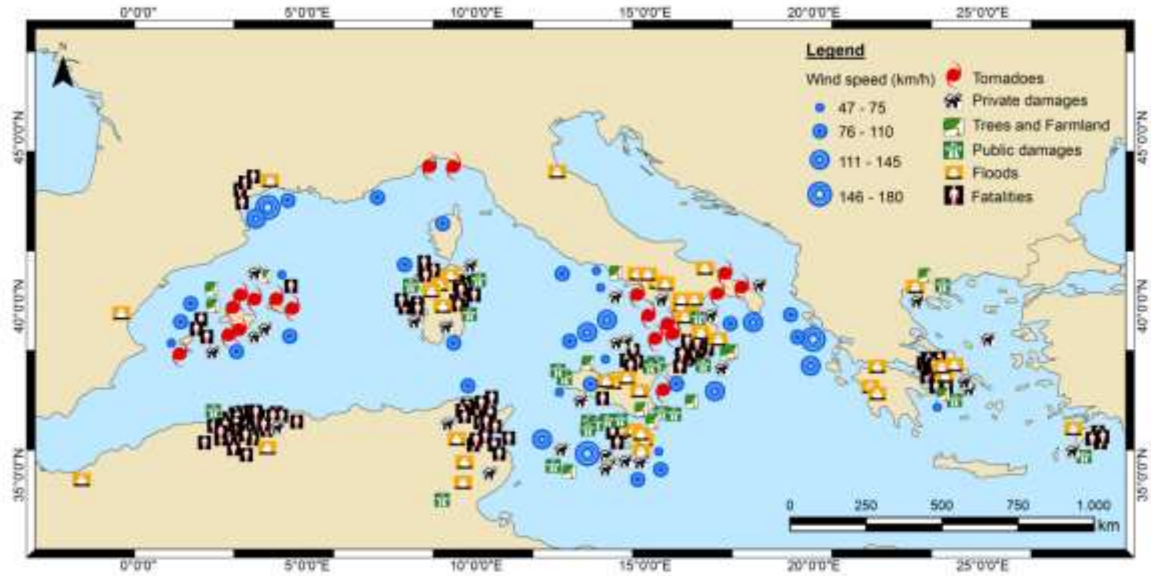


Figure 3: TLC impacts based on the 65 recorded cases over Mediterranean during the study period 1947-2014.

As far as floods are concerned, southern Italy and Sicily are the most affected areas, with nearby islands, like Malta, also having impacts caused by many flood incidents. The wind speed ranges from 47 to 180 km/h among the different cases reported. It is evident that private and public damages occur mainly in areas affected by flood episodes. However, the Balearics Islands seem to be an exception to this rule, with no floods, against many tornadoes reported. In the eastern Mediterranean, there are reduced reports on TLC impacts mainly occurred in urban agglomerations, that is the case of Athens, in western Peloponnese and Cyprus Island.
Regarding the temporal variability of TLC impacts, tornadoes develop mainly during September, followed by November and October. However, the majority of the TLC impacts, as they have been classified in Figure 3, occur during November, followed by September and October. There is an increasing concern that extreme events may be changing in frequency and intensity as a result of human influences on climate (IPCC, 2014). The results indicate that the number of such systems decreases in a warmer world, particularly in winter, due to an increasingly hostile environment for storm formation, combined with a general poleward shift in the incidence of wintertime lows over western Europe (Walsh *et al*., 2014).

4. Conclusions

The findings of the performed analysis, based on a sample of 65 recorded TLC cases over the Mediterranean, during the study period 1947-2014, revealed that TLCs mostly happen in September, due to warm sea waters established during that month, indicating the highest frequency (15 TLCs), followed by October (13 TLCs), December (12 TLCs) and January (8TLCs). The majority of the recorded impacts appears favorably in the Balearic Islands, Aeolian Islands, Sardinia, Sicily and also south Italy, although there is a large number of casualties regarding the northern coasts of Tunisia.

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