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Tropicalization process of the 7 November 2014 Mediterranean cyclone: Numerical sensitivity study

D.S. Carrió[a,*], V. Homar[a], A. Jansa[a], R. Romero[a], M.A. Picornell[b]

[a] Meteorology Group, Department of Physics, Universitat de les Illes Balears, Palma de Mallorca, Spain
[b] Agencia Estatal de Meteorología, Palma de Mallorca, Spain

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ABSTRACT

Tropical-like Mediterranean cyclones (medicanes) have been documented and investigated in the literature, revealing that their physical mechanisms are still poorly understood and likely not unique across cases. During late hours of 7 November 2014 a small-scale cyclone was detected over the Sicilian channel, affecting the Islands of Lampedusa, Pantelleria and Malta. Gust wind values exceeding 42.7 m s^{-1} and a pressure drop above 20 hPa in 6 h were registered in Malta. Clear signatures of a well-defined cloud-free eye surrounded with convective activity of axisymmetric character were identifiable through IR satellite imagery during the late stages of the cyclone, resembling the properties of a hurricane. We investigate the cyclogenesis and posterior development of this small-scale cyclone as well as its physical nature; to this aim, a set of high-resolution sensitivity numerical experiments were performed. Hart's phase diagrams adapted to the Mediterranean region clearly reveal the tropical characteristics of the simulated storm. A numerical sensitivity analysis by means of a factor separation technique is used to gain quantitative insight on the roles latent heat release, surface heat fluxes and upper-level PV signatures (dynamically isolated through a PV-Inversion technique) have on the unfold of this singular event. Results show the importance of the upper-level dynamics to generate a baroclinic environment prone to surface cyclogenesis and in supporting the posterior tropicalization of the system. On the contrary, latent heat release and surface heat fluxes factors do not seem to contribute, as individual processes, to the genesis of the cyclone as much as it could be suspected, considering it behaves as a tropical-like cyclone. However, the asynchronous synergism between latent heat release and PV factors plays a crucial role for the intensification of the cyclone towards reaching the pure diabatic phase.

1. Introduction

Cyclogenesis and Mediterranean region are closely linked, with the frequency of cyclones in the basin ranking among the highest in the world (Pettersen, 1956; Radinovic, 1987). Mediterranean cyclones occasionally produce hazardous weather, generating high impacts on exposed people and property assets (Jansa et al., 2001; Gómez et al., 2002; De Zolt et al., 2006). There is an extensive body of literature analyzing the physical and climatological characteristics of these cyclones (e.g. Jansa et al., 2014 for a recent review) and various approaches have been used to formulate conceptual models that either explain the mechanisms of their formation or outline their features. The deepest and most intense cyclones are associated with all kinds of high-impact weather, in particular strong winds and torrential precipitations (Jansa et al., 2001; Lionello et al., 2006). One descriptive way to classify Mediterranean cyclones is based on their location, morphological characteristics (Alpert et al., 1990; Trigo et al., 1999; Campins et al., 2000; Hoskins and Hodges, 2002; Wernli and Schwierz, 2006; Campins et al., 2011) and even the preceding synoptic conditions that led to their formation (Homar et al., 2006; Garcies and Homar, 2009). A complementary but linked classification is based on the physical mechanisms involved in the genesis, intensification, evolution and decay of the cyclonic system.

In recent years, a relatively rare type of Mediterranean cyclone with some tropical characteristics, has got the attention of the meteorological scientific community. These cyclones are relatively small in size and associated to strong winds and usually heavy precipitations (Ernst and Matson, 1983; Rasmussen and Zick, 1987; Lagouvardos et al., 1999; Fita et al., 2007). They share morphological characteristics with hurricanes such as a warm core, axisymmetry and cloud-free eye, and have been consequently named Mediterranean hurricanes (Emanuel, 2005) or simply medicanes.

Various studies highlight the role of surface heat fluxes in medicanes, along with high values of mid-tropospheric relative humidity

* Corresponding author at: Dept. of Physics, Universitat de les Illes Balears, 07122 Palma de Mallorca, Spain.
E-mail address: diego.carrio@uib.es (D.S. Carrió).

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and low values of wind shear (Rasmussen and Zick, 1987; Lagouvardos et al., 1999; Pytharoulis et al., 1999; Pytharoulis et al., 2000; Homar et al., 2003; Moscatello et al., 2008; Tous et al., 2013; Cavicchia et al., 2014). Additionally, Businger and Reed (1989), described this kind of cyclones over the Mediterranean Sea as a subclass of polar lows. The accepted conceptual model for the intensification and maintenance of medicanes is similar to that of tropical cyclones, being governed by surface energy fluxes within pre-existing organized cyclonic environments, although with the very substantial difference of the requirement for an upper-level cold trough that contributes to cool and moisten the low and mid-tropospheric environment, thus increasing the air-sea gradient of saturation moist static energy (Emanuel, 2005). Therefore, a key factor for classical baroclinic cyclogenesis in the Mediterranean, such as an upper-level trough, may also positively contribute to generate tropical-like cyclone prone environment, especially during the mature development, when the vertical wind shear -both directional and in magnitude- tends to decrease. The rarity of medicanes as opposed to the commonness of synoptic troughs affecting the region is an obvious indication that further conditions must be met for medicane formation (Tous and Romero, 2011; Cavicchia and von Storch, 2012; Tous and Romero, 2013). As highlighted by Cioni et al. (2016), the physical mechanisms contributing to a certain sea-level pressure distribution (e.g. a cyclonic area) alternate and even coexist in the same area and period of time, thus making the attempt to classify some systems within pure baroclinic (i.e., extratropical) or diabatically driven (i.e. tropical-like) classes a daring and unrealistic objective. Some baroclinic cyclones evolve into symmetrical structures during its occlusion phase, with intense latent heat release around its core, posing a serious forecast challenge similar to that found in the so-called extratropical transition of tropical cyclones. Jones et al. (2003) allude to the continuum spectrum between pure tropical and pure baroclinic synoptic systems and to the difficult forecast implications of extratropical transitions, mainly due to the lack of observations over the maritime areas as well as the model limitations to reliably simulate physical interactions between baroclinic and thermodynamic processes at high resolution.

During 7 November 2014, a mid-levels synoptic trough extended across the Western Mediterranean, reaching as far south as southern Algeria. Cyclonic conditions were present at low levels over the western Mediterranean since 4 November. On 7 November a small intense cyclone formed in the South Central Mediterranean Sea and moved northeasterly towards southern Sicily, affecting the Islands of Pantelleria, Lampedusa and Malta (Figs. 1 and 2). The small and rapidly-rotating system dissipated as it crossed the Catanian coast (eastern Sicily), during the first hours of 8 November.

The main scope of this study is to advance in our understanding of the physical mechanisms involved in the genesis of quasi-tropical like cyclones (Homar et al., 2003), such as the case of 7 November 2014, with special focus on the diagnosis of the extratropical and tropical characteristics based on satellite, gridded analysis and high-resolution numerical simulations.

Section 2 describes the event using synoptic charts, satellite imagery and observations from METARs (METeorological Aerodrome Reports). Section 3 presents the characteristics of the control simulation and its verification against observations. Sensitivity experiments taking into account the roles of a set of relevant factors are discussed in Section 4. Finally, Section 5 provides the discussion and conclusions of this research work.

2. Description of the event

From 5 to 8 November 2014, the Western Mediterranean was under the influence of an intense upper-level trough and general cyclonic flow at low levels. The Global Forecast System (GFS) analyses, produced by the National Centers for Environmental Prediction (NCEP), are used to diagnose the synoptic setting of the event. The synoptic situation at mid-levels over the Western Mediterranean on 5 and 6 November 2016 was dominated by a prominent ridge over the Atlantic and the intense trough moving southwards along western Europe, with an associated intense PV streamer extending from northern Europe and reaching the southern Algerian lands during 6 November (Fig. 3). The general cyclonic circulation over the Western Mediterranean was influenced by the North Atlantic Subtropical High and high-pressures over the Eastern Mediterranean (Fig. 4). The cold and warm fronts associated with the cyclonic circulation were reinforced by a persistent northward advection of a warm and moist plume across the central Mediterranean during 5, 6 and 7 November. During 6 November, the upper-level trough became negatively tilted and the PV streamer eventually disconnected from the northern nucleus, evolving into an intense (reaching 8 PVU at 300 hPa; 1 PVU = 10^{-6} K m^2 s^{-1} kg^{-1}) upper-level cut-off during the late hours of 7 November (Fig. 3).

During the first hours of 7 November, the enhanced vorticity advection aloft forced general uplifts and further low-level cyclogenesis over the Sicily area. Infrared Meteosat Second Generation (MSG2) imagery show that, in addition to the convective activity already identifiable along the cold and warm fronts, deep convective systems formed during the night and first hours of 7 November around the initiation area of this quasi-tropical Mediterranean cyclone (Fig. 1a). During the midday hours of 7 November, a small well-defined spiral-to-circular shaped cloud formed just south of Sicily and evolved east-northeastward (Fig. 1b), reaching its maximum measured intensity over Malta. The small cyclonic circulation, which possessed distinct circulation from the larger cyclone, continued progressing until the last hours of 7 November. A clear and well-defined eye was visible all along its trajectory, although deep convection around the eye was only intermittent. Finally, the small cyclonic system dissipated as it crossed the Catanian (eastern) coast of Sicily (Fig. 1c), moving over land.

Since the small cyclone initiated and moved over the sea (Fig. 2), a quite limited number of observations are available. METAR reports from land locations close to the cyclone path (i.e., Pantelleria, Lampedusa, Malta and Catanian coast; see Fig. 2 for geographical references) provide in-situ measurements of the small cyclone. During the first hours of 7 November, an incipient depression was recorded in Pantelleria, still fairly shallow at this time. Despite the center of the cyclone progressed eastwards some 100 km north of Lampedusa, surface pressure records in the island show a 10 hPa drop in 1.5 h. The barometer in Malta recorded a pressure drop of nearly 20 hPa in 6 h, from 1046 to 1645 UTC, and a minimum recorded pressure for the event of 985 hPa at 1645 UTC (Fig. 5c). The wind record in Malta provides a clear signature of the structure of the eye, with intense wind speeds (gusts exceeding 42.7 m s^{-1}) that precedes and follows a relatively calm period around 1645 UTC. Ten hours later, the signature over the Catania pressure record is much attenuated, with winds still showing a calmed period followed by gusts reaching 40 m s^{-1}.

The intensity, pressure record and some morphological characteristics such as the central eye and cloud symmetry, more clear at the end of the process than at the beginning (see Fig. 1c) contribute to the idea of a cyclonic entity with mostly tropical mechanisms driving its circulation and pressure pattern, at least at the end of the process. However, the lack of continuous and persistent deep convective activity in the central part of the system, as evidenced by the time series of satellite images, and the presence of dry air intrusions turning around the cyclone center, like in many extratropical mature disturbances (see Fig. 1b), lead us to hypothesize a certain coexistence of various cyclogenetic mechanisms. It should be noted that the lack of deep convective activity is not exclusive of this medicane event (see, for instance (Luque et al., 2007, Claud et al., 2010 and Miglietta et al., 2013)).

In order to investigate and better diagnose the physical mechanisms involved in this intense and localized Mediterranean cyclogenesis, numerical experiments were performed and are presented in the following sections.