Remote sensing of deep convection within a tropical-like cyclone over the Mediterranean Sea

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Funding information
Earth2Observe, Grant/Award Number: 603608; Centre National d’Études Spatiales; ANR-MUSIC project, Grant/Award Number: 14-CE01-0014; Direction générale de l’armement—Ministère des Armées (DGA)

The Mediterranean basin occasionally hosts tropical-like cyclones named “Medicanes”. Medicanes may have intensity comparable to hurricanes in terms of wind speeds along with an axisymmetric cloud structure. Although these events can be particularly violent, very few studies so far have investigated the distribution and temporal evolution of deep convection within these cyclones. In this study, the characteristics and lifetime of deep convection and lightning activity surrounding the core of the longest-lasting and probably the most intense Medicane ever recorded in terms of wind speed (Rolf, November 2011) are presented by all available means of microwave and infrared satellite retrievals and a lightning detection system. Results showed that deep convective clouds penetrated the lowest stratosphere and were wrapped around the cyclone centre during the intensification period. Lightning activity was mostly active about a day before the maximum strength of the cyclone studied and it was not temporarily correlated with the most intense deep convection activity. Overall, this study reveals that spatial and temporal distribution of deep convection and lightning activity around the centre of Rolf show more similarities with Tropical Cyclones than intense Mediterranean cyclones.

KEYWORDS
convection, lightning, Medicane, Mediterranean, satellite, tropical-like cyclone

1 | INTRODUCTION

The risk assessment related to the formation of intense tropical-like cyclones (TLC) or the so-called “Medicanes” over the Mediterranean Sea is crucial in order to limit the socioeconomic damages mostly in islands and coastal areas (Michaelides et al., 2017). Even though cyclones that attain characteristics of tropical cyclones in the Mediterranean is a debatable issue, a Medicane can be defined as an intense, maritime warm-core cyclone that forms in the Mediterranean basin with a cloud-free eye formation and surface winds above gale force. Very few studies exist so far regarding surface or 3D observations of Medicanes and the main reason is that these systems very rarely make landfall and thus, our understanding of the role of deep convection within these systems is limited to satellite retrievals. Lagouvardos et al. (1999) investigated the case of a TLC between Sicily and Greece in 1995 using infrared imagery and documented the presence of deep convection (DC) prior to TLC genesis, as well as the weak baroclinic instability contribution to the evolution of the cyclone, by using a mesoscale model. Luque et al. (2007) analysed satellite retrievals to construct the trajectories of three Medicanes between 1995 and 2005 and estimated precipitation features from microwave measurements. They concluded that the temporal evolution of Medicanes consists of three stages: the pre-eye, the stationary phase and the itinerant phase. Claud et al. (2010) used NOAA/MetOp satellite observations to investigate three
Medicanes and showed that convection and precipitation areas are large in the early stage of the cyclones, but significantly reduced afterwards. Convection maximum was found just after the upper-level trough, located upstream of cold mid-tropospheric air, when Medicanes reached their maximum intensity. Miglietta et al. (2013) studied 14 TLC in the Mediterranean and showed that deep convection, heavy rainfall and intense lightning activity preceded the maximum wind speed.

There is no common measure for the intensity of a cyclone, yet it usually inferred in the literature as the period when cyclones reach their minimum sea-level pressure (SLP) or their maximum wind speeds (e.g., Claud et al., 2010; Miglietta et al., 2013). Deep convection, rainfall and latent heat release play a crucial role in the intensification of tropical cyclones, as studies that use satellite techniques and high resolution models, show around the globe (e.g., Homar et al., 2003; Zagrodnik and Jiang, 2014). The source of energy for tropical cyclones is the release of latent heat due to condensation in moist convection. For developing tropical storms, such convection is quite disorganized relative to the cyclonic wind field. Nonetheless, a portion of the heat released in these convective updrafts is transformed into energy of two forms: the kinetic energy of the quasi-symmetric wind field and the convective available potential energy associated with the warm core, which is necessary to hold the cyclonic wind field in hydrostatic and gradient wind balance. Even though studies show that typical baroclinic cyclones in the Mediterranean basin present a similar life cycle (Flaounas et al., 2015), Medicanes exhibit rather peculiar characteristics, resembling TCs.

In this study the lifetime of deep convection of the 6 to November 9, 2011 TLC in NW Mediterranean Sea is studied and compared to similar studies referring to tropical storms and hurricanes around the globe. It is the first study that introduces the use of convective overshooting top detection from infrared satellite observations, along with microwave diagnostics, providing a unique insight to the evolution of deep convection of Medicane Rolf.

2  |  DATA AND METHODS

2.1  |  Satellite diagnostics

In order to investigate the evolution of deep moist convection around the TLC during the period 6 to November 9, 2011, the cross-scanning microwave sounder MHS (Microwave Humidity Sounder), on-board NOAA and MetOp polar orbiting satellites were used. In particular, three documented diagnostics, already validated in the Mediterranean basin, were calculated: “Convective Overshooting” (COV), “Deep Convection” (DC) and “Moderate Rainfall” (MR) (Hong et al., 2005; Funatsu et al., 2007; 2018; Rysman et al., 2016; 2017). The detection is performed using a combination of three humidity sounding channels around 183 GHz. Microwave radiation in these bands is sensitive to the presence of frozen hydrometeors, such that the deeper (more convective) the cloud, the lower the brightness temperatures.

In addition to microwave observations, brightness temperatures (TB) derived from SEVIRI infrared channels 10.8 μm (IR) and 6.2 μm (WV) on-board Meteosat-9 (MSG-2) geostationary satellite were used to calculate the occurrence of overshooting tops (OT), based on the technique proposed by Schmetz et al. (1997). Overshooting tops are defined by the positive brightness temperature difference (ΔTB) between WV and IR, as the WV spectral response peak is about 350 hPa and it is typically colder than IR which has a maximum spectral response near the surface. The OT diagnostic was calculated every 15 min from 6 November 00:00 UTC until 9 November 12:00 UTC.

Note that SEVIRI’s spatial resolution is 3 km, while MHS has a near nadir instantaneous field of view of approximately 16 km, that is relatively large when compared to typical updrafts, thus the observed brightness temperatures represent a combination of effects over a relatively large area. Finally, microwave diagnostics are available five times per day, while geostationary data every 15 min.

2.2  |  Lightning detection

The characteristics of global lightning activity of the TLC were studied by using data from the European Cooperation for Lightning Detection (EUCLID), a long-range detection system that detects both cloud-to-ground (CG) and intra-cloud (IC) lightning flashes. Schultz et al. (2016) evaluated the location accuracy and detection efficiency of EUCLID system in the northwest Mediterranean basin using a 9-yr dataset of observations (2006–2014). Results showed that the location error of EUCLID is of the order of 100–500 m for CG flashes and the detection efficiency is in the order of 70% for CG flashes and about 20% for IC flashes.

3  |  EVOLUTION OF THE TLC BETWEEN THE SIXTH AND NINTH OF NOVEMBER 2011

3.1  |  Synoptic conditions

Satellite images derived from SEVIRI, specifically from High Resolution Visible (HRV) channel (3.6 μm), between 6 and November 9, 2011 at 12:00 UTC and the estimated track of the TLC are shown in Figure 1. Track positions were produced by the National Oceanic and Atmospheric Administration (NOAA) and the National Environmental Satellite Data and Information Service (NESDIS). Prior to November 6, Balearic Islands were under the influence of an extensive cold-core low pressure system and its profound
cold front reached the northwest coasts of Italy causing tremendous flash floods with 11 confirmed fatalities (information from European Severe Weather Database—ESWD—Dotzek et al., 2009).

The Integrated Forecast System (IFS) analysis data were employed to study an extensive upper-level trough with a slightly positive tilted axis entering the West Mediterranean basin on November 6, 2011, associated with advection of substantial Potential Vorticity (PV) and a jet streak at 300 hPa (not shown). At the surface, a low-pressure system evolved into a baroclinic environment near the Balearic Islands, where deep layer shear was gradually weakening and a weak steering flow at 850 hPa assisted in the formation of a banding convective structure close to the centre of the cyclone (Figure 1). Several studies have shown the significant role of low (high) vertical wind shear regarding the intensification (filling) of the tropical cyclones (e.g., DeMaria and Kaplan, 1994).

On 7 November, the system revealed tropical characteristics such as a warm quasi-symmetric core and convective bands were now wrapped around the centre and became better organized, especially on 8 November (Figure 1). Sea surface temperature (SST) fluctuated from 18°C to 22°C throughout the studied period (buoy reports from NOAA) and ASCAT non-contaminated wind data revealed sustained wind speeds up to 40 kts in the northwest quadrant of the system within 50 km radial distance from the cyclone centre (not shown). It was then the first time since NOAA/NESDIS started monitoring the system, and by using the Dvorak classification technique, classified the TLC as a T3.0 system in the afternoon of November 8, because convection persisted for an adequate time atop the centre of the cyclone (personal communication with A. Schwartz and M. Turk from NOAA/NESDIS). The peak cyclone intensity took place between 00:00 UTC and 03:00 UTC on November 8 when the minimum sea-level pressure (SLP) was estimated at 991 hPa (NOAA/NESDIS and Miglietta et al., 2013). During the afternoon of November 9, Rolf made landfall in Southeast France (Figure 1), weakened rapidly and was losing its structure. At that time ground meteorological stations reported wind gusts of less than 30 kts in Toulon and Marseille.

3.2 Evolution of convection characteristics

In Figure 2a, brightness temperature derived from WV6.2 SEVIRI channel and overlapped microwave diagnostics within a 20-min time window, show the convective bands surrounding the centre of the cyclone at 01:15 UTC on November 8. The IR10.8 channel provides insight into the deep convective clouds at the same time (Figure 2b). Convective bands were wrapped around the cyclone centre and microwave diagnostics provide a clear evidence for deep convection development in contrast to IR channel that may provide misleading information about the actual deep moist convection areas due to high-level clouds (e.g., Cirrus canopy) (Olander and Velden, 2009).

Despite the differing fields of view, scan geometries and temporal resolution, of COV and OT, Figure 2 shows that COV values occur roughly at the same location as OT for
the same scanning period, giving confidence in the methodology.

The spatial distribution of flashes detected within a radial distance of 200 km from the centre of the TLC, bounded by 25 km annular rings, is shown in Figure 3. Flashes were found at all quadrants, but the maximum density was located northwest of the cyclone centre, with a sum of 2492 flashes from 12:00 UTC November 6 until 12:00 UTC November 9. Moreover, the maximum 1-hr flashing rate was recorded between 23:00 UTC on 6 November and midnight of November 7, about 27 hr before the maximum intensity of the TLC. The study performed by Miglietta et al. (2013) showed the highest lightning frequency about 20 hr before the peak of the EUCLID flashes. This could be due to (a) the larger investigated area compared to our study where we focus only to the most intense part of the cyclone and (b) to the efficiency of the lightning detections used, in particular the efficiency of EUCLID to detect IC flashes.

Lightning temporal patterns of the TLC resembled those of tropical cyclones in the oceans rather than Mediterranean cyclones. Galanaki et al. (2016) showed that intense cyclones associated with lightning activity present their highest lightning activity on average about 6 hr prior to the maximum intensity, whilst similar studies for tropical cyclones and hurricanes show a temporal lag of 24–30 hr before their maximum intensity (Price et al., 2009; Zhang et al., 2012).

Even though the maximum lightning activity was detected during the late night on 6 November, microwave diagnostics revealed a more active convective activity in terms of DC, MR and COV during the second half of November 7, a few hours before the maximum intensity of the cyclone. In Figure 4 the occurrence of MR, DC and COV is provided, calculated five times per day, approximately at 01:15, 02:15, 13:15, 14:15 and 20:30 UTC. IFS analysis provided the maximum wind speed and SLP data every 3 hr, although the minimum SLP which was estimated by NOAA/NESDIS at 03:00 UTC on 8 November
(991 hPa), was underestimated by IFS. The peak of MR occurrence coincided with the maximum intensity of the TLC between 00:00 UTC and 03:00 UTC on 8 November (Miglietta et al., 2013), while DC and COV were mostly detected about 12 hr before that period.

Figure 5 shows the azimuthal distribution of microwave and infrared diagnostics. On 6 November, deep convection is mostly detected further from the cyclone centre (>200 km from the core). On 7 and 8 November, the eyewall region and inner rain-band region precipitation features (<200 km from the core), as defined by MR diagnostic, produce more deep convection (DC) and overshooting tops (COV & OT) than the outer rain-band regions.

There are several examples of asymmetric convection patterns in developing tropical cyclones that have been seen or inferred in observations (e.g., Simpson et al., 1998; Lonfat et al., 2004; Reasor et al., 2005) which are linked with the intensification of tropical storms. The aforementioned studies suggest that DC is distributed mostly close to the...
centre of the tropical cyclones, within 200 km radial distance, rather than at the outer rain-bands like in the Mediterranean cyclones (fronts). The evolution of DC during Rolf has more similarities with tropical cyclones studied over the oceans, rather than their baroclinic Mediterranean counterparts in terms of spatial and temporal characteristics.

4 | SUMMARY

In this paper, we combined, for the first-time, diagnostics from geostationary and polar orbiting satellites to study the evolution of a TLC in the Mediterranean Sea. Our technique provides a unique insight on deep moist convection of the most long-lasting and probably the largest (widest) TLC in the Mediterranean Sea between 6 and November 8, 2011. Lightning activity and convection during this Medicane deviated from the typical life-cycle of Mediterranean (baroclinic) cyclones and resembled Tropical Cyclones or Hurricanes as studies have documented their behaviour along the storm tracks of the globe.

Our main results are as follows:

- Deep convective clouds penetrating the lowest stratosphere and heavy rainfall peak 0–12 hr before the maximum strength of the cyclone studied, close to the cyclone centre as the cyclone was intensifying on November 8, 2011. In contrast, maximum lightning activity was observed about 27 hr before the minimum SLP with a significant temporal lag between the peak of lightning activity and the maximum DC/COV occurrence.

- Deep convection during a TLC in the Mediterranean was studied in conjunction with OT and DC/COV, providing new insights for the spatial and temporal evolution of deep convection which, along with lightning activity, exhibit more similarities with tropical cyclones over the oceans than with intense Mediterranean cyclones.

Increasing advances in remote sensing enhance our ability to observe moist physical processes, and therefore to evaluate the potential for a depression to undergo a transition to a TLC, based mostly on an estimate of the azimuthally distribution of convection. The observational techniques proposed will be used in more TLC cases to draw more general conclusions on the convective characteristics of Medicanes. The results of this study will have useful application on validating numerical simulations of TCCs which are planned by the authors in the near future.

ACKNOWLEDGEMENTS
This study was partially sponsored by the Earth2Observe project under grant agreement number 603608, ANR-14-CE01-0014 MUSIC project, the Centre National d’Études Spatiales (CNES) and the Direction générale de l’armement—Ministère des Armées (DGA). The authors would like to thank A. Schwartz and M. Turk for providing the observational data from NOAA NESDIS. We are also thankful to E. Defer and Meteorage (http://www.meteorage.fr/) for making available the lightning data. Meteosat data were retrieved from the Earth Observational Portal of EUMETSAT. MHS data were obtained through the French Mixed Service Unit project ICARE/Climserv/Aeris.

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How to cite this article: Dafis S, Rysman J-F, Claud C, Flaounas E. Remote sensing of deep convection within a tropical-like cyclone over the Mediterranean Sea. Atmos Sci Lett. 2018;19:e823. https://doi.org/10.1002/asl.823