# TROPICAL-LIKE MEDITERRANEAN STORMS: AN ANALYSIS FROM SATELLITE 

Angel Luque, Lluis Fita, Romualdo Romero, Sergio Alonso<br>Meteorology Group, Balearic Islands University, Spain


#### Abstract

Tropical-like storms in the Mediterranean Sea with a clear eye surrounded by an axisymmetric cloud structure are quite unusual. Almost one case per year on average is identified in satellite images in all the Mediterranean basin. These storms, once generated over the sea, can affect islands and continental coastal lands. Although, documented tropical-like cyclones have not usually achieved hurricane intensity, their potential for damage is high due to the densely populated Mediterranean coastal regions.

In this work, different features of a set of these storms are analysed from a satellite point of view: storm trajectories, areas of influence and eye displacement speeds are calculated. In a second phase, precipitation and wind speed fields are estimated from Meteosat infrared images. As a result, three different stages in the life of these storms are obseved in general: pre-eye, stationary phase and itinerant phase. According to this classification, a clear reduction of the number of precipitation points in the trasition from the stationary to the itinerant phase is detected and a gradual increase of estimated wind speeds during this third phase is observed.


## INTRODUCTION

Tropical-like storms in the Mediterranean Sea or Medicanes, as called in previous publications (Emanuel, 2005) are not frequent meteorological features. Clear cases in the last 20 years were observed on satellite images (see figure 1). They are formed typically under the effects of a cold and isolated depression at the medium and high levels of the troposphere as shown by Emanuel (2005) and more recently by Fita et al (2007). Under these conditions a strong sea-air thermal disequilibrium seems to be an important ingredient and the most probable cause of the high proportion of these events in the months of September and October in the Western Mediterranean Sea (Romero and Emanuel, 2006). During these months the sea surface temperature is relatively high because much heat energy has been stored the summer season. However, instability conditions as the ones described occur very often in any place of the Mediterranean basin and the factors that force the formation of a Medicane instead of an ordinary depression are still not very well known (Fita et al, 2007).

These storms, once generated over the sea, can affect islands and continental coastal lands, although documented tropical-like cyclones have not usually achieved category one hurricane intensity (33.3 $\mathrm{m} / \mathrm{s}$ ). Surface winds of $20 \mathrm{~m} / \mathrm{s}$ to $27 \mathrm{~m} / \mathrm{s}$ have been measured in SSM/I and QuikScat images in sea areas affected by medicanes.

| Case (YYMMDD) | Beginning ( $\mathrm{DD} / \mathrm{MM} \mathrm{HH}^{\text {MM }}$ ) | Ending (DD/MM HH ${ }^{\text {MM }}$ ) | Affected Area |
| :---: | :---: | :---: | :---: |
| 950116 | $14 / 0112^{00}$ | 18/01 $20^{00}$ | CM |
| 960912 (a) | 11/09 $21{ }^{00}$ | 13/09 0230 | WM |
| 961007 | 06/10 $03^{30}$ | $11 / 1003^{00}$ | WM-CM |
| 030527 | 25/03 12 ${ }^{00}$ | 28/05 $04{ }^{30}$ | WM |
| 031018 (b) | $17 / 1000{ }^{00}$ | 19/10 04 ${ }^{00}$ | WM |
| 051027 | 26/10 $20^{30}$ | 29/10 $14^{30}$ | CM |
| 051215 (c) | 13/12 05 ${ }^{00}$ | $16 / 1212{ }^{15}$ | CM-EM |

Table 1: List of medicane cases monitored by our group. In bold, cases studied in the present research. An example of each case is illustrated in figure 1. YY: Year, MM: Month, DD: Day, HH: Hour, MM: Minute. WM: Western Mediterranean. CM: Central Mediterranean, EM: Eastern Mediterranean.

A list of cases that are under study by our group is shown in table 1, however more information about cases, satellite images and animations can be found in the following web pages:
http://www.uib.es/depart/dfs/meteorologia/METEOROLOGIA/MEDICANES/
http://www.fenomenitemporaleschi.it/ciclone.htm


Figure 1: Examples of medicanes in Meteosat visible images corresponding to three different cases: (a) 960912 at 0500 UTC, (b) 031018 at 1200 UTC and (c) 051215 at 0845 UTC. A black arrow is pointing to the medican`s eye in each frame.

## DYNAMIC STUDY OF THREE CASES

Visible and infrared Meteosat images and SSM/I, QuikScat images of wind were used to track manually the centre (storm eye, if observed) and to delineate cyclonic cloud area of the storm at the times in which both features could be easily identified. Nevertheless from time to time the storm eye and size couldn't be clearly distinguished for relatively long periods (more than 4 hours) making this task difficult and subjective. For this reason and to be sure that the medicane is captured in intermediate time steps, which is important for the intensity, rain and wind estimations, the radius of the storm is intentionally incremented around 20 km . This enhanced medicane radius is what we have used to define the medicane cloud circular area of influence.
The complete medicane life cycle from the beginning phase of the storm shown as a weak vortex to residual post-stormy cloud systems is screened. Trajectories, total distances and mean speeds of displacement for the three cases are analysed and illustrated in figure 2.
Other important observations from this dynamic study are summarized below.

- Heavy convective clouds are observed before the eye of the storm appears for the cases: 960912 (a) and 051215 (c).
- For the case 031018 (b), the active convective system initially over the Iberian Peninsula and moving slowly to the east seems to converge with a small cyclonic vortex coming from the south resulting a medicane over the Mallorca Island.
- Once the storm is formed, the eye is identified and the complete system begins to move, it tens to move in a well defined direction at a mean speed of 20 knots or $10.3 \mathrm{~m} / \mathrm{s}$.


Figure 2: Dynamic analysis of the three studied medicanes; (a) 960912, (b) 031018 and (c) 051215. The red arrow indicates the time in which the eye of the storm is observed for the first time.

## INTENSITY, PRECIPITATION AND HORIZONTAL WINDS IN THE MEDICANES

## 1. Intensity

There are different methods to evaluate the intensity of a tropical cyclone from geostationary satellite images (Velden et al, 1998). In this first attempt we have used the infrared brightness temperature of the $11.5 \mu \mathrm{~m}$ band averaged over the area of influence centred on the medicane. This method is based on the simple assumption (not always true) that the more developed and colder the clouds are the more intense is the storm. The evolution of the averaged brightness temperature over the medicane's area of influence for the three studied cases is illustrated in figure 3 . Here the centres location and the sizes of the areas of influence have been linearly estimated for each satellite image time step.


Figure 3: Evolution of the mean infrared temperature (red curve) over the areas of influence by screening the three medicanes along their life cycles. (a) Correspond to 960912 , (b) to 031018 and (c) to 051215 . The green curve is the number of cold infrared pixels, those with $\mathrm{T}<240 \mathrm{~K}$, and the blue curve is the mean temperature taking into account only cold pixels in the area of influence. The vertical discontinuous lines in each graph indicate storm position as shown in figure 2 and red arrows specify important instants in the life of a medicane, such as, the first time the eye is observed or times in which the storm pass over an island or arrive to mainland (compare with previous figure 2). For the dates: DD is the day, MM is the month and HH the hour.

On the graphs b) and c) enclosed in figure 3 it is significant the correlation between medicane's mean brightness temperature minima (or storm intensity maxima) shown by the red curve and the first time that the storm eye is observed (first red arrow on the left). On the other hand, secondary minima are nearly coincident with the moments in which the storms are passing over Sardinia, as shown by point 8 in graph a) and point 10 in graph b) and when the medicane is moving very close to the African coast, point 11 in graph c). However storm mean temperatures are falling when they reach mainland in two of the cases, a) and c), while it is high and constant for the case b).

## 2. Precipitation Estimation

The technique applied was the Probability Matching Method (PMM) as documented by Turk et al (2000) and Kidd et al (2003). Rain rate images over the Mediterranean Sea are provided by Remote Sensing System (http://www.ssmi.com/) for the three cases under study. These precipitation images are obtained from passive microwave measurements produced by SSM/I and AMRS sensors on board polar orbit platforms. These are combined with coincident and simultaneous Meteosat infrared images ( $11.5 \mu \mathrm{~m}$ band) in units of brightness temperature in Kelvin to delineate precipitation areas and to develop rainfall curves by applying the PMM.
Following the same procedure that was applied for the medicane`s intensities we have estimated the mean rain rate and the number of precipitation points in the areas of influence of each storm along its life cycles (figure 4). Unfortunately at the time of writing this report it was not possible to us to show results concerning to precipitation of the third studied medicane (051215). On the other hand mean rain rates show a very variable behaviour for occasions with relatively low number of rain points. So that in order to improve the view of the graphs, the mean rain rates (red line) supported by less than 50 rainy points have been removed.


Figure 4: Evolution of the mean rain rate in $\mathrm{mm} / \mathrm{h}$ by taking into account zeros (green curve) and without (red curve) and number of precipitation points in the area of influence (blue curve). Precipitation of only two of the three cases is shown. (a) corresponds to case 960912 and (b) to 031018.

In the two graphs shown in figure 4 it can be observed how the number of precipitation points (blue line) reaches a maximum close to the time in which the storm eye is observed for the first time (first red arrow on the left) and few hours later it droops very fast. It is also clear the increment of the number of rainy points when the medicane is passing over Sardinia in the two cases (point 8 in graph a) and point 10 in b)), probably caused by orographic effects. However precipitation results are very different for both medicanes at the moment they reach Italy mainland (compare points 10 and 13 in graphs a) and b) respectively).

## 3. Wind Estimation

Two consecutive infrared images can provide useful information about low level clouds movement over a thermaly homogeneous sea surface. The basic points of the cross-correlation wind estimator algorithm developed for this study are:

- Low level cloud pixels are selected using an infrared temperature threshold between 240 K and 280 K.
- A grid area of $27 \times 27$ pixels centred in each cloud point that satisfies the previous condition is defined. This size produced to us the best results with the lower computational cost.
- In the previous satellite image the neighbour $27 \times 27$ grid area that provides the maximum correlation coefficient is selected.
- Only targets with a correlation coefficient greater than 0.7 are used.
- Distances and speeds are computed from the two grids central points.

Once wind vectors are well aligned, and wind speeds show reasonable values for low tropospheric layers compared qualitatively with Quitscat images (not shown), the algorithm is applied to the three medicanes. The evolution of the mean wind speed within the number of wind points provided by the algorithm in the cloud area of influence along the storm life cycle are calculated and plotted in figure 5.


Figure 5: Evolution of mean wind speed in $\mathrm{m} / \mathrm{s}$ (red line) and number of wind speed points (blue line) provided by the wind algorithm in the area of influence for each of the three medicanes: (a) 960912, (b) 031018 and (c) 051215.

The most important feature observed in this figure 5 is that the mean wind (red line) has a general tendency to increase after the eye of the storm appears (first red arrow on the left). Nevertheless in the case b) the mean wind drops after the medicane pass over Sardinia (see red line after point 10), and in the case c) the mean wind tendency is not clear between the points 12 and 15.

## CONCLUSIONS

The results from the dynamic analysis of the three tropical-like mediterranean storms studied in this work together with the intensity, rain and wind estimations, can give an idea about the general evolution of these storms. In summary, three stages in the life of a medicane are observed:

- Pre-eye: The storm region before the eye formation is occupied by heavy convective clouds.
- For the cases 960912 and 051215, it was observed strong convection and heavy rainfalls but no clear vortex.
- For the case 031018 a clear small vortex was detected travelling initially in the southern side of the convective system. After, it evolved within the whole system over Mallorca Island approximately.
- Stationary phase: An eye is observed for the first time surrounded by an axisymmetric cloud structure. The whole system is travelling slowly and it has a clear cyclonic rotation. In this phase heavy rainfalls (max $17 \mathrm{~mm} / \mathrm{h}$ ), and winds (mean $12 \mathrm{~m} / \mathrm{s}$ ) are measured from satellite.
- Itinerant phase: The medicane is moving fast in a clear direction, not much rainfall is produced in this phase but strong wind speeds are estimated (mean $18 \mathrm{~m} / \mathrm{s}$ ).

Other important observations are that:

- The number of precipitation points is reduced significantly when the medicane evolves to its itinerant phase.
- Convection and rainfall are increased in general when the medicane pass over an island or when it arrives to mainland.
- Wind speed seems to increase gradually during the itinerant phase.


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