Tethys
Journal of Mediterranean Meteorology & Climatology

Tethys 2011, **8**, 53–61
www.tethys.cat
ISSN-1697-1523
eISSN-1139-3394
DOI:10.3369/tethys.2011.8.06
Journal edited by **ACAM**

Medicanes: cataloguing criteria and exploration of meteorological environments

M. Tous and R. Romero

Meteorology Group, Physics Department, Universitat de les Illes Balears, Cra. de Valldemossa, km. 7,5, 07122 Palma

Received: 15-XI-2010 – Accepted: 1-VI-2011 – **Translated version**

Correspondence to: maria.tous@uib.es

Abstract

Depressions with a similar structure to tropical cyclones, that can reach the intensity of hurricanes, are occasionally generated in the Mediterranean. Such phenomena are called "medicanes". Although the geographical dimensions of tropical oceans and the Mediterranean Sea are clearly different, the precursor mechanisms of these perturbations, based on the air-sea thermodynamic imbalance, are similar. This fact made us think about the existence of a physical parallelism between both phenomena. We tried to identify such cases from historical images of the Meteosat satellite, for the period 1982-2005. Different lists have been created, each of them increasingly delimiting the selection criteria based on the cyclone structure in the infrared channel. Some of these criteria are, for instance, the size of the cyclone, the clear existence of an eye and the lifetime of the system. This identification has been made in a subjective way. In total, twelve cases of medicanes were identified. The characterization of meteorological environments that are a precursor to medicanes can help us understand the genesis mechanisms and to improve forecasts. This study compares the values of several meteorological variables of interest in the cases of medicanes with those of cyclones catalogued in the database of the MEDEX project to try to identify the environments that favor the genesis and development of medicanes instead of other Mediterranean cyclones. In this sense, the sea surface temperature, the diabatic contribution to the local trend of surface equivalent potential temperature and an empirical index derived from the genesis of tropical cyclones are presented as possible discriminatory parameters.

Key words: medicanes, tropical cyclones, Mediterranean Sea, meteorological environments

1 Introduction

Medicanes, or Mediterranean tropical-like cyclones, as they are also known, are warm-core cyclones developed over the Mediterranean Sea (Ernest and Matson, 1983; Reale and Atlas, 2001; Jansà, 2003) with characteristics similar to tropical cyclones. Like hurricanes, medicanes cause sudden pressure and wind changes in the affected areas, but they normally do not reach the same intensities. In both cases, the satellite images show a central eye around which there is a dense cloud mass distributed in axial symmetry. The physical basis of these cyclones is sustained on the thermodynamic imbalance between the sea and the atmosphere. The synoptic analysis of the cases studied show the precursor role of a deep, cold and isolated depression, set in the middle and high levels of the troposphere. The fact that there are few cases of medicanes identified suggests that very special meteorological conditions are needed for its formation, when compared to ordinary cyclonic depressions.

Due to the small size of medicanes and the marine characteristics of the processes involved in the development and intensification of these perturbations, they are difficult if not impossible to detect in the climatology of the MEDEX project (Mediterranean Experiment on Cyclones that produce high impact weather in the Mediterranean, http://medex.aemet.uib.es/). This would only be possible with analysis fields on grids of high resolution and a very high density of observations over the Med-

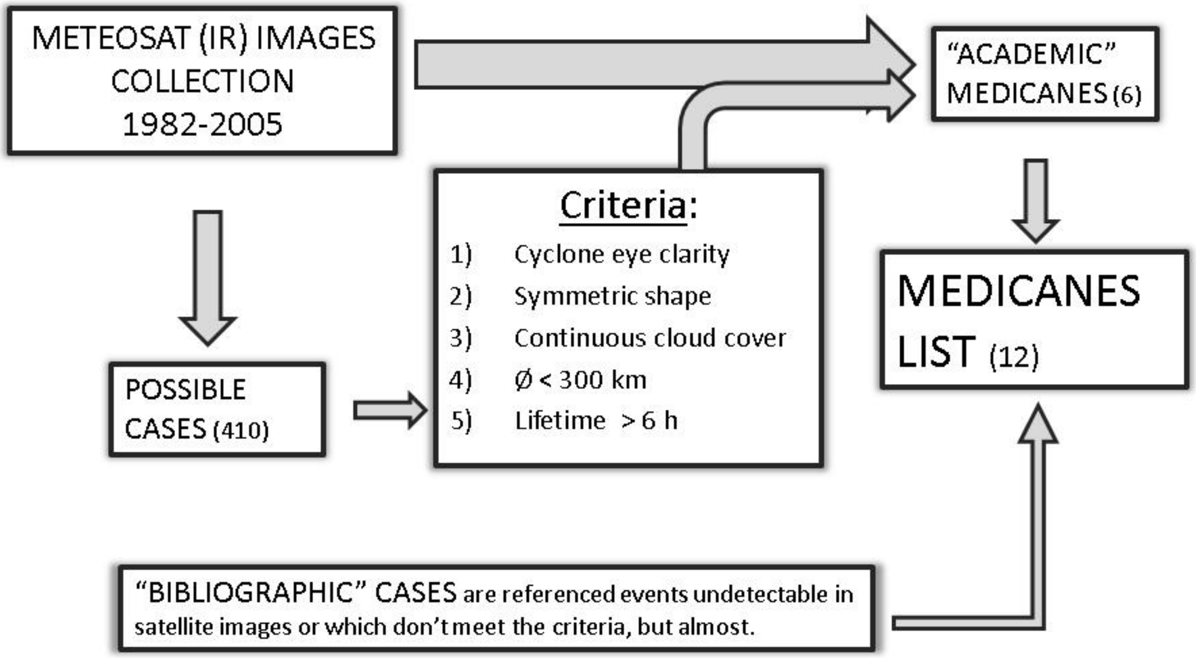

Figure 1. Diagram of the creation procedure of a medicanes database through IR images of the Meteosat satellite during the period 1982-2005.

iterranean Sea. Therefore, it is now impossible in practice.

This study aims to achieve a basis from which it can be possible to characterize the meteorological environments that are favorable to the development and maintenance of the medicanes through dynamically oriented climatologies. For this purpose we build a database of cases from satellite images.

This article explains the procedure for creating the medicanes database from which we will proceed. Further on, it shows the description of the meteorological parameters that will be taken into account, and finally presents the most significant results of this study, identifying the meteorological variables that better distinguish cases of medicanes from the rest of Mediterranean cyclones.

Table 1. Date of a mature phase of the medicanes detected. In bold, cases that fulfill all the criteria established.

Dates
1983-09-28
1984-04-07
1984-12-29
1985-12-14
1991-12-05
1995-01-15
1996-09-12
1996-10-07
1999-12-10
1998-01-26
1999-03-19
2003-05-27

2 Medicane classification criteria

Preliminary studies have determined that the size (diameter) of a medicane is usually less than 300 km (equivalent to 3 grid points of the ERA-40, which is the analysis source used in this study). This fact does not allow reaching the minimum necessary threshold to implement the MEDEX procedure (Picornell et al., 2001) or any other objective cyclone detection procedure appropriate to the characteristics needed.

The display of the images provided by Meteosat satellite is presented as the best possible alternative to detect medicanes. The limits of the study period were set between February 1982 and December 2005. After evaluating the volume of images to look at, focusing on IR images was considered sufficient to create the initial database, due to its temporal continuity and easy interpretation.

The display of all satellite images of medicanes was carried out by the assembly of monthly films (where each frame is an IR image, ie, every 30 minutes) focused on the Mediterranean. Structures similar to those of tropical cyclones (with a clear eye surrounded by a wall of clouds with nearly axial symmetry (Mayengon, 1984) have been searched, paying special attention to not confuse them with small baroclinic or topographic cyclones.

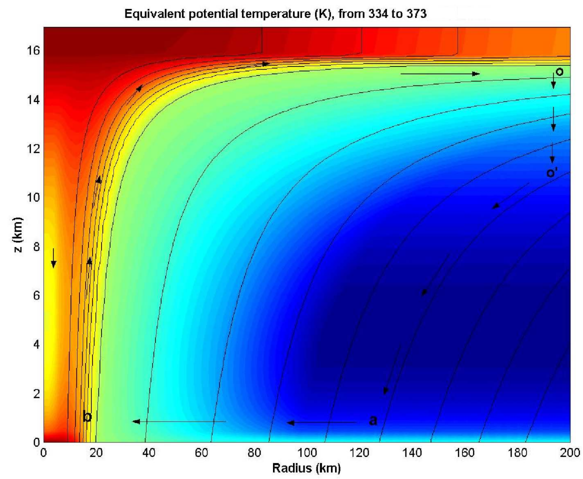

Figure 2. Vertical section of a tropical cyclone, showing the equivalent potential temperature field (shaded, increasing in value inwards) and of specific absolute angular momentum around the cyclone axis (lines, increasing outwards) (Romero and Emanuel, 2006).

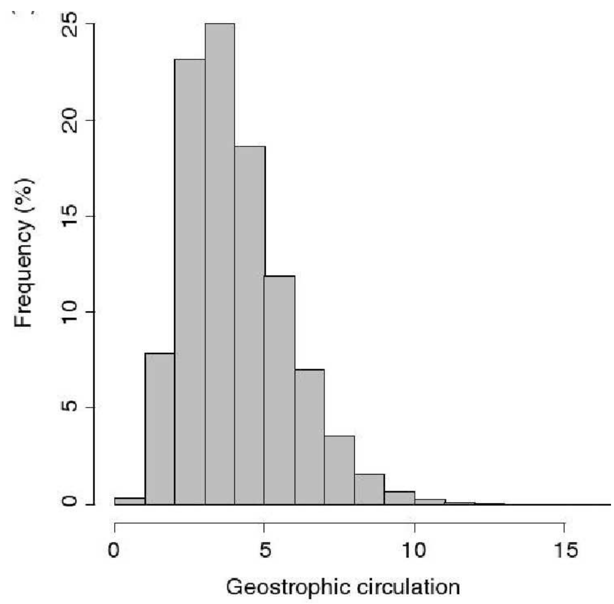

Figure 3. Histogram of geostrophic circulation (in gcu) of MEDEX Mediterranean cyclones from the reanalysis data ERA-40, during the period 1957-2002 (Campins et al., 2010).

After analyzing this information (Figure 1), 410 structures similar to those described above were identified. From these cases, after observing the development also through the same channel, some of them were revealed as baroclinic in nature, which lead us to conclude that it is necessary to impose stricter criteria to identify medicanes by using satellite images.

Considering previous studies that have studied some particular cases of medicanes, it was considered that the criteria which medicanes must meet are: 1) existence of a well-defined eye, 2) symmetry of the cloud mass around the eye; 3) continuity of the cloud mass, 4) diameter less than 300 km, 5) duration exceeding 6 hours. In applying these criteria (Figure 1), 6 cases of medicanes have been identified ("academic medicanes").

Being aware of the major constraints that these criteria involve, and owing to bibliographically documented case studies (eg Homar et al., 2003), it was considered that other situations that do not strictly meet all the criteria (but almost) can also be in the database on which we will work (Figure 1). Thus, the list of identified cases has risen to twelve (Table 1). The duration of these twelve cyclones is between 6 and 72 hours, depending on the case. In situations of longer duration, the cyclone has different states of intensification. In these cases, the date has been determined as the first mature moment.

As it is a small number of medicane cases, later studies will also include the set of cyclones that remained as doubtful, raising the number of cases studied to the 410 named above ("possible cases"), in order to try to spot general trends and behaviors in cases with some similarities with medicanes, but which are not considered exactly as such.

3 Meteorological parameters

Several synoptic analyses performed on known cases of medicanes (eg Pytharoulis et al., 2000; Homar et al., 2003) show how their structures are not detached from the general atmospheric circulation, but based on a large-scale baroclinic disturbance that affects the Mediterranean, and it is only in the mature phase that they are detached to create their own development and life. Generally, medicanes originate in deep cyclone conditions, with cut-off (closed circulation at high levels, extended to the surface) and cold-core (where the interior isotherms are cooler than outside) forming in the middle and upper troposphere, from the "break" of Rossby waves.

When a low is close to the Mediterranean (or is formed above), the air of the lower layers rises, generally through large vertical movements, the air is cooled and its relative humidity rises until reaching saturation and releasing (perhaps massively) condensational latent heat. It therefore becomes a system which could lead to the evolution of a medicane. Assuming that the vertical wind shear is not great either, and the local potential intensity (representing the maximum surface wind speed that it can reach) increases, the sea-atmosphere thermodynamic imbalance is intensified. This humid air may inhibit the formation of descending convective fluxes, which are one of the factors that prevent tropical cyclogenesis. Numerical experiments carried out by Emanuel (2005), using a non-hydrostatic model, show that these deep cut-off lows are the perfect setting for incubating warm-core cyclones on a small scale, such as medicanes.

Despite these arguments, the existence of these cold and deep lows over the Mediterranean is more frequent than real

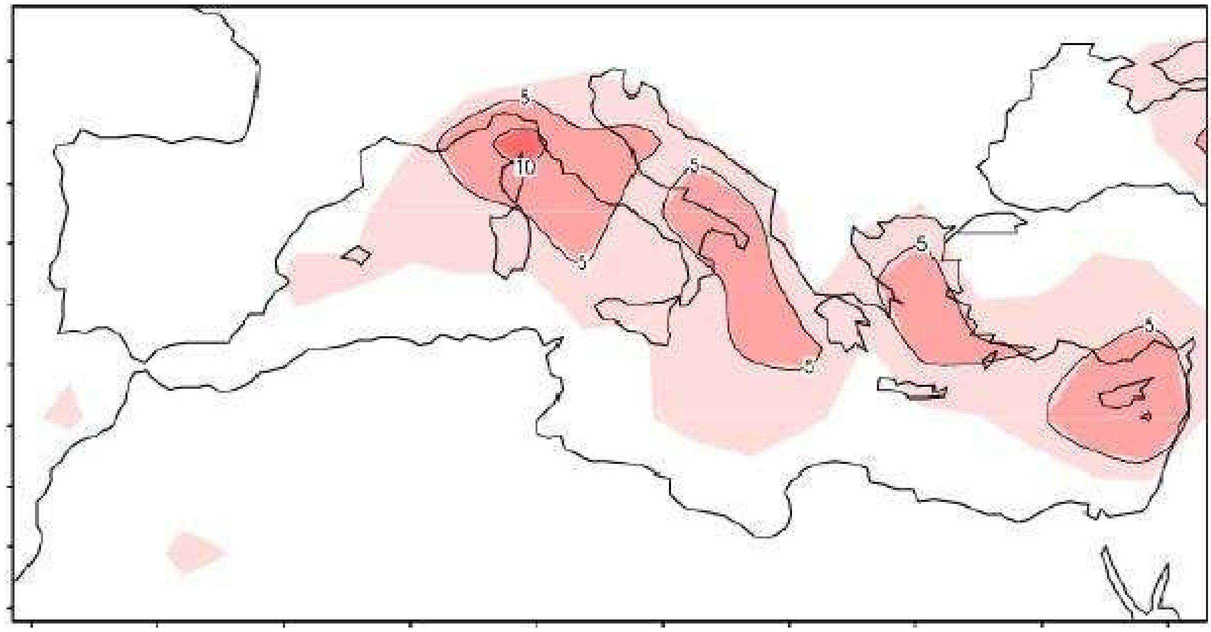

Figure 4. Seasonal frequency (winter) of cyclonic centers. The contours correspond to 2.5 (shaded), 5, 10, 20 cyclones in winter for an area of $2.25 \times 2.25°$ (Tous et al., 2009).

cases of medicanes. For this reason, it is presumable that some very special meteorological conditions are needed for medicanes to be developed. These conditions are not yet fully known and are difficult to determine because of the few case studies available. Therefore, this paper proposes a set of meteorological variables that, compared with the climatologies of the Mediterranean cyclones of the MEDEX project, will attempt to distinguish precursor and non-precursor factors of large-scale cyclones associated with medicanes.

There are a number of large-scale meteorological parameters that we know are related to the genesis and development of tropical cyclones, and by extension we also suppose that they are related to medicanes. Thus, the existence of vorticity at low levels, high levels of humidity in middle tropospheric levels or small vertical shear in winds throughout the troposphere, are factors that favor the formation of medicanes; in addition the existence of a thermal imbalance between the sea and the atmosphere is essential (Emanuel, 2003).

Therefore, the meteorological parameters on which we will focus are:

- AVOR850: absolute vorticity at 850 hPa level (in 10^{-5} s^{-1}).
- RH600: relative humidity at 600 hPa level (in %).
- VSHEAR8525: module of wind difference between the levels of 850 and 250 hPa (in m s^{-1}).
- SST: sea surface temperature (in °C).
- DIAB1000: diabatic contribution to the local trend of surface equivalent potential temperature (in °C 12 h^{-1}).

The value of these parameters has been averaged in a square of 600×600 km^2 centered at the cyclonic center detected in satellite images. It is worth to note that the position of the cyclonic center has been assigned to the nearest ERA-40 reanalysis grid point.

Because of the temporal discretization of the fields from which we can calculate the value of the different parameters (reanalysis of the ERA-40, every 6 hours), the DIAB1000 that we can approximate is given by:

$$DIAB1000 = \left[\frac{\theta_e(t+6h) - \theta_e(t-6h)}{12h} - Adv\theta_e(t) \right] 12h \quad (1)$$

where the advection term, $Adv\theta_e(t)$, is formulated using finite differences centered at time t, and the factor on the right (multiplication by 12 h) intends to rescale at °C 12 h^{-1}.

Moreover, an additional parameter has also been sought, related to the parameters previously explained, in order to characterize the probability of medicane genesis. The theory of air-sea interaction that explains the mechanics and energy of tropical cyclones (Emanuel, 2003), which in our case is assimilated to medicanes, shows that the stationary state of these depressions can be idealized as a Carnot engine. With this similarity, the energy cycle of a mature tropical cyclone follows a process of isothermal expansion (with addition of enthalpy), adiabatic expansion, isothermal compression and adiabatic compression.

Taking Figure 2 as reference, the air of the tropical cyclone begins to move along a spiral path from the outside (point a in Figure 2) towards the center of the depression. Then it experiences a decrease in pressure and its entropy increases obeying the transfer of enthalpy from the sea surface (mostly in the form of evaporation) and the dissipation of kinetic energy in the planetary boundary layer. At the same time, its angular momentum decreases due to friction with

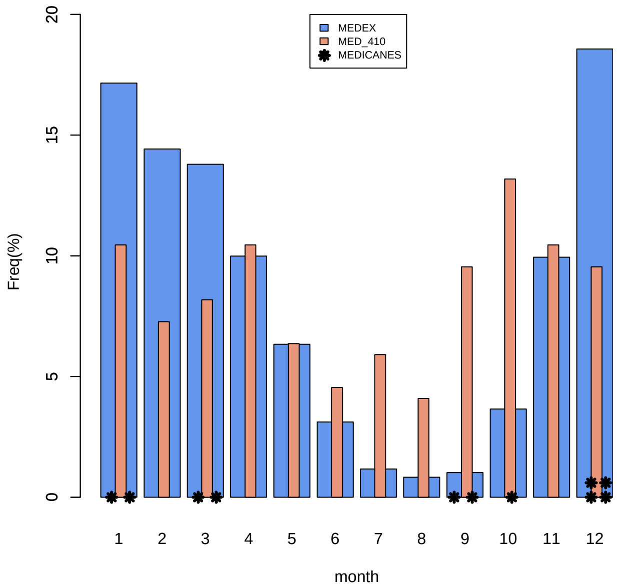

Figure 5. Temporal distribution of cyclones: intense MEDEX cyclones (blue), dubious list of medicanes (orange), medicanes (stars).

the sea surface. The temperature in this section $a-b$ remains almost unchanged. On the walls of the eye of the hurricane (point b), the flow turns upward approximately along surfaces of constant entropy and angular momentum, while the pressure obviously decreases. This stretch is approximately adiabatic and free of friction. Later, on the periphery of the system, the air turns downward (stretch $o-o'$) and the entropy gained in the initial convergent stretch is lost to the space by thermal radiation, while it acquires angular momentum by mixing with the environment. This stretch is largely isothermal. Finally, the circuit is closed between the points o' and a, keeping the angular momentum and without much entropy available for the production of kinetic energy.

The difference between the theoretical engine and tropical cyclones is that in the latter case, heat absorption occurs mainly in the form of latent heat of vaporization, acquired from the surface of the sea by converging air currents. The other key difference is that the energy available in the traditional Carnot cycle is used to perform work on its environment, while in tropical cyclones the work is consumed in turbulent dissipation at the boundary layer.

Given these facts, we can obtain, from atmospheric conditions and temperature of the sea, the value of the maximum intensity that can be reached by the surface wind of a tropical cyclone (V_{max}) if it is formed:

$$|V_{max}^2| \approx \frac{C_k}{C_D}\frac{T_S-T_0}{T_0}(k_0^\star - k) \qquad (2)$$

where C_k and C_D are dimensionless coefficients of momentum and enthalpy transfer between the sea and the air that appear in the traditional formulation of the surface turbulent fluxes, T_S is the temperature of the sea surface (hot source in the Carnot cycle), T_0 is the average temperature of the upper area of the cyclone (cold source of the Carnot cycle), k is the specific humid enthalpy of the air near the surface, and $k_0^\star$ is the value of the enthalpy for the air in contact with the sea, which is considered saturated with water vapor at the temperature of the sea.

Based on this theory, we will add to the list of parameters another variable:

- MAXWS (= V_{max}): potential intensity or theoretical maximum speed that can be reached by a mature medicane if it is developed, according to the Air-Sea Interaction Theory that assimilates the operation of a tropical cyclone as a Carnot cycle (in m s^{-1}).

This value is also averaged in a square of 600×600 km^2 centered in the cyclonic center detected.

Although there is still a lack of theoretical knowledge regarding the genesis of tropical cyclones, Emanuel has formulated an empirical index of genesis (I) adjusted to the genesis episodes that have been routinely observed for decades over the tropical oceans, which combines factors that regulate this process and have already been mentioned. This index (I, with units of number of cyclones per decade and by area of $2.5 \times 2.5°$) is given by:

$$I = |10^5\eta|^{3/2}\left(\frac{H}{50}\right)^3\left(\frac{V_{max}}{70}\right)^3(1+0.1V_{shear})^{-2} \qquad (3)$$

calculated in SI units, where η is the absolute vorticity in the lower troposphere (AVOR850), H is relative humidity (in %) in the middle troposphere (RH600), V_{max} is calculated in Equation 2 (MAXWS), and V_{shear} is the module of the difference of winds at 850 and 250 hPa (VSHEAR8525). From the definition, we can see that η, H and V_{max} are ingredients that favor genesis, while higher values of vertical shear V_{shear} act as inhibitors. Adjustment of the index was carried out through the study of a large number of tropical cyclones over the Atlantic and Pacific. This index, which can satisfactorily describe the probability of hurricane genesis observed (high values of this index represent high probability of hurricane genesis), will also be used in our study of medicanes.

From this index we calculated:

- GENPDF: averaged value of the index I within a square of 600×600 km^2 centered on the studied cyclone.
- GENPDFmax: maximum value of the index I within a square of the same features described above.
- GENPDFmax24h: maximum value of GENPDFmax in the prior 24 hours.

In short, the large-scale weather variables that we calculated for each case of medicane are: AVOR850, RH600, DIAB1000, VSHEAR8525, SST, MAXWS, GENPDF, GENPDFmax and GENPDFmax24h. The results shown below are the most significant from the SST, DIAB1000 and GENPDFmax (which include by definition the parameters AVOR850, RH600, MAXWS and VSHEAR8525).

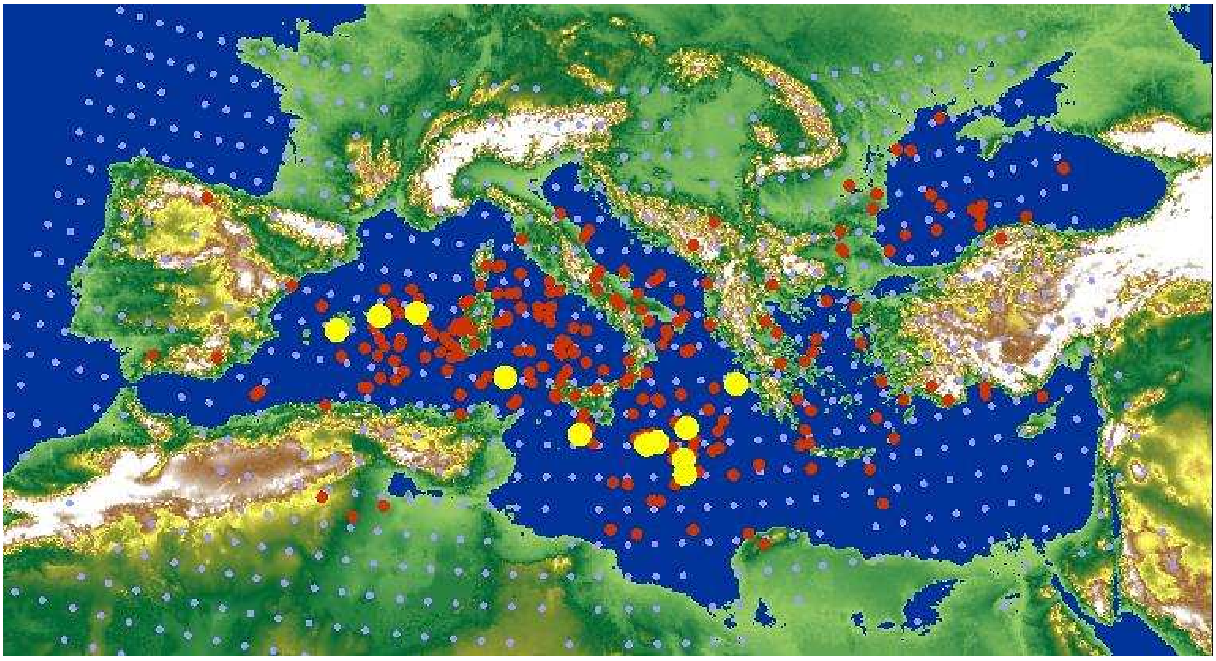

Figure 6. Spatial distribution of cyclones: intense MEDEX cyclones (blue), dubious list of medicanes (red), medicanes (yellow).

4 Results

In this study, a comparison of meteorological environments was made between intense cyclones typical of the Mediterranean and medicanes. As this comparison was made with the results of the database of the MEDEX project (which works on reanalysis fields of the ERA-40, operating from 1957 until August 2002), the data of the meteorological environments of the cases of medicanes will also be based on these reanalysis fields. For this reason, only medicanes in this period will be taken into account.

Moreover, from the large number of cyclones that occur in the Mediterranean, we pay particular attention to intense cyclones (cyclones with circulation greater than or equal to 7 gcu, where 1 gcu = 10^7 m^2 s^{-1}) because it is known that medicanes have high values of vorticity. Annually, an average of 47 intense cyclones are generated in the Mediterranean, representing 6.2% of all cyclones generated in the Mediterranean (Figure 3). These cyclones occur mainly during the winter, and are located in four cyclogenetic cores: Gulf of Genoa, Ionian Sea, Aegean Sea and Sea of Crete (Figure 4).

Paying attention to Figure 5 we can see how medicanes are more frequent in cold seasons (autumn and winter), just like the rest of intense cyclones in the Mediterranean. This distribution represents a change from tropical cyclones, characterized by a short season during a few months of the year (for example, in the Atlantic basin lasts between June and November).

In Figure 6 we can see the occurrence of at least one intense MEDEX cyclone on almost every grid point of the ERA-40 reanalysis (blue dots). If instead of these intense cyclones the cases located are the ones on the list of "possible medicanes" (410, red dots), we observe that in a mature state most cases are located in the central and western Mediterranean. The yellow dots correspond to the time of the mature state of the 11 medicanes detected (11 of 12 medicanes identified, as one of them does not belong to the period of the ERA-40 that runs until August 2002) and they are clearly located on the western and central Mediterranean.

It must be highlighted that despite that the more intense MEDEX cyclogenetic center is located in the Gulf of Genoa (Figure 6), no medicane is detected near this area; instead, they are located to the south and southeast of Italy (Ionian Sea) or on the western Mediterranean (Balearic Sea). It is also striking that no case has been detected in the vicinity of Cyprus, although it is considered one of the most active areas for cyclogenesis.

Following the trajectory of the center of the medicane throughout its lifespan, since we are able to predict the first traces until the trail disappears completely, we calculate the value of the selected meteorological parameters and indices.

In Figures 7, 8 and 9 we can see how typical values of medicanes are above the average of cases of severe MEDEX cyclones, and even practically in all cases, above the third quartile. Also, as expected, we have also observed how higher values of the SST correspond to the three fall medicanes. During this season, water has not had time to cold enough, and that is why the temperatures are around 20°C. The opposite case is the spring medicane (1999/03), which shows the lowest SST values, meaning that the sea has not received enough sunlight to heat it.

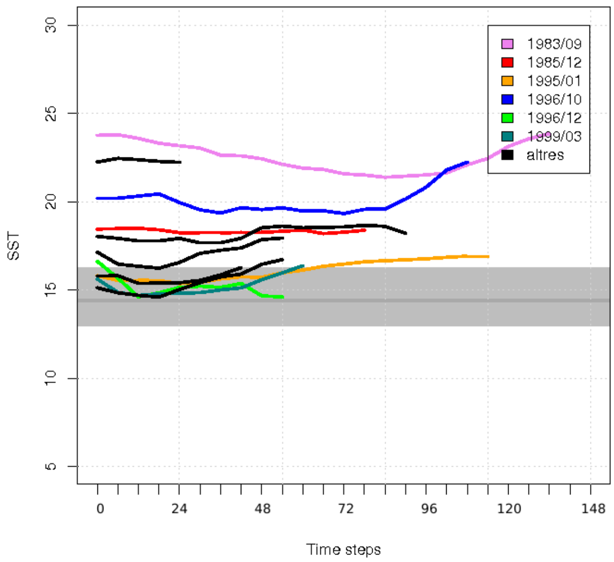

Figure 7. SST values (in °C) in the center of the cyclone, during its lifespan (time step = 6 h), of the six cases that fulfill all requisites to be considered medicanes (color) and the other cases (black) in the database. The dark grey line represents the mean value of the intense MEDEX cyclones distribution and the shaded area, the interquartile.

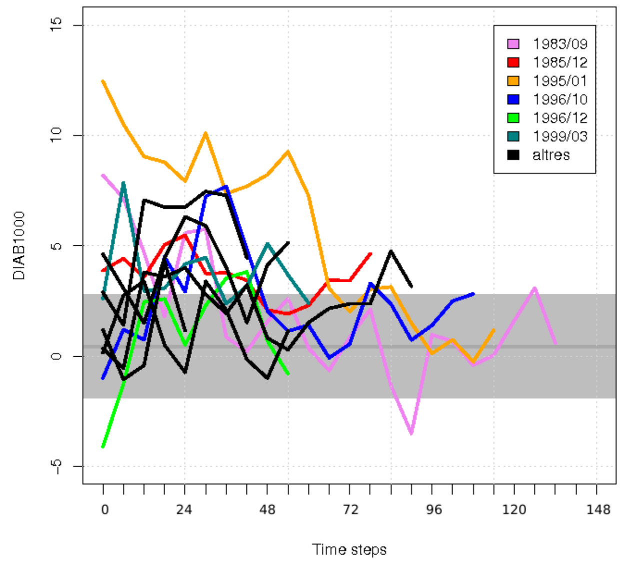

Figure 8. DIAB1000 values (°C 12 h^{-1}) in the center of the cyclone, during its lifespan (time step = 6 h), of the six cases that fulfill all requisites to be considered medicanes (color) and the other cases (black) in the database. The dark grey line represents the mean value of the intense MEDEX cyclones distribution and the shaded area, the interquartile.

In winter medicanes we can observe how the SST is higher than 15°C, especially in the initial moments. In winter, 15°C is the upper bound of the SST typical of the Mediterranean.

For DIAB100, we observe that the maximum values are around 7°C 12 h^{-1}. In fact, the lowest maximum is at 5°C 12 h^{-1}, a much higher value than the rest of intense Mediterranean cyclones. But the most striking case is that of 1995/01, with values exceeding 12°C 12 h^{-1}, with three differentiated peaks up to values of 10°C 12 h^{-1}. This case is one of the most studied and referenced regarding studies of tropical-like cyclones in the Mediterranean (eg Pytharoulis et al., 2000; Emanuel, 2005; etc.). This diabatic contribution due to latent and sensible heat transfer between sea and air is the trigger for hurricanes, in this case for medicanes, and the higher is the temperature difference between the two environments, the larger is this contribution.

Also the index GENPDFmax shows an unusual behavior for cases of medicanes. Except for the case 1983/09, within the first four time steps there is a sharp rise and fall in the value of this index. If the cyclone lasts long enough, there is a succession of peaks. This sequence represents the feedback that the medicane has had to stay alive.

The case 1983/09 presents a slightly different behavior, as it starts with a decline in the value of GENPDFmax and the characteristic peak is not found until about the tenth time step. This is because this parameter was calculated from the moment when, according to satellite images, we can predict the location of what will become the eye of the medicane. In this specific case, the formation of the medicane is the revitalization of a disturbance coming from the disappearance of a baroclinic cyclone; that is to say, a baroclinic cyclone was created, and when it seems about to disappear, it is revitalized as a medicane. Therefore the values from the first time steps still correspond to the phase of a baroclinic cyclone, while approximately from the tenth step they refer to the medicane.

Another aspect that stands out is that the maximum values of this index are reached by the medicane of September 1996 (Figure 9, black) and the 1996/10 medicane. Until now, these cyclones have passed unnoticed, with typical values of medicanes, while here they show a remarkable performance. In the case of the 1996/10 one, each of the peaks that are represented as an increase of the GENPDFmax corresponds to a moment of intensification of the medicane.

In general, the parameters AVOR850, VSHEAR8525, MAXWS (not shown in this article), SST, DIAB1000, and the various applications of GENPDF, show distinctive behaviors in the cases of medicanes during their time of evolution.

After observing the meteorological parameters that have been considered in this study (as they are, a priori, important elements in the genesis and development of tropical cyclones and, by extension, medicanes), no parameter has been found that shows sufficiently clear signatures as to be able to consider it a fully distinguishing factor against the rest of intense Mediterranean cyclones. Currently, the DIAB1000 and the GENPDF empirical index (and its variants) are the ones that show the greatest differences between each other. In eight of the eleven cases studied in this work, the GENPDF index is

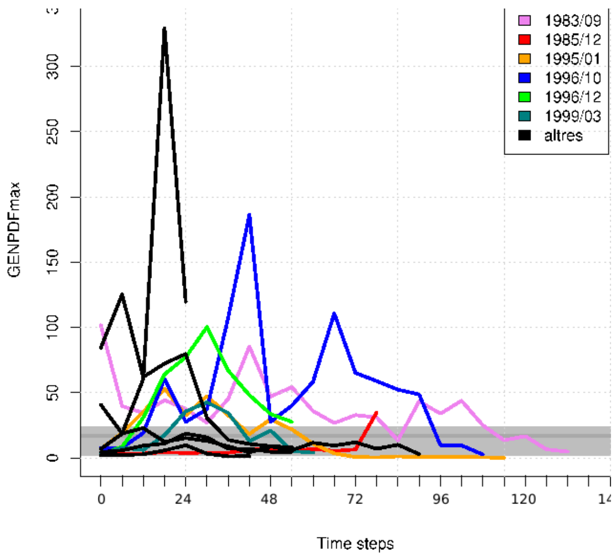

Figure 9. GENPDFmax values in the center of the cyclone, during its lifespan (time step = 6 h), of the six cases that fulfill all requisites to be considered medicanes (color) and the other cases (black) in the database. The dark grey line represents the mean value of the intense MEDEX cyclones distribution and the shaded area, the interquartile.

much higher than normal values. So it could be said that if we obtain a high value of this index in a particular meteorological environment, there is a possibility of the genesis of a medicane.

5 Conclusions

Five necessary criteria to be able to classify a Mediterranean cyclone as a medicane have been established based on satellite images. As a result, twelve cases have been found during the study period, from which we have studied which large-scale weather environments encourage its development, by comparing physical values with those associated with MEDEX intense cyclones.

Based on the similarities between medicanes and tropical cyclones and on the knowledge of the latter, some specific variables are preferred among the variety of diagnostic indicators. For example, we know that for a tropical cyclone to be formed, there must be a high relative humidity at mid levels, the presence of high vorticity at low levels, a large temperature difference between sea and air at high levels, and small vertical wind shear between low and high levels. While verifying that these conditions are met by medicanes too, we have also seen certain differences. The most notable one is related to the minimum SST leading to a temperature difference sufficient to create the storm. In the case of hurricanes, the minimum SST from which they can be formed is 26°C (remember that the Atlantic hurricane season is between June and November). For medicanes, much lower SST has been found, up to 15°C (most cases are generated during the autumn and winter).

We have been able to verify the unusual behavior of some meteorological variables, such as DIAB1000 and GENPDF during the hours preceding the appearance of a medicane: about a day and a half before in the case of DIAB1000, and half a day before for GENPDF. In addition, if the medicane has a long duration, it is possible to see how both the heat transfer between the sea and air (DIAB1000) and the value of the GENPDF index increase during the lifespan of the medicane, indicating the continuity of the processes needed to sustain it and to avoid its disappearance before it reaches the coast.

The GENPDF index, developed through comparing the mechanism of maintenance of tropical cyclones with the Carnot cycle and studying the behavior of several tropical cyclones, also shares meaning in the case of medicanes: high values of the index indicate a higher probability of medicane genesis.

Acknowledgements. We would like to acknowledge the Ministry of Education and Science for the predoctoral grant BES-student 2009-022616 associated to the research project MEDICANES (CGL2008-01271), through which this research line can be carried out. At the same time we would also like to acknowledge the EUMETSAT for providing the satellite images.

References

Campins, J., Genovés, A., Picornell, M., and Jansà, A., 2010: *Climatology of Mediterranean cyclones using the ERA-40 dataset*, Int J Climatol, **31**, doi: 10.1002/joc.2183.

Emanuel, K., 2003: *Tropical cyclones*, Annu Rev Earth Planet Sci, **31**, 75–104.

Emanuel, K., 2005: *Genesis and maintenance of Mediterranean hurricanes*, Adv Geosci, **2**, 217–220.

Ernest, J. and Matson, M., 1983: *A Mediterranean tropical storm?*, Weather, **38**, 332–337.

Homar, V., Romero, R., Stensrud, D., Ramis, C., and Alonso, S., 2003: *Numerical Diagnosis of a Small, Quasi-Tropical Cyclone over the Western Mediterranean: Dynamical vs. boundary factors*, Q J R Meteorol Soc, **129**, 1469–1490.

Jansà, A., 2003: Miniciclons a la Mediterrània, IX Jornades de Meteorologia Eduard Fontserè, Associació Catalana de Meteorologia (ACAM), Barcelona, ISBN: 84-930328-6-7, 75-85.

Mayengon, R., 1984: *Warm core cyclones in the Mediterranean*, Mariners Weather Log, **28**, 6–9.

Picornell, M., Jansà, A., Genovés, A., and Campins, J., 2001: *Automated database of mesocyclones from the Hirlam(INM)-0.5 analyses in the western mediterranean*, Int J Climatol, **21**, 335–354.

Pytharoulis, I., Craig, G., and Ballard, S., 2000: *The hurricane-like Mediterranean cyclone of January 1995*, Meteorol Appl, **7**, 261–279.

Reale, O. and Atlas, R., 2001: *Tropical cyclone-like vortices in the extratropics: observational evidence and synoptic analysis*, Weather Forecast, **16**, 7–34.

Romero, R. and Emanuel, K., 2006: Space-time probability density of Mediterranean hurricane genesis in the light of an empirical tropical index, 5^a Assambleia Luso-Espanhola de Geodesia e Geofisica, Sevilla, CD-Rom, Ministerio Medio Ambiente, ISBN: 84-8320-373-1.

Tous, M., Genovés, A., Campins, J., Picornell, M., Jansà, A., and Mizuta, R., 2009: Mediterranean Cyclones in a changing climate. Results from JMA-GSM model, 11th Plinius Conference on Mediterranean Storms, Barcelona, final Book programme, 11, p. 102.