A long-term climatology of medicanes

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Abstract

Medicanes, intense and destructive mesoscale cyclones exhibiting several similarities with tropical hurricanes, are known to struck occasionally the Mediterranean Sea. Thanks to a high-resolution dynamical downscaling effort, we are able to study for the first time the long-term climatology of those rare storms in a systematic way. The distribution of medicanes frequency in space and time is discussed, and the environmental factors responsible for their formation are investigated. We find that medicanes develop in those areas of the Mediterranean region where intrusions of cold air in the upper troposphere can produce configurations of thermodynamical disequilibrium of the atmosphere similar to those associated with the formation of tropical cyclones.

1 Introduction

Among the large quantity of cyclones developing over the Mediterranean Sea, reports of a number of small but exceptionally severe storms, feared by sailors for the harm produced to ships and causing damages on coastal areas, date back to ancient times. In the last centuries, after European sailors started to navigate the Atlantic Ocean, those storms have been compared to hurricanes, due to the strength of the associated winds. However it is only in the last decades of 20th century, after the advent of satellite imagery in the 80's, that the evidence of this peculiar kind of storms started to emerge in a modern meteorological sense. Due to their resemblance with hurricanes, those mesoscale Mediterranean storms in recent years have been referred to as "medicanes" (from *Medi*terranean hurri*canes*). Severe damage on coastal areas due to extreme weather, such as strong winds and flooding, associated with medicanes has been reported.

Several case-based studies have investigated the main features of medicanes, including observational evidence (Ernst and Matson, 1983; Rasmussen and Zick, 1987; Lagouvardos et al., 1999; Pytharoulis et al., 2000; Reale and Atlas, 2001; Moscatello et al., 2008a; Luque et al., 2007), modeling aspects (Fita et al., 2007; Homar et al., 2003; Moscatello et al., 2008b; Davolio et al., 2009; Miglietta et al., 2011; Tous et al., 2012) and theoretical mechanisms (Emanuel, 2005). The picture emerging from the aforementioned studies is that of low pressure systems that, even if often originally of baroclinic nature, whenever they meet specific environmental conditions, can enter a new stage of development driven by convection and air-sea interaction rather than baroclinic instability assuming features similar to those of of tropical vortices, such as an almost perfect vertical symmetry, a spirally shaped cloud cover with an aye in the middle corresponding to a windless air column above the center of the storm, and a warm core visible in the positive anomalies in the temperature field. In many cases synoptic analysis shows the present of a cold cut-off low in the upper atmospheric layers associate with the formation of the medicane. It has been shown by Emanuel (2005) that such a configuration can enhance the maximum potential intensity to the values typical of hurricanes even when the sea surface temperature is as low as 15 $^\circ$ C. A recent work (Miglietta et al., 2013), analyzing a larger sample of events with a combined analysis of model and satellite data, provided further evidence of the dynamical analogies between medicanes and tropical hurricanes.

The attempts to give a systematic assessment of the frequency and statistical properties of medicanes, on the other hand, have faced so far a number of difficulties. Medicanes are considered rare phenomena, due to the small number of observations. Apart from the medicanes studied in the literature, mentioned above, only a few more cases are known. A list of possible medicanes events, detected in satellite images from various sources is maintained on the website `http://www.uib.es/depart/dfs/meteorologia/METEOROLOGIA/MEDICANES`, and amounts to a few tens of events over a 25 years period (1982-2007).

Objective detection in reanalyses datasets, a procedure routinely used for synoptic scale cyclones, is not applicable in the case of medicanes. The spatial scale of medicanes, that can be as low as less than one hundred kilometers, is a challenge even for the most modern reanalysis products (Cavicchia and von Storch, 2012). On the other hand, products with a resolution high enough to resolve the characteristc spatial scale of medicanes, such as operational analyses or high resolution reanalyses, typically are not available in a homogeneous way for time periods long enough to allow a robust assessment of the statistical properties of rare phenomena such as medicanes.

Satellite-based searches of medicanes also met some difficulties. An exhaustive analysis of satellite imagery in the period 1982-2005 has been performed in Tous and Romero (2013). Around four hundred cyclonic events over 20 years have been classified as possible medicane cases. After the application of strict selection conditions related to the symmetry of the cloud shape and the presence of an eye-like structure, however, only 6 events are classified as medicanes. Some of the cases classified as medicanes in the literature from direct observations do not meet strictly the selection criteria.

A recent study (Walsh et al., 2013), based on the analysis of regional model data at 25 km resolution, found sixteen "medicane-like" storms in a 20-years time slice of downscaled ERA40 data. For a number of reasons, however, only one of those events, corresponds to a real-world medicane. Those reasons, as suggested by the authors, include the lack of reinitialization in the model, and the fact that the detection algorithm used has been designed for tropical cyclones and it has been not been adapted to the case of medicanes. Moreover, it has been shown in (Cavicchia and von Storch, 2012), that in order to apply stringent criteria for medicanes detection, a higher resolution is needed.

A further recent work (Romero and Emanuel, 2013) studied the statistical properties of past and future medicanes, exploiting a technique based on the synthetic generation of medicanes. The drawback of this approach is that some *a priori* assumption on the distribution of medicanes is needed, and given the lack of a large enough sample of observations, one has to rely on indirect information obtained from large-scale atmospheric fields.

The aforementioned issues reflect, on one hand, the fact that the Mediterranean region is one of the most active cyclogenetic regions in the world, with a climatological average of a few thousands cyclones per year (e.g Gil et al. 2003). Moreover, it is not easy to draw a clear-cut demarcation line between medicanes and "ordinary" Mediterranean cyclones, since medicanes are often baroclinic disturbances in the first phases of their life, that undergo a transition to tropical-like dynamics whenever a number of favorable environmental factors are present.

In climatological studies on polar lows (Zahn et al., 2008; Zahn and von Storch, 2008; Zahn and von Storch, 2010; Chen et al., 2012) and typhoons (Feser and von Storch, 2008; von Storch et al., 2011), a dynamical downscaling strategy has been been employed, in which large-scale state descriptions provided by re-analysis are dynamically downscaled running an atmospheric limited area model in climate mode, using the concept of spectral nudging (von Storch et al., 2000) in order to obtain large samples of simulated real-world cyclones. In Cavicchia and von Storch (2012) it has been shown that a methodology based on the same downscaling concept, is successful to reproduce with a good accuracy and in a robust way a number of medicanes previously studied in the literature, provided the model configuration and resolution is adapted to the small spatial scale of medicanes. The crucial role of spectral nudging to ensure that the model is able to reproduce real-world cyclones has been highlighted.

The aim of the present study is to apply the downscaling methodology to the six decades of NCEP/NCAR reanalyses data-set, exploiting the added value of high-resolution atmospheric fields and of a detection algorithm designed specifically for medicanes to analyze the climatology of past medicanes in a systematic way. The paper is organized as follows. In Sec. 2 the model configuration and the detection algorithm are described. In Sec. 3 the results on the geographical distribution, seasonal cycle and inter-annual variability of medicanes are presented and discussed. In Sec. 4 the synoptic patterns that explain the statistics of medicanes are analyzed.

2 Methods

2.1 Model configuration

High resolution downscaled field are obtained by the atmospheric limited area model CCLM, the climate version of the COSMO model, originally developed by the German weather service. Boundary and initial conditions are obtained by the NCEP/NCAR reanalyses. This choice is motivated, in spite of the availability of products at higher spatial resolution, by their longer time coverage. The downscaling is obtained in two steps: the model is first run at 25 km resolution on a domain covering the whole mediterranean area; a second simulation is then performed on a domain nested into the previous one, at a resolution of ten kilometers. Only this higher resolution simulation is used for the analysis. The atmospheric fields produced by the model are saved every hour, on nineteen pressure levels. In all the simulations, spectral nudging is applied on the horizontal components of the wind field. The concept of spectra nudging is based on the assumption that the large scale component of the forcing fields give a good description of the state of the atmosphere even when the system is run at higher resolution; the large-scale components of the regional model fields are thus forced to relax towards the reanalyses value, while the small-scale components and the lower vertical levels are let free to evolve freely, following the small scale dynamics and high resolution orography. Spectral nudging has been proved to give added value to the dynamical downscaling approach in several applications (Feser et al., 2011).

A detailed account of the performance of the model in the configuration described above in the simulation of several historical medicane cases has been given in Cavicchia and von Storch (2012).

2.2 Objective detection of medicanes

The systematic study of medicanes requires objective detection criteria, designed specifically to single out the peculiar dynamical and phenomenological features of medicanes. The detection routine is crucial to discriminate the rare storms that are driven by the air-sea interaction from the large amount of baroclinic cyclones that characterize the Mediterranean region.

An objective medicanes detection algorithm has been developed and implemented in the current analysis. The algorithm consists of the following steps:

1. All the sea level pressure minima with pressure gradient greater than ΔP =20 Pa over 3 grid points are registered in the hourly model output
2. A clustering algorithm assigning to the same track the pressure minima within a radius of 100 km at two consecutive hourly output steps is applied. Only the tracks composed of at least 6 points are saved.
3. A number of criteria related to the geometrical and geographical features are imposed, and all the tracks respecting those criteria are kept for further analysis:
    - no more than half of the positions of a given track can correspond to land-covered model grid points;
    - the two most distant positions in the track must be separated by at least 200km;

- a change in the propagation direction at consecutive time-steps greater than $\pi/3$ is allowed for at most half of the point in the track.

4. A medicane is detected when all the following criteria related to the storm dynamics are fulfilled.
    - The symmetry and warm core criteria of the storm are analyzed, The phase space criteria prescribed in Hart (2003) are used ($B <$ 10 m, -$V_T^{L(U)} > 0$ and -$V_T^{L(D)} > 0$); the radius used to calculate the parameters has been modified to $R_{wc} = 100$ km. A cyclone is classified as medicane if it shows vertical symmetry and a warm core for more than 10% of the track or more than 6 hours.
    - A cyclone is classified as a medicane if the wind speed averaged in a circle of radius 50 km around the pressure minimum is higher than V_{av}=18 m/s for more than 10% of the track or more than 6 hours.
    - A cyclone is classified as a medicane if the wind speed (averaged in a circle of radius 50 km around the pressure minimum) at 850 hPa is higher than tthe wind speed at 300 hPa.
    - A cyclone is classified as a medicane if the maximum wind speed in a circle of radius 50 km around the pressure minimum is higher than V_{max}=29 m/s for a time longer than $t_{vmax} = 4$ h.

The threshold parameters used in the algorithm have been validated over a five-years test period (1995-1999), using the data from available databases, and visual inspection of METEOSAT satellite imagery. An extensive analysis of the sensitivity of the algorithm performance on the different threshold values has been carried out. As it can be read from table 1, the sensitivity is rather mild for all parameters, with the exception of the maximum wind speed V_{max}.

Table 1: Number of medicanes detected in a five years period (1995-1999), varying the algorithm parameters as indicated.

R_{wc}= 100 km, t_{vmax}= 6h

V_{av} \ V_{max}	25	26	27	28	29	30
14	21	18	14	10	9	7
15	21	18	14	10	9	7
16	21	18	14	10	9	7
17	21	18	14	10	9	7
18	21	18	14	10	9	7

R_{wc}= 100 km, t_{vmax}= 4h

V_{av} \ V_{max}	25	26	27	28	29	30
14	22	20	16	12	11	8
15	22	20	16	12	11	8
16	22	20	16	12	11	8
17	22	20	16	12	11	8
18	21	20	16	12	11	8

R_{wc}= 150 km, t_{vmax}= 6h

V_{av} \ V_{max}	25	26	27	28	29	30
14	21	18	14	10	9	7
15	21	18	14	10	9	7
16	21	18	14	10	9	7
17	21	18	14	10	9	7
18	21	18	14	10	9	7

R_{wc}= 200 km, t_{vmax}= 6h

V_{av} \ V_{max}	25	26	27	28	29	30
14	21	18	14	10	9	7
15	21	18	14	10	9	7
16	21	18	14	10	9	7
17	21	18	14	10	9	7
18	21	18	14	10	9	7

3 Results: multi-decadal statistics of medicanes

Applying the detection algorithm described in Sect. 2.2 above to the downscaled atmospheric fields for the period 1948-2011, 99 medicanes are detected . The frequency of medicanes is thus extremely low, 1.57 ± 1.30 events per season (a medicane season is defined to last from August of each year through July of the following year), consistently with the empirical understanding of medicanes as rare events. After applying all the selection criteria, only one event over a few thousands is classified as a medicane (Table 2). This extremely high efficiency is consistent with the knowledge of the climatology of baroclinic cyclones in the Mediterranean. The analysis has been repeated changing the value of the parameters V_{max} to 25 m/s and 30 m/s; the total number of detected medicanes changes respectively to 202 and 70 events per year, but the long-term statistical properties described below, such as geographical pattern and seasonal cycle, are mostly unchanged.

Table 2: Efficiency of the selection cuts (number of tracks per year).

ΔP	V_{av}	B & V_T	Geometry	V_{shape}	V_{max}
1606	24.6	9.7	7.1	3.75	1

3.1 Geographical distribution, annual cycle and inter-annual variability

The geographical patterns of genesis and trajectories of the medicanes detected over the six decades under study are shown in Fig. 1. A great part of the medicanes are formed in two specific areas of the Mediteranean. The region where medicane genesis occurs more frequently is the western Mediterranean, roughly delimited by the Balearic islands and the Spanish coast on the west, southern France on the north, and the western coast of Corsica and Sardinia on the east. The second preferred formation region is located in the Ionian Sea, between Sicily and Greece, extending southward to the coast of Libya. Two more formation areas, characterized by a lower number of events, are the Aegean Sea and the Adriatic Sea. Very low activity is found in the Levantine basin in the eastern Mediterranean.

The geographical pattern of medicanes formation is quite different from that of "ordinary" Mediterranean cyclogenesis. According to climatological studies (see e.g Trigo et al. 1999b,a, the cyclonic activity over the gulf of Genoa, the area around the island of Cyprus, the region corresponding to the Atlas mountains in northern Africa, and the part of the Iberian peninsula south of the Pyrenees mountains accounts for around half of the total number of cyclones detected in the whole Mediterranean region.

Figure 2 shows the seasonal distribution of the detected medicanes. The distribution is characterized by no events in Summer, an high activity during all Autumn, a peak in January, and a flattish tail extending from February through May.

The number of medicanes per season is reported in Fig. 3. The year-to-year variability is strong. The overall trend is negligible (+ 0.015 events/year).

It is worth to point out that both the geographical pattern and the seasonal cycle of medicanes formation do not occur in areas where the sea surface temperature is higher than the threshold of 26 ° C empirically determined for tropical cyclones. This result supports the hypothesis that the formation of medicanes requires cold air intrusions enhancing instability. Further investigation on the factors associated with medicanes genesis is presented in

Sec. 4 below.

3.2 Sub-regional features

Due to its complex geography and orography, the Mediterranean region exhibits a great variety of subregional weather features. It is thus interesting to study in further detail the statistical properties of medicanes in different areas within the Mediterranean. We focus on the two areas where the larger number of medicanes is formed, the western Mediterranean and the "Ionian" regions (see the map in Fig. 4 for the exact definition of those regions).

The seasonal cycle for, respectively, the western Mediterranean and Ionian region is reported in Fig. 5, in analogy with Fig. 2. There is a marked difference in the annual cycle in the two areas: the frequency of medicanes formation in the western Mediterranean steadily increases during Fall and starts to decrease in January with a long tail extending in the Spring. On the other hand, the events in the Ionian Sea exhibit a sharp peak in January, with much less activity during Fall and Spring.

The inter-annual variability of the frequency of medicanes in the two considered regions is reported in Fig. 6. The average number of events is 0.75 ± 0.95 per season in the western Mediterranean, and 0.32 ± 0.50 in the Ionian Sea. The variability looks mostly uncorrelated between the two regions (the Pearson's correlation coefficient between the two time series is $\rho = -0.03$).

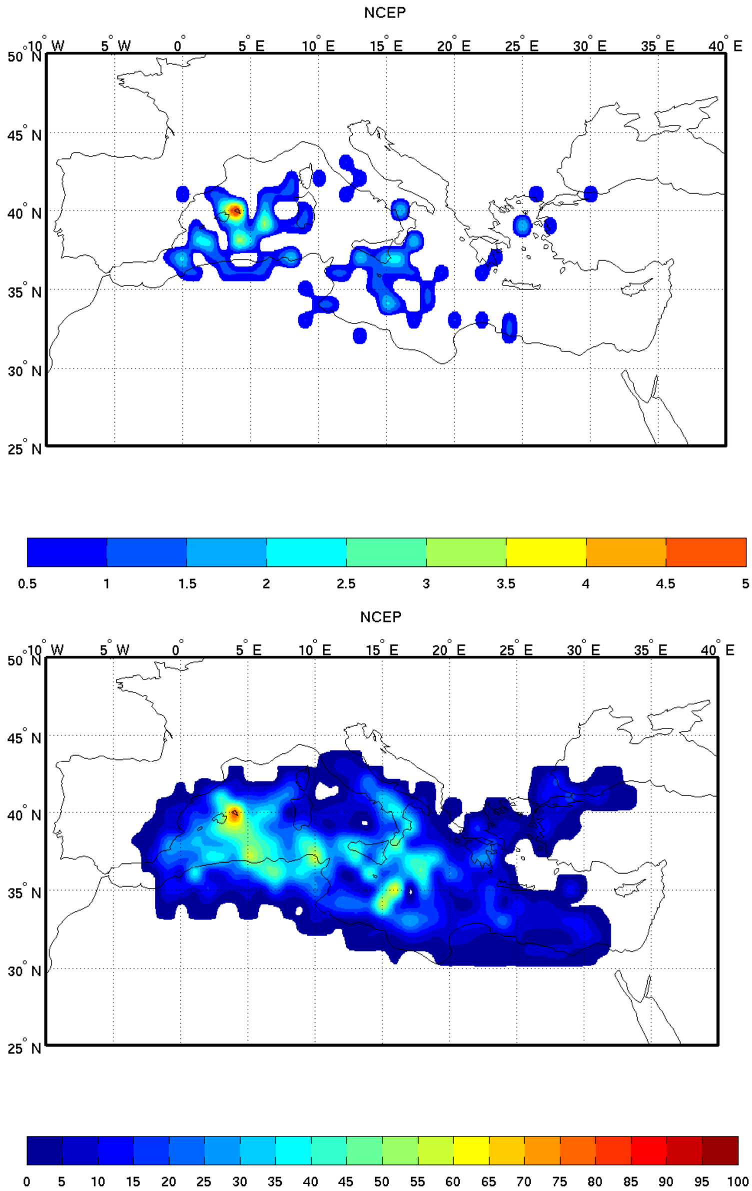

Figure 1: Locations of all the medicanes detected . Top: genesis density (first location in the track) per 2 ° x 2 ° box. Bottom: track density per 2 ° x 2 ° box.

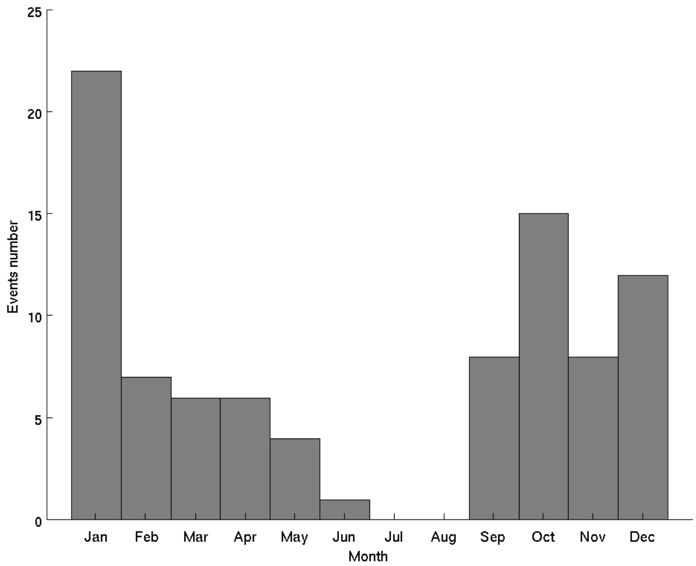

Figure 2: Number of medicanes per month (total number in the period 1948-2011).

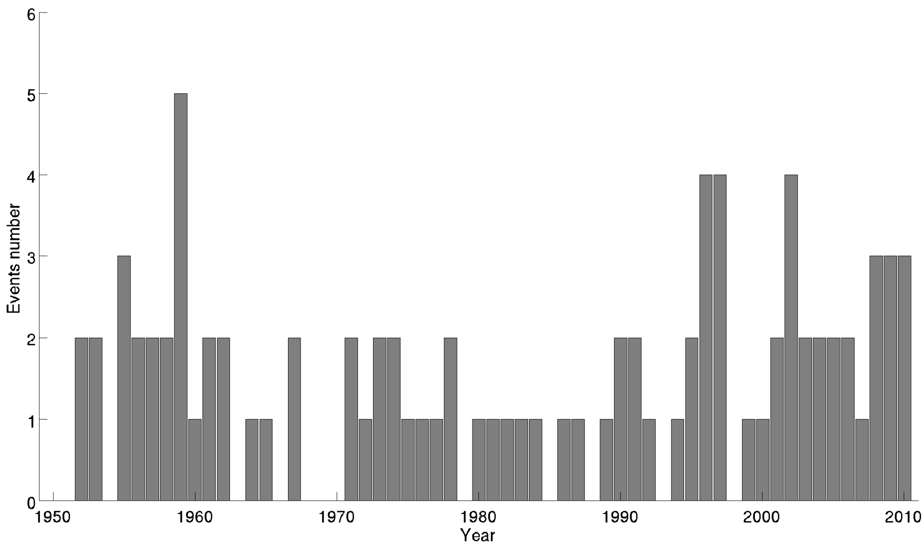

Figure 3: Number of medicanes per season.

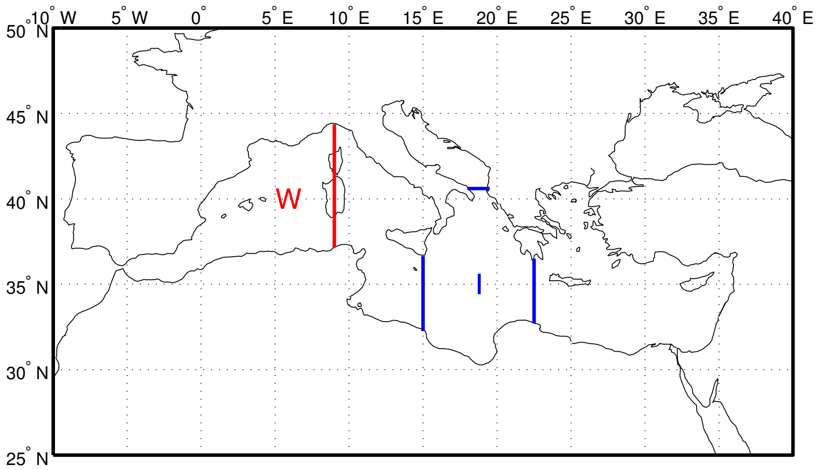

Figure 4: Areas used for the analysis of medicanes in western Mediterranean (red line, label W) and Ionian (blue lines, label I) regions.

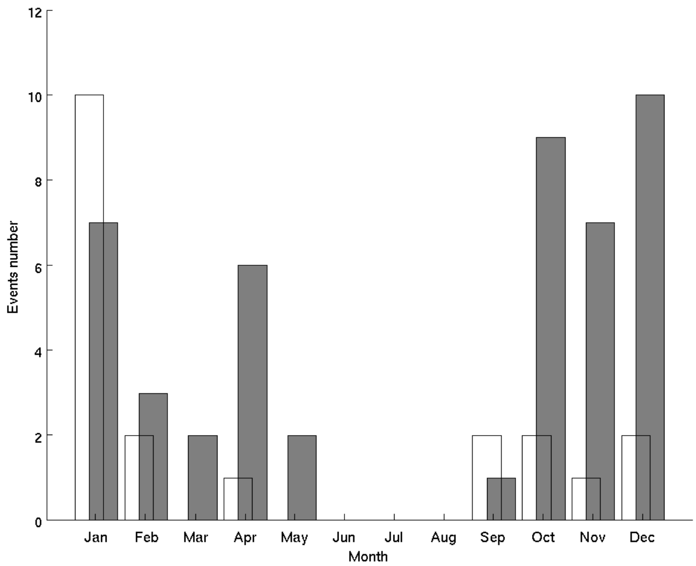

Figure 5: Number of medicanes per month (total number in the period 1948-2011) formed in the western Mediterranean (grey shaded bars) and in the Ionian area (white unshaded bars).

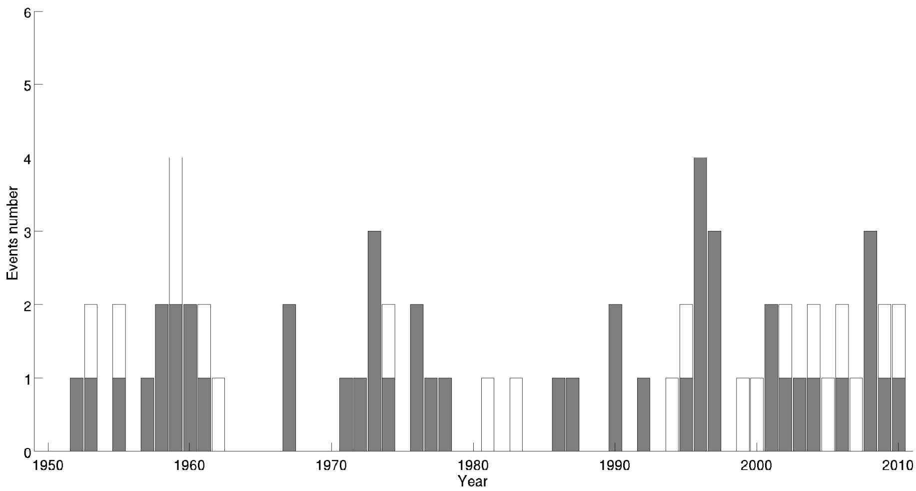

Figure 6: Number of medicanes per season formed in the western Mediterranean (grey shaded bars) and in the Ionian area (white bars).

4 Results: linkage between medicanes statistics and large-scale patterns

Several hypotheses on the environmental factors associated with the formation and development of medicanes have been advanced in the literature, based on different event-based studies. Tous et al. (2012) showed that, for the twelve cases they analyzed, the Genesis Potential Index developed to describe the formation of tropical hurricanes exhibits statistically significative high values at the time of medicanes formation.

In the current work, thanks to the availability for the first time of a large sample of simulated real-world medicanes, we take the approach to analyze the synoptic patterns associated with their formation without aprioristic assumptions on the exact parametrization defining their statistical relationship with medicanes genesis. The factors that we consider are:

- the vertical temperature gradient between the surface and the middle troposphere, and the two factors contributing to such gradient (sea surface temperature and the air temperature at 350 hPa;
- the vertical wind shear;
- the moisture content of the atmosphere;
- pre-existent low level vorticity.

4.1 Synoptic patterns associated with medicanes formation

All the events detected in the six decades simulation are analyzed systematically, in order to assess which environmental factors can be associated to the formation of medicanes on general grounds. In Figs. 7 and 8 are reported the composite plots of the anomalies with respect to the climatological monthly mean of the aforementioned variables, for all the medicanes formed in respectively the western Mediterranean and Ionian Sea (similar results hold for the other formation regions). The composites are calculated from the daily mean values of the fields, on the day when the pressure minimum is tracked by the detection algorithm for the first time. The patterns of environmental conditions shown in the composite plots can thus be considered to be representative of the precursor conditions of medicanes formation.

A clear signal is visible in the difference ΔT between the air temperature at 350 hPa and the sea surface temperature (Fig. 7, top), showing a negative anomaly ranging between 3° C and 5° C. The deviation from the mean state of the 350 hPa temperature alone (Fig. 9, top) shows a pattern very similar

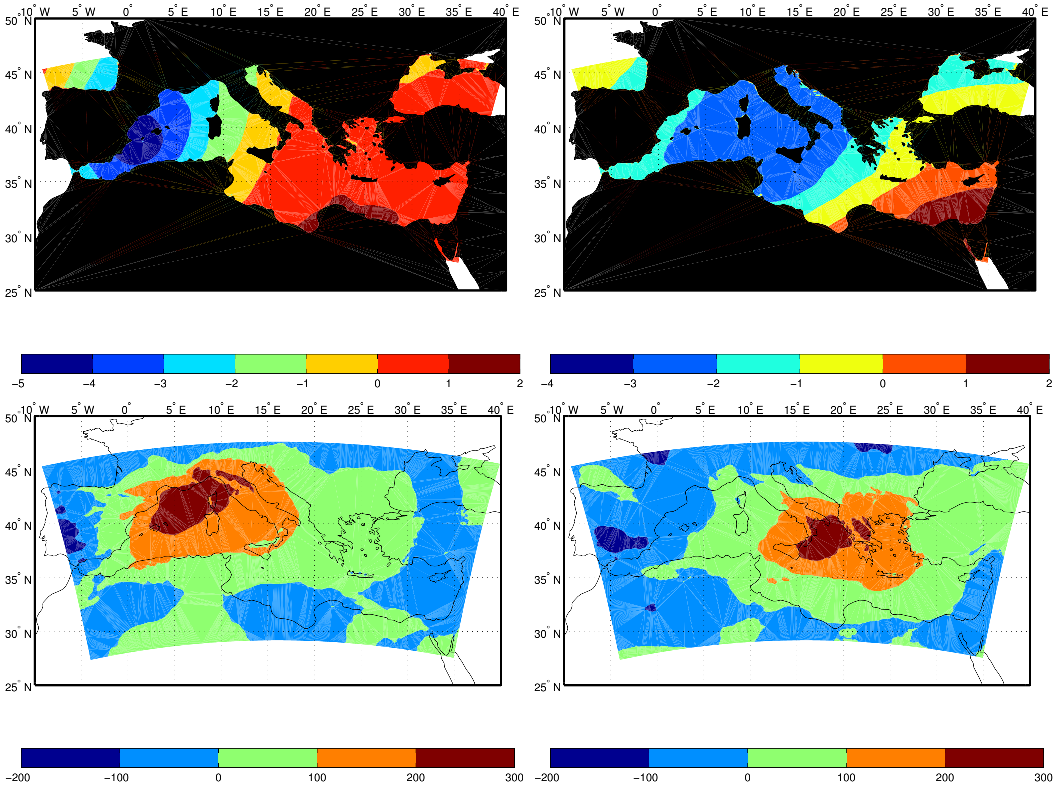

Figure 7: Composite plots of the daily means, on the day corresponding to the first point in the track, for medicanes in the western Mediterranean (left panels) and Ionian Sea (right panels) of the anomalies with respect to the climatological monthly means. Top: difference between 350 hPa temperature and SST (1° C contours). Bottom: relative humidity integrated along the atmosphere column (adimensional units, contours at steps of 100).

in both its shape and magnitude to that of ΔT. On the other hand, the sea surface temperature field (Fig. 9, bottom) does not show significant anomalies associated to medicanes formation. Analyzing the available data, it can thus be inferred that the anomalies of the temperature difference ΔT, leading to the instability responsible for the development of medicanes, are controlled by cold air intrusions in the upper atmospheric levels rather than to a warming of the sea surface. The investigation whether relevant sea surface temperature anomalies associated with medicanes emerge analyzing a fully resolved SST field will be the subject of further work.

The wind shear field (850 hPa - 250 hPa) shows (Fig. 8, top) as well significative anomalies - the absolute value of wind shear at the time of medicanes formation is around 10 - 15 m/s lower than the mean value in the

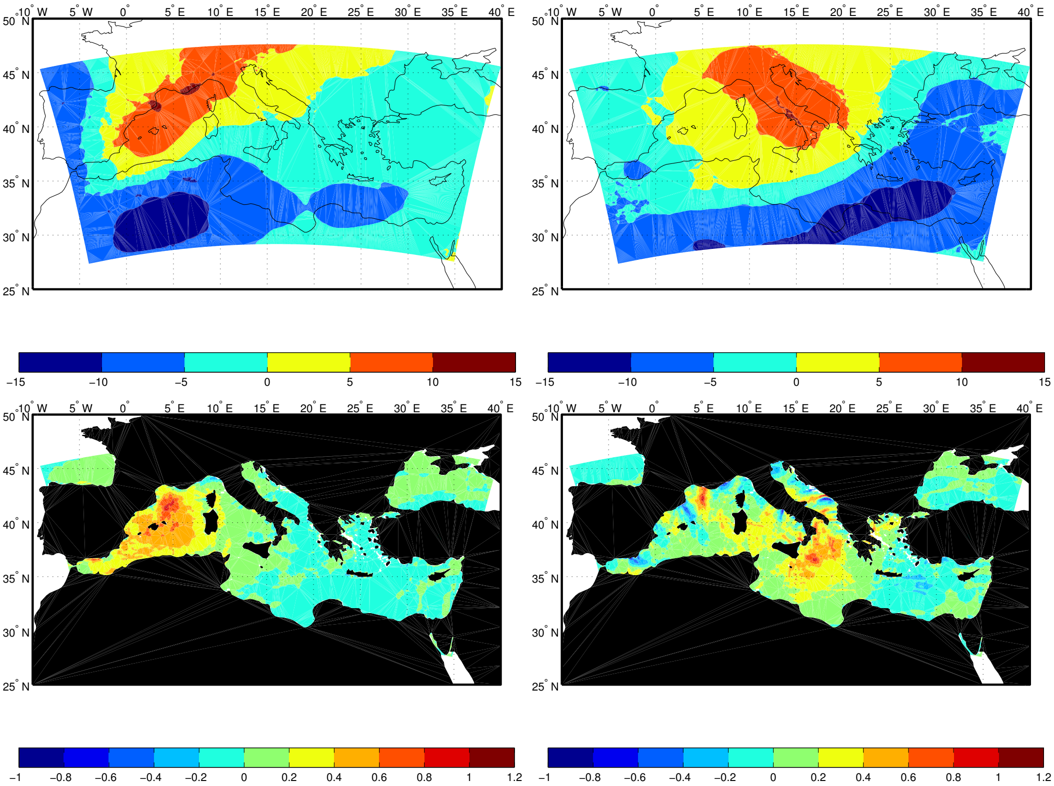

Figure 8: Composite plots of the daily means, on the day corresponding to the first point in the track, for medicanes in the western Mediterranean (left panels) and Ionian Sea (right panels) of the anomalies with respect to the climatological monthly means. Top: 850-250 hPa wind shear (5 m/s contours). Bottom: 850 hPa relative vorticity (0.5 $s^{-1} \times 10^{-4}$ contours).

area. The humidity field (integrated over the atmosphere column, Fig. 7, bottom) and the relative vorticity field at 850 hPa (Fig. 8, bottom) show both positive anomalies at the time of formation of medicanes. It can thus be concluded that all those environmental factors - low wind shear, high moisture and vorticity - favor the formation of medicanes, in a similar way as they do for tropical cyclones.

4.2 Explanation of medicanes distribution in space and time in terms of synoptic patterns

Having singled out a number of variables that exhibit significant deviations from the mean state in correspondence with the formation of medicanes, we

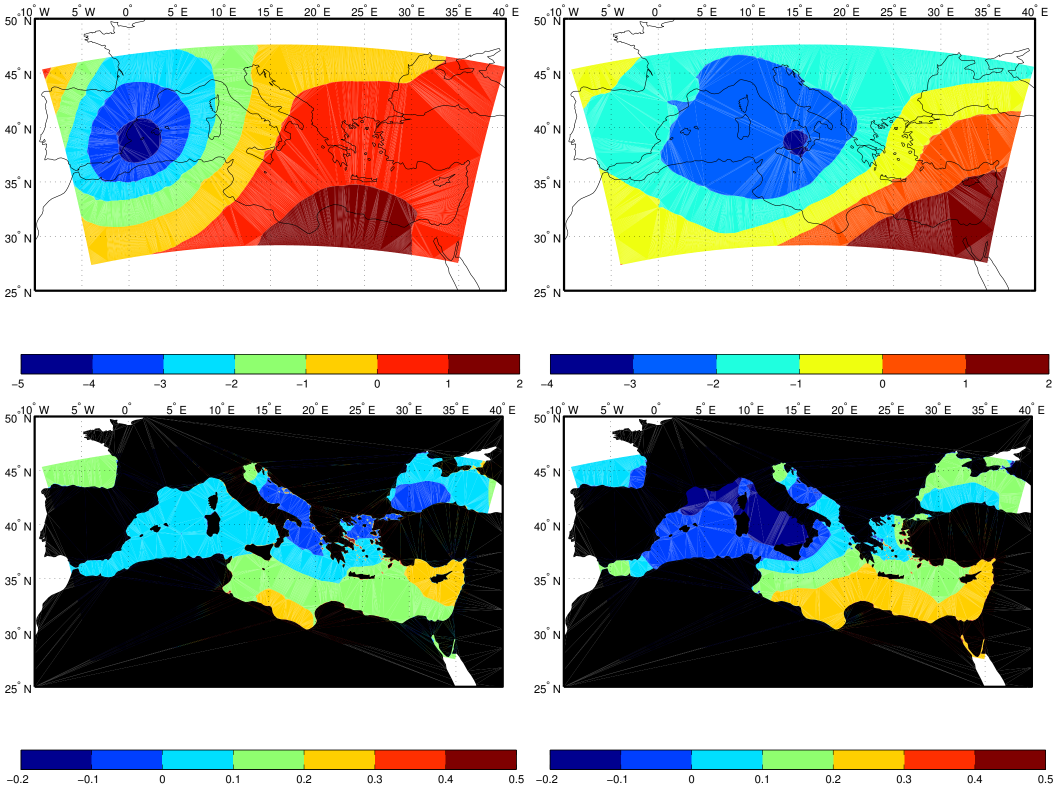

Figure 9: Composite plots of the daily means, on the day corresponding to the first point in the track, for medicanes in the western Mediterranean (left panels) and Ionian Sea (right panels) of the anomalies with respect to the climatological monthly means. 350 hPa temperature (top, 1° C contours), sea surface temperature (bottom, 0.1° C contours).

further investigate whether the aforementioned deviations are able to explain the main features of the statistics of medicanes, in particular the geographical distribution and seasonal cycle.

In order to assess to what extent the geographical distribution of medicanes formation can be explained by the realization of patterns of environmental factors similar to those described above, we computed for each of the four factors identified (ΔT, wind shear, relative humidity and vorticity) the probability that it exceeds a threshold corresponding to the value observed in association to the formation of medicanes[1]. The threshold values are fixed as follows:

[1]The probabilities are computed from the daily mean values over all the simulation period as the percentage of days in which the condition is realized.

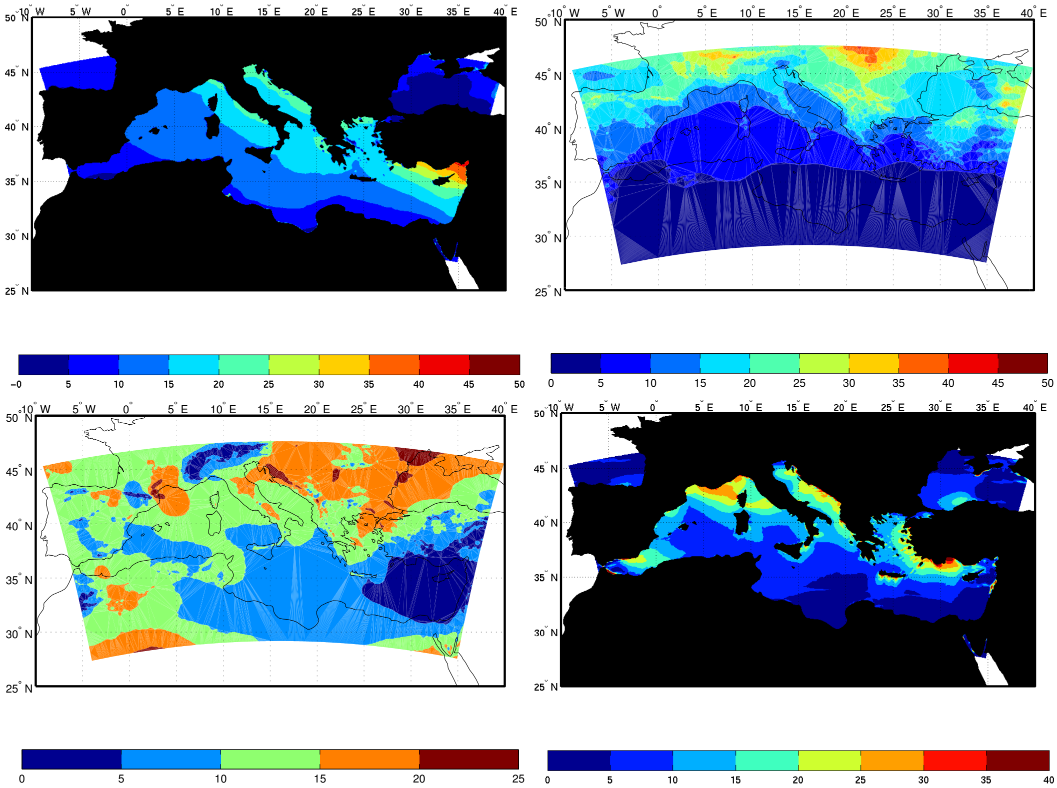

Figure 10: Probability for each of the following factors to exceed the threshold value corresponding to medicanes formation: ΔT (top left, 5% contours), RH (top right, 5% contours), WS (bottom left, 5% contours), VORT (bottom right, 5% contours).

- $\Delta T < -58°$ C;
- a wind shear (WS) lower than 4 ms^{-1} (in absolute value);
- a value of the integrated relative humidity (RH) larger than 1100;
- 850 hPa vorticity (VORT) larger than 0.5 $s^{-1} \times 10^{-4}$.

The maps of the probability distributions for the four variables are reported in Fig. 10. All the thresholds are significative - selecting between 5% and 15% of the distribution of the respective variable in the areas of medicanes formation. On the other hand none of the factors, if considered alone, seems to be able to explain the geographical distribution of medicanes events.

Assuming that all the environmental conditions considered have to be realized simultaneously in order to make possible the formation of a medicane, the probability that the four factors exceed the respective threshold at the same time has been compute (Fig. 11). Under this assumption, we

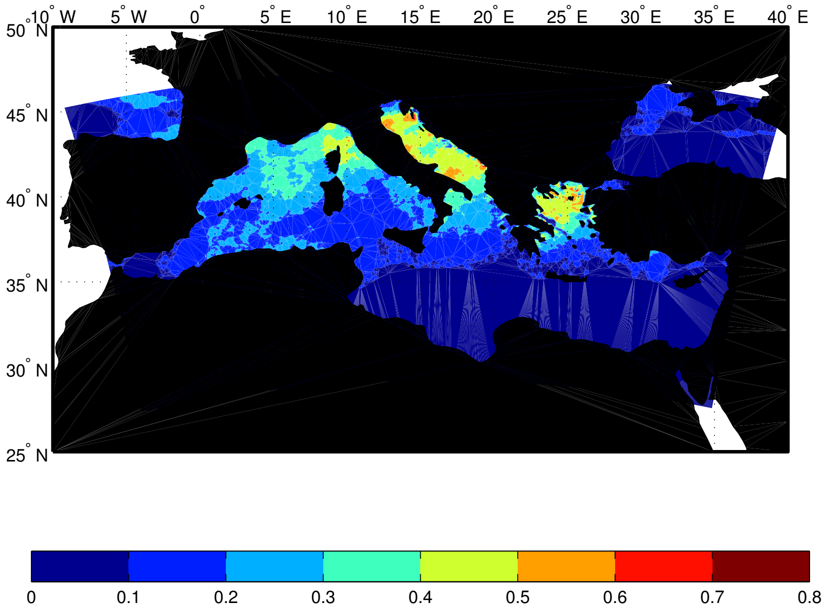

Figure 11: Probability of realization of the environmental conditions favorable for medicanes formation (0.1% contours).

find that the probability of having conditions favorable for medicanes development is higher in the north-western part of the Mediterranean basin. Those conditions are realized most frequently over the Adriatic and Aegean seas. We argue, however, that the semi-closed geography of those sub-basins is a limiting factor for the full development of medicanes, as most of the low-pressure systems crossing them stay over sea for a short time. The environmental conditions favorable for medicane formation occur over the Ionan Sea approximately half of the times as they do in the western Mediterranean, compatibly with the frequency of detected medicanes.

In order to assess whether the frequency of realization of the specific patterns of environmental factors described above can explain the seasonal cycle of medicanes, we computed the number of days for each months in which such conditions are realized by defining an index $\mathcal{M}$ that takes the value 1 if all the four factors exceed the respective thresholds over an area larger than 2000 grid-points, and 0 otherwise. The index has been computed in the two boxes shown in Fig. 12, that correspond to the areas where the large scale conditions associated to the formation of the detected medicanes respectively in the western Mediterranean and Ionian Sea are observed. In Fig. 13 is reported, for each month, the value of the index $\mathcal{M}$ summed for the whole simulation period. Comparing Fig.13 with Fig. 5, we find that

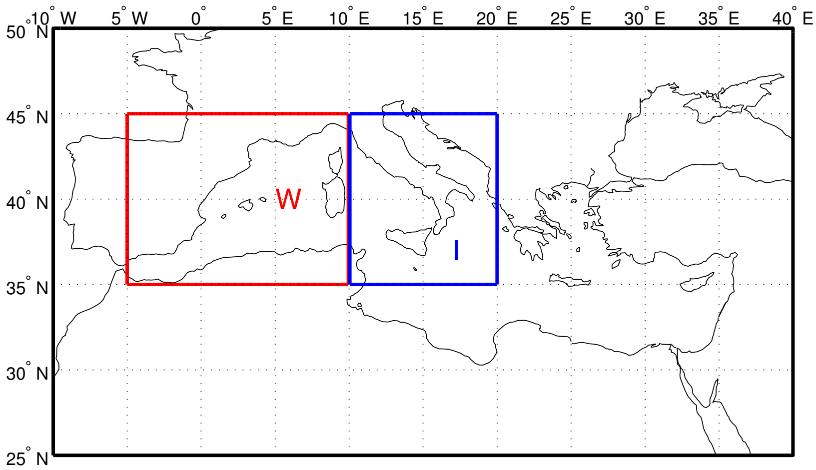

Figure 12: Boxes used for the calculation of the index $\mathcal{M}$ for medicanes in western Mediterranean (red box, label W) and Ionian (blue box, label I) regions.

the seasonal cycle of the index $\mathcal{M}$ is comparable with that of medicanes formation in both the western Mediterranean and the Ionian Sea.

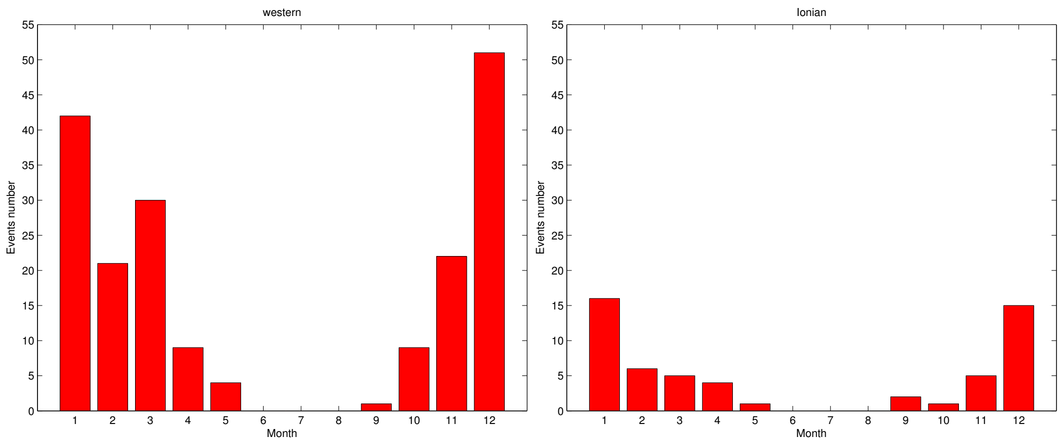

Figure 13: Total number of days in the 1948-2011 period where the index $\mathcal{M}$ is equal to 1 in the western Mediterranean (left) and Ionian region (right).

5 Conclusions & Outlook

Exploiting the dynamical downscaling of the atmospheric fields obtained from the NCEP/NCAR reanalyses, a systematic and homogeneous statistics of medicanes has been obtained for the first time, over a six-decades period.

We find that medicanes occur with a very low frequency (about 1.6 per year over the whole Mediterranean basin), and that they are formed mostly in the western Mediterranean and in the region extending between the Ionian Sea and the North-African coast. The annual cycle of medicanes formation has a peak at the beginning of Winter, with a relevant number of events during Fall, and a few over Spring. The year-to-year variability is strong, but no significant trend is found in the last sixty years.

We investigated the environmental factors related with the formation of medicanes. We find that the triggering of medicanes requires a sufficiently large difference between the sea surface temperature and the temperature in the upper atmospheric layers, in order to increase the atmospheric instability. For the detected medicanes, such a difference is generally produced by the presence of a cold temperature anomaly in the high troposphere, rather than by a large deviation of the sea surface temperature from the mean state. A low wind shear, high moisture content, and high low-level vorticity are all factors that favor the development of medicanes. It was shown that the frequency of simultaneous realization of all the favorable conditions described above exhibits a geographical distribution and a seasonal cycle compatible with the frequency of medicanes formation.

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