UIMP Universidad Internacional Menéndez Pelayo

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Universitat de les Illes Balears

FUTURE PROJECTIONS OF THE FREQUENCY OF MEDITERRANEAN CYCLONES

Programa oficial de Postgrado.
Memoria final de Máster en Cambio Global.

Antoni López Mayol

Directores:

Dr. Romualdo Romero March   Dr. Víctor Homar Santaner

ABSTRACT

The Mediterranean region is a well known cyclogenetic area, which is climatologically prone to the formation of a wide range of cyclone magnitudes and intensities, which occur across both eastern and western basins. In order to characterize the cyclonic frequency and distribution, an automated method has been developed to detect cyclones on gridded geopotential height fields from five regional climate models nested in ECMWF ERA-40 reanalysis data for the current climate and forced with the SRES-A1B scenario for the future climate. The detection algorithm is based on two main cyclonic features: relative minima of 1000 mb heights and closed isohypses. This procedure allows identifying the areas with higher frequency of ciclonic circulation, as well as assessing its projected future tendencies, to elucidate the effects of climate change on Mediterranean cyclones. Results show that the areas with most cyclonic activity are the eastern Alboran Sea, the Gulf of Genoa, the Adriatic Sea and, with less concurrence, the Tirrenean Sea. They also show lower cyclonic density in the open sea, especially between Catalonia (Spain) and the canal of Sicily and Tunez, and higher frequencies near the areas along the coasts. The future scenarios predict less cyclonic density in areas of open waters and larger increase in zones near the coasts, incrementing the number of cyclones in the Alboran Sea, in the Gulf of Genoa and on the coast of Venice.

Key Words: Cyclones, detection, Mediterranean, climate change, tendencies.

1. INTRODUCTION

The Mediterranean, specially the eastern region, has for quite a while been demonstrating its notable cyclogenetic activity. Such so, that many of the cyclones can even stand out in a severe way, thus bring forth singular meteorological events and afflict great impact on society. Extreme precipitation, frequently associated with deep cyclones, produces major impacts along the Mediterranean coastlands, although other phenomena associated with these cyclones such as hail, thunderstorms and above all strong winds are also present during many of these cyclonic episodes. On rare occasions these areas of low pressure can become small sub-tropical cyclones, otherwise known as Medicanes (during the last 25 years, 20 cases have been reported and documented (Tous,M. R. Romero, 2011 and 2012), the best example being in 1985, with a small cyclogenetic core formed between Greece and Italy and eventually covered an area of a thousand kilometers, dying over the Libyan coast).

With its 46.000 kilometers of coastline, the Mediterranean Sea congregates a high population due to its excellent climate, partially due to its proximity to the sea and to its mild and confortable latitude (remarkably, 75% of the world population lives on this latitude belt, between 30º and 45º degrees. The development of these sectors in most of the regions in this basin, for example, maritime commerce and tourism industry, generated such a potentially evolvable area that in the present, it can be threatened both from a natural and social perspectives. Therefore it is important to try to understand and interpret the evolution of the cyclone behavior in the Mediterranean and how its meteorological consequences can change the population's standards under a scenario of global change.

The Earth's atmosphere has been under constant change from the moment it was formed. During the last century, the CO_2 emissions have drastically augmented in accordance with the human activity and its evolution based on the fundamental goal of *continuous growth*, a questionable principle. This unyielding increment has significantly altered the contribution of the greenhouse effect to the global energy balance, that has always existed on the planet, and which regulates the temperature to a global average of about 15ºC. We know today that the greenhouse gases emitted by modern societies are intensifying the natural greenhouse effect, raising the global averaged temperature. These specific changes are posing myriad of challenges to the human kind from various points of view: physical, biological, political and, above all, economical. Evidence in the prognostics of the climatic scenarios completed by the Intergovernmental Group of Experts on Climate Change show that the frequency of tropical cyclones are changing in some regions (IPCC, 2001). Although these type of cyclones are unreported in the Mediterranean region, it supports and restates the hypothesis that the rise of temperatures in partially closed seas (these work as boiling pots for cyclones) will contribute towards the evolution and development of a greater number of cyclones, or in any case the severity of these and the weather events associated with them. Therefore, it is important to directly relate all these changes that derive from human activity, because they are modifying the processes that determine how the Earth's system works. It must be made clear that the cyclones that are present in the Mediterranean are more of a general type and not tropical, therefore the severity of the previously mentioned factors will further affect other zones of the planet Earth. Nonetheless, both are affected, but in very different levels concerning their presence and development.

Many alterations included in Global Change like climate change are increasing the number of cyclonic events due to the environmental upsets caused by human actions on the planet; an exponential tendency. The increment of the temperature in the environment along with the changes that this would bring, such as alterations in atmospheric and oceanic currents, and the possible rise of the Mediterranean sea surface temperature are the perfect combination for frequent cyclogenesis and deep cyclone formations. However, the temperature can be more determining for tropical cyclones, but not so much for baroclinic cyclones (the dominant kind in our area of study), even though it can affect their state of intensification. More precisely, the type of cyclone of interest in this work will be (i) of thermal origin (Romero et al. 2001) with the warm nucleus resting on terrestrial masses (light storms), (ii) of a topographic (Romero et al. 2001), and most importantly (iii) Baroclinic developments characteristic of the mid latitudes and with considerable vertical extent.

Today, the Mediterranean climate is highly seasonal (Sumner et al. 2001), with a very dry season during the summer months, when the warm air masses remain on the Mediterranean for a long time. But at the same time, it is precisely those areas that suffer from torrential rains and catastrophic floods (Font 1983, Romero et al. 1998a), so on certain occasions they have to modify the natural flows of rivers and torrents due to the effect they have on human settlements, reaching levels of a maximum of 400 millimeters in some parts of the Western Mediterranean and therefore disturbing human activities. The cyclonic disturbances are the birth of the conditions that create temperature and humidity fronts in its nucleus, causing to generate a space for the development of convective instability.

As a product of this Global Change, the evaporating capacity of the Mediterranean Sea will be even greater and would permit more effective cyclone-derived events like convective processes, which generate heavy precipitations during short periods of time. The agricultural sector and transport systems, as well as the incidents that are connected to severe meteorological events such as the presence of strong storms, which can affect the electrical infrastructure of wide territorial areas, thus making connections and other similar services impossible, therefore showing how seriously can these weather phenomena affect such things.

There is a clear connection between cyclones and precipitation in the Western Mediterranean. In fact, climate studies proof that approximately 90% of the intense events that occur, happen within the same time as a depression is taking place in the same area. (Jansà et al. 2001). This way, the tendency is towards the increment of the probabilities that these intense precipitations will take place along with their consequences due to a larger availability of water steam.

During the last few years, there have been multiple studies concerning cyclonic activity in the Mediterranean basin, like *Picornell et al.* (2001). In this work, there is an automated mesocyclone database from the HIRLAM (INM) with a distance of 50 kilometers between the grid points, and with algorithms for their detection as well as determining their course. This work intends to demonstrate the possible future cyclonic scenarios in the Mediterranean basin, using ensemble models (regional climate models to simulate climate scenarios), all based on the re-analysis project ERA-40 40 (control experiments) for the current climate, and on SRESA2 emission scenario (future experiments).

Concerning the Western Mediterranean, a recurrent pattern can be established because it is known that most of the cyclones concentrate at certain places. These places are the Gulf of Genoa, south of the Pyrenees, south of the Iberian Peninsula and the Alboran Sea.

To conclude, this research project aims at detecting Mediterranean cyclone events in the ENSEMBLES data set for the present and future climates.

The first part of the work discusses the quality of the technique used for the detection of the cyclones, clarifying estimations and methodological anomalies. Further on, the work shows concrete examples. After presenting derived products like the recurrence of a cyclonic center on the same point, or the recurrence of a point inside a cyclonic domain, the most important aspects and findings of the study will be summarized and new lines of work for the future will be suggested.

2. METHODOLOGY

The following models were selected from the ENSEMBLES data base RCM (regional climate models) CAIRCA3 (MettEire, Ireland), DMI-HIRHAM5 (DMI, Denmark) KNMI-RACM02 (KNMI, Netherlands) and SMHIRCA (SMHI, Sweden) in the field of investigation RT3, characterized for the formulation of Regional Climate Model Ensembles for Europe in very high resolution and responsible for providing improved climate model tools developed in the context of regional models and contributing to high-resolution modeling in general, first at spatial scales of 50 km at a European-wide scale within ENSEMBLES and further on at a resolution of 25 km for specified sub-regions. The grid spans 29.125°N to 71.375°N in latitude and 23.875°W to 45.375°E in longitude, with a regular 0.25° step (170x278 points in latitude per longitude). The ENSEMBLE data base also constains data from the re-analysis of the project ERA-40 from the ECMWF, allowing to analyse present and future scenarios, from 1971 to 2000, and from 2070 to 2100, respectively. The future scenarios have been obliged through a model of general circulation and at the same time obliged with the emissions scenario SRESA1B. The database is published and can be obtained at the ensembles project web page (http://www.ensembles-eu.org/).

The field used to apply the cyclone detection algorithm on is the geopotential height at 1000hpa. The contains data every 6 hours, at 00:00, 06:00, 12:00 and 18:00 UTC, and a resolution of 25km. Taking into account that the main subject of study in this work is the entire Mediterranean basin, including all of its coast and significant geographical accidents in context. The different models use a regional area that is very similar but not identical. Nonetheless, the analysis will cover the totality of the European continent (Figure 1).

2.1. Cyclone Detection Method

The work has used a grid of 190x190 grid points, this being the measure that best adjusts to the processing of the presented models thus achieving to complete the resulting analysis. The study performs a smoothing of the geoptential field's values to homogenize it, and although it will not be mathematically essential for the established calculation, it will facilitate the work and make it easier to the eye when interpreting the resulting data, with greater absence of noise by presenting with the original values. For every point on the grid, it obtains an average value for the 25 adjacent grid points, including the first one. This fact helps in smoothing the "noise" that is generated by the mountainous systems on the geopotential field values.

The initial criterium to detect a cyclone by searching for relative 1000-mb geopotential height minima. Then, only when the gradient increases on the eight cardinal directions (N, NE, E, SE, S, SO, O, NO), up to a minimum distance of a 100 kilometers a cyclone is detected. This way, each grid point must always have a geopontetial value larger than the preceding one in the 8 directions and in a diameter of 200 kilometers.

Once this criteria has been established, the filtered data results in the detection of relative minimums that at first show the presence of a cyclone in each one of them. Here appears one problem: these being relative minimums, it is possible that a shallow depression with a very soft gradient, without a continuous cyclonic structure and occasionally adjacent to the margins of cyclonic systems clear of diverse consideration is detected. This is solved in a posterior process of analysis that eliminates these relative minimums and assures the treatment of absolute minimums, applying the criteria that the detected cyclones with domains under a total of 100 grid points in conjunct should be discarded. Therefore, the criteria for the definition of the domain will be the one that will define a center as an absolute minimum as well or as a cyclone. This aspect will be further discussed.

2.2. Cyclone domain

To establish the domain of the detected minimums, the first step is to search the value that will act as a limit to the domain. This is done the following way: placing the condition that the domain a cyclone covers can be defined as the area obtained by expanding from its center towards the 8 cardinal points until each one of them changes the sign of slope. Once the points where the change of the sign are identified, the second lowest is selected. The second lowest is taken as a more robust measure of the cyclonic domain, eliminating the possibility of obtaining a value far from the center that can hold more than one cyclone in the same isohypse. Finally, 85% of its geopotential value is defined as the bounding value for the cyclonic domain.

On the other hand, if two cyclonic centers exist with one domain invading the other, the method detects it and goes on to subtract the geopotential value as the respective value for the limit of the domain, 10% of the actual value and goes on successively (regressing) until there is no further contact with any other cyclonic domain relatively close. Therefore, cyclonic domains detected with our algorithm never overlap with one each other.

Finally, as has been previously mentioned, the cyclonic centers that appeared as relative minimums and did not actually represent a cyclonic structure have been eliminated. The minimum number of grid points that cyclone must contain in its domain is a total of 100 this number is sustained on previous findings on the matter, because 100 grid points result in the square root of 10 grid points. Although the number of cyclones and their tendencies can reflect in a relative way the future capacity of presence that a Medicane would have on the Mediterranean, a domain of a 100 grid points leaves out the possibility of detecting this type of structures in the present work, since we must remain in minimum domains of 36 grid points.

3. VALIDATION AND RESULTS

Some anomalies in the method applied have been detected during the manipulation and creation of the data base, and as a consequence of the obtained results, the main focus of study is assigned to the model C4IRCA3 with the climatic distribution being in decades following the order of 1971-1980, 1981-1990, 1991-2000 for the present (CTL) and a decade distribution of 2071-2080, 2081-2090, 2091-2099 for the future scenarios (A1B). The three remaining models will be used in relation of their scenarios compared to the ones in the principal model, and above all, in the general and subjective context of the given results. Nonetheless, an anomaly is present in a result at the easternmost part of the Mediterranean, with abnormal values (excessively elevated) that are probably due to the methodology or an unknown error that will be sorted out in the future.

Once the efficiency of the method is demonstrated, it produces two types of climatic products that are interconnected, on one hand, the number of detected cyclones and the situation of the points with the greatest recurrence, and on the other, the density of the cyclonic domains in all of the Mediterranean Sea.

All the value units are presented in cyclones by decades (cycl/dec), estimating the amount of cyclones per year and dividing the value by 40 (value/dec* records H+6).

3.1. The Number of times that a grid point has been the center of a cyclone (centr/cycl/dec)

Once the climatic maps of 30 years have been completed for the model C4IRCA3 (Figure 2), it is clear in which direction the tendency will steer: the future scenario presents a greater cyclonic potential in its concurrent points, in the Gulf of Genoa, in the north Adriatic Sea, on the coast of Morocco, Argelia, Tunisia and finally on the southeast coast of Spain (there is a greater recurrence) and a loss of cyclones in the open sea, but becomes lighter in the western part of the

Mediterranean. The Alboran Sea stands out (reaching measures of 23 cycl/dec and even maxima of 50 cycl/dec), with many low pressure points in the same area scattered along the African and Spanish coasts. The number of cyclones augments right next to the coast of Valencia until they reach an average of 13 cycl/dec. The Tyrrenean Sea also generates areas of significant maxima near the Italian coast. We must highlight aside from everything else the Adriatic Sea, which seems to turn into a boiling pot in this type of context.

Present scenarios

The models C4IRCA3 CTL demonstrate how the most elevated recurrences of the cyclonic centers are in their totality found near the coast. Clear examples are the African coast of the western Mediterranean, the Spanish eastern coast, The Gulf of Genoa and the high recurrence in the Adriatic Sea. Even though there are light drops of cyclones in the central Mediterranean and in the canal between Sicily and Tunisia, on a general scale, there are no significant changes in the open sea (an average of 3-4 cyclones). There is also a fall in the recurrence in the western Mediterranean of 1 cycl/dec. The number of cyclones in the Gulf of Genoa remained regular during the transition from 1971 to 2000, but the Adriatic Sea shows a decline in the recurrence of cyclonic centers. There are barely any changes in the Alboran Sea, which has well marked "hot points" that stay with similar values during the transitioin of 30 years, and on some occasions even rising the maxima with values that reach up to 30 cycl/dec. On the other hand, the Aegean Sea presents a decrease, which becomes much more clear during the third decade of the scenario (Figure 3).

The model DMI-HIRHAM5 in general presents elevated values in the totality of the Mediterranean area. The Gulf of Genoa does not show an appreciable variation as well as does the westernmost area of the basin, maintaining the number of cyclones between 5 and 6 cycl/dec, reaching peaks of 25 cycl/dec in the Gulf of Genoa. The Alboran Sea increases in the number of cyclones and the potential areas of maxima, but does not do so with the whole set. The Tyrrenean Sea also shows a small reduction going from values of 7-8 cycl/dec to 4 cycl/dec. It shows a generalized diminution of the number of cyclones in the central and eastern parts of the Mediterranean, especially in the coastal waters of Libya and Egypt.

Future Scenarios

In general, the model C4IRCA3 displays a slight tendency of less cyclonic centers in the open sea and the following displacement towards the coastal areas, where many maximum zones grow, like in the Tyrrenean Sea or the Golf of Genoa (value points that go from 28 cycl/dec for 2071 and 24 for 2081 to a scarce maximum above 19 cycl/dec for 2099), specially in the coasts of Venice and in the waters of Croatia. The Aegean Sea proportionally decreases the set of cyclones. The Gulf of Genoa lowers its area of recurrences in general but it slightly raises the value of its maximum absolutes. There is also a focal point with values of 12 cycl/dec in front of the coast of Valencia (Spain), where it also decreases, both in its maximum and in its focal area. Therefore, during this climate period of 30 years in a future scenario, it shows that the areas with more recurrence of cyclonic centers are more compact and with higher "peaks", clearly determining the regions where the cyclonic systems of the Mediterranean Sea are generated (Figure 4). The evidence of climate change show maxima values in the future scenarios, which are much more elevated than the ones in the present scenarios. For example, the number of cyclonic centers is much more elevated for the future although these include lower area domains as can also be seen in the Adriatic Sea, which presents a very homogenic present scenario but its future scenario is much more irregular with maxima in the north. Finally, the most significant changes appear in the Alboran Sea where the future scenarios predict an increase of cyclonic centers. The totality of the basin looses cyclones in the open sea during the future, at the same time the present shows a very regular distribution along the whole sea (with the exception of the areas along the coast that were mentioned earlier).

The model KNMI_RACMO2AIB in general presents a bit more elevated values than C4IRCA3 (Figure 5), except for the Alboran Sea and the rest of the north African coastline which stay on very similar levels. It doesn't show such a clear decline in the open sea (with the exception of the coast of Catalonia (Spain), part of the Gulf of Leon and the Egypt coast) but it does highlight the increase of cyclones in the Tyrrenean sea and all along the Adriatic Sea. The Gulf of Genoa barely presents changes, maybe a light increment with lower maxima. In this case, the number of cyclones in front of the coast of Valencia (Spain) increases to values of 8 cycl/dec.

3.2 Number of times that a grid point has formed part of a cyclonic domain (dom/cycl/dec).

In the process of observing the general map (Figure 6), one can clearly see the outstanding traits of the general cyclonic distribution in the European Continent; the high density of low pressure systems in Iceland and the low pressure thermal systems that are formed in the North of Africa, as well as the flow pattern of the "Storm Tracks", which start at the most western part of the Atlantic Ocean and flow onto high latitudes oscillating in a continuous form thus generating great contrasts of temperature between the air masses from the north, south and the Jet Stream at a high altitude: baroclinic instability. This process leads to the formation of cyclones, which are more abundant during winter.

The climatic maps of 30 years of densities in the cyclonic domains for the model C4IRCA (Figue 7) show a very well contrasted future scenario, with an overwhelming density in the Alboran Sea which is reinforced mostly by the high density of cyclones that occur south of Spain and along the western part of the Moroccan coast, with cyclonic domains that on many occasions go on to cover the Alboran Sea even when the low pressure centers are not in the Mediterranean, and surpass the average of 2500 dom/cycl/dec in the northern coast of Morocco. On the other hand, the Tyrrenean, Adriatic Seas, and the Golf of Genoa loose intensity of the cyclonic domains going from 1050 dom/cycl/dec to 750 dom/cycl/dec. However, the present climatic scenario shows that the Venice coast (Italy) is the one that presents a greater density of cyclonic domains, but is barely noticed in the future scenario.

Present Scenarios

Concerning the Mediterranean Sea, the average values indicate that the totality of the area has at some point formed part of a cyclonic domain, with an average of 13 times a year on each grid point.

The maps of the model C41RCA CTL show that the highest concentration of cyclonic domains are found in the Gulf of Genoa (of the order 1150 dom/cycl/dec), in the eastern region of the Alboran Sea (of the order 1100 dom/cycl/dec), and in the Adriatic and Tyrrenean Seas but with less incurrence. During the transition of decades in CTL, these densities have varied irregularly, loosing density in the Gulf of Genoa and in the Adriatic and Tyrrenean Seas but maintaining it in the Alboran Sea. However, there is also a decline in the areas of Sicily, Tunisia and the canal of Menorca-Sardinia to a level of 350 dom/cycl/dec per area when it was up to 400-450 dom/cycl/dec, appearing as a diagonal corridor of low intensity between Catalonia and Malta. The coast of Catalonia is also one of the areas that present low values and a negative tendency, with 300-350 dom/cycl/dec (Figure 8).

The model SMHIRCA CTL presents the same proportional distributions in general, but with much lower values, reaching 150 dom/cyclo/dec in Sicilian and Tunisian waters and even 100 dom/cycl/dec in the Gulf of Leon. In conclusion, it shows a notable increase of the density of cyclonic domains in the Alboran Sea and a decrease in the Gulf of Genoa as well as a slight decline in the Adriatic and Tirrene Seas.

The model DMI_HIRHAM5 CTL also demonstrates the same distribution, but in this case the values are slightly higher. It presents a diminution in the Gulf of Genoa and quite notable increment of the cyclonic domain density in the Alboran Sea with values that oscillate around 1900 dom/cycl/dec. It also shows the decrease in the Adriatic and Tyrrenean Seas. There is a small decline (near 50 dom/cycl/dec) in the central Mediterranean.

Future Scenarios

The model C4IRCA3 A1B shows a varied increase of the values of the zones that have a high density of cyclonic domains, and at the same time, presents an important general decrease of density, especially in the diagonal between Catalonia and Malta, highlighting the more prone areas, in which Mallorca is included with values of 700 dom/cycl/dec. The Alboran Sea region mainly stands out for the increments that oscillate around 2100 dom/cycl/dec in concentrated areas, showing values up to 2500 dom/cycl/dec near the Strait of Gibraltar. Also, its area of cyclonic influence has grown in both expansion and recurrence drawing closer to the Balearic Islands and the Tunisian coast. It must be emphasized that the last decade is based on 9 years and not 10. Therefore, the values should be a bit greater, but not enough to produce changes in the expressed arguments (Figure 9).

The models KNMI_RACMO2 A1B show much more elevated minimum values and lower maximum values. The totality of the basin remains above 500 dom/cycl/dec except and in a slight way, the diagonal between Catalonia and Malta. The Alboran Sea shows an imperceptible decline of density but the Adriatic Sea presents a significant growth.

4. DISCUSSION AND CONCLUSIONS

The method of detection that was used for this work is applied as a tool for localizing most of the cyclones at synoptic scale in the region of interest, yielding acceptable but clearly improvable precision. Meteorological fields like the geostrofic vorticity and finer gradient criteria could improve the quality of the results, although the general picture of the results would presumably be similar. The method has been uniformly applied to the whole area.

To establish the cyclonic domains of all the detected centers, a condition has been included which eliminates the center with the highest geopotential height when there are two centers very close together, otherwise this would impede to capture in the results such particular type of cyclonic domains.

The number of cyclones that are detected is relative to the function of the cyclonic limit, established in domain filters, where the cyclones that have an inferior domain than the set limit, which in the present work is 50.625km2 (100 grid points in each domain), are eliminated. This margin was established after completing various tests because it does not modify the general tendency of the results and it eliminates a vast quantity of noise. Nevertheless, this constant should decline in accordance with the type of cyclone or derived structure that is intended for detection; in the case of detecting a Medicane, for instance, we would need to establish a domain not lower than 15.625km2 (36 gridpoints in each of the cyclone's domains) and not higher than 90.000km2 (169 gridpoints in each of cyclone's domains).

The problems that arrive with the diverse scenarios of some of the models during the production of the database and in other aspects have to be taken in to mind during future improvements of this technique, such as the extension towards more variables, so as not to leave the whole weight of the results on a sole model and relying on others that contain all the scenarios, which give a subjective view that reinforces the main model's hypothesis. This especially takes place in future scenarios where the same models do not have present scenarios thus making it statistically inappropriate to use the facts in an objective form and therefore stop having in any significant (numerical) weight in the study. However, they still demonstrate information elaborated with the same technique for a future scenario and the patterns involved support the results of the principal model, C4IRCA3.

In comparison with previous studies, above all *Picornell et al. (2001)*, the results that were obtained coincide very closely. The majority of the potentially cyclonic zones are independently located, even the ones that are excluded from the area of study above the terrestrial surface. Nonetheless, the study that has been referred to is based on the western Mediterranean.

There is no table available for the absolute values of the results because the area of calculation includes the totality of Figure 1 and the favorable values are contaminated by anomalies given outside of the area of study, as would be the case of the false maxima situated south of Turkey (Syrian coast).

Finally, in terms of discussion, we detect a problem in the most eastern part of the Mediterranean, where it is possible that the database has been damaged during the method or just that it hasn't been able to adapt in the most favorable way. In any case, it is an aspect worth checking and synthesizing in the future. Due to this, even though it appears in the area of study and on the maps, its waters are not mentioned in any moment, with the exception of the waters of Libya and in less form Turkey.

To conclude, the future tendency of the cyclonic centers in the Mediterranean Sea, as is shown on the present and future scenarios, is decreasing and therefore so is the contraction of the density in the zones which have at some point or another been in a cyclonic context. On the other hand, and even though this is true, there are key points or very recurrent points in which the majority increase their maximum absolute but at the same time, others slightly decrease it. As was mentioned previously, there is a cyclonic divergence with the minimums in the diagonal between Catalonia (Spain) and the canal of Sicily. While observing the maps, we can see an explosion of colors in the maxima.

The study shows how the density of the Alboran Sea grows in a noticeable way which in part comes from the rise of the cyclonic centers that occur in the western coast of Morocco and in the southeast of Spain. In the future they will mainly focus in the Gulf of Cadiz. This being the zone with the most potential that affects the Mediterranean without being in its influence, it will cause the area of the Alboran to increase its cyclonic domain status. It is also evident that the number of cyclones intensify along the coasts of Almeria and Malaga (Spain), the coast of Morocco and part of Algeria.

With the exception of the western Mediterranean (above all between the waters of the Balearic Islands and the south of France), the totality of this sea has declined in the numbers of cyclones for the future scenarios, in both the central and eastern Mediterranean.

Finally, the future scenarios show a basin with a lower number of cyclones, but a greater density that is contrasted by areas, many of them resulting in elevated values due to "hot points" in cyclonic centers that are few kilometers away from the Mediterranean coast. The model for the future KNMI-RACMO2 also shows a scenario that is proportionally similar to C4IRCA3 A1B, where it can be concluded that the Alboran Sea takes a protagonist role because it has a strong increase in cyclones. However, the remaining locations of the cyclonic centers close to the coast and more in the Western Mediterranean are strengthened and stand out because most of them reach the average of 45 cycl/dec in their maxima.

BIBLIOGRAPHY

R. Romero, 2001: *Sensitivity of a heavy rain producing Western Mediterranean cyclone to embedded potential vorticity anomalies*. Quart. J. R. Meteorol. Soc., 127, 2559-2597.

Jansa, A., Genoves, A., Picornell, M. A., Campins, J., Riosalido, R., and Carretero, O.: Western Mediterranean cyclones and heavy rain. Part 2: Statistical approach, Meteorol. Appl., 8, 43–56, 2001.

Font, I. Climarologia de Espafiay Portugal. Instituto Nacional de Meteo- rologia, Madrid. 1983.

Picornell, M. A., A. Jansa´, A. Genove´s, and J. Campins (2001*), Automateddatabase of mesocyclones from the HIRLAM-0.5 analyses in the westernMediterranean*, Int. J. Climatol., 21, 335– 354.

G. SUMNER, V. HOMAR and C. RAMIS. PRECIPITATION SEASONALITY IN EASTERN AND SOUTHERN COASTAL SPAIN. Int. J. Climatol. 21: 219–247 (2001).

Tous, M., and R. Romero. Medicanes: cataloguing criteria and exploration of meteorological environments. Tethys, 8, 53-61. 2011.

Tous, M., R. Romero. MEteorological environtments associated with medicane development.

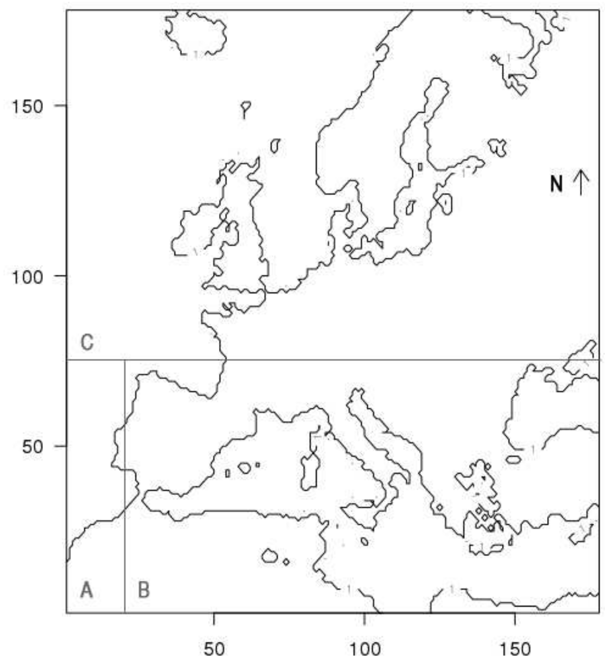

Figure 1. Area analyzed where "A" represents the area of the model C4IRCA3 (A+B); B represents the area of the models KNMI-RACM02, DMI-HIRHAM5 and SMHIRCA; C represents the area excluded from the study.

Fi

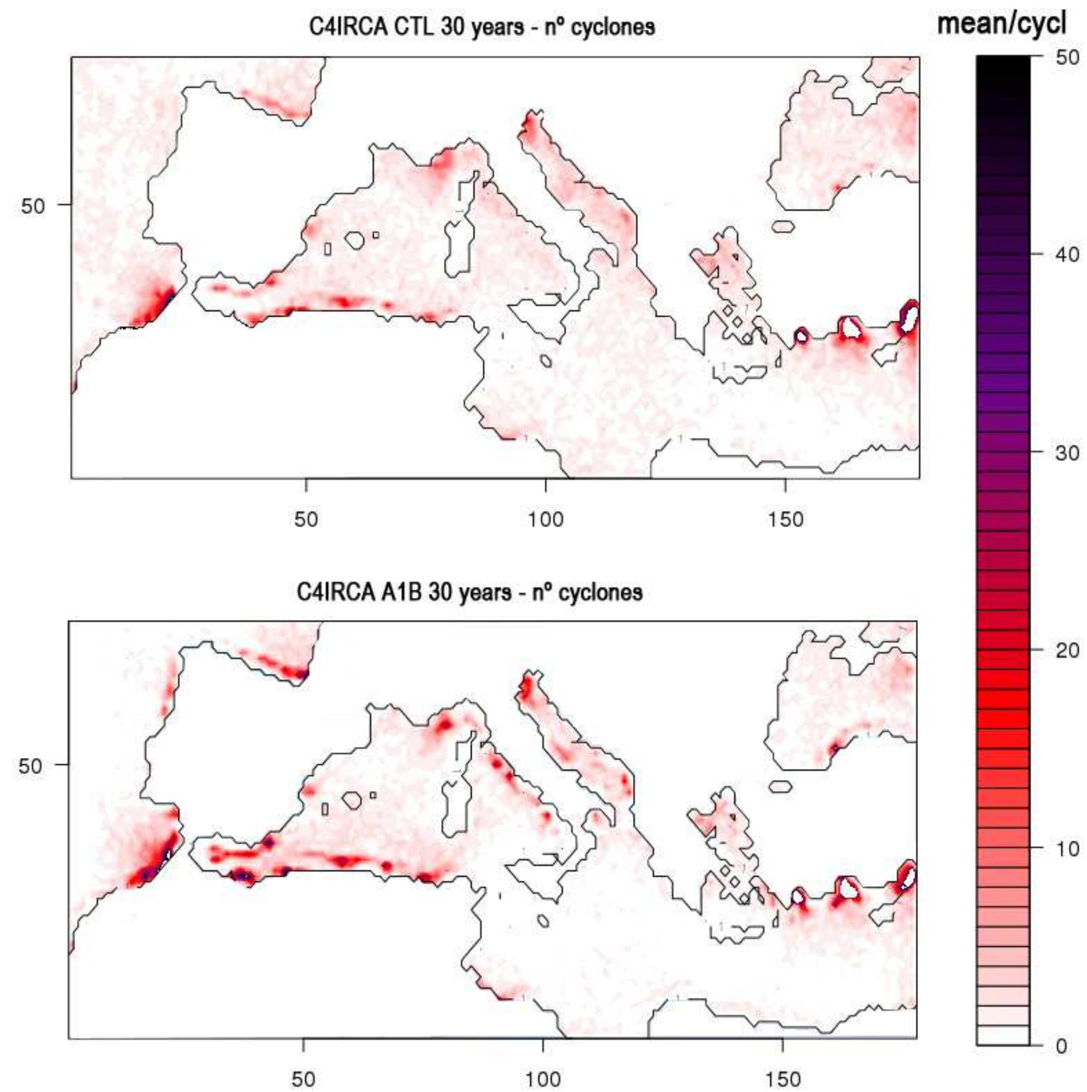

Figure 2. Number of cyclones for the present (1971-2000) and future scenarios (2071-2099) for the model C4IRCA3 based on 30 year cycles.

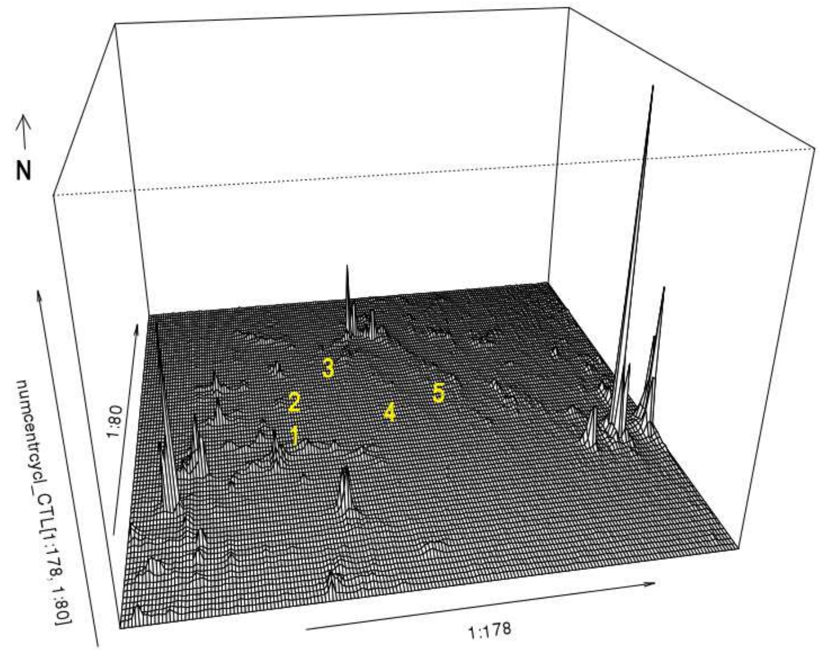

Figure 3. 3D perspective of the number of cyclones in the present scenario of the model C4IRCA3 in a 30 year cycle where: 1, Alboran Sea; 2, coast of Valencia (Spain); 3, the Gulf of Genoa; 4, the Tyrrenean Sea; 5, the Adriatic Sea.

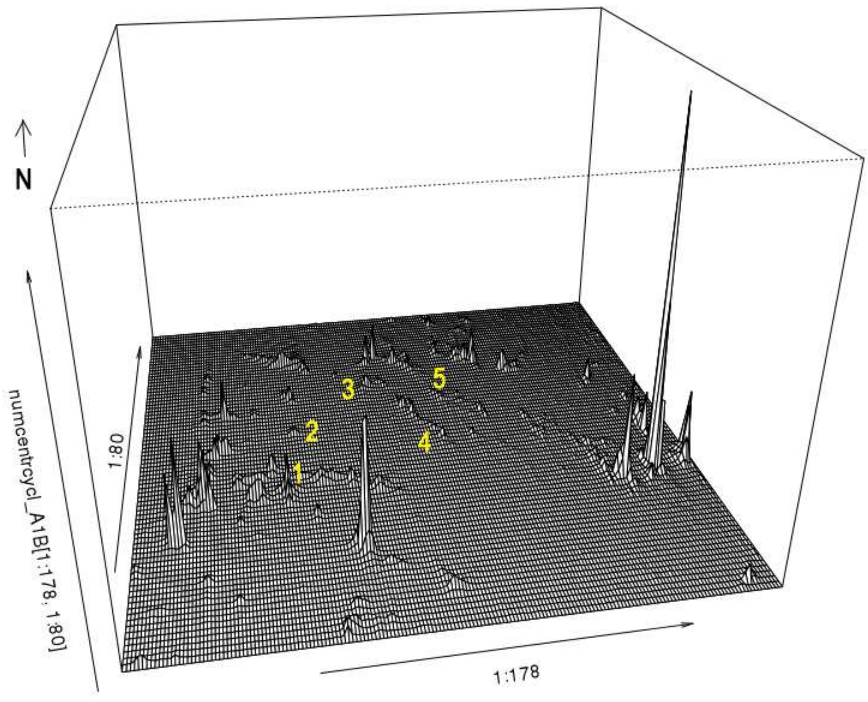

Figure 4. 3D perspective of the average number of cyclones of the future scenario for the model C4IRCA3 in a 30 year cycle, where 1; the Alboran Sea; 2, coast of Valencia (Spain); 3, Gulf of Genoa; 4, Tyrrenean Sea; 5, Adriatic Sea.

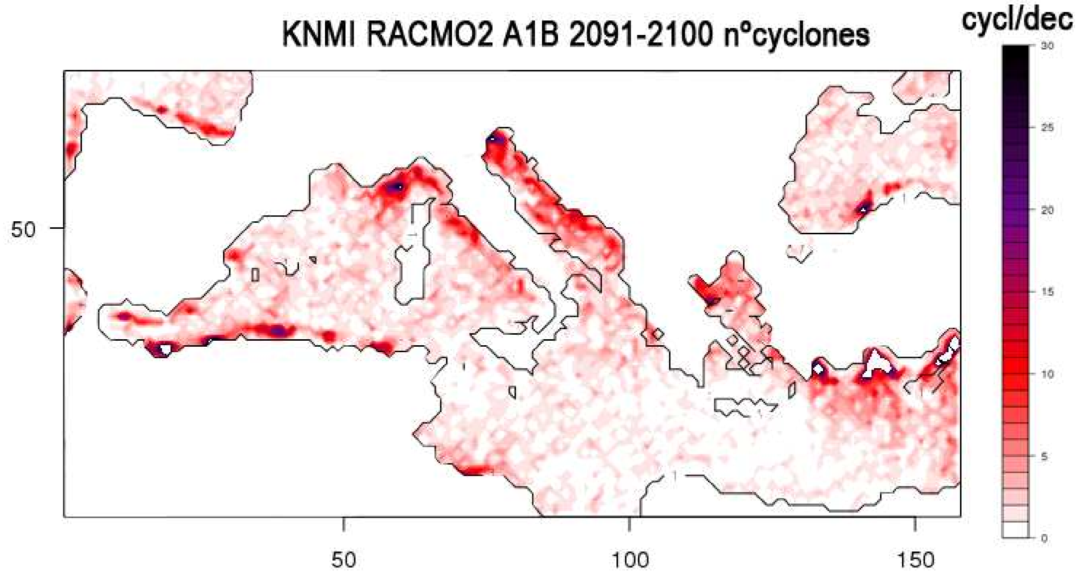

Figure 5.

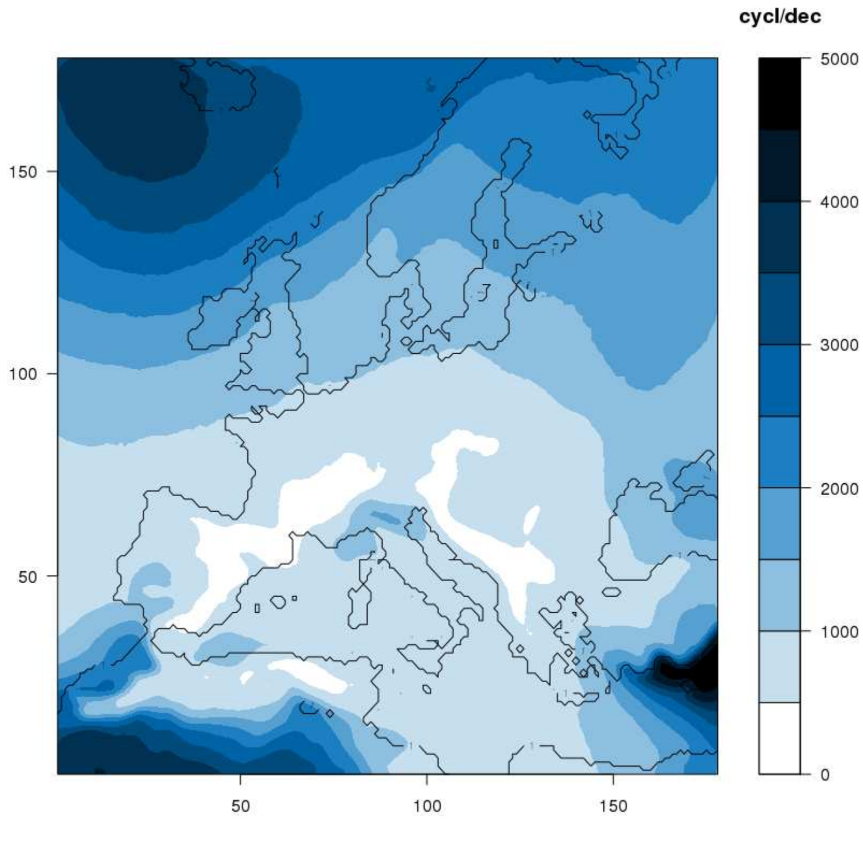

Figure 6. Map of cyclonic density. Model C4IRCA CTL 1971-1981.

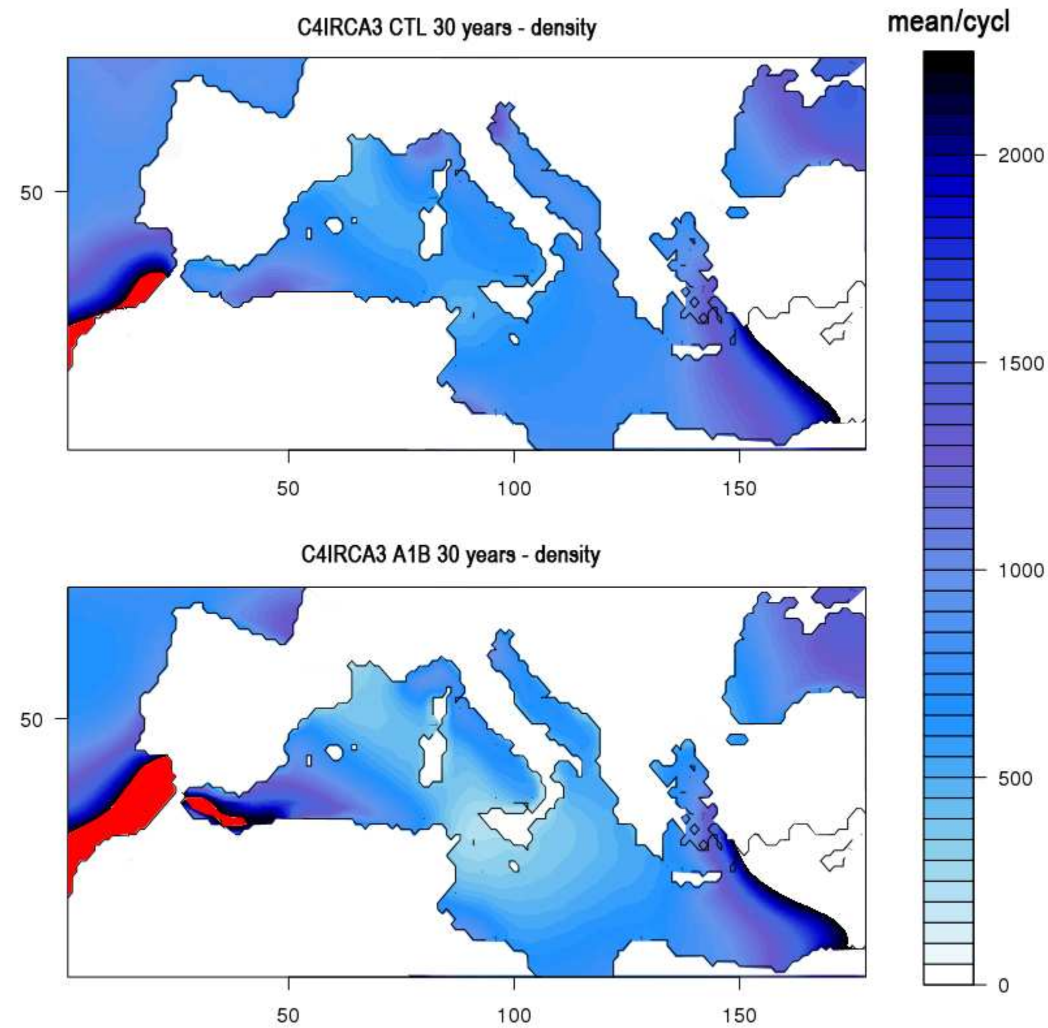

Figure 7. Maps for the average density of the present scenarios (1971-2000) and future (2071-2099) for the model C4IRCA3 based on 30 year cycles.

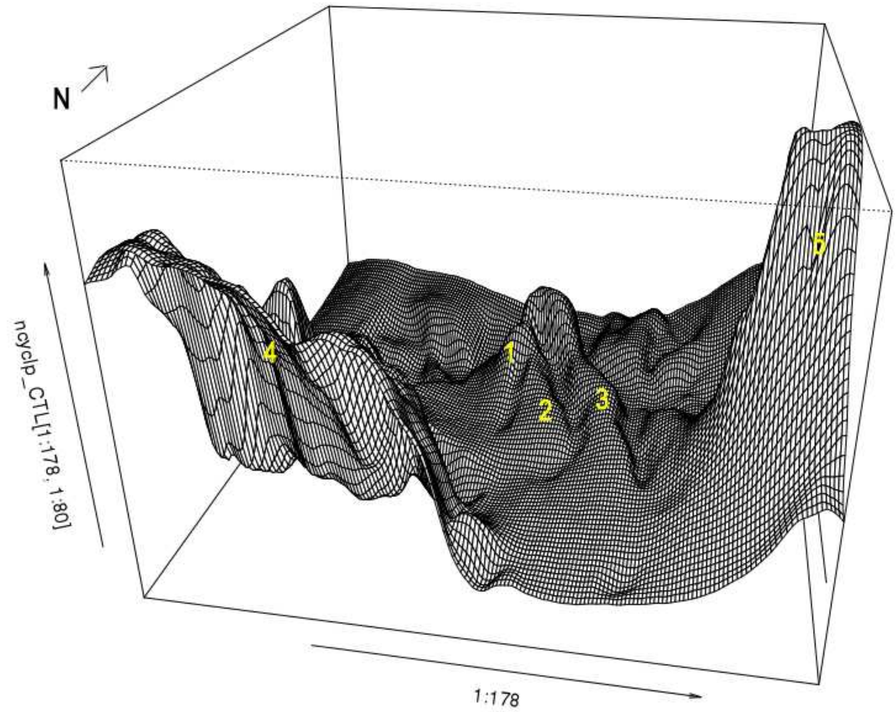

Figure 8. 3D perspective of the density in the cyclonic domain for the present scenario of the model C4IRCA3 in a cycle of 30 years, where 1; Gulf of Genoa; 2, Tyrrenean Sea; 3, Adriatic Sea; 4, densily cyclonic area of the Alboran Sea and south of the Spanish Peninsula; 5, Anomalies in Turkey.

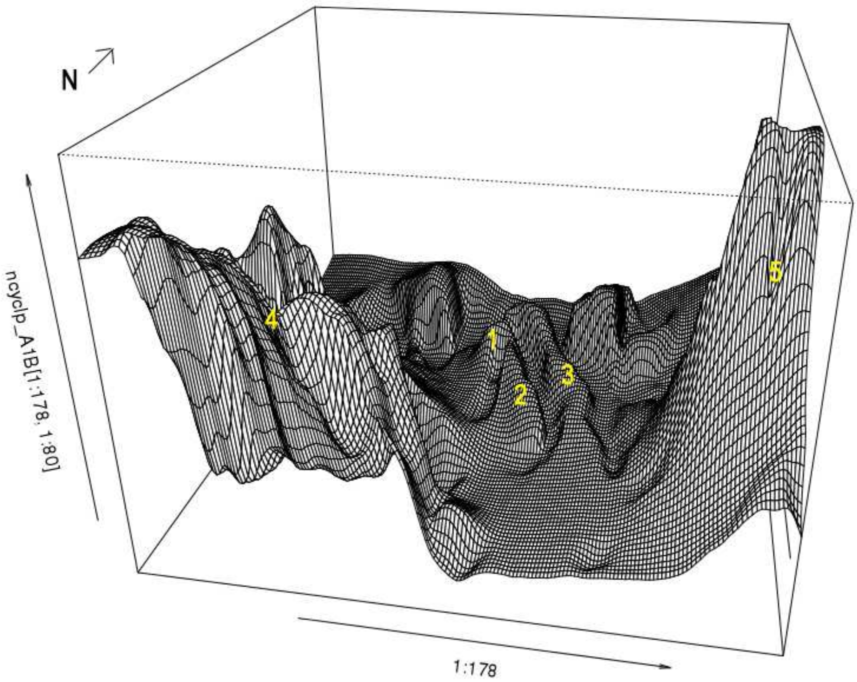

Figure 9. 3D perspective of the density in the cyclonic domain for the future scenario of the model C4IRCA3 in a cycle of 30 years, where 1; Gulf of Genoa; 2, Tyrrenean Sea; 3, Adriatic Sea; 4, densily cyclonic area of the Alboran Sea and south of the Spanish Peninsula; 5, Anomalies in Turkey.