



## RESEARCH ARTICLE

## Climate study of the Cyclonic Tracks over the Atlantic and Sahara Mediterranean Regions

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### Abstract

The tracks of cyclones generated over the Atlantic and Saharan Mediterranean regions have been studied using the SLP data from NCEP/NCAR reanalysis data set for the period of 1970 to 2011 over the winter half period (December to May). The distribution of generated Cyclones appears both of the eastern coast of USA and the extra-tropical region in Sahara as a main areas of the cyclone tracks.

The first principle mode of inter-annual variation of cyclone tracks were obtained by the Empirical Orthogonal Function (EOF) shows that, the winter half year is affected by two ant-correlated systems, one affected eastern coast of USA, while the second affected Saharan region. The first system is the mainly marked in winter season, while the second is mainly pronounced in Spring season.

The surface variation pattern associated with the first principle mode of cyclone tracks indicates that, more cyclone tracks accompanied larger deepening of low pressure systems at both of high latitude Atlantic Ocean, in winter, and at Saharan Mediterranean region, in spring. At the same time, the upper wind variation at 250hPa shows that, most of cyclone tracks, in winter, are accompany of the south and north shifting of the upper maximum wind at Atlantic and Saharan Mediterranean regions; respectively, while they are accompany of the strength of the upper wind at both regions, in spring.

The Explosive cyclone tracks confirm the results of the study, and show that, the numbers of the explosive cyclone tracks at winter are large, and deep, in spite of, the total numbers of cyclone tracks at spring are slightly larger.

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### Introduction

Cyclone activity represents an important measure of the state of the atmosphere. Cyclones of certain regions are closely related to its climate, and thus, the variability of the cyclones is one of the important key in the climate research. Information on the characteristics and paths of cyclones are important both in terms of understanding variations of local weather and for a characterization of climate.

Extratropical cyclones are one of the most important features of the climate of mid-latitudes. Their genesis occurs typically along the polar front, a hyper baroclinic zone between the warm subtropical air masses and the cold polar air masses stretching over the mid-latitudes of both hemispheres, Trigo et al. 2002 and Pinto, et al. 2009.

The origin of the Mediterranean cyclones, in wet months, comes from the North Atlantic synoptic systems (HMSO, 1962). Also, Mediterranean cyclones formed when upper air troughs interact with lower orography ( as in the cyclogenesis in the lee of the Alps, e.g., Buzzi and Tibaldi, 1978), and/or through the interaction with the northern Mediterranean low level baroclinicity ( as in the case of the cyclogenetic areas over the Aegean and Black Sea, e.g., Flocas and Karacostas, 1996; Trigo et al., 1999).

Obviously, the North Atlantic, located upstream of the Mediterranean region, has an important impact on the climate of the Mediterranean region, by, e.g., cyclones travelling into the Mediterranean region (Raible 2007), or

blocking events ( Martin et al. 2004), which prevent cyclones in the western part of the Mediterranean region and lead to polar intrusions further downstream in the eastern part ( Ziv et al. 2006). Other factors affecting the Mediterranean region are the north Atlantic Oscillation ( Jacobeit et al. 2003) and the west Atlantic-East Russia Oscillation (Krichak and Alpert 2005).

The main object of this work is the climate study of the cyclonic tracks and their associated synoptic features over the Atlantic and the Saharan Mediterranean regions through the half winter year period.

The paper is organized as follows: Data and methodology are outlined in the next section. In section 2 the distribution of the Tracks and their statistical study are described. The empirical orthogonal function analysis of the winter half year and its own seasons (winter and spring) are presented in section 3. While the climate of the synoptic features accompanies the cyclones tracks are studied in sections 4 and 5. The explosive cyclones as a case study are presented in section 6. Section 7 provides Discussion and Conclusion.

## 1- Data and methodology

### 1-1 Data

The data used in this paper for the winter half year through the period 1970-2011 are 6-hourly sea level pressure (SLP), horizontal wind at 250hPa, from the National Center for Environmental Prediction and the National Center for Atmospheric Research ( NCEP/NCAR ) re-analyses (Kistler et al. 2001 and Kalnay et al. 1996 ). The NCEP/NCAR SLP re-analyses are provided on a regular  $2.5^{\circ} \times 2.5^{\circ}$  latitude-longitude grid. The SLP data used to identify the cyclones and their tracks, which based on previous findings, for example, (Simmonds et al. 1999), that indicate the inclusion of the upper level data does not significantly change the structure of the identified tracks. Also, because other authors indicate that the SLP field can be used on its own for cyclone and track detection (Schink 1993; WASA 1998; Alexandersson et al. 2000; Gulev et al. 2001; Hoskins and Hodges 2002; Hannachi et al. 2011, and Almazroui et al. 2014).

Two separate areas were determined for the research. The area of cylogenesis, which represents the area of generating cyclones ( $15^{\circ}\text{N}-75^{\circ}\text{N}$  ,  $95^{\circ}\text{W}-35^{\circ}\text{E}$ ), and it contains; Atlantic and Saharan Mediterranean sectors. In other hand, for the climate study a much larger area ( $00^{\circ}\text{N}-85^{\circ}\text{N}$ ,  $100^{\circ}\text{W}-90^{\circ}\text{E}$ ) is used. The winter half year period defined by the months from December to May used as a period of study, which represents the period of the most intense storms affecting North Atlantic, Europe, and Sahara Mediterranean (cf. Klawa and Ulbrich 2003; Hannachi et al. 2011; and Almazroui et al. 2014).

### 1-2 methodology

The cyclone center is identified at a grid point if its SLP value is smaller than or equal to the value at each of its eight neighboring grid points, (Hannachi et al.2011; and Almazroui et al. 2014). The using of the coarse grid input data, gives a coarse resolution of results cyclone centers. Because the cyclone centers determined using the procedures will be located at the same grid points. This problem is solved by transforming the data to a finer grid (resolution of  $0.5^{\circ} \times 0.5^{\circ}$ , instead of the coarse resolution  $2.5^{\circ} \times 2.5^{\circ}$  ), before starting the identification procedure ( e.g. Alpert et al. 1990, Hodges 1994, Haak and Ulbrich 19996).

After a cyclone center is detected we track it for the next 6 hours using a Polygon containing 20 grid points (of resolution  $0.5^{\circ} \times 0.5^{\circ}$ ) surrounding the target grid point,(Hannachi et al. 2011; and Almazroui et al. 2014). The new center is used as a new target center for new search at the next 6 hours and a Polygon containing 20 grid points (of resolution  $0.5^{\circ} \times 0.5^{\circ}$ ) surrounding this grid point will used. If in the next three time steps, that is for duration of 18 hours, no cyclone center is detected, we will consider the track has terminated. A new track search begins using initial grid point that represented a new generated cyclone.

The total number of tracks detected using the previous procedure are 7818 tracks. But, to avoid spurious detections, a minimum lifetime of two days is required. It is found that the remaining tracks are 3044 tracks, represented a ratio of about 38.9% of total detected tracks, as shown in figure 1-a.

## 2- Tracks distribution and statistical study

### 2-1 Total tracks

The frequency of the cyclonic tracks passes through the study region are shown, figure 1-b. For Atlantic sector, the frequency of the cyclones increases with latitude, and with proximity to the USA east coast. As in Hydden (1981) the location of this frequency maximum coincides with the baroclinic zone separating the cold main land from the warmer ocean water, as pronounced at offshore.

Also, the figure shows that, the main cyclonic activity areas are concentrated along the east of the USA, to the northeast of Newfoundland and to the southeast of Greenland, where cylogenesis is concentrated (Dickson et al.

2000; Hanson 2004). It is worth to mention that, the distribution of the cyclonic tracks frequency similar to finding of (Rudeva and Gulev 2011).

In addition, the algorithm detects a maximum frequency of cyclonic tracks at lower extra-tropical region over Africa and Arabian Peninsula. Also, secondary areas were found over south of Libya and Egypt, east of Atlas mountain, as found at (Hannachi et al. 2011), and the west area parallel to the Arabian Gulf and over Pakistan and Northern India as found at (Wernli and Schwierz 2006).

Furthermore, the distribution of lifespan of cyclonic tracks, figure 2, indicates that most lifespan of the tracks (96% of all tracks with a minimum lifespan 48h) concentrated at six days, while a few number of tracks, 4%, stayed for a long time reached thirteen days, this result agree with the average duration 2.5 and 4.2 days for the cyclone and explosive cyclones; respectively, Trigo 2006.

For more details about the distribution of the tracks, we will divide the winter half years season into its own traditional seasons winter (December-February) and spring (March-May) seasons. The distribution of tracks at each season separately will describe in the following subsections.

## 2-2 Tracks of winter season

The cyclonic tracks of this season cover the period from December into February. The total number of tracks detected in this season are 3630 tracks, but the tracks of a minimum lifetime of two days are 1354 tracks, which represent a ratio of about 37.3% of total season tracks, as shown in figure 3-a. It is interesting to note that, a most cyclones in this season are concentrated in Atlantic region, while a few numbers of cyclones exist at Sahara Mediterranean region, which complies with (Ulbrich et al. 2009) that classified the Mediterranean region as a secondary cyclogenesis region.

## 2-3 Tracks of spring season

The total number 4188 tracks are detected in spring seasons (March-May) through the period from 1970 to 2011. But the tracks of a minimum lifetime of two days are 1690 tracks, represented a ratio of about 40.35% of total season tracks, figure 3-b. It is interesting to note that, most of cyclones in this season are concentrated in Sahara Mediterranean region, while relatively less number of cyclones exists in Atlantic region.

For more depth about the variation of the cyclonic tracks through the seasons, the statistical analysis of their distribution, using a root mean square error (RMSE), for the value departures from means for the tracks number at each grid points, will describe in the following subsection.

## 2-4 statistical analysis

The RMSE of the tracks of the winter half year, figure 1-c, show that, there are two areas of maximum variation. One located at the eastern coast of the USA with extension into the northeast to Europe. This area match with cyclogenesis area described by (Trigo IF 2006 and Pintto et al 2009). The other area cover the lowest extra-tropical region in the Africa and The Arabian Peninsula, inside the secondary area over the Sahara as mentioned on EOF analysis.

While, the variation of the cyclonic tracks of the winter season, figure 3-c, indicates that there is only one area of maximum variation. This area covers eastern coast of USA, with an extension into the northeast to Europe. The interesting point in this result is the existing of a secondary maximum region at Mediterranean, corresponds with the results of (Ulbrich et al 2009).

In the other hand, the variation of the spring cyclonic tracks, figure 3-d, indicates that there is only one area of maximum variation located over Africa and Arabian Peninsula, with an extension into Iran and Pakistan. While in this season the east coast of USA is represented as a secondary maximum region.

As mentioned on many studies (Wang et al. 2006b; Notaro et al. 2006; and Walter and Graf 2005), cyclones are related to large-scale patterns due to the influence of these patterns on their development, and conversely due to the cyclones' statistical and physical effects on the patterns. Under this consideration, we will study variation of the cyclonic tracks using an empirical orthogonal function analysis (EOF) of the value departures from means for the parameters. Then, study the relationship between EOF variation and SLP and upper wind at 250hPa.

# 3- Tracks variability (EOF) analysis

## 3-1 Winter Half Year Variation

The interesting feature appears from the distribution of the first EOF mode, figure 4-a, is the existing of two regions of ant-correlation coincide with those areas of maximum variation shown at RMSE analysis. Also, we noted that, the variation at the eastern coast of USA is stronger than that over Sahara.

This ant-correlation indicates that, there are two different atmospheric mechanisms, each of them affects separately at one of these regions.

In addition, the first principle component "PC" of the analysis, figure 4-b, shows two distinct periods. The first one from 1970 until 1997, in which there is, generally, an increase in the cyclones eigenvalue. Whilst, the eigenvalue decreases through the later period, that is from 1998 until 2011. Also it is shown that the years 1976, 1985, 1991 and 1996 have a maximum eigenvalues, while the years of 1977, 1987 and 2000 have the local minimum eigenvalues.

For more details, it will be better to divide the winter half season into own traditional winter and spring seasons.

### 3-2 winter variation

The first eigenvector mode of the EOF for winter season, figure 4-c, points into the existing of pronounced two neighbor regions of anti-correlations. They located at onshore and offshore of the USA, with high positive values at offshore. It is of interesting to note here, the disappearing of the Sahara area of a pronounced maximum value that has appeared in winter half year.

The first PC for the winter season, figure 4-d, indicates that, the most of the years have negative values. But, the years 1980, 1982, 1998, 2002 and 2007 have a relative maximum positive eigenvalue, and the years 1972, 1976, 1981, 1984 and 1991 have the local maximum negative eigenvalues.

### 3-3 spring variations

The first mode of eigenvector of the cyclones variation for the spring season, figure 4-e, displayed the dominant mode of the cyclones frequency with a maximum positive variation is located over African's tropical region, with an extension into Iran and Pakistan. Moreover, this area neighbored with a weak negative area beside the western coast of Africa. It is of interesting to note here that, the eastern coast of USA had a weak negative variation area. In comparing with the first eigenvector mode at winter half year, figure 4-a, we note that the positive value over Sahara at the spring season, is intensive while the negative value at east coast of USA is weakness.

The first PC of the spring season, figure 4-f, indicates that, the positive values are largest than the negative values, until 1995, while later the negative values become larger. However, we noted that, the years 1975, 1976, 1985, 1991, and 1996, have a largest maximum positive eigenvalues, while the years of 1977, 1987, 1999, 2000 and 2004 have a largest maximum negative eigenvalues.

The previous study indicated that the cyclone tracks over the Atlantic and Sahara Mediterranean regions are distinct from each other. Each one has own characteristics, for more details about the two regions, in the next two sections the climate synoptic features accompany the tracks will be analyzed.

## 4- Correlation of first PC mode with SLP and Upper wind at 250hPa

In this section, we will discuss the correlation relationship between the inter-annual variation of the tracks, as shown in "PC", and the inter-annual variation of both SLP and Upper wind over each grid inside the larger area of study.

### 4-1 Correlation for winter season

The correlation for the winter SLP, figure 5-a, displayed a high negative relationship over high latitude Atlantic Ocean, with a maximum core over eastern USA off shore. Further, the correlation shows a low negative relationship over the Mediterranean. The previous results can be interpreted as follows, the tracks number in winter season increases as the pressure over high latitude Western Atlantic Ocean decreases, or as the Ice-landing low pressure system over Atlantic region deepening.

In other hand, the correlation with winter upper wind, figure 5-b, shows a positive correlation over the mid-latitude zone. This positive zone has a highest core value over Atlantic Ocean and a secondary core over western Mediterranean. Also, this zone surrounded by two negative zones. The northern negative zone has a highest core over high latitude Atlantic Ocean, while, the south negative zone has a highest core value located over western Africa. This results show that, the upper wind variation at 250hPa are accompany with more cyclone tracks with its south shifting over Atlantic region, and with north shifting over Sahara Mediterranean region.

#### 4-2 Correlation for Spring season

At spring the correlation of variation of cyclone tracks and SLP, figure 6-a, shows a high negative relationship over Sahara Mediterranean region, with a maximum core over northern Africa offshore. Moreover, this relationship shows a relative low negative correlation over USA and high latitude Atlantic Ocean. This results can be interpreted as follows, the tracks number in spring season increases as the pressure over Sahara Mediterranean region decreases, or as the Saharan low pressure system over this region deepening.

Although, the correlation of spring cyclone tracks with upper wind, figure 6-b, is low, but a sequence of negative and positive correlation zones have been distinguished. In this distribution, the positive correlation zone located over mid-latitude. Three positive high cores could be distinguished, over Atlantic, western and northeastern Africa. At the same time, the cores of negative values exist at South Atlantic Ocean, Northern Mediterranean, and northern Middle East.

### 5- Composition of positive and negative years selected from the first EOF modes

In this section we composite SLP and Upper wind at 250hPa for the highest negative and positive five years appeared at the principle components (PC) of the EOF analysis of the tracks variation for both of spring and winter seasons.

#### 5-1 Composition study of winter season

The SLP composition of the negative years, figure 7-c, shows a connection between the Azores High, Siberian High and the atmospheric High pressure over the America, producing a belt of High belt systems. But this belt not appeared clearly at positive years composition, as shown in figure 7-a. Also, we notice that, the pressure on Azores High for the negative composition is larger comparing with that at the positive composition. At the same time, the trough of the Ice-landing Low system on the positive composition is shifted south to about 35°N comparing 40°N at negative composition.

The pressure difference between the positive and negative compositions, figure 7-e, shows that, the pressure at positive composition is less on both of High and low pressure systems. Where it is means that, the low pressure system in the positive years deeper than that in the negative years. Moreover, the difference reached its maximum over the area of maximum pressure gradient, as shown over Atlantic Ocean and Russia. Also, the difference shows that the pressure at the positive composition is larger over Africa and north western the study region.

Over Sahara the core of the maximum Upper wind at 250hPa is elongated and located at the north of the negative composition, figure 7-d, comparing with that at the positive composition, figures 7-b. While, in the Atlantic region, the orientation and the center of the core of the upper wind for the positive composition is relatively south and larger than those of the negative composition.

The difference between the two wind compositions, figure 7-f, shows that, two anti-cells of difference values appeared over the Atlantic region. The positive differences are at the south of the negative differences. Also, the difference indicates that, the negative value over African region make anti-cell with that positive difference over African Atlantic coast which emanating north eastward toward south east Europe. Where it is signifies that over African region the positive difference values are at the north.

#### 5-2 Composition study of spring season

The composition of SLP at spring season for the positive and negative years are shown at figures 8-a and 8-c; respectively. These compositions give two interesting points, first, the position of the low center at positive years, figure 8-a, is relatively south that for negative years, figure 8-c. Although, the minimum isobar value at both compositions is less than 1008hPa. The second point is that, the extension of the Azores High at positive years is to the west rather than that of negative years, but the maximum isobar values (greater than 1020hPa) is the same in both compositions. The situation at previous point provide a favorable condition for the low system over Sahara, at positive years, to extended northern than that for negative years.

In other hand, the difference of SLP between the two compositions, figure 8-e, shows a series of anti-cells over the study region. Over Atlantic region, the negative cell is larger and at the north of the positive cell. While, over Sahara Mediterranean region, the negative cell exists at the south, although, the values at the two cells are the same.

For, Upper wind at 250hPa, as shown in figures 8-b and 8-d, the core of the maximum wind over Sahara is elongated at positive years, as shown in figure 8-d, although the maximum value of both compositions is the same.

While over the Atlantic region we notice that the core of the maximum wind for the positive years is greater than that of the negative years, by about 10m/s. Also we noted that, center of the core at positive years is to the north of that for the negative years.

The difference between the two upper wind compositions, figure 8-f, shows that, two anti-cells of difference values over the Atlantic and Sahara regions. But, over Atlantic the positive differences is to the North, while, over Sahara region the positive difference values is to the south.

For more details, in the next section, we will study the tracks of especial cyclones systems, called explosive cyclones.

## 6- The tracks accompany with explosive cyclones

### 6-1 method and result tracks

The cyclones are classified as explosive cyclones when the central pressure changes, geostrophically adjusted to 60°N, varying from 28hPa (24h)<sup>-1</sup> at the pole to 12hPa (24h)<sup>-1</sup> at latitude 25°N, criterion of (Sanders and Gyakum 1980). Also, following this criterion the resulting critical rate, which they denote as 1 Bergeron, is defined as:

$$\frac{dP}{dt_{adj}} = \frac{dP}{\partial t} \frac{\sin(\varphi_{ref})}{\sin(\varphi)}$$

where  $\varphi$  is the cyclone latitude, and  $\varphi_{ref}$  is 60°N.

We select in this current study the critical rate of 15hPa (24h)<sup>-1</sup> for our area of interest, as selected in (Almazroui et al. 2014). The results of using the previous criteria for winter and spring seasons are shown in Figure 9-a, and 9-b; respectively. At the same time, the distribution of the explosive cyclones tracks per years, figure 9, indicate that, most of the winter cyclones are explosive, while few number of the spring cyclones are explosive. The number of the tracks selected depend on the previous criteria are, 587 and 255 tracks for winter and spring seasons; respectively. This result declares that, the number of the tracks in spring season is less than 50 percent of these are in winter season. The results can be explained by the existence of the thermal contrast in winter between the warm Gulf Stream water and the cold northern USA land that produces a favorable area for occurrence of the explosive cyclones, Trigo 2006.

The spatial distribution of the explosive cyclone tracks for winter and spring seasons, figures 10-a, and 11-a; respectively, indicates that, the Atlantic region is the region has the highest number of these types of tracks, in both of winter and spring seasons.

### 6-2 The composition of the winter explosive cyclones tracks

The compositions of the mean sea level pressure and the upper wind at 250hPa are calculated for the years of maximum number of explosive cyclones. Simultaneously, these years classified into positive or negative depend on their sign in its own "PC" of the first EOF mode for the season. The five positive years 1987, 1992, 2002, 2003, and 2010, and the five negative years 1975, 1986, 1989, 1997 and 2006 are selected for winter season. While, at the spring season, the selected five positive years are 1976, 1978, 1985, 1991, and 1996, while the five negative years are 1987, 1997, 2004, 2006, and 2007.

It is of interesting to know that, the discussion of the composition of the explosive cyclone tracks will concentrate on the difference between the positive and negative years. Because, the compositions of these years not give more information than those gotten from the total tracks compositions, except that, the pressure inside the lows and Highs is decreased and the High pressure belt is shifted south.

#### 6-2-1- The winter composition

The difference of SLP, figure 10-b, display a zonal belt of negative values with three deep centers, on the eastern USA coast, on the Western Europe coast, and over Russia. While relative low positive difference values are concentrated to the south and north east of the negative belt.

At the upper wind at 250hPa, figure 10-c, the difference produces a series of meridional negative, positive and negative values inside the stripe between 40°W to 20°W. This series indicates that, the positive difference (high wind) is to south over Atlantic region, while becomes at the north over Sahara and Mediterranean region.

### 6-2-2- The Spring composition

The difference of SLP, figure 11-b, declares two areas of positive differences, on the southern Atlantic region, and over Russia. Associated with this positive difference, the negative values are appeared at the northern Atlantic Ocean and over land on USA. Also, at the east of the Atlantic region, the negative region extends from Atlantic Ocean to the south for both Africa and Arabian Peninsula.

It is interesting to note that, the differences on the upper wind at 250hPa, figure 11-c, are similar to those at SLP, but in inverse sign, where the negative values of SLP are associated with positive values at the upper wind, and vice versa. Moreover, in this season the positive difference over Atlantic region is to north, while it is to south over Sahara Mediterranean region.

## 7- Discussion and Conclusion

Cyclonic tracks over Atlantic and Saharan Mediterranean regions have been studied using the SLP data from NCEP/NCAR reanalysis data set with transformed fine resolution  $0.5^{\circ} \times 0.5^{\circ}$ , for the winter half year over the period from 1970 into 2011. The cyclone center is identified at a grid point if its SLP value is smaller than or equal to the value at each of its eight neighboring grid points. After a cyclone center is detected, its track to the next 6 hours determined using a Polygon containing 20 finer grid points centered at the target grid point. The new center is used as a new target center for new search for the next 6 hours. If in the next three time steps, which are for duration of 18 hours, no cyclone center is detected, the current track terminated. A new track search begins using initial grid point that represented a new generated cyclone.

The total numbers of tracks detected are 7818 tracks. But, to avoid spurious detections, a minimum lifetime of two days is required. It is found that the remaining tracks are 3044 tracks, represented a ratio of about 38.9% of total detected tracks.

Furthermore, the distribution of lifespan of cyclonic tracks indicates that most lifespan of the tracks (96% of all tracks with a minimum lifespan 48h) concentrated at six days, while a few number of tracks, 4%, stayed for a long time reached thirteen days.

The statistical analysis of the result cyclonic tracks indicates that; there are two anti-correlation areas of cyclonic tracks, one over the eastern coast of USA and the second over the extratropical Saharan region. These two regions appear clearly on the first EOF mode and confirmed in the RMSE.

For more details about the distribution of the tracks, the winter half year season divide into its traditional seasons winter (December-February) and spring (March-May) seasons. It was found that, the total numbers of tracks detected in winter season are 3630 tracks, but the tracks of a minimum lifetime of two days are 1354 tracks, which represent a ratio of about 37.3% of total tracks. While, the total numbers of tracks detected in spring season are 4188 tracks; contain 1690 tracks of a minimum lifetime of two days, which represent a ratio of about 40.35% of total tracks.

Each season has studied separately, in which applies the EOF and RMSE on the tracks of the cyclones generated on the two regions. The result indicates that, the east coast of USA is the pronounced area of cyclones on the winter season, while the extratropical area in Sahara is the pronounced area of cyclones on the spring season.

For deep study for the cyclonic tracks we analysis the relation between the tracks and both of SLP and Upper wind at 250hPa.

In the winter season, while on the positive composition the Azores and Siberian Highs are separated, they are connected together, at negative composition, and formed, what is called, high belt system. This belt affected the orientation of the ice-landing low to become into the ocean at negative years, while it is oriented into land at positive years. Also, this situation allows the ice-landing low to extend more south at positive year.

In addition, at winter the position of the maximum core and the orientation of the upper wind above Atlantic region are southerly at positive years in comparing with that at the negative years. But, the core above Sahara Mediterranean region is elongated at positive years.

In the spring season, although the Azores High is located mainly over Atlantic region, it is relatively elongated to western Mediterranean on the negative years. In addition to the above, the Saharan low is more northerly extended at the positive years, but the ice-landing low has, generally, the same position and orientation at both compositions. Above the Atlantic region the upper wind is weak at negative years by 10 m/s than positive years value, although,

both of them are less than what are over Sahara Mediterranean region. Also, we notice that, the core of the maximum wind at positive years is elongated and higher than those at negative years.

To give deep view, the distribution of the tracks that has explosive cyclones is studied at each of the winter and spring seasons.

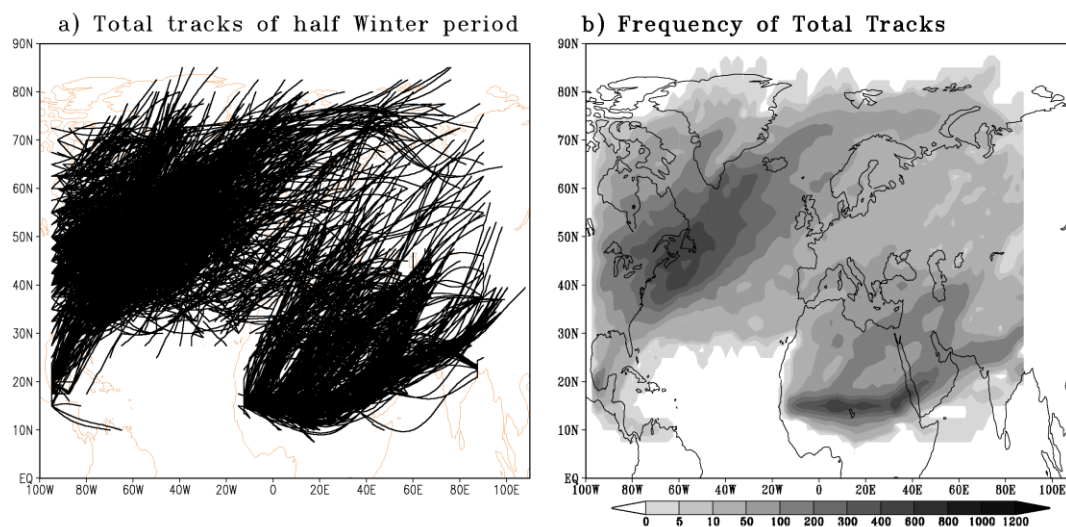
The study indicates that, the number of the explosive cyclones on winter season is larger than those on the spring season. Also, the number of explosive cyclones over Atlantic region is larger than those over Sahara Mediterranean region.

In addition to the above, the difference between the compositions of both of the SLP and upper wind for winter and spring seasons are studied. At winter, the difference of SLP compositions displayed a zonal belt of negative values surrounded by a relative low positive difference values. At the same time, the difference of the upper wind appeared a series of meridional negative, positive and negative values between  $40^{\circ}\text{W}$  to  $20^{\circ}\text{W}$ . Where these series indicates that, the positive difference is to south over Atlantic region and at the north over Sahara Mediterranean region.

At spring, the difference of SLP declared two areas of positive differences, on the southern Atlantic region, and over Russia. While the negative values displayed at northern Atlantic Ocean and inland at USA. In addition, at the east of the Atlantic region, the negative values extend toward the south of Sahara and Arabian Peninsula. In other hand, the differences on the upper wind appeared similar to those at SLP, but in inverse sign. Where the negative SLP values are accompany with the positive upper wind values, and vice versa. Moreover, in this season the positive difference over Atlantic region is to north, while becomes at south over Sahara Mediterranean region.

From above discussion we conclude the following:

- 1- We have distinguished two distinct seasons, winter (December to February) and spring (March to May) for the Tracks over the Atlantic and Saharan Mediterranean regions. Each one has own climate synoptic features.
- 2- The total number of tracks in spring season is larger than those in winter season, but the number of the explosive cyclones in winter season is larger than those in the spring season. Also, the number of explosive cyclones over Atlantic region is larger than those over Sahara Mediterranean region.
- 3- The Icelanding low and the Azores high pressure system over Atlantic Ocean are the climate systems that have a pronounced effect in the distribution of the cyclonic tracks at winter season, and it is associated with high wind at 250hPa pressure level. While the Siberian High and the Saharan low system are the climate system that have a pronounced effect at spring season, and it is associated with high wind at 250hPa pressure level over Sahara Mediterranean region. Also we note that, if the wind at 250hPa increases over the Atlantic region, with deepening on ice-landing low, the number of cyclonic tracks increase over Atlantic region in compare with Sahara Mediterranean region.



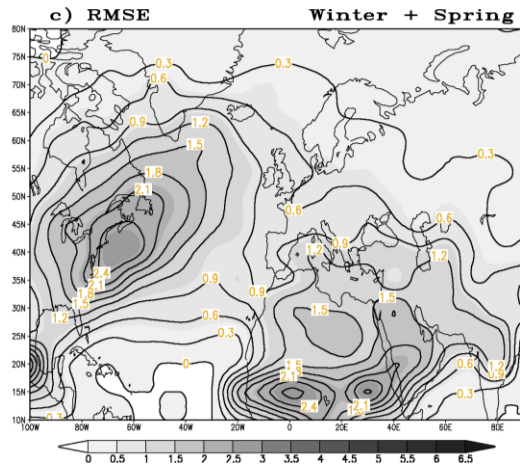


Figure 1 The totality of the identified cyclones for a) tracks for the winter half period of 1970-2011, b) density of cyclones as measured by the number of storms at each grid, and c) number of generated cyclones ( cyclogenesis area of cyclones), and c) variation of the cyclones; as measured from the Root Mean Square Error of each grid.

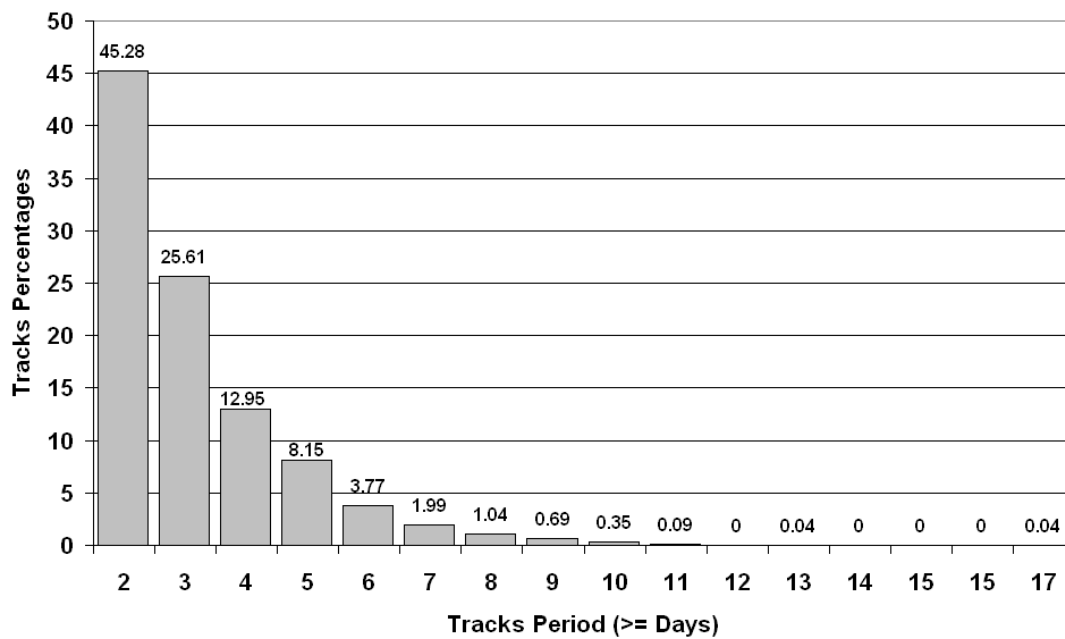


Figure 2 Number of cyclone tracks defined by longevity for all tracks.

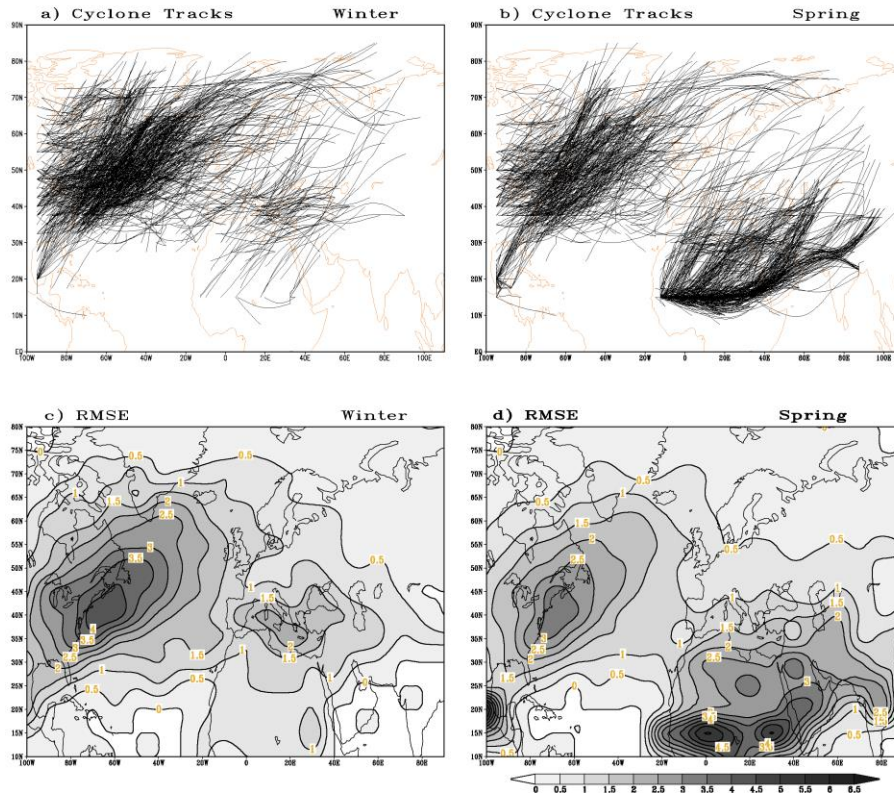


Figure 3 The totality of the identified cyclonic tracks for the period 1970-2011 for a) Winter season, b) Spring season, c) variation of the cyclones in winter season, and d) variation of the cyclones in spring season.

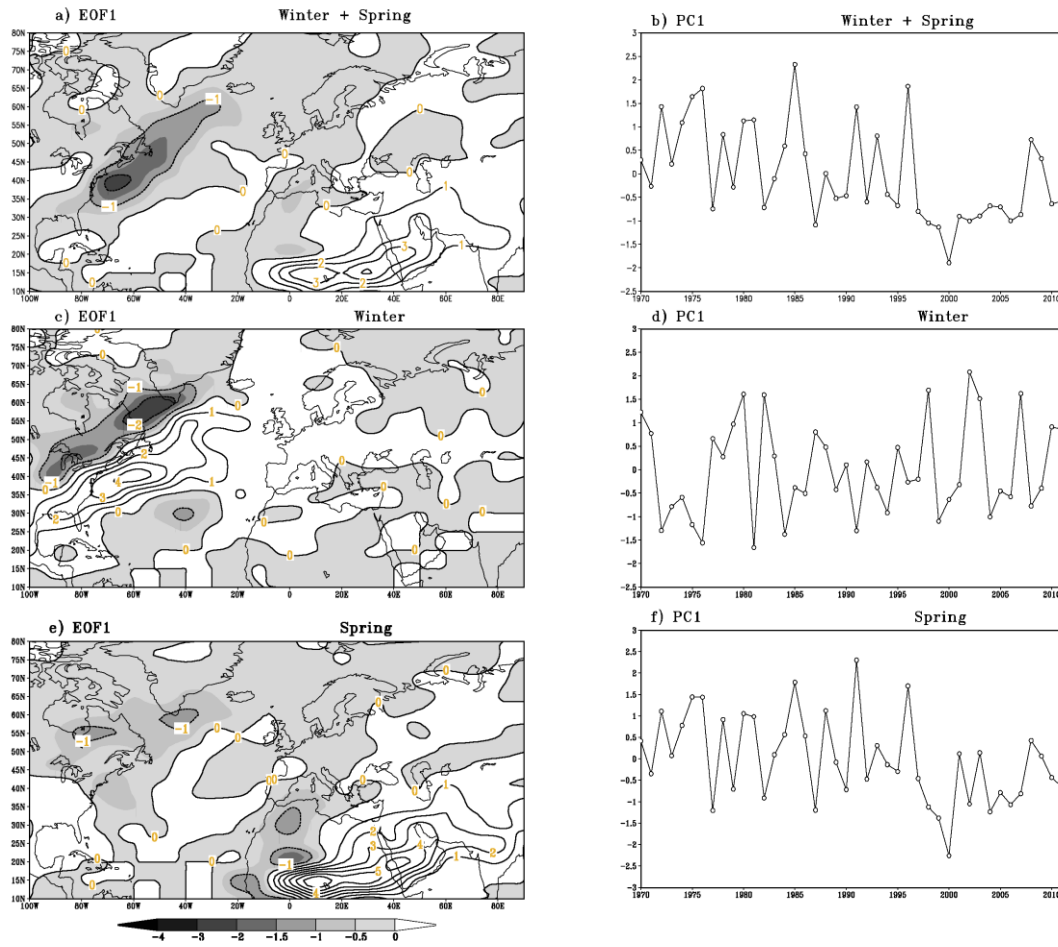


Figure 4 the distribution of the first empirical orthogonal function analysis of the tracks of a) winter half period, c) winter season, and e) spring season, and the distribution of the first principles component analysis of the tracks of b) winter half period, d) winter season, and f) spring season.

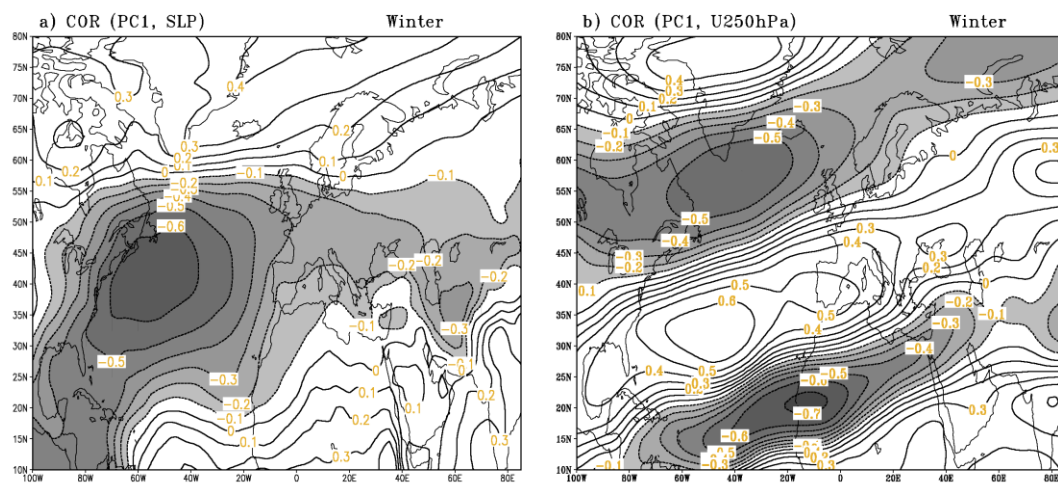


Figure 5 the correlation coefficient between the first principles component analysis (Pc1) of winter season and the variations of winter total tracks and a) winter SLP, and b) winter upper wind at 250hPa.

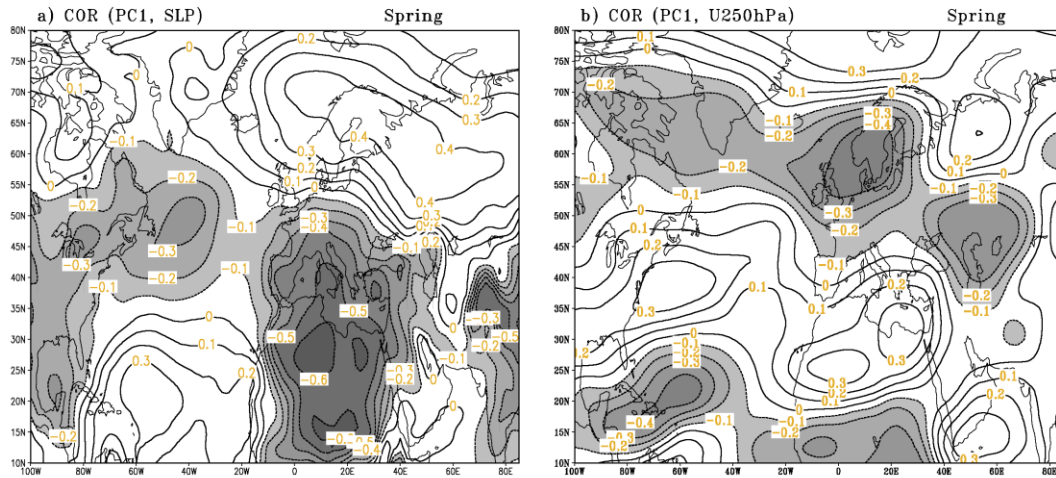


Figure 6 the correlation coefficient between the first principles component analysis (Pc1) of spring season and the variations of spring total tracks and a) spring SLP, and b) spring upper wind at 250hPa.

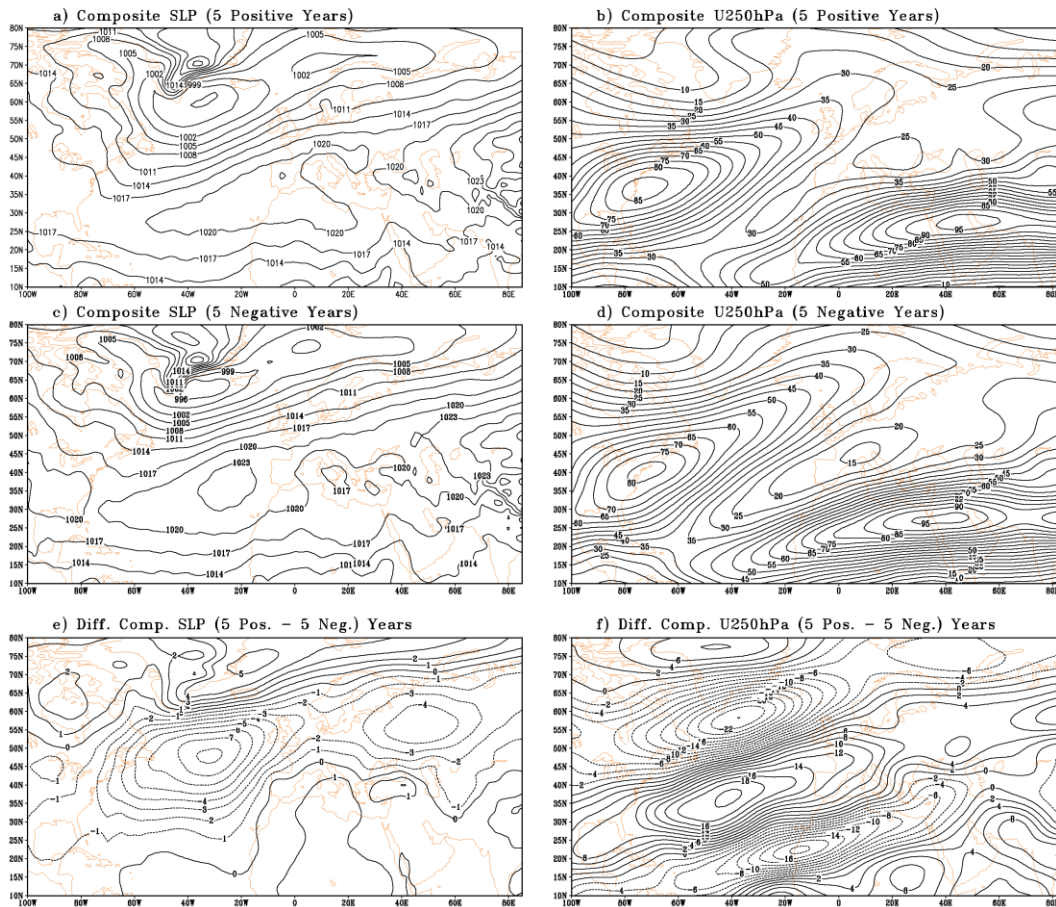


Figure 7 (a) and (c) The SLP compositions, (b) and (d) the upper wind at 250hPa compositions; of the maximum positive and negative five years for winter season; respectively, e) the difference between the positive and the negative SLP compositions and f) the difference between the positive and the negative upper wind compositions.

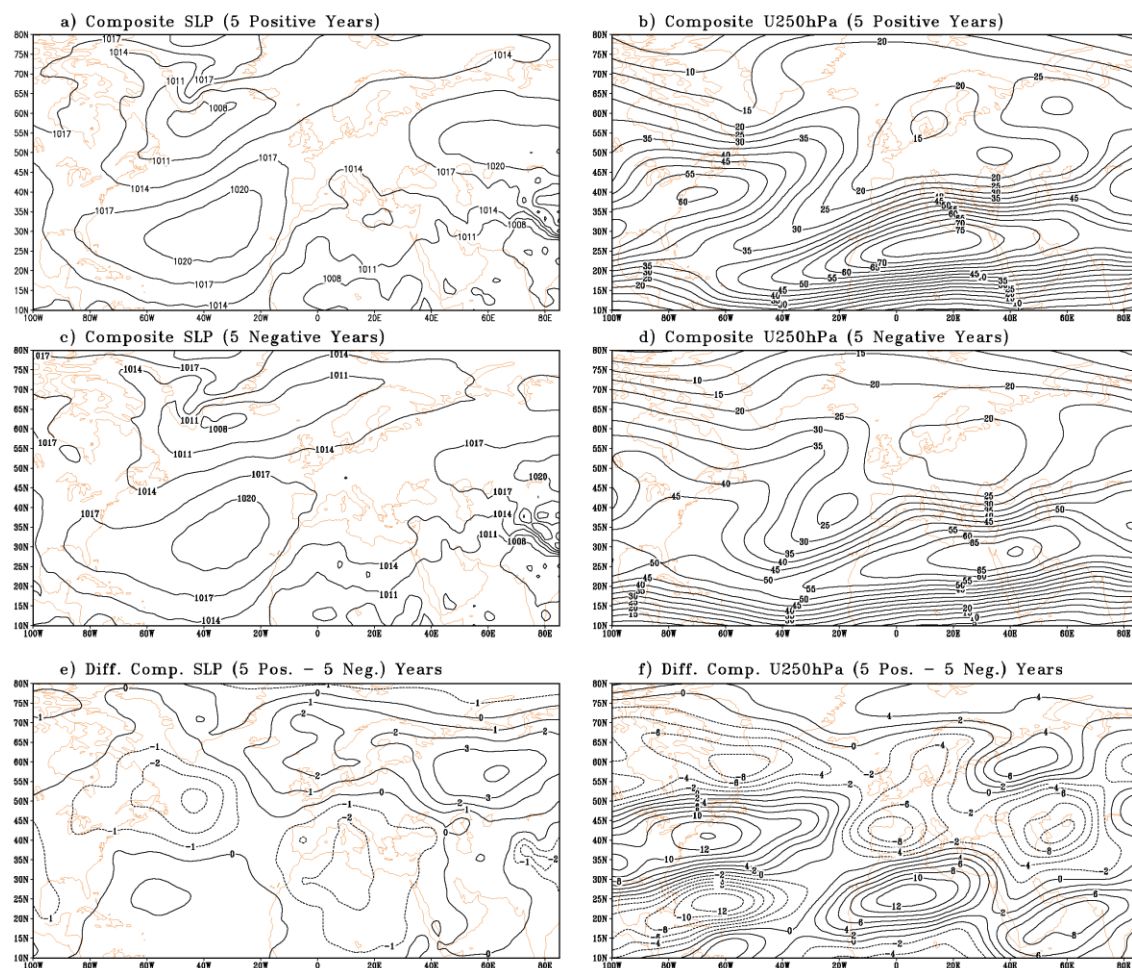


Figure 8 (a) and (c) The SLP compositions, (b) and (d) the upper wind at 250hPa compositions; of the maximum positive and negative five years for spring season; respectively, e) the difference between the positive and the negative SLP compositions, and f) the difference between the positive and the negative upper wind compositions.

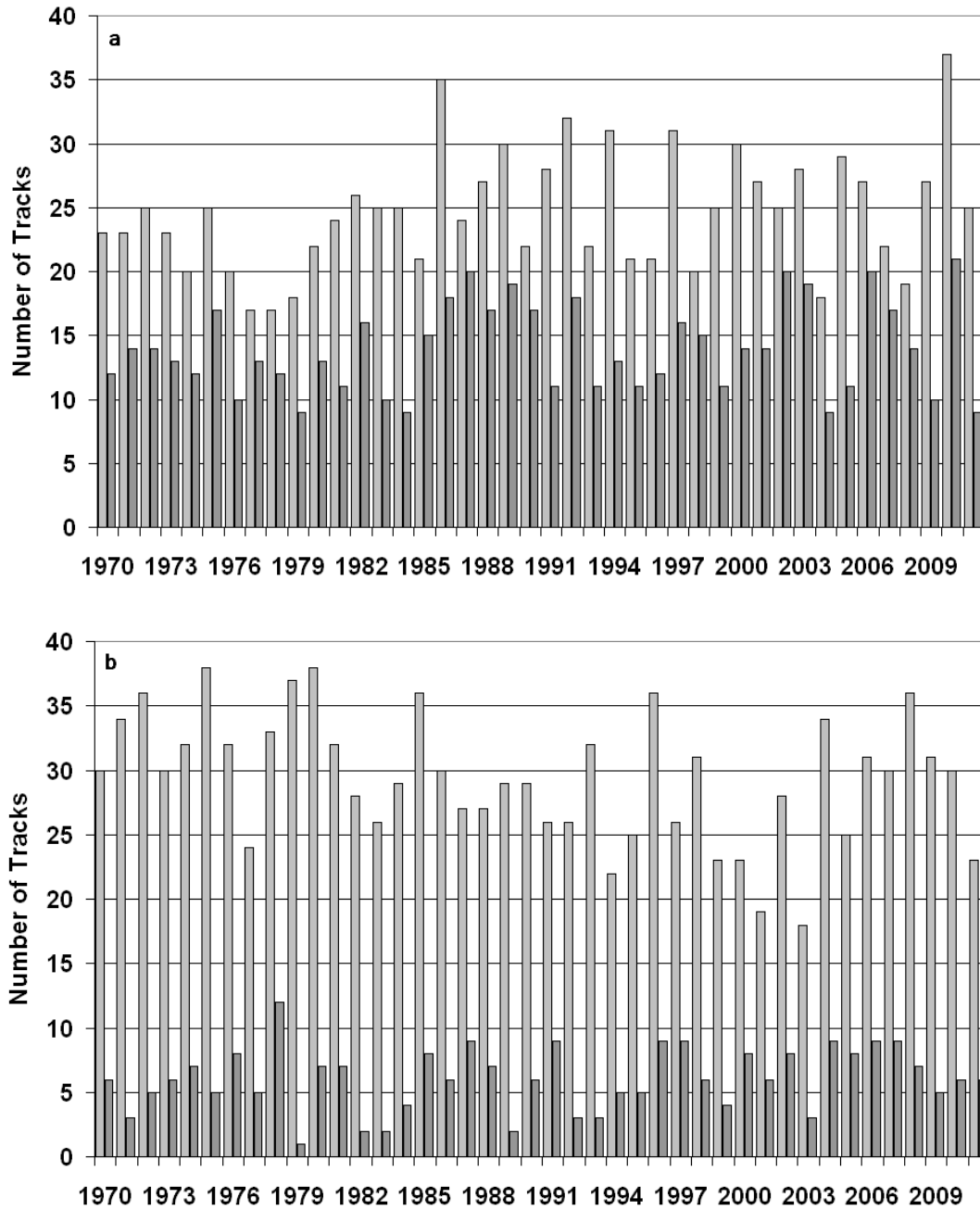


Figure 9 Yearly distribution of total (grey column) and explosive (dark grey column) tracks for a) winter and b) spring seasons.

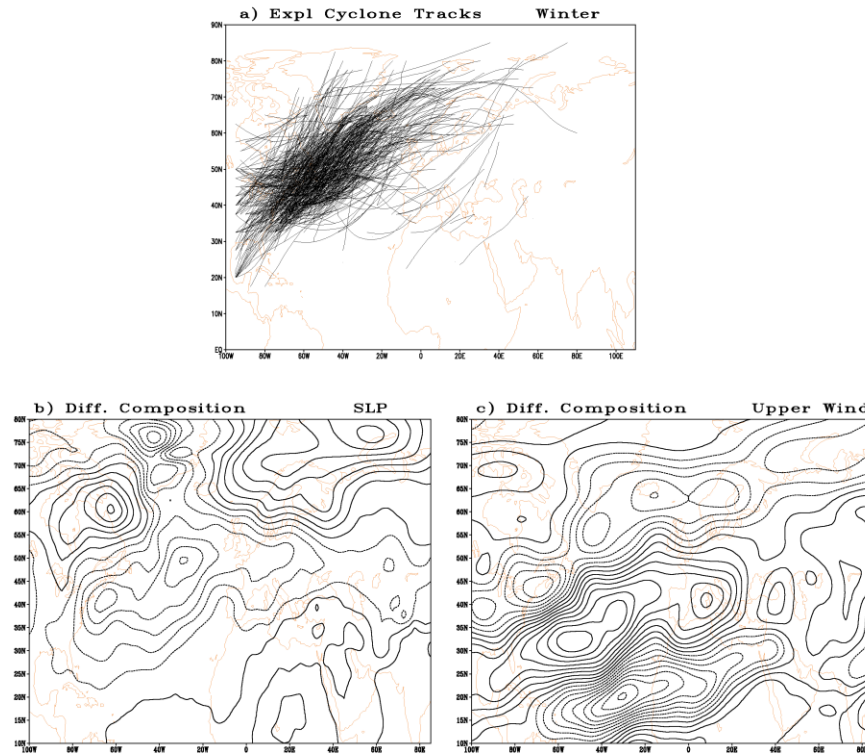


Figure 10 (a) the horizontal distribution of the winter explosive tracks, b) the difference between the positive and the negative SLP compositions, and f) the difference between the positive and the negative upper wind compositions for explosive cyclones tracks in winter season.

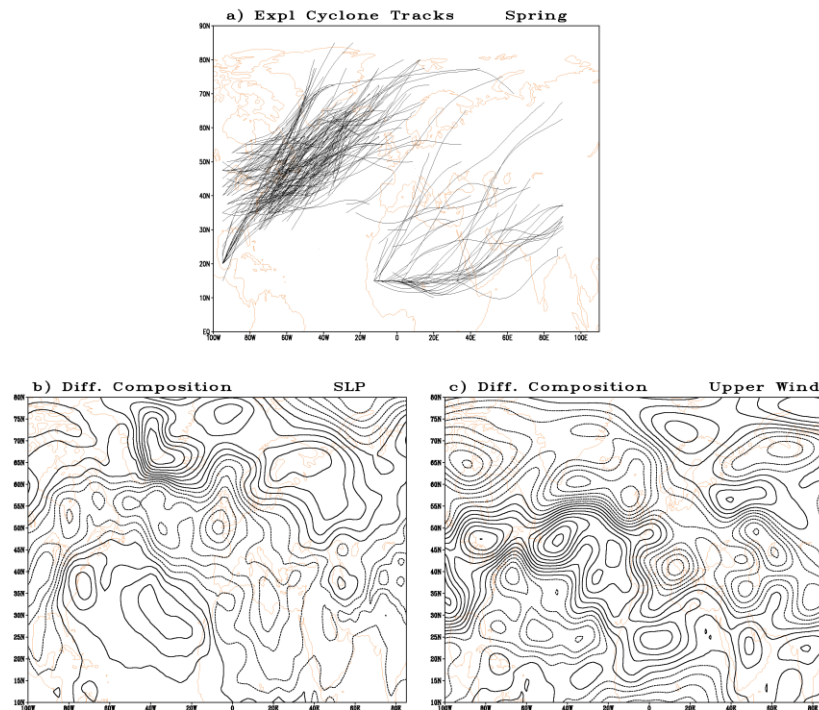


Figure 11 (a) the horizontal distribution of the spring explosive tracks, b) the difference between the positive and the negative SLP compositions, and f) the difference between the positive and the negative upper wind compositions for explosive cyclones tracks in spring season

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