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Full Length Research Paper

Overview of synoptic conditions over West Africa and North Atlantic before cyclogenesis

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The objective of this study is to describe the large scale conditions over West Africa and the Atlantic Ocean before the occurrence of a cyclogenesis over the North Atlantic by comparing synoptic conditions of a 3 day average before the genesis days of all cyclones (269 cyclones given by the National Hurricane Center; NHC) with the mean Aug-Oct climatology from 1980 to 2004. Over West Africa, the mean synoptic pattern before cyclogenesis is characterized by the presence of a stronger monsoon layer and lower values of Outgoing Longwave Radiation than the climatology depicting the presence of deeper convection. Moreover, the potential of genesis is stronger before cyclogenesis over the West African coast than the climatology showing that strong low-level cyclonic vortices propagate from land to ocean in an atmosphere characterized by strong upper level support. Generally, before the occurrence of a cyclonic activity, the atmosphere is more unstable and African Easterly Waves are more active over West Africa than the climatology. Over the Atlantic Ocean, large scale conditions before cyclogenesis are characterized by the presence of high cyclogenesis contributors such as warmer waters, lower pressure, stronger mid-level humidity and higher degree of atmospheric instability.

Key words: African easterly waves, cyclogenesis, African monsoon.

INTRODUCTION

Gray (1968, 1979) suggested that there are some necessary but not sufficient conditions for the initiation of a cyclonic activity over the North Atlantic. Warm waters (at least 26.5°C) are needed to heat the full engine of the cyclone. An atmosphere with moist mid-layers, which also cools fast enough with the height, is necessary to promote deep convection. A non-negligible amount of Coriolis force (a minimum distance of at least 500 km from the equator) is required to generate cyclonic spiralling. Low values (less than 10 m s) of vertical wind shear (VWS) between the surface and the upper troposphere are also necessary to organize deep convection. To develop, a North Atlantic Tropical Cyclone (TC) needs a precursor; African Easterly Waves (AEWs) are known to initiate most TCs over the North Atlantic (Carlson, 1969; Avila et Pasch, 1992; Burpee, 1972; Landsea, 1993; Chen et al., 2008; Thorncroft and Hodges, 2001; Ross and Krishnamurti, 2007; Berry et al., 2007).

The AEWs originated from the mixed baroclinic - barotropic instability of the African Easterly Jet (Burpee, 1972) and propagate westward with a period of 3 - 5 days and a wavelength of 3000 km (Burpee, 1972; Diedhiou et al., 1999). Their associated cyclonic vortices usually propagate along two tracks over West Africa (North and South of the African Easterly Jet; AEJ) that merge to become one track over the North Atlantic Ocean (Pytharoulis and Thorncroft, 1999; Diedhiou et al., 1999). AEW are known to modulate West African daily rainfall including mesoscale convective systems (Payne and McGarry, 1977; Fink and Reiner, 2003). The AEJ is a region of strong winds which results from the temperature contrast between the cool low-levels wind flow from the Guinea Gulf and the hot Saharan desert air (Burpee, 1972)

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and it extends from Lake Chad to Cap Verde and between 850 hPa and 500 hPa during the boreal summer.

A TC is a non-frontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection and specified cyclonic surface wind circulation (Holland, 1993). Landsea (1993) noted that only 60% of North Atlantic tropical storms and minor hurricanes originated from AEWs but nearly 85% of the intense (or major) hurricanes have their origins as AEWs. Tropical storm (respectively hurricane) is a TC in which the maximum sustained wind speed ranges from 17 m/s to 34 m/s (respectively greater than 34 m/s). Intense hurricanes are defined as those TC with maximum sustained wind greater than 50 m/s during some part of their lifetimes (Hebert and Taylor, 1978).

In this study, large scale conditions over West Africa and the Atlantic ocean before the occurrence of a cyclogenesis over North Atlantic are investigated by comparing the main synoptic conditions of a 3 day average before the genesis days of all cyclones (269 cyclones between 1980 and 2004) with the climatology.

The data (NHC Best Track Archives, Sea Surface Temperature, Outgoing Longwave Radiation and NCEP/NCAR reanalysis data) used in this study are presented in section 2. A composite study is performed in section 3 in order to detect large scale conditions before a cyclogenesis that is associated with the West African monsoon, the convection and the African Easterly Waves. The same study is done over the North Atlantic in section 4 in order to depict conditions over the Main Development Region before a cyclogenesis. A conclusion is put forward in section 5.

DATA AND METHOD

The Atlantic basin tropical cyclone "best track" data are provided by the United States Tropical Prediction Center / National Hurricane Center (NHC) based on six hourly positions and intensities of all tropical cyclones having reached a storm status. The genesis day of a cyclone corresponds to the first position in the NHC "best track". Daily reanalysis data of the National Center for Environmental Prediction/National Center for Atmospheric Research reanalysis project (NCEP/NCAR) for the 1980 - 2004 period are used (Kalnay et al., 1996; Kistler et al., 2001) to conduct the composite study.

Sea Surface Temperature (SST) data are obtained from the high resolution data set of Reynolds and Smith (1995). The data are derived from an optimal interpolation of *in situ* ship and buoy data supplemented by satellite SST retrieval on a 1° grid spacing.

Outgoing Longwave Radiation (OLR) data from NOAA (National Oceanic and Atmospheric Administration) are used to evaluate deep convection through low values (Grueber and Krueger, 1974). The composite study performed here is an average of atmospheric and sea surface features over West Africa and the Atlantic Ocean during 3 days before the genesis of all cyclones (269 cyclones from the NHC archives). The use of 25 years (1980 - 2004) of data allows us to have a large sample (269 cases) which is necessary for obtaining solid results.

This composite is compared to the climatology made with the average from August to October (the peak of Atlantic hurricane season) in the 1980 - 2004 periods. The locations of genesis of all the cyclones (named storms) are plotted on Figure 1 (top). Cyclogenesis generally occurs along two axis, one is between 10°N - 15°N in the Main Development Region (MDR) and the second is located around 25°N. The MDR is the Atlantic Ocean region that lies between 10°N and 20°N and corresponds to the main cyclonic activity area over the North Atlantic (Goldenberg and Shapiro, 1996). Figure 1 (middle) shows that the Southern genesis axis is located in the same region as the maximum of the relative cyclonic vorticity at 850 hPa and the similarity in longitudinal extension suggests that Atlantic TCs generated in this region may come from African Easterly disturbances.

The Northern axis is probably due to upper level cold lows and baroclinic disturbances of subtropical latitude which can change into tropical storms (Fitzpatrick et al., 1995; Hess et al., 1995; Avila et al., 2000; Franck, 1975). Figure 1 (bottom) shows that the so-called Major hurricanes genesis regions (by the NHC) are generally situated in the MDR suggesting that these TCs are well linked to African climate features. These results are consistent with the conclusions of Landsea (1993) who suggested that 60% of Atlantic TCs are of AEW origins, but nearly 85% of major hurricanes originated from AEWs. These major hurricanes are of critical importance because they are responsible for 80% of human and material losses caused by TCs over the Caribbean regions and the East coast of the United States (Landsea, 1993).

LARGE SCALE CONDITIONS BEFORE CYCLOGENESIS OVER WEST AFRICA

A composite study is performed to detect large scale conditions before cyclogenesis associated with the West African monsoon, the convection and the AEWs. Figure 2 (top) shows that low–level monsoon flow (wind field at 925 hPa) extends more northward over land than the climatology. The monsoon flow advects over West Africa the humid air necessary for the development of convective activity. This means that favourable conditions for upstream cyclonic activities are present over West Africa before North Atlantic cyclogenesis. This assertion is confirmed by the presence of lower values of OLR both in the continent and in the ocean suggesting that convection before cyclogenesis is deeper than the climatology (Figure 2; bottom). We verified also that the African Easterly Jet (AEJ) is well defined and extends further over the North Atlantic before cyclogenesis (figure not shown). The Tropical Easterly Jet (TEJ) before a cyclogenesis is also stronger than the climatology (figure not shown). These characteristics of AEJ were noted by Bell et al. (2004) as one of the favourable contributors to the high cyclonic activity of the 2003 hurricane season.

The genesis potential (GP) has been computed according to Karyampudi et Pierce (2002) who used the following formula:

$$GP = \xi_{925} - \xi_{200} \quad (1)$$

Where ξ_{925} and ξ_{200} are respectively relative vorticity at 925 hPa and 200 hPa. Cyclogenesis over the Atlantic Ocean are favoured by high values of low-level cyclonic vorticity and strong upper level anticyclonic vorticity. Thus, high values of GP are necessary for the genesis of

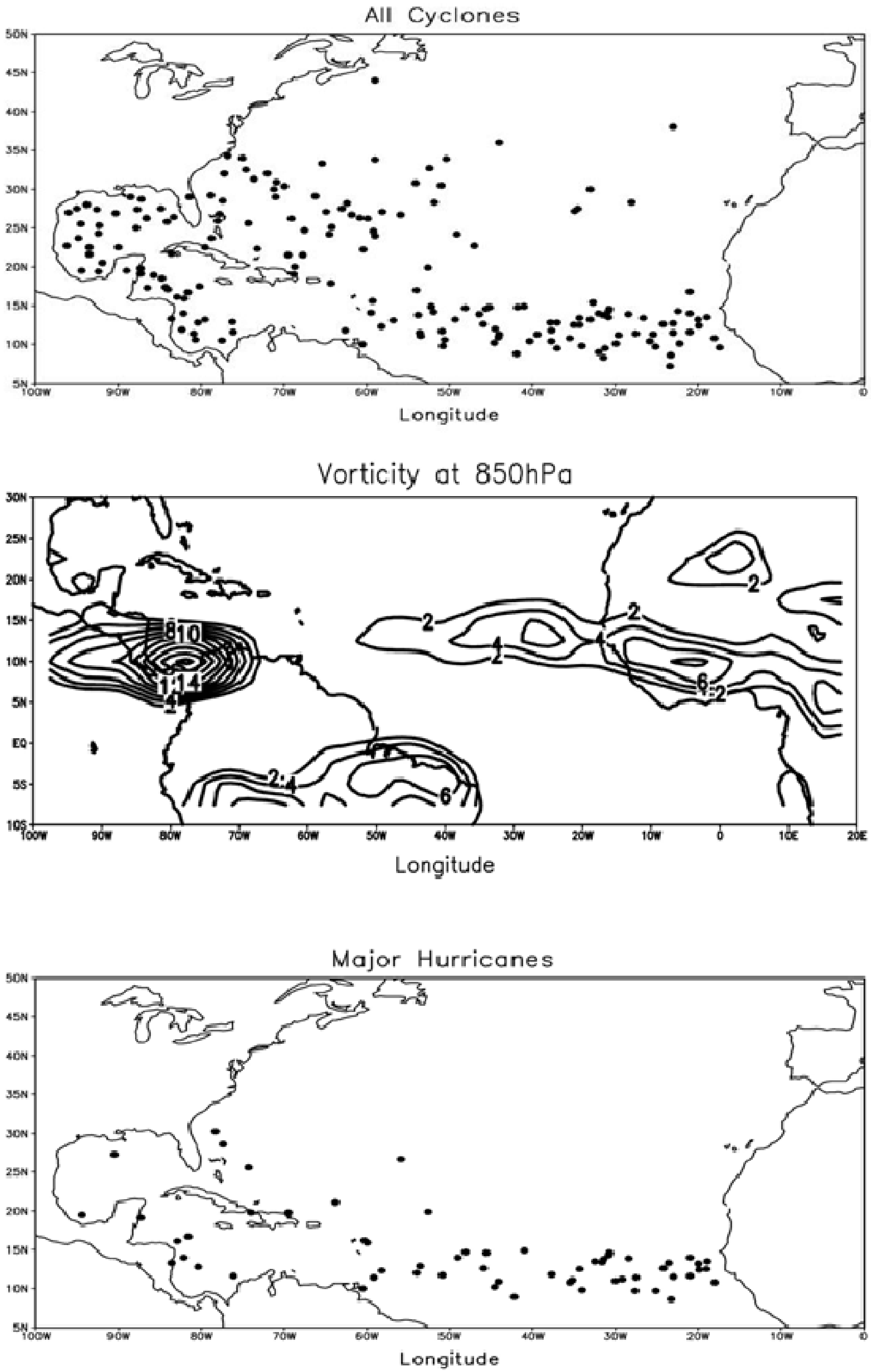

Figure 1. Genesis location of all named Atlantic TCs (top), relative vorticity at 850 hPa before cyclogenesis (middle) and genesis location of all major hurricanes (bottom). Unit is $10^{-6}s^{-1}$ for relative vorticity.

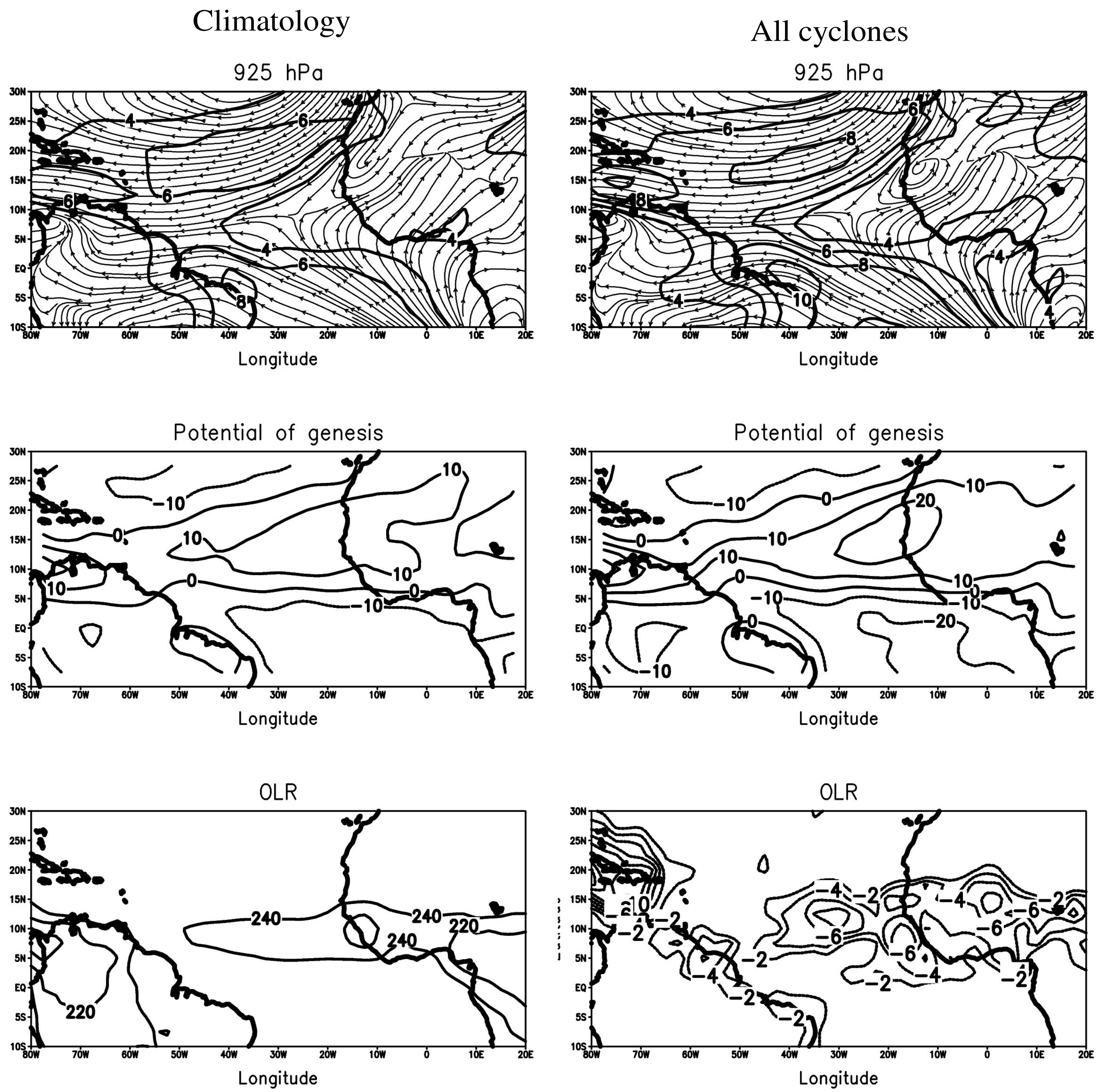

Figure 2: Streamlines and modulus (contour) of Wind at 925 hPa (top), genesis potential (middle) and OLR and the anomaly of OLR (bottom) respectively before cyclogenesis (right) and for the climatology (left). Unit is m/s for wind modulus, 10-6s-1 for Genesis Potential and w/m2 for OLR.

TCs. Figure 2 (middle) shows before cyclogenesis, the presence of stronger values of GP than the climatology over the West African coast, resulting an enhancement of the propagation from the continent to the ocean of strong low-level cyclonic vortices within an atmosphere characterized by high upper level anticyclonic support. These low-level cyclonic vortices may rapidly develop into tropical cyclones over the North Atlantic (Karyampudi et Pierce, 2002).

The AEJ is a barotropic-baroclinic unstable jet in which develop AEWs that are the main precursors of Atlantic TCs (Burpee, 1972; Ross and Krishnamurti, 2007). These combined baroclinic – barotropic instabilities are studied using the meridional gradient of potential vorticity (PV) over isobaric levels according to Balasubramanian and Yau, (1996) who used the following formula:

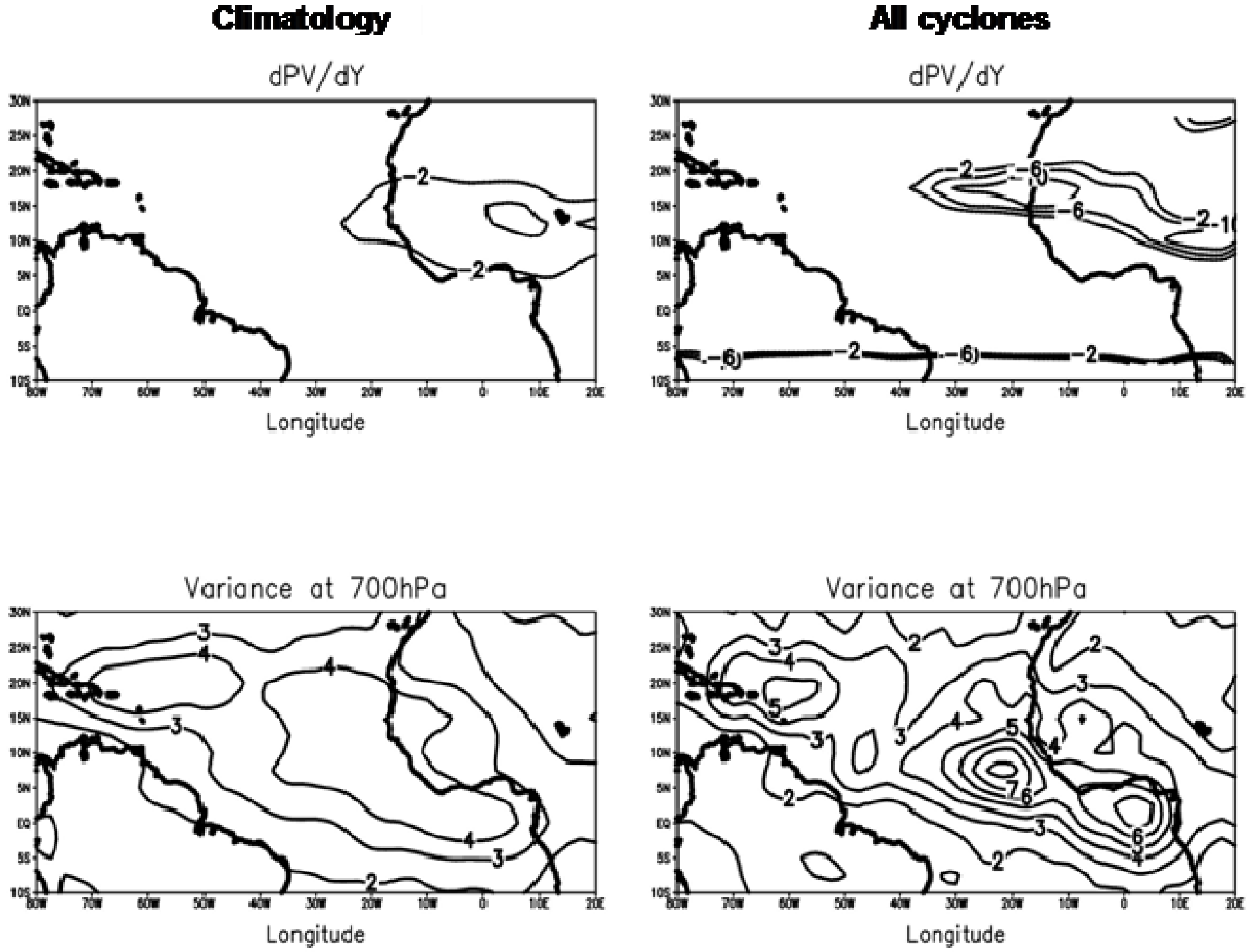

Figure 3. Meridional gradient of Potential Vorticity at 700 hPa (top) (dPV/dY), variance of meridional wind at 700 hPa filtered between 3 and 5 days and relative vorticity at 850 hPa before cyclogenesis (right) and for the climatology (left). Units are 10^{-14}m.K.s^{-1}.Kg^{-1} for dPV/dY, m^{2}s^{-2} for the variance of meridional wind at 700 hPa.

$$PV = -g\left[\left(f + \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)\frac{\partial \theta}{\partial p} + \frac{\partial u}{\partial p}\frac{\partial \theta}{\partial y} - \frac{\partial v}{\partial p}\frac{\partial \theta}{\partial x}\right] \quad (2)$$

with

$$\theta = T\left(\frac{1000}{P}\right)^{\frac{R}{Cp}}$$

and where θ, U, V, T and P are respectively potential temperature, zonal wind, meridional wind, temperature and pressure.

Areas of negative values of meridional gradient of PV at mid-levels are favourable for the growth of AEWs (Lau and Lau, 1990). The meridional gradient of PV at 700 hPa shows that these instabilities are stronger and extend further over the North Atlantic before a cyclogenesis (Figure 3 (top)) suggesting that AEWs before cyclogenesis may have stronger amplitude than the climatology.

The activity of the AEWs are diagnosed by using the variance of the meridional wind at 700 hPa filtered between 3 and 5 days (Figure 3 (bottom)). The AEWs before cyclogenesis are more developed than the climatology, mainly over the Southern track in West Africa. This statement is consistent with the conclusion of Thorncroft and Hodges (2001) who suggested that Southern AEWs are more involved in cyclonic activity over the North Atlantic than Northern AEWs.

LARGE SCALE CONDITIONS BEFORE CYCLOGENESIS OVER THE NORTH ATLANTIC

Low values of Vertical Wind Shear (VWS) between low and high levels are known to be favourable for cyclogenesis. Figure 4 (top) shows that when we consider all the cyclones, the VWS over the MDR presents lower values before cyclogenesis than the climatology. When we compute the VWS separately before cyclogenesis for cyclones formed in the Southern and in the Northern axis

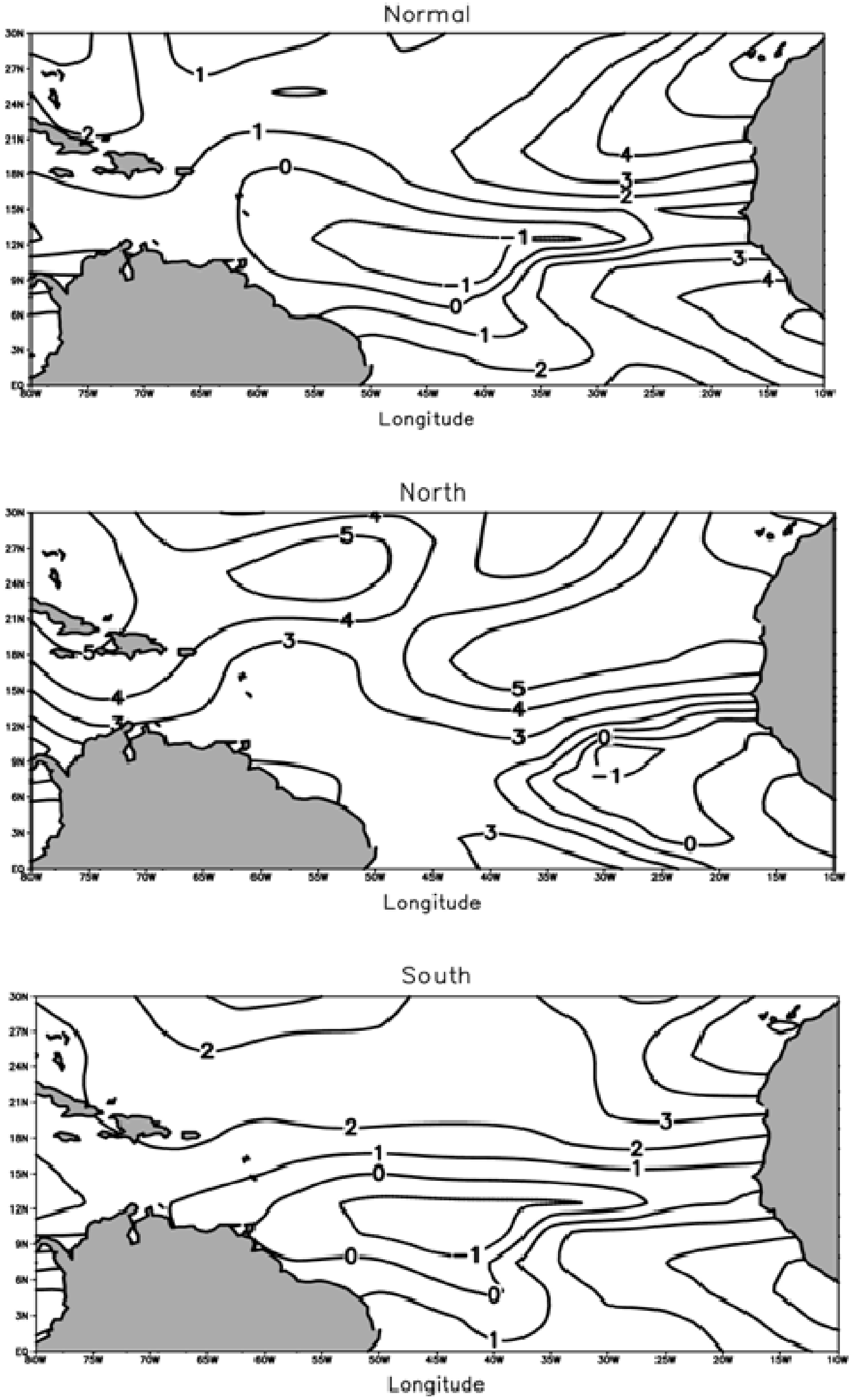

Figure 4. Vertical wind shear (VWS) between low and high levels: Anomaly from the climatology before the genesis of all cyclones (top), before the genesis of cyclones at the North of 20°N (middle) and before the genesis of cyclones at the south of 20°N (bottom). Unit is m/s.

(respectively Figure 4 (middle) and 4 (bottom)), we found that the VWS is weaker than the climatology over the Southern part of the MDR for the composite of cyclones born in the Southern axis and higher over the MDR for

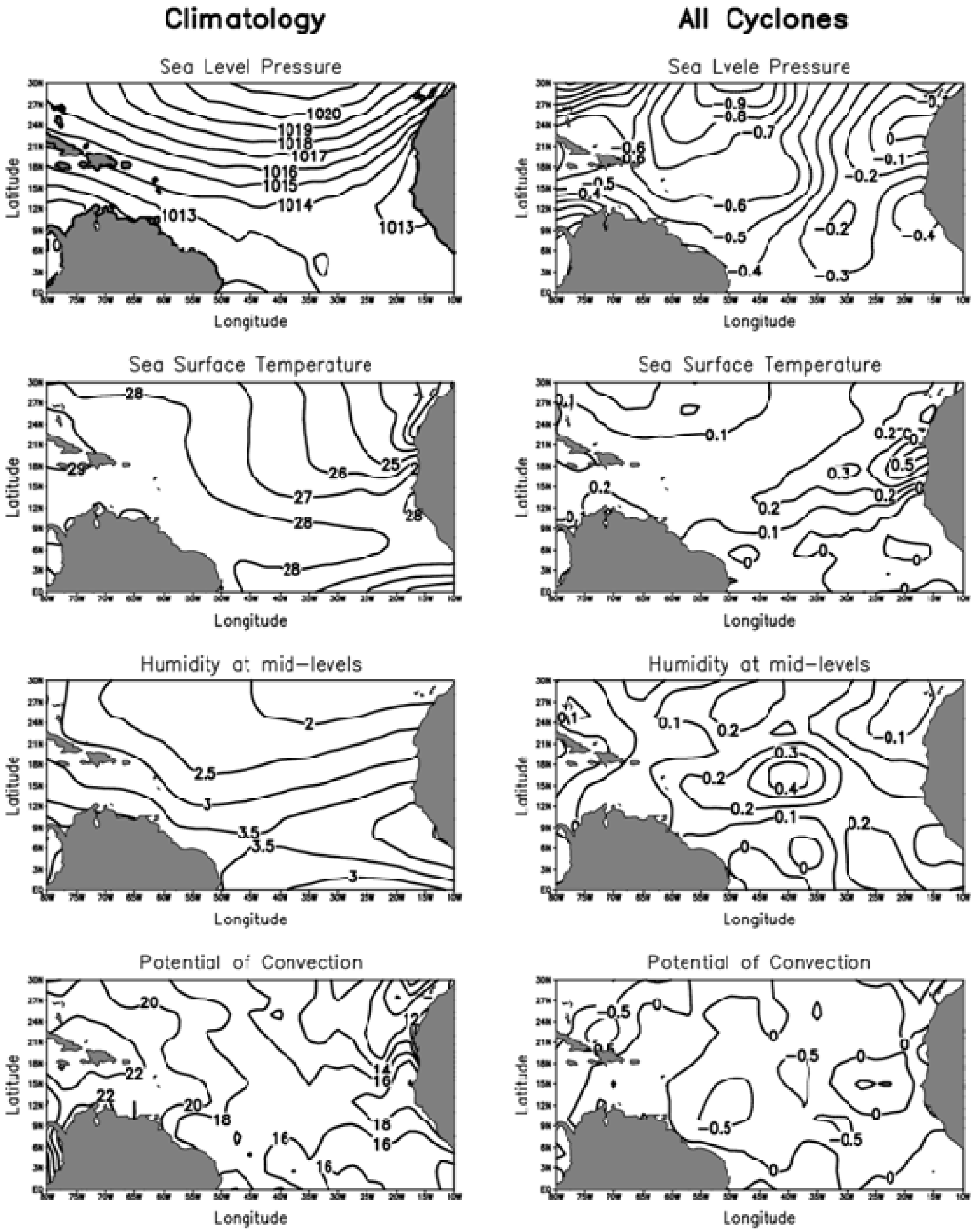

Figure 5. Sea Level Pressure (SLP), Sea Surface Temperature (SST), mid-level specific humidity and the Potential of Convection (PC) for the climatology (right) and for the anomaly from the climatology before cyclogenesis (left). Units are hPa for SLP, °C for SST, g/kg for humidity and K for the PC.

cyclones born in the Northern axis. Another composite of the VWS has been done by separately considering cyclones formed in the August - September - October (ASO) period and outside the ASO period (not shown). Cyclones born over the northern axis generally occurs at the beginning (May - July) and at the end (September - November) of the hurricane season and the VWS shows smaller (stronger) values of VWS over the Southern part of the MDR for cyclones occurring in the ASO period than those outside the ASO period. Then, the stronger values of VWS over the MDR when considering all the cyclones may be due to the contribution from cyclones generated north of 20°N and outside the ASO period.

Figure 5 shows large scale conditions over the North Atlantic Ocean based on the climatology from August to October compared to the 3 days anomaly before the cyclogenesis of all the cyclones.

Figure 5 (1st panel) shows that lower values of sea level pressure (SLP) are present before cyclogenesis over the North Atlantic picturing that a favourable environment for deep convection exists in this case. Figure 5 (2nd panel) shows that Sea Surface Temperature (SST) shows values between 26°C and 29°C over the North Atlantic for the climatology. The SST presents warmer values before the cyclogenesis. These warmer conditions over the Atlantic Ocean are associated with stronger mid-level humidity as shown in Figure 5 (3rd panel).

The Potential of convection (PC) is a thermodynamic parameter used to study the degree of atmospheric instability. PC is the difference between the equivalent potential temperature at 1000 hPa (surface) and at 500 hPa (mid-troposphere):

$$PC = \theta_e(1000) - \theta_e(500) \quad (3)$$

with θ_e is the equivalent potential temperature.

Gray (1979) used the parameter (PC + 5) to show that PC values are higher than 10K over ocean basins where occur the cyclogenesis. The climatology of PC on Figure 5 (4th panel) confirms that the PC is stronger than 10K over the MDR. Prior to a cyclogenesis, these values become stronger than the climatology over a large part of the MDR, especially over the Eastern and the Central part indicating the high degree of the atmospheric instability. From a thermodynamic point of view, the synoptic conditions before cyclogenesis are more favourable for moist convection over the Atlantic Ocean.

Conclusion

In this study, we tried to figure out the large scale conditions over Africa and the Atlantic Ocean before the occurrence of a cyclogenesis over the North Atlantic. During the 1980 - 2004 period, 269 cyclones were generated in the whole Atlantic basin. Cyclogenesis occurs generally along two axes, one is between 10°N - 15°N in MDR. We showed that this Southern axis concerns mainly the major hurricanes and is well linked to African climate features when compared with the relative vorticity at 850 hPa and with the AEWs. These results are consistent with the conclusion of Landsea (1993) who suggested that 60% of Atlantic TCs are of AEWs origins, but nearly 85% of major hurricanes originated from AEWs.

Over West Africa, the monsoon layer before the occurrence of cyclogenesis is stronger and extends more northward over land than the climatology. The Genesis Potential shows stronger values before a cyclogenesis over West Africa suggesting that strong low-level cyclonic vortices propagate from land to ocean in an atmosphere characterized by strong upper level support. These low-level cyclonic vortices may rapidly develop into TCs. The AEWs are more developed before cyclogenesis than the climatology over their southern track indicating the importance of this track in a cyclonic activity as suggested by Thorncroft and Hodges (2001).

Over the ocean, warmer waters, lower pressure, stronger mid-level humidity and higher degree of atmospheric instability over the MDR are present before a cyclogenesis suggesting that the atmosphere is more unstable. These results show that environmental conditions favourable for deep convection and cyclonic activity exist over Africa and the Atlantic ocean a few days before cyclogenesis. This situation suggests that it is possible to predict North Atlantic cyclogenesis 3 days in advance.

This research will continue through the use of a long time series to confirm our results. We will also consider new cyclogenesis indexes and a combination of these indexes with the aim to well describe the large scale conditions associated with cyclogenesis over the North Atlantic.

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