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Full Length Research Paper

Spatial and temporal distribution of North Atlantic tropical cyclones

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The aim of this work is to provide a classification of tropical cyclones (TC) according to their location, month of genesis and their lifecycles and to study the role of African Easterly Waves (AEWs) in North Atlantic cyclogenesis. Between 1980 and 2004, 269 tropical cyclones (TCs) were formed over the North Atlantic, 77% of which occurred during the August- October period and 95% of major hurricanes (TCs in which the maximum sustained wind was greater or equal to 50 m/s) were generated in the same period. The high activity of the August-October period was due to the favourable thermodynamic and dynamic conditions that simultaneously exist over the main development region (MDR). A classification of TCs according to their months of genesis and lifecycles showed that TCs generated before August and after October have no preferential latitude and longitude of genesis. TCs generated at the East of 60°W and over the southern part of the MDR have long lifecycles. Major hurricanes have long lifecycles and are generally initiated over the southern part of the MDR and East of 60°W. The spatial representation of the cyclogenesis area shows that cyclones are generated along two main axes; one is situated around 12.5°N (southern axis) and the second around 27.5°N (northern axis). 56% (44%) of TCs are generated over the southern axis (northern axis). 92% of TCs initiated along the southern axis originate from African Easterly Waves. While 64% of those generated over the northern axis are linked to mid-latitude baroclinic systems and upper level cold lows. This study contributes to a better understanding of North Atlantic cyclogenesis characteristics as well as the role of AEWs.

Key words: North Atlantic tropical cyclones, major hurricanes, African easterly waves.

INTRODUCTION

The Atlantic hurricane season extends from the 1st June to 30 November according to the National Hurricane Center, but the August-October period was the most active, accounting for 78% of named storms, 87% of hurricane days and 96% of intense hurricane days (Landsea, 1993).

A TC is the generic term for a non- frontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection and definite cyclonic surface wind circulation (Holland, 1993). Tropical storm (respectively hurricane) is a TC in which the maximum sustained wind speed is 17 - 32.5 ms $^{-1}$ (33 ms $^{-1}$ or greater). Intense hurricanes are defined as those with maximum sustained wind of 50 ms^{-1} or greater during some part of their lifetimes (Hebert and Taylor, 1978).

According to Gray (1968, 1979), the inter and intra-annual variability of tropical cyclones is linked to both thermodynamic and dynamic conditions. Sea surface temperature > 26°C, high mid-level humidity, an atmosphere which cools fast with height and a low vertical wind shear are needed for tropical cyclone formation. In addition, there is also the need of a precursor in order to develop a tropical cyclone. African Easterly Waves (AEWs) are the main precursors of cyclonic activity over the North Atlantic (Landsea, 1993; Chen et al., 2008; Thorncroft and Hodges, 2001; Ross and Krishnamurti, 2007; Berry et al., 2007). AEWs originate over North Africa and propagate westward with a period of 3 - 5 days and a wavelength of 3000 km (Burpee, 1972; Diedhiou et al., 1999). AEWs are also known to modulate the daily rainfall over West Africa (G u et al., 2004; Mekonnen et al. 2006; Futyan and Del Genio, 2007).

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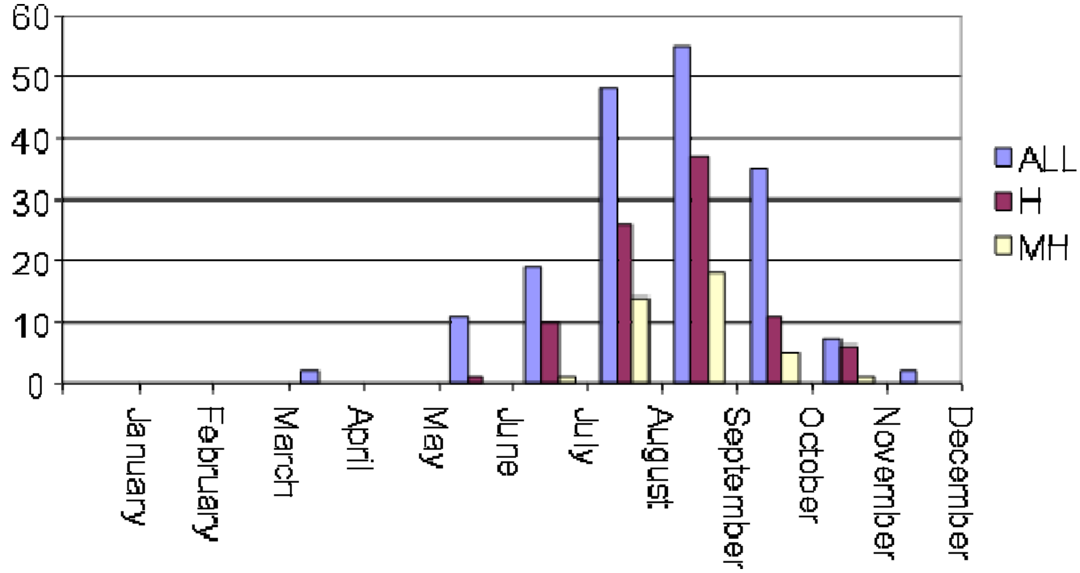

Figure 1. Seasonal cycle in the 1980-2004 period of the number of cyclones (All), the number of hurricanes (H) and the number major hurricanes (MH).

Tropical cyclones can also originate from frontal zones and upper level cold lows (Franck, 1975; Fitzpatrick et al., 1995; Hess et al., 1995).

In this study, we considered a set of 269 cyclones that occurred during the 1980 -2004 period to allow us to have a good sample to do simple statistical analyses.

In the first part of this study, a classification of TCs according to their longitude, latitude, month of genesis and lifecycle will be discuss with the aim to construct a climatology of tropical cyclones over the North Atlantic. The second part will depict the role of AEWs in the cyclogenesis over the North Atlantic.

Data and Method

Reanalysis data from the National Center for Environmental Prediction/National Center for Atmospheric Research reanalysis project (NCEP/NCAR) for the 1980 - 2004 period were used (Kalnay et al., 1996) to study thermodynamic and dynamic conditions over West Africa and the North Atlantic. These data, obtained by assimilating observations into a GCM, provide physically consistent representations of the main characteristics of atmospheric circulation. Nicholson and Grist (2003) show the agreement between the meteorological profiles obtained by rawinsounding and retrieved by the NCEP/NCAR reanalyses over West Africa.

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

The Atlantic basin tropical cyclone “best track” data archives are provided by the United States Tropical Prediction Center / National Hurricane Center (NHC) in the form of six hourly positions and intensities of all tropical cyclones reaching named storm status. The genesis day of a cyclone corresponds to the first position in the NHC best track. AEWs are detected using simultaneously two methods: the wavelet analysis technique (Farge, 1992; Torrence and Compo, 1998; Diedhiou et al., 1999) and the fluctuation of the meridional component of the wind field filtered between 3 - 5 days at 700 hPa (Burpee, 1972; Diedhiou et al., 1999). Dates associated with a strong energy level in the wavelet analysis and showing a strong fluctuation in the 700 hPa meridional wind filtered between 3 and 5 days are considered to be affected by AEWs. For each cyclone, we used those two techniques to determine if an AEW is present or not over the genesis area and then we conclude if that cyclone is generated or not by an AEW.

RESULTS

During the 1980 - 2004 period, 269 tropical cyclones or named storms were generated over the North Atlantic. The date that genesis occurred is define by the time when a named storm first became a tropical depression according to the National Hurricane Center (NHC) archives. 59% (22%) of TCs reached the hurricane (major hurricane) stage. The genesis of TCs as well as hurricanes and major hurricanes peaked during the August - September - October (ASO) period with a maximum in September, followed by August (Figure 1). These three months encompass 77% of TCs, 81% of hurricanes and 95% of major hurricanes. The percentage of TCs formed outside the ASO period is 15% (7%). 63% of major hurricanes considered in this study were formed during the recent period (1995 - 2004), consistent with the increase in human and material losses due to cyclones as major hurricanes are responsible for 80% of these losses (Landsea, 1993).

Figure 2 shows the seasonal cycle of some thermo dynamic (sea surface temperature, potential of convection, mid-levels humidity) and dynamic parameters (the vertical wind shear), which are known to influence cyclo-

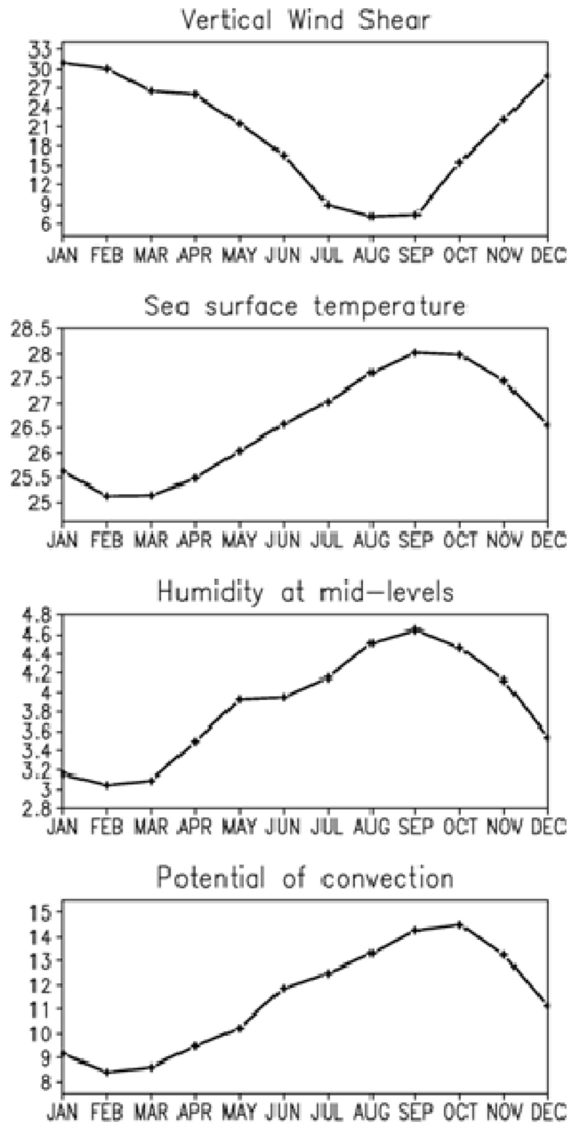

Figure 2. Seasonal cycle in the 1980 - 2004 periods of (left) Vertical Wind Shear (top), Sea Surface Temperature (bottom), (right) Specific Humidity at mid- levels (top) and the Potential of Convection (bottom). Parameters used are averaged over the MDR (80°W - 20°W; 10°N - 20°N). Unit is m/s for vertical wind shear, °C for SST, g/kg for specific humidity and K for the Potential of convection.

genesis over the North Atlantic. These parameters are averaged over the MDR. Vertical wind shear shows weak values during the July - September period, while the potential of convection (Pc) and the sea surface temperature present strong values in the September - October period. Humidity at mid-levels as the cyclonic activity peaks from August to October. Dynamic (vertical wind shear) and thermodynamic (Potential of convection and sea surface temperature) parameters present favourable conditions simultaneously during August - October, in coherence with the great cyclonic activity of this period.

We noted also that the vertical wind shear was favourable for cyclonic activity at the beginning of the cyclone season, while the sea surface temperature and the Pc peak at the end of the season. This result is consistent with the conclusions of De Maria et al. (2001) who showed that during the 1991 - 1999 hurricane season and over the Eastern part of the Main Deve-lopment Region (MDR), tropical cyclone genesis is limited in the early part of the season by thermodynamic parameters, while at the end of the season, cyclogenesis is limited by dynamic parameters.

Figure 3 shows the genesis location as indicated by the first positions in the NHC best track of all named storms, hurricanes and major hurricanes over the North Atlantic. Cyclogenesis occurs generally along two axis, one is between 10 - 15°N (southern axis) in the MDR and the second is located around 27.5°N (northern axis). The southern axis concerns mainly the major hurricanes, 92% of these major hurricanes are formed over the main genesis area called Main Development Region (MDR); this region is the North Atlantic region which lies between the 10 - 20°N latitudinal bands.

During the 1980 - 2004 period, the mean lifecycle of the 269 cyclones that propagated over the North Atlantic Ocean was 8 days. Figure 4 shows the evolution of the lifecycle of TCs and major hurricanes according to their longitude and latitude of genesis. The cyclones that formed off the African coast (East of 40°W) have long lifecycles (lifecycle > 8 days), while those formed West of 60°W have generally short lifecycles. 92% of Major hurricanes have long lifecycles. This result suggests that Major Hurricanes have generally long lifecycles and especially when they are formed off the West African coast.

The cyclones generated over the southern axis (around 12.5°N) have long lifecycles, while the northern ones (around 27.5°N) generally, have short lifecycles.

A classification of cyclones according to their period of genesis shows that cyclones and major hurricanes that occur early (before August) and late (after October) during the cyclone season show no preferential latitude or longitude of genesis (Figure not shown).

Figure 5 (top and middle panels) shows the location of all named storms and major hurricanes generated or not by African Easterly Waves (AEWs). Southern TCs (South of 20°N) are mainly generated by AEWs. While northern TCs are linked to mid-latitude baroclinic systems and upper level cold lows (Fitzpatrick et al., 1995; Hess et al., 1995). We found that 85% of the major hurricanes and 64% of named storms are generated by AEWs. These results are consistent with findings by Landsea (1993), that 60% of Atlantic TCs are of AEW origin, but nearly 85% of major hurricane originated from AEWs. The proportion of cyclones generated by AEWs was calcu-lated from June to November (the official hurricane season according to the NHC). From estimation, it was found that the proportion of TCs generated by AEWs increases from June to August and decreases after

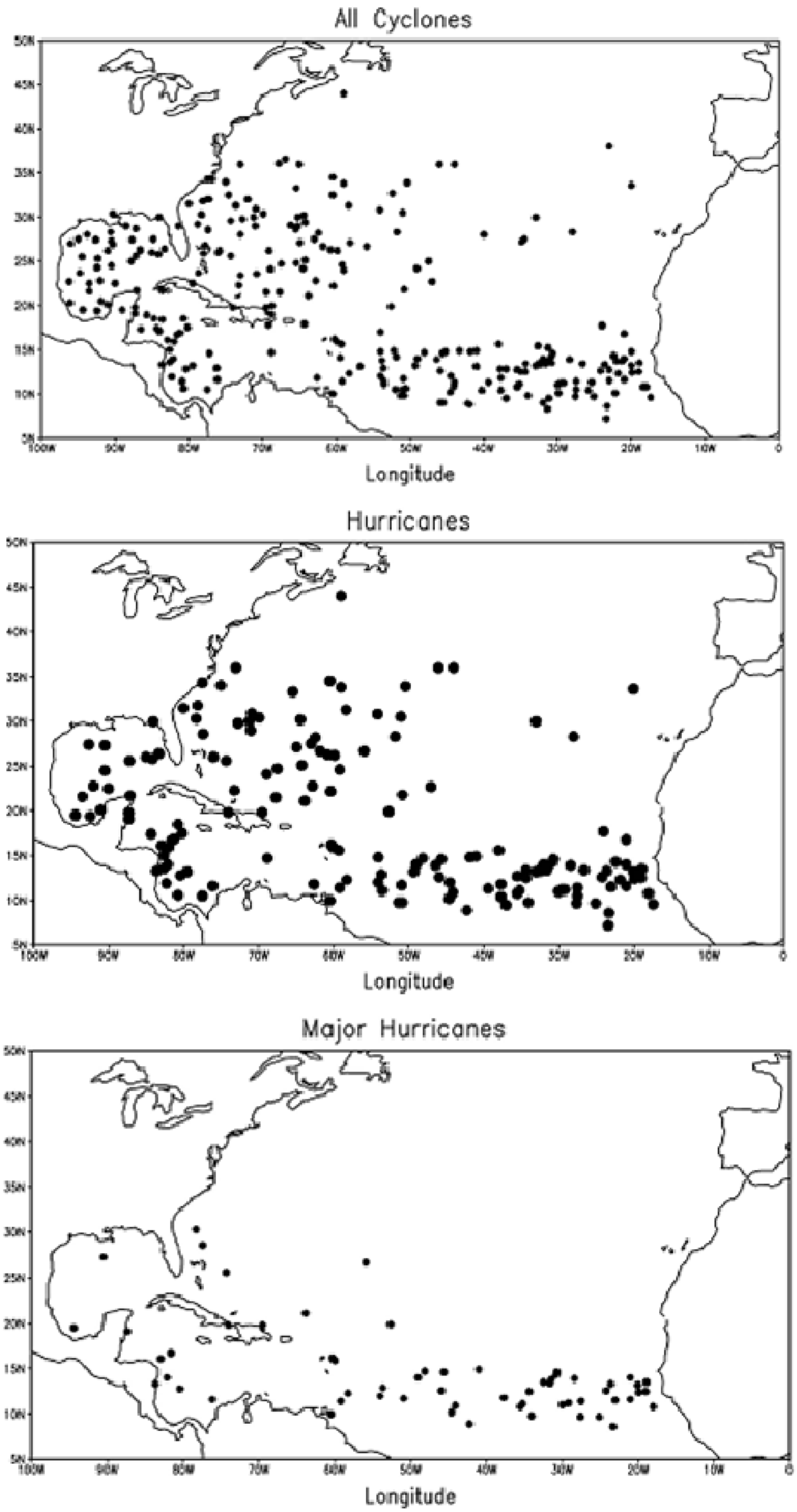

Figure 3. Genesis location of all named storms (top), hurricanes (middle) and major hurricanes (bottom).

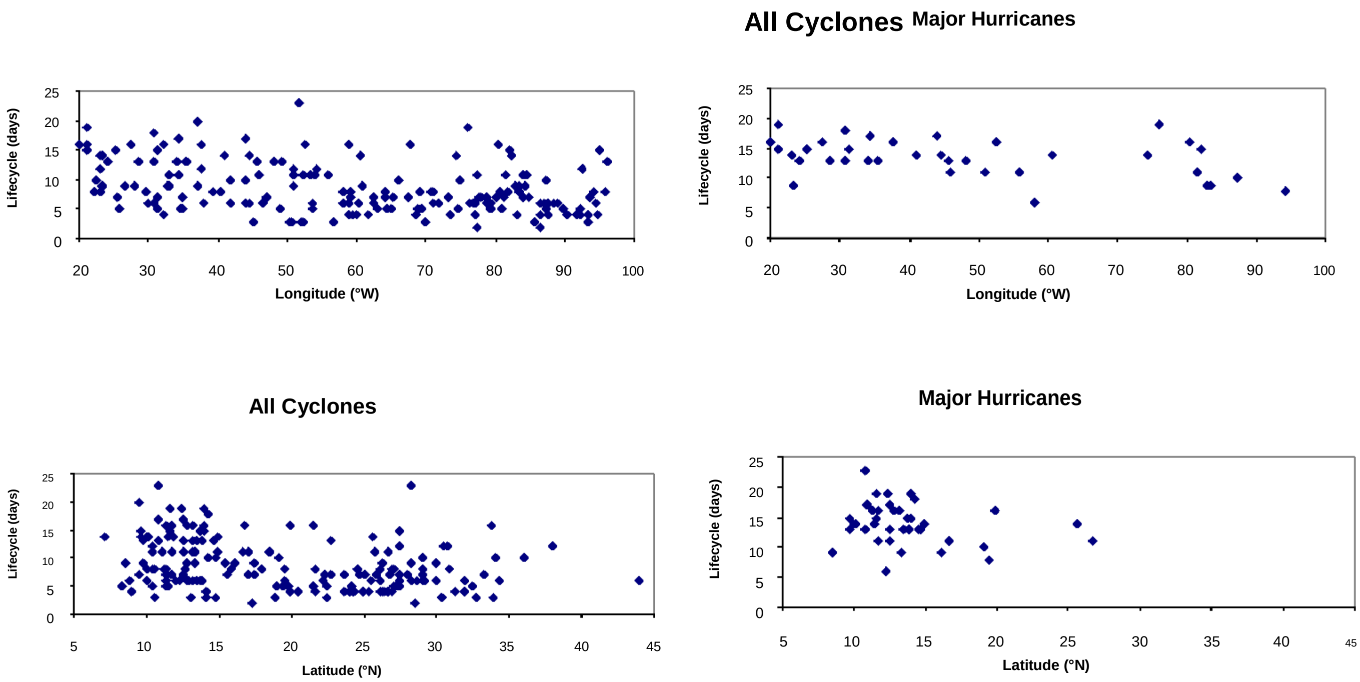

Figure 4 . Longitude and latitude of cyclones genesis versus lifecycle of all named North Atlantic TCs (1st and 2nd panel) and major hurricanes (3rd and 4th panel).

(Figure not shown). Then, during the peak of the hurricane season (August-September -October), cyclogenesis was more (less) influenced by AEWs in August (October). During October, 50% of cyclones were generated by the other precursors (frontal zones and upper levels cold lows).

The relative vorticity at 850 hPa (Figure 5 (bottom)) shows an axis of positive values around 12.5°N extending from West Africa to the Atlantic Ocean, confirming that AEWs may affect genesis of TCs over the southern axis.

Conclusion

The aim of this study was to do a classification of tropical cyclones according to their location, month of genesis and their lifecycles and to study the role of AEWs in this cyclogenesis.

This study confirms that tropical cyclones peak in the August-October period. This is due to the fact that thermodynamic and dynamic conditions are simultaneously favourable for cyclogenesis during these three months. Tropical cyclone genesis was limited in the early part of the season by thermodynamic parameters, while at the end of the season, formation of cyclones was limited by dynamic parameters.

A classification of TCs according to their latitude, longitude and month of genesis shows that cyclones born before and after the peak of the hurricane season have no preferential latitude and longitude of genesis. Tropical cyclones that form off the West African coast or over the southern part of the MDR (10 - 15°N latitudinal band) have long lifecycles. Major Hurricanes are generally formed over the southern part of the MDR, East of 60°W and have long lifecycles; they also are generated during the August-October period.

TCs are generated mainly around two axes; one is situated around 12.5°N and the second is located around 27.5°N. The southern axis TCs are generated by African Easterly Waves (AEWs) coming from West Africa and the northern axis TCs are initiated by baroclinic systems of mid-latitude and upper level cold lows. It appears that major hurricanes are generally of AEW origins.

Study of the main differences over the African continent and the Eastern Atlantic Ocean between an AEW associated with an Atlantic cyclone and an AEW which is not, will contribute to clarify importance of AEWs and to improve our knowledge of the large scale conditions over West Africa and the Atlantic Ocean before the occurrence of a cyclogenesis over the North Atlantic.

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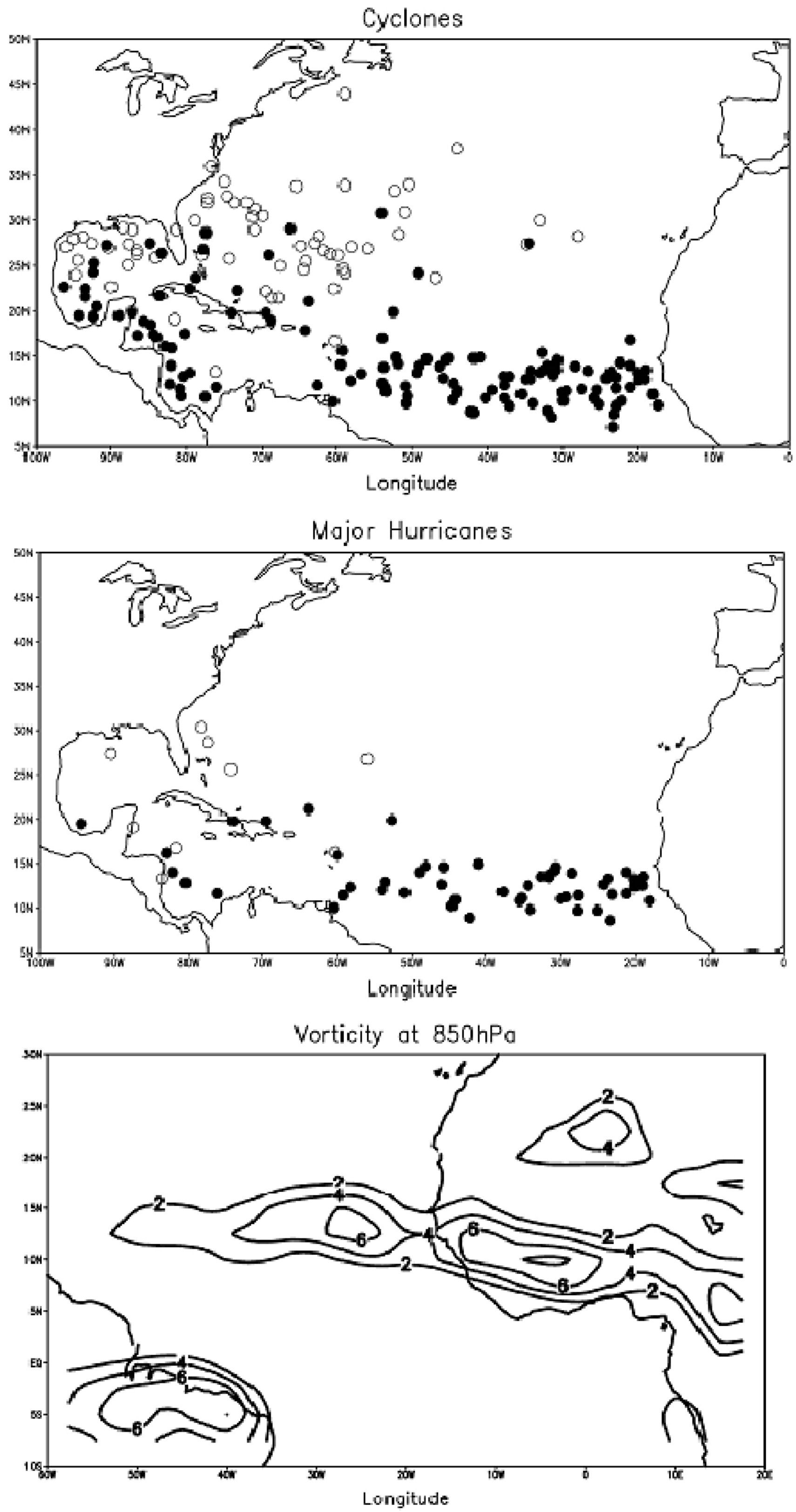

Figure 5. Genesis location of all named storms (top), major hurricanes (middle) and relative vorticity at 850 hPa (bottom) . For the 1st and 2nd panel, closed circle refers to TCs which are generated by AEWs and open circle refers to TCs which are not generated by AEWs.

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