TROPICAL CYCLOGENESIS AS REVEALED BY THE NOGAPS ANALYSIS

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1. INTRODUCTION

Recent improvements in satellite retrievals, data assimilation schemes and numerical models have all contributed to a significant improvement in the quality of global analyzed fields, rendering them capable of representing realistic atmospheric states in data sparse regions such as open oceans. To understand the processes associated with tropical cyclogenesis, the Naval Operational Global Atmospheric Prediction System (NOGAPS) analysis fields are used to study tropical synoptic-scale disturbances pre-exist hurricanes occurred in the North Atlantic summer season of 2004. A 3-8-day bandpass filter is applied to the analyzed fields to extract out the synoptic-scale disturbances.

2. DATA AND METHODS

The data used for this study are the daily operational global analysis fields from NOGAPS (Hogan and Rosmond 1991). NOGAPS is a global spectral model with 239 triangular truncation (about 45 km resolution) and 30 vertical levels. An update cycle is carried out continuously in which the model integrates 6 hours in time and assimilates observation data using a 3D variational method (Daley and Barker 2001) every 6 hours. The resolution of the analyzed data we used is one degree longitude/latitude.

To extract African Easterly Waves (AEWs) from full-spectrum disturbances, a band-pass filter is applied. A 3 to 8 day period is chosen following pervious studies on the characteristics of AEWs (Carlson 1969a, Burpee 1972). The time filtering is carried out for every grid point time series using the technique by Christiano and Fitzgerald (2003), originally designed for applications on economic data. The filtered wind field and derived 850hPa vorticity are the main fields we examined. We trace these tropical waves upstream and prior to the genesis of tropical depressions as defined by the National Hurricane Center (NHC).

3. RESULTS

The 850hPa 3-8-day filtered vorticity from the NOGAPS analyses averaged between 8°N and 18°N is plotted as a function of time and longitude from 1 August to 30 September in Fig. 1. This figure shows the propagation of wave crests from east to west with time, represented by positive vorticity associated with the cyclonic circulation.

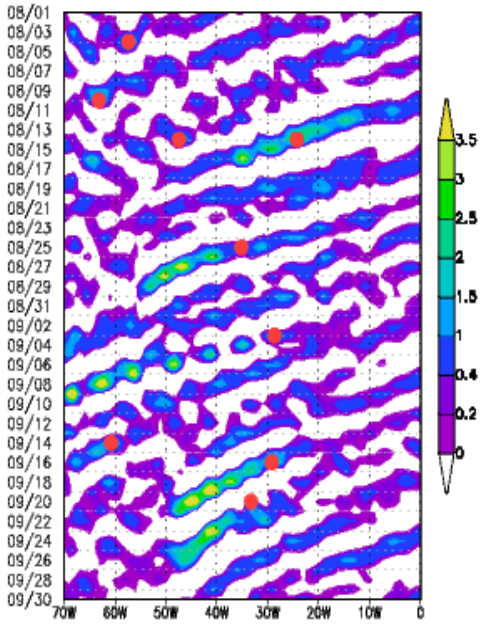

Fig. 1 Time-longitude plot of the 850hPa vorticity ($10^{-5}s^{-1}$) averaged within the 8°N-18°N latitudinal band from 1 August to 30 September between 70°W to 0°E. Positive values indicate cyclonic vorticity and negative vorticity are not plotted. Red dots represent the longitude and date when TCs formed.

9 of 12 TCs we studied can be found in this figure. The red dots marked the longitude and date when they formed. All these dots are located in the westward propagating wave track. That suggests their origins of easterly waves. This result is consistent with the synoptic analysis reported by NHC.

One of interesting example for 2004 hurricane season is two storms formed from one easterly wave. Figure 2 shows that Danielle and Earl formed from one easterly wave on 14 August 2004. On the 12 August (Fig. 2a), both future genesis locations of Earl and Danielle are in the anticyclonic circulation of the easterly wave. The wave continues moving westward (Fig 2b) and formed Earl and Danielle on 14 August (Fig. 2c). From these daily time sequences, it is clear that there were coherent waves propagating through the genesis sites of Danielle and Earl, marked by "D" and "E" in Fig. 2, respectively. Comparing Fig. 2a and 2c indicates that the distance

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between the two cyclone genesis locations is approximately one wavelength of the easterly

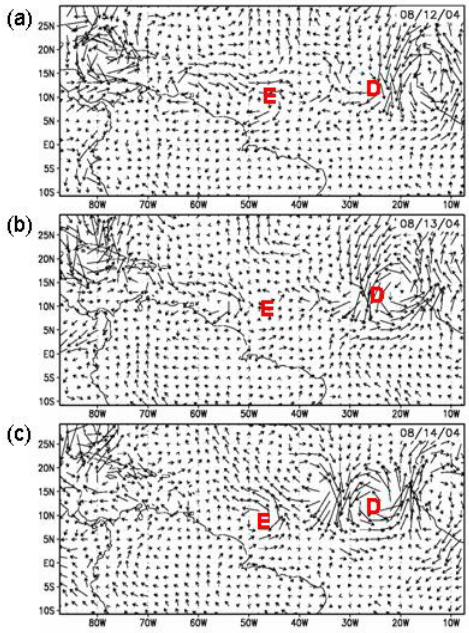

Fig. 2 Band-pass filtered (3-8 days) 850hPa vorticity field on: a) 12 August, b) 13 August, and c) 14 August. "D" and "E" denotes the genesis location for Danielle and Earl on 14 August, respectively

wave passing through them and the period of the wave is about 4 days.

The time sequence of the 850hPa vorticity, averaged within a four by four degree longitude/latitude box centered at the genesis locations of Danielle and Earl (Fig. 2), are depicted in Fig. 3 for both the unfiltered and filtered data. For the unfiltered data (Fig. 3a), the vorticity became very large at both locations on 14 August, corresponding to the rapid development of Danielle and Earl simultaneously. Prior to it, the time sequences from the unfiltered data at these two locations do not show clear wave signals or any relation between them. With the 3-8-day band pass filter applied (Fig. 3b), the time sequences of the 850hPa vorticity show an in-phase propagation of the AEWs at these two locations. Figs. 2 and 3 present a unique situation where two tropical cyclones germinated within a single train of an easterly wave with their locations one-wavelength apart.

Figure 4 is the figure showing the propagation of Danielle. Fig. 4a and 4b are time-longitude plots for the 3-8-day band pass filtered relative vorticity with latitudinal average in the 5°N-15°N and 15°N-25°N respectively. Fig. 4c is a combined figure which taking the left part of the marked vertical line in Fig. 4a and the right side of the figure coming from Fig. 4b. In this patched figure, Danielle propagated smoothly with the easterly wave until 18 August. The continuity of the movement of Danielle in the patched figure indicates that Danielle was riding the easterly wave as it moved westward, even as it recurved more than 10 degrees north.

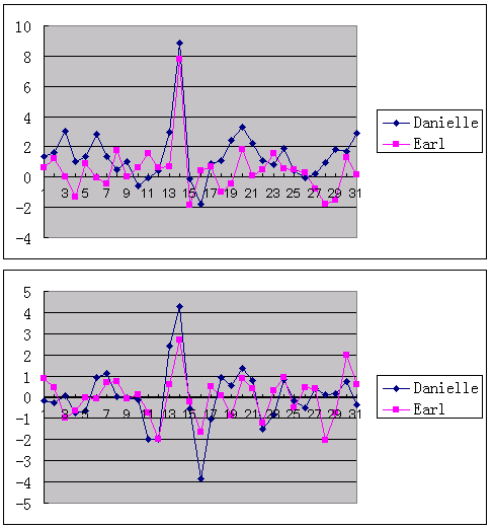

Fig. 3 Time sequence of the 850hPa vorticity for the 4-degree box average centered at the location of the formation of Danielle (blue line) and Earl (pink line) from 1 August to 31 August. (Upper) unfiltered, and (Lower) 3-8-day band pass filtered.

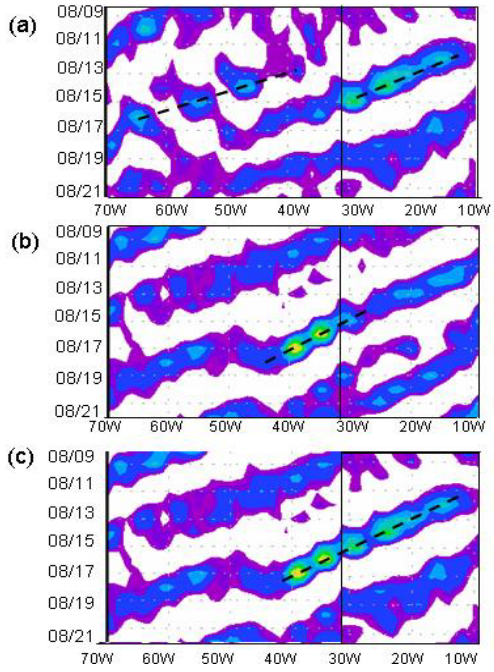

Fig. 4 Time longitude 3-8-day filtered vorticity at 850hPa for (a) the 5°N-15°N latitudinal band, (b) the 15°N-25°N latitudinal band and (c) patched figure of (a) and (b) marked by the vertical thin line. In (c), the part to the left of the line comes from the left part of (b) and the part to right of the line comes from the right part of (a) to highlight a continued movement of Danielle and the propagation of the AEWs at different latitudes

4. SUMMARY

By applying a 3-8-day band pass filter to globally analyzed atmospheric wind fields and derived relative vorticity field, we identified that most of the Atlantic TCs in 2004 are originated from easterly waves. We show a unique situation where two tropical cyclones, Danielle and Earl, developed simultaneously on 14 August 2004 in the Atlantic within the passage of one African easterly wave train. The characteristics of the waves bear very similar patterns prior to the formation of Danielle and Earl. The movement of the two cyclones also followed the propagation of the easterly waves from east to west. Using piecewise analysis of the easterly waves for different latitude bands, it is demonstrated that Danielle still rode with the westward propagating AEW even when it was recurving poleward. Another example, Hurricane Frances, was identified for the similar type of movement during the same period. The relation between the tropical cyclone movement and the AEWs at different latitudes, as revealed by our piecewise analysis, may occur commonly.

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