North Atlantic Hurricanes Contributed By African Easterly Waves North and South of the African Easterly Jet, Part II

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ABSTRACT

This project aims to examine African Easterly Waves (AEWs). Some of these waves dissipate quickly, but others develop into TCs and in some cases, powerful hurricanes. It is hypothesized that waves that develop north of the African Easterly Jet (AEJ), or northern waves (AEW_Ns), generally do not strengthen. On the contrary, it is hypothesized that waves traveling south of the AEJ, or southern waves (AEW_Ss), have a greater likelihood of development and eventual intensification due to ample moisture. This study aims to explore these hypotheses. In addition, Hurricane Karl (2010) is examined. This TC began as an AEW_N but managed to cross south of the AEJ, which likely resulted in its eventual intensification. Results show that Karl's perturbation was at a lower height than the base of the African Easterly Jet, allowing Karl to cross the jet into the moisture-rich atmosphere.

1. Introduction

Although tropical cyclone (TC) track forecasting has improved within the last 10 years, intensification forecasting remains difficult. Understanding TC intensification is of utmost importance, as intensification is not well predicted by operational meteorological models. A better understanding of the physical processes behind intensification will likely improve models, which will ultimately result in more accurate forecasts, saving property and lives.

African Easterly Waves (AEWs), which are weather disturbances that travel westward from the western coast of Africa, transform into TCs and powerful hurricanes in favorable atmospheric conditions. Therefore, it is important to understand the growth and maintenance of AEWs, as strong hurricanes can cause substantial damage to the United States. Moreover, strong AEWs can carry ample moisture to cause severe flooding.

Current theory suggests that the genesis location of AEWs plays an important role in their eventual intensification. It is believed that waves that develop north of the African Easterly Jet (AEJ), or northern waves (AEW_Ns), generally do not strengthen, as moisture is restricted in this region due to the Saharan Air Layer (SAL). Fig. 1 shows

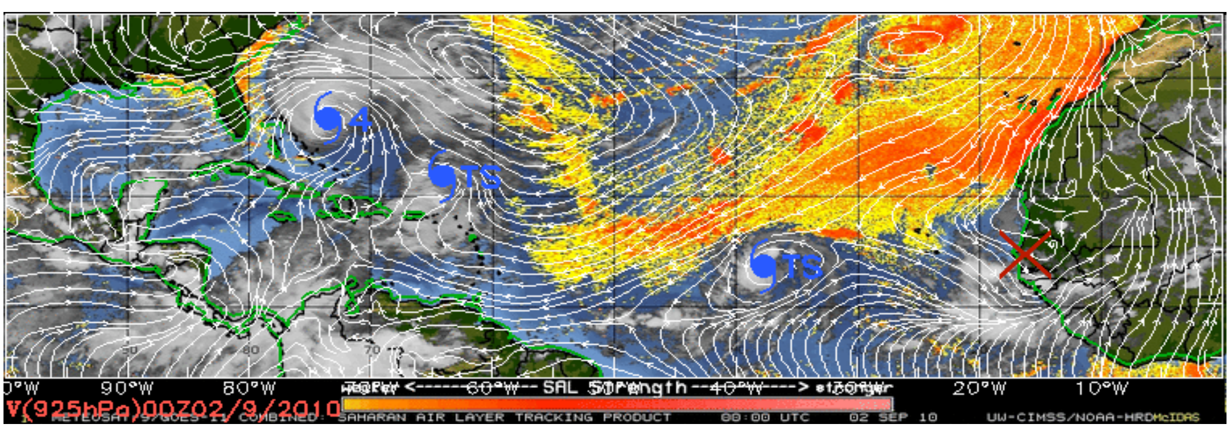

Fig. 1. SAL overlaid by streamlines (white) at 925 hPa at 0000 UTC on 2 Sept.. Existing TCs are in blue and Karl's perturbation is in red.

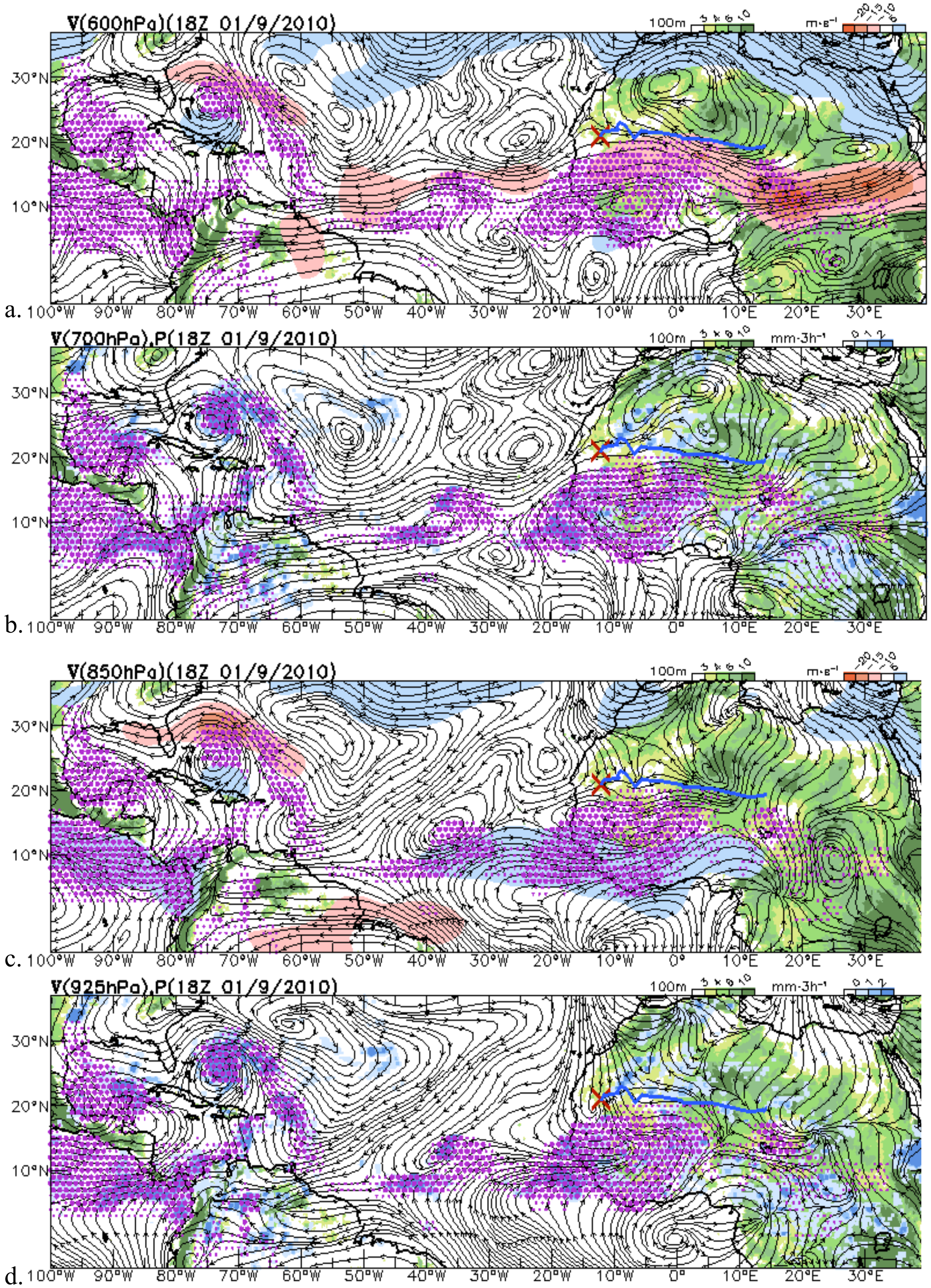

Fig. 2. Streamlines (black) and zonal wind at (a) 600 hPa at 1800 UTC on 1 Sept., (c) 850 hPa at 1800 UTC on 1 Sept., and (e) 600 hPa at 0600 UTC on 2 Sept.. Streamlines (black) and 6-hourly accumulated precipitation at (b) 700 hPa at 1800 UTC on 1 Sept., and (d) 925 hPa at 1800 UTC on 1 Sept..

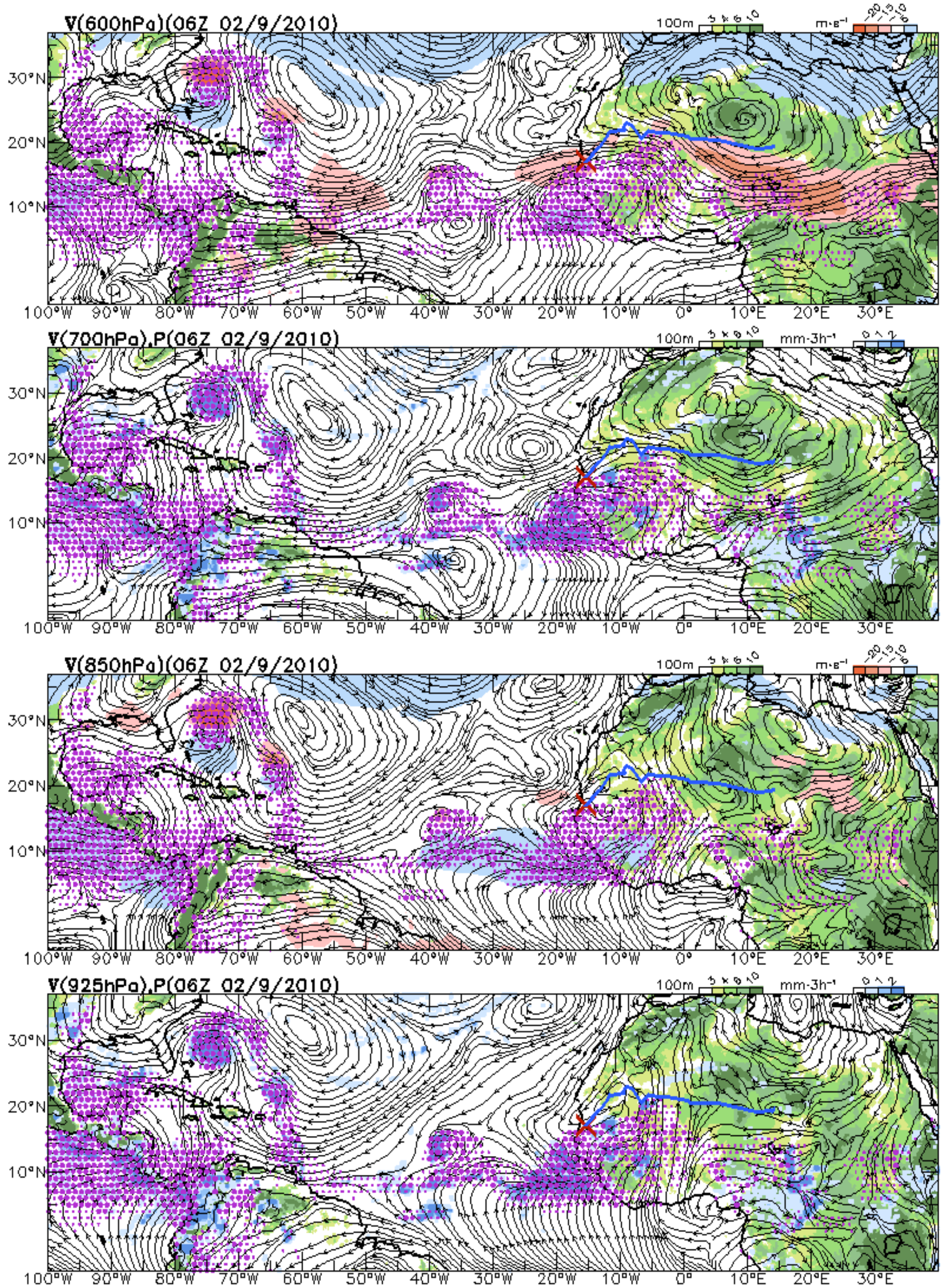

Fig. 3. Streamlines (black) and zonal wind at (a) 600 hPa at 1800 UTC on 1 Sept., (c) 850 hPa at 1800 UTC on 2 Sept., and (e) 600 hPa at 0600 UTC on 2 Sept.. Streamlines (black) and 6-hourly accumulated precipitation at (b) 700 hPa at 1800 UTC on 1 Sept., and (d) 925 hPa at 1800 UTC on 2 Sept..

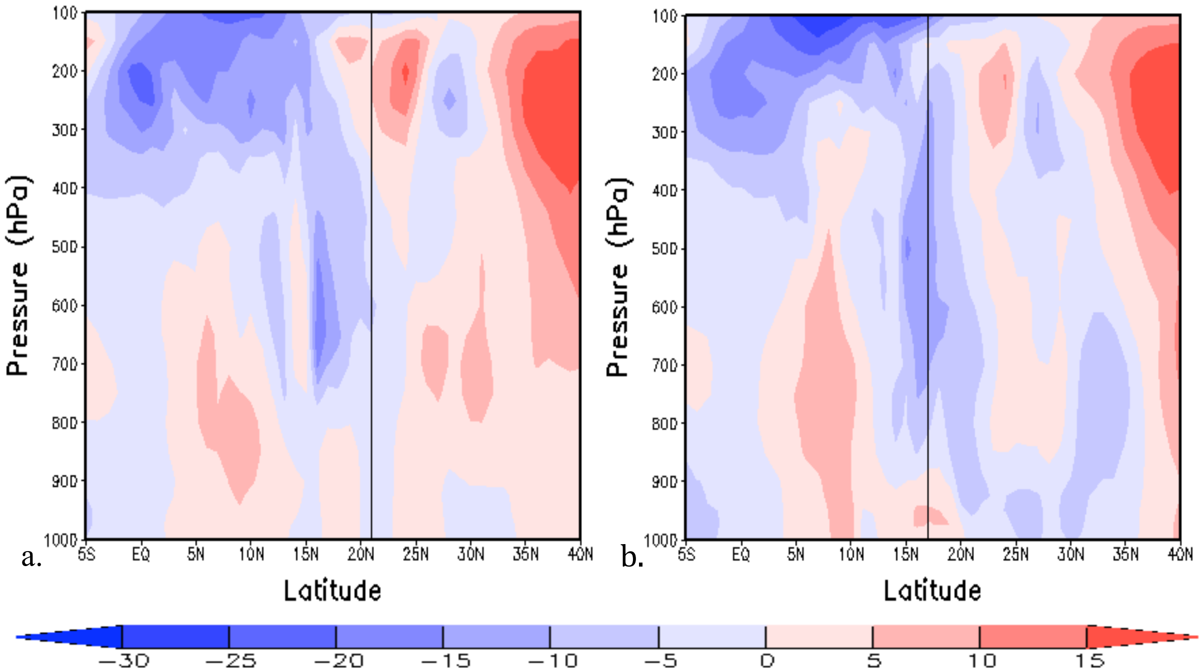

Fig. 4. Vertical latitudinal cross sections of zonal wind (ms^{-1}) at (a) 1800 UTC on 1 Sept. and (b) 0600 UTC on 2 Sept.. Karl's position is represented by a solid vertical line (black).

the SAL and TCs at 0000 UTC on 2 September. Note that all developed TCs are south of the SAL. On the contrary, waves traveling south of the AEJ, or southern waves (AEW_Ss), have a greater likelihood of development and eventual intensification due to ample moisture. This is certainly true in Fig. 1.

This study aims to explore this theory by examining Hurricane Karl, which began as an AEW_N. Unlike many other AEW_N, this storm strengthed and eventually became a major TC in the Gulf of Mexico. It is hypothesized that this was due to the fact that Karl crossed the AEJ from the north to south, so it did not encounter the negative impacts of the SAL. Instead, it had ample moisture to the south of the AEJ to strengthen. This study also aims to determine the mechanism that caused Karl to cross the AEJ, as many AEW_N do not cross the jet and quickly dissipate. If the mechanism behind the crossing can be determined, it may be possible to better-predict if an AEW_N will penetrate and cross the AEJ. This is important, as weather disturbances positioned south of the AEJ generally have a greater probability of strengthening into strong hurricanes that could impact the United States.

2. Data methods and procedures

Karl's perturbation is backtracked to its genesis location in order to observe its evolution and track with time. Streamlines are plotted using National Center for Environmental Protection (NCEP) and Global forecast System (GFS) reanalysis data at 600 hPa, 700 hPa, 850 hPa, and 925 hPa to analyze the atmospheric flow pattern near Karl. Additionally, this data is used to plot the AEJ, which generally is strongest in the middle to upper troposphere.

Tropical Rainfall Measuring Mission (TRMM) data is used to plot 6-hourly precipitation in order to observe the position of Karl with time. European Centre for Medium-Range Weather Forecasting (ECMWF) reanalysis data is used to plot vertically integrated liquid water, which gives an idea of the location of the greatest moisture content.

Lastly, NCEP and GFS reanalysis data are used to plot latitudinal vertical cross sections of the zonal wind structure before and during Karl's penetration of the AEJ. This will be used to compare the height of the jet base with the depth of Karl's vertical circulation.

3. Results

Fig. 2a displays plotted trajectories at 600 hPa with the AEJ shown in orange at 1800 UTC on 1

September. At this time, Karl was north of the AEJ. Vertically integrated liquid water above 50 kg m^{-2} is plotted with purple dots, which indicates high water content in the atmosphere. Notice that high liquid water content is present only to the south of the AEJ, not at Karl's position. Fig. 2b corresponds to the accumulated 6-hour precipitation. Notice that precipitation is present at this time and location, but a closed circulation was not defined at 700 hPa, as the streamlines do not form a closed circular system. Also note that Karl is north of the AEJ, so the dry air from the SAL likely inhibited its development and kept its vertical circulation shallow.

Fig. 2c shows the wind structure at the same time and location, but at 850 hPa. Notice that a closed circulation is not evident, meaning that Karl's circulation is below 850 hPa. Fig. 2d displays the wind structure at 925 hPa, which is even lower in the atmosphere. Still, there is no sign of a closed circulation. This makes sense with current theory, as northern waves generally have shallow vertical structures due to deteriorating effects of the SAL.

Within 12 hours, Karl began to cross the AEJ. Figs. 3a-d presents the wind structure of Karl at 600 hPa (a), 700 hPa (b), 850 hPa (c), and 925 hPa (d) at 0600 UTC. A comparison of these streamlines indicates that Karl does not have a closed circulation at any level. This means that Karl's circulation is still below 925 hPa while crossing the jet. Also notice that Karl is moving into a region of high water content, which will likely result in intensification. The general wind pattern at the lowest level, 925 hPa, guides Karl to the southwest, allowing Karl to penetrate the AEJ.

How did Karl penetrate and pass through the AEJ? The vertical shallowness of Karl's circulation would allow it to penetrate and pass only if Karl's circulation was under the base of the AEJ. If the storm had a circulation above the AEJ, it would not be able to penetrate and cross the jet. Thus, the vertical jet structure is shown in Figs. 4a-b. Fig 4a corresponds to 1800 UTC on 1 September, before Karl crossed the AEJ, while Fig 4b corresponds to 0600 UTC on 2 September, during Karl's crossing. Zonal wind is plotted, with red colors corresponding to westerly winds and blue colors corresponding to easterly winds. It is shown in Fig. 4a that the AEJ base is around 700 hPa, which is above the vertical extent of Karl's circulation. Thus, the steering flow, represented by the streamlines in Fig. 2d, was able to direct Karl under the AEJ. At the time Karl crossed the AEJ, Fig. 4b shows that the jet base has lowered to about 850 hPa. At this time, Karl's circulation still has not extended above 925 hPa, as shown my Fig. 2d. Therefore, Karl's circulation is still under the jet base, allowing Karl to continue to cross to the south of the jet. By 1200 UTC on 2 September, Karl moves south of the jet and showes a closed circulation at 925 hPa, implying that the moisture-rich air strengthened the system.

With time, Karl remains south of the AEJ and travels toward the Gulf of Mexico. It weakens a bit while moving in the open Atlantic. The reasoning behind the weakening is unknown at this point. Once it reaches the Gulf of Mexico, however, it quickly strengthens due to the warm sea surface temperatures in this region, ultimately making landfall in eastern Mexico.

4. Conclusions

This study examined the perturbation of Karl from its genesis to determine the mechanism behind its crossing of the AEJ. It was shown that Karl's vertical circulation was shallow and below the base of the AEJ, allowing it to penetrate and cross the jet. Once Karl crossed the AEJ, it developed a closed circulation around 850 hPa, implying that the large moisture content south of the jet allowed it to intensify. Once it reached the Gulf of Mexico, the warm sea surface temperatures likely allowed Karl to rapidly intensify into a Category 3 hurricane.

Further studies should be conducted with many AEWs to determine why some storms do not cross the AEJ while others do. For example, do some AEW_N stay north of the AEJ and dissipate? Does a perturbation's ability to cross the AEJ only depend on the jet base, or are there other factors involved. Additionally, what are the mechanisms behind other AEWs crossing the AEJ?

REFERENCES

Chen, T.-C., 2006: Characteristics of African Easterly Waves Depicted by ECMWF Reanalyses for 1991–2000. *Mon. Wea. Rev.*, **134,** 3539–3566.