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EARLY DEVELOPMENT OF AFRICAN EASTERLY WAVES IN THE EASTERN ATLANTIC

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1. INTRODUCTION

The West African coast is a region characterized by complicated weather interactions that have been studied for many decades. African Easterly waves (AEWs) are westward propagating disturbances originating over the African continent and sustained by baroclinic and barotropic growth at the expense of the African Easterly Jet (Charney & Stern 1966). As these waves propagate over the Eastern Atlantic and main development region they can spawn the seedlings of tropical cyclones with around 85% of major hurricanes forming from this source (Landsea 1993).

Recently this pathway to genesis has received with research into differences between developing and non-developing seedlings and consequently differences between AEWs that spawn developing disturbances and those that do not.

Hopsch *et al.* (2010) conducted a broad composite analysis of the differences between AEWs at the West African Coast (~12°N, 15°W), with developing waves showing stronger low-level development in vorticity and moisture fields in the trough of the wave. This research uses this finding and looks at the possible influences and feedbacks of West African weather on the wave and potential influences on the downstream development potential of the wave

The weather regime over the West African coast is predominantly modulated by the West African monsoon, driving a southwesterly onshore flow throughout the summer. A strong diurnal cycle of precipitation in this region has also been noted since the early GATE experiments (e.g. McGarry & Reed 1978, Albright *et al.* 1981). Since then coarse resolution global studies have confirmed the early observations (e.g. Yang & Slingo 2001) and with increasingly higher resolution datasets further understanding and research is possible.

This work will mainly focus on the interaction between AEWs, convective systems and the diurnal cycle of the region. Diurnal modulation of convective structures is hypothesized to potentially feedback on the large scale through influencing local vorticity and moisture fluxes.

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2. DATA & METHODOLOGY

This research utilizes the TRMM (Tropical Rainfall Monitoring Mission) 3B42 dataset, which is a 0.25°x0.25° gridded precipitation analysis available at 3-hour intervals for 1998 through present. The 3B42 dataset is a merged precipitation analysis dataset combining data from the TRMM satellite, other geostationary satellites and rainfall gauges (Huffman *et al.* 1997).

Dynamical fields are obtained from the CFSR 0.5°x0.5° gridded reanalysis dataset (Saha *et al.* 2010). CFSR is available at 6-hour time intervals this temporal resolution is inadequate to accurately capture the diurnal influence and future work will aim to use high-resolution modeling to better understand the shorter timescale processes.

The climatological coherent diurnal cycle of TRMM precipitation was calculated by taking the first four harmonics of the mean annual cycle, over the 13 years of available data, for each 3-hour interval. For precipitation intensity results the data were binned into 0.5 mm/hr bounds from 0–10 mm/hr at each grid point and for each 3-hour analysis time. These were then standardized by total number of events at each intensity bin over all hours.

AEWs were objectively analyzed using a combination of 2-10 filtered meridional wind averaged over 5°N to 12.5°N defining the trough where $v = 0$ with $\frac{dv}{dt} > 0$. This allowed for a simple way to locate and track the AEWs, for maps and analysis however the troughs were plotted using the objective trough lines from Berry & Thorncroft (2005).

3. RESULTS

The results will first outline the coherent diurnal cycle of precipitation at the West African coast and the modulation in precipitation intensity. The interaction between AEWs and the diurnal cycle will then be exemplified by a case study of Hurricane Igor.

3.1. Diurnal Cycle

The climatological diurnal cycle of the West African region over land exhibits increased precipitation over land during the evening hours and a minimum in precipitation during the late morning hours (fig 1). Over

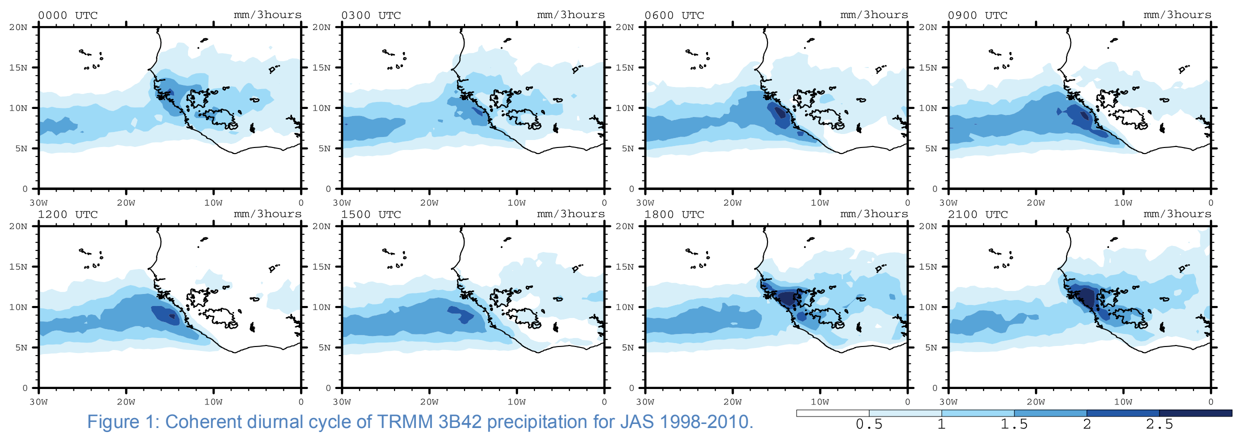

Figure 1: Coherent diurnal cycle of TRMM 3B42 precipitation for JAS 1998-2010. The black contours represent the 500m topography of the guinea highlands.

the ocean the peak precipitation is usually ~9-12 hours out of phase, with a peak rainfall in the morning hours. This is in agreement with the basic diurnal cycle over land and over ocean of the tropics (e.g. Gray & Jacobson 1977, Nesbitt & Zipser 2003).

The diurnal cycle portrayed through the harmonic analysis is a very smooth climatological representation and does not assess how the diurnal cycle affects events of different intensities, i.e. are intense precipitation rates such as those that would be expected to be associated with MCSs and AEWs diurnally modulated? For this, the percentage frequency of precipitation intensity occurring at each 3-hour period of the day was calculated. Figure 2 shows that the precipitation of all intensities over land is heavily modulated by the diurnal cycle, with over 20% of the more intense precipitation rates occurring 2100UTC whereas at 0900UTC less than 5% of the intense precipitation rates occur. This shows that MCSs triggered upstream and propagating through the area are still heavily modulated by the local diurnal cycle. The diurnal modulation of systems has the potential to have a large feedback on the synoptic scale system through diabatic heating within the convective system.

3.2. *AEWs & Genesis*

As AEWs leave the West African coast a small number of them spawn disturbances that undergo tropical cyclogenesis very quickly. This can be an inherent property of the parent wave leading to this development, early developing waves tend to have higher levels of vorticity at low-levels, and have a higher column moisture values than non-developing waves (Hopsch *et al*. 2010). A metric used by Hopsch *et al*. (2010) was the ratio of 850-600hPa relative vorticity, showing the early developing waves had higher ratios of low-level vorticity at the coast. By combining this difference in vorticity between levels, the vertical structure and intensity of the disturbance can be easily quantified and low-level vorticity spin-up can be measured.

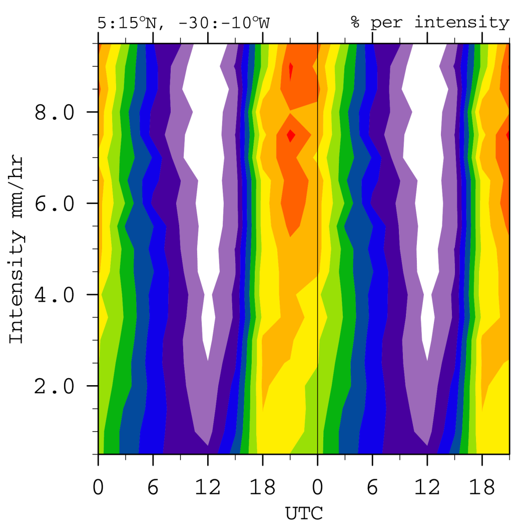

Figure 2: Percentage of rain intensity occurrence for each 3-hour period. The x-axis is repeated to highlight the diurnal oscillation. The size of the domain is noted in the top left corner, only grid cells over land were included in the analysis.

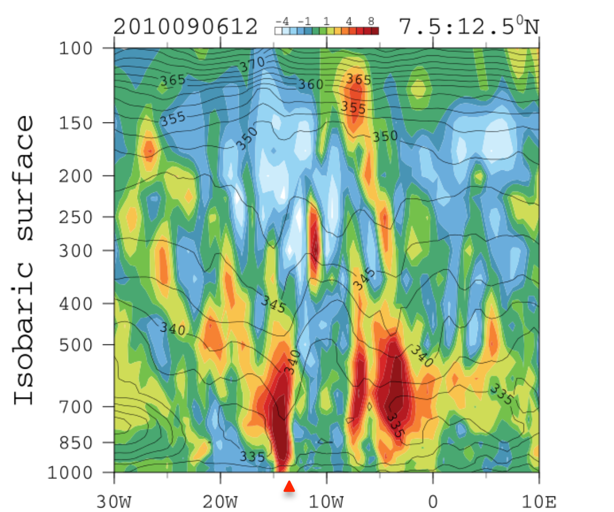

Figure 3: Relative vorticity (shaded, units $10^{-5}ms^{-1}$) and equivalent potential temperature (contoured, 5° intervals) vertical cross section averaged 7.5N to 12.5N. The wave associated with Igor is marked at 15W by the red triangle.

The case of Hurricane Igor (2010) is presented here to assess the hypotheses of diurnal influences on the waves potential to develop. Igor was initially reported as a tropical storm on September 8th at 13.7°N, 23.5°W. Using filtered meridional wind, analysis maps of brightness temperature and dynamic fields the genesis of Igor can be traced back to an AEW around 4°W on the 4th September. As the wave propagates west, the associated cloud clusters are modulated by the continental diurnal cycle. Accumulated rainfall of this wave (not shown here), shows that while the wave had associated convection from near 0°W, surface precipitation was only observed as the wave approached the Guinea Highlands where storm relative precipitation accumulations ~25 mm were measured over the coastal region.

The southern vortex of this AEW has a strong signal from early on the 4th through to genesis with an easily trackable Okubo-Weiss maximum. As the vorticity maximum approaches the coast it increases in magnitude while undergoing some interactions with shorter lived vorticity centers. The vertical cross section of relative vorticity and equivalent potential temperature (θ_e; fig 3) shows the vertical structure of the vorticity as the system leaves the coast. The θ_e contours start to bow down into the vorticity maximum from 700hPa upwards indicating a moist and warm column, indicative of the transformation towards a moist warm core tropical system.

To assess how the vorticity associated with the wave changes over this time frame, the difference between mid-level and low-level vorticity has been computed at each time step in a wave relative system. This is done by taking the difference in the average positive vorticity within a 4° radius circle of the 700hPa Okubo-Weiss maximum using the levels in Hopsch *et al.* (2010) of 600hPa from 850hPa. Positive (negative) values of the difference therefore represent greater (less) relative vorticity at 850hPa than at 600hPa. This method defines the location based on the filtered meridional wind trough location and then fine-tunes the center of the circular region to that of the 700hPa Okubo-Weiss maximum.

The time series of this metric (fig 4) show that while the system is over land, there is a consistent increase in low-level relative vorticity relative to mid-level vorticity from 1800LST to 0600LST on the 4th and 5th. This is consistent with the phasing of convection associated with the diurnal cycle generating low-level vorticity. As the system leaves the coast on the 6th the vorticity becomes more vertically distributed reducing the difference between levels.

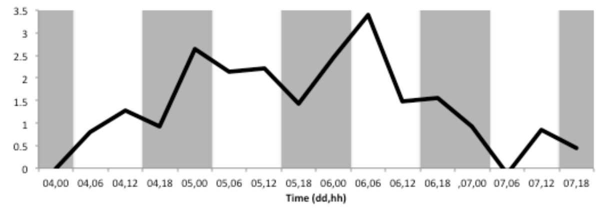

Figure 4: Time series of storm following, relative vorticity difference (units $10^{-5}ms^{-1}$) between 850hPa to 600hPa. Grey shading represents night-time (6pm to 6am).

For brevity only the Igor case has been included here, but 2010 saw Hurricane Earl and Tropical Storm Julia also initially develop within a short time of leaving the coast. The parent waves associated with these storms also interacted in a similar manner with the diurnal cycle of precipitation at the West African coast. Interactions between the diurnal cycle and AEWs have also been noted with respect to the convectively coupled kelvin waves for the genesis of Tropical Storm Debby (2006; Ventrice *et al*. 2012).

4. CONCLUSIONS

Using satellite estimated precipitation over 13 years a coherent diurnal cycle in precipitation has been diagnosed. As well as this smooth coherent diurnal cycle it has been shown that the diurnal forcing modulates events of all magnitudes.

Using storm relative metrics a case study of the AEW and vorticity maxima associated with the genesis of Hurricane Igor (2010) have been presented. Analysis of low-level and mid-level vorticity has shown a diurnal influence in low-level vorticity generation in the evening. At the coast increased precipitation in conjunction with the diurnal cycle moistens the column and begins to develop a moist warm core system while still located over the West African coast. These influences result in a wave that resembles the mean developing wave of Hopsch *et al*. (2010) and leads to genesis of Igor 2 days later.

This research still requires systematic analysis of multiple developing and non-developing cases to assess whether this is a common occurrence among waves or whether larger scale features account for the signals observed.

There are many potential influences on AEWs, convection and tropical cyclogenesis in the Eastern Atlantic. This work aims to highlight the potential significance of the diurnal cycle of precipitation over the West African coast and possible feedbacks with AEWs.

References

Albright, M. D., D. R., Mock, E. E., Recker & R. J. Reed 1981: A Diagnostic Study of the Diurnal Variation in the GATE B-Scale area. *J. Atmos Sci.* 38, 1429-1445

Berry, G. J., & C. Thorncroft, 2005: Case study of an intense African easterly wave. *Mon. Wea. Rev.*, *133*, 752–766.

Charney, J.G., and M.E. Stern, 1962: On the stability of internal baroclinic jets in a rotating atmosphere. *J. Atmos. Sci.,* 19, 159-172.

Gray, W. M., & R. W. Jacobson, 1977: Diurnal variation of deep cumulus convection. *Mon. Wea. Rev.*, *105*(9), 1171–1188.

Huffman, G.J., R.F. Adler, B. Rudolf, U. Schneider, and P.R. Keehn, 1995: Global precipitation estimates based on a technique for combining satellite-based estimates, rain gauge analysis, and NWP model precipitation information, *J. Clim.*, 8, 1284-1295.

Hopsch, S. B., Thorncroft, C. D., & K. R. Tyle, 2010: Analysis of African Easterly Wave Structures and Their Role in Influencing Tropical Cyclogenesis. *Mon. Wea. Rev.*, *138*(4),

Landsea, C.W. 1993: A climatology of intense (or major) Atlantic hurricanes Mon. Wea. Rev., 121, 1703-1713

McGarry, M. M., & R. J. Reed, 1978: Diurnal variations in convective activity and precipitation during phases II and III of GATE. *Mon. Wea. Rev.*, *106*, 101–113.

Nesbitt, S. W., and E. J. Zipser, 2003: The diurnal cycle of rainfall and convective intensity according to three years of TRMM measurements. *J. Clim.*, 16, 1456-1475

Suranjana S., *et al*. 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Met. Soc.* 91, 1015-1057.

Ventrice, M. J., C.D. Thorncroft, and M. A. Janiga, 2012: Atlantic tropical cyclogenesis: A three-way interaction between an African easterly wave, diurnally varying convection, and a convectively-coupled atmospheric Kelvin wave. *Mon. Wea. Rev.,*(in press).

Yang, G. Y., & J. Slingo, 2001: The diurnal cycle in the tropics. *Mon. Wea. Rev.*, *129*, 784.