10B.4 A composite study of African Easterly Waves and tropical cyclogenesis: Do African Easterly Waves matter?

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Introduction:

Tropical cyclone activity over the tropical North Atlantic has often been related to changes in the large-scale environment such as variations in North Atlantic sea surface temperatures (SSTs, Landsea et al. 1998; Goldenberg et al. 2001; Mann and Emanuel 2006), various phases of ENSO (Goldenberg and Shapiro 1996) and tropospheric deep wind shear (Aiyyer and Thorncroft 2006). In such studies the timescales usually considered range from seasonal to multi-decadal. While the focus for numerous earlier studies has been the variability of tropical storms, hurricanes and/or the large scale environment, the variability of the precursor disturbances for these storms has not been discussed as much.

African easterly waves (AEWs) have for many decades been recognized to be an integral part of the weather and climate over both West Africa and the tropical North Atlantic. The pioneering work of Erickson (1963), Carlson (1969), Simpson et al. (1969, Frank (1970) and Burpee (1972) introduced the concept of African disturbances being able to serve as seedlings for Atlantic tropical cyclones – a detail that is now well established (Avila and Pasch 1992; Landsea et al. 1998). These early studies consisted mostly of case studies, as seen in annual reviews of hurricane activity, or of composite studies using a few AEWs based on data obtained during field experiments, such as GATE (Reed et al. 1977). In those studies, the waves were composited regardless of their future outcome – of whether the waves were associated with development of Atlantic hurricanes or non-development – to provide an overview of the typical spatial structure and to also provide initial ideas about their energetics and lifecycle.

AEWs are synoptic scale systems with a typical wavelength of 2000-4000km and are most intense at a level around 700 to 600hPa (e.g. Reed 1977; Kiladis et al. 2006, K06). In addition, it is very important to realize that AEWs also possess sub-synoptic scale structures, i.e. features of smaller space-scales than the large scale AEW. These features are associated with non-linear developments (Thorncroft and Hoskins 1994b), potential vorticity (PV) anomalies generated by convection in Mesoscale Convective Systems (MCSs, e.g. Schubert et al. 1991) or a combination of these. In a recent study by Hopsch et al. 2007 a thorough investigation of the nature and variability of the sub-synoptic scale features of AEWs was provided.

While AEWs have been the focus of intense research over the years, there are still unanswered question on the variability of AEWs that will be associated with downstream development and AEWs that don't develop. In this paper, the ERA-40 dataset has been used to generate a climatology of AEWs leaving the West African coast. By identifying all AEWs that were associated with tropical storms and hurricanes over the main development region (MDR), we obtain a composite view of the structure and characteristics of these AEWs and their large-scale environment. This is compared to the composite of all AEWs that ultimately failed to develop into named tropical cyclones. It will be shown that there exist

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substantial differences in structure and characteristics of AEWs that become associated with named tropical cyclones and the ones that do not.

Data and Methodology:

For much of this study, data for July through September from the reanalysis project, ERA-40, from ECMWF is used (Uppala, et al. 2005). We chose to restrict our investigation to only include years when satellite data was fully incorporated into the datastream (1979 through 2001). The reason for this is that the dataset relies more heavily on the model than observations in the pre-satellite era due to the limited amount of observations over the tropics and oceans. The low-resolution (2.5° latitude and longitude grid-resolution) data was used to derive the 2-6day filtered wind field and calculated the streamfunction thereof on the 600hPa level. From our previous work we know that the streamfunction of the 2-6day filtered wind on 600hPa can be used as a proxy for the large-scale aspect of AEWs, in particular that the streamfunction minimum is a representation of the AEW trough. The 600hPa level was chosen as the basis for climatology of all AEWs for July through September from 1979 to 2001. In order to be counted as an AEW, the streamfunction minimum needs to be equal or less than 1 standard deviation from the July through September average of all years. The high-resolution ERA-40 data (1.125° grid resolution) was then used to generate composites of all developing (close to coast developing) and non-developing waves for day -2 to day +2, with day 0 being defined as the date when the trough passes over 15°W. These composites provide us with the unique opportunity to identify the key-components in the structure of the developing systems for comparison with the composite structure of the non-developing AEWs.

The best-track dataset of the National Hurricane Center (NHC) is used to provide the time and location for named storms in the MDR. The first point in the best-track dataset is used here as “genesis-point”.

Results:

Horizontal structure

Let us first consider the composite of all AEWs that were associated with named storms that formed in close proximity to the West African coast. This sample consists of all named tropical storms and hurricanes that have their genesis point east of 30°W. Figure 1 shows the PV at 600hPa in shading, and the large scale AEW (i.e. the streamfunction of the 2-6day filtered wind) in blue contours. Here, negative (dashed) contours correspond to AEW troughs. The composite AEW is found around 15°W on day 0 (by definition, the longitude of AEW passage for day 0), see Fig. 1a. The composite of the PV field at 600hPa shows a strip of enhanced PV along inland regions north of the Gulf of Guinea and extending out over the eastern tropical Atlantic. The high-PV strip spans approximately 5° to 10° of latitude and is accompanied by a PV minimum to the north over the heat low region of the Sahara Desert. Both the streamfunction and PV fields at 600hPa show distinctive maxima over the coastal area south of Dakar. The main PV maximum is found just off the coast of West Africa, and shows that he area covered by closed PV contour of 0.35 PVU covers almost 5°x 5°.

It is suggested that much of this increase in PV is generated diabatically by strong deep convective activity over the Guinea Highlands and adjacent coastal region. Figure 1b shows the composite of the non-developing AEWs. Compared to the composite of the developing AEWs, it can be seen that the non-developing composite wave trough is weaker. This is indicated in both the streamfunction of the 2-6day filtered wind at 600hPa, where a reduction by about 35% is obtained, as well as in a reduction by 0.1PVU of the PV field.

Vertical structure

Further insight into the differences in structure of the developing and non-developing AEWs can be gained by considering the vertical structure of the obtained composites. Figure 2 shows the cross-section of the generated AEW composite for day 0 using two panels for the developing (Fig. 2a) and non-developing (Fig. 2b) AEW composite respectively. The cross sections are taken along 11.25°N and from 40°W to 10° E in the horizontal, and from 1000hPa to 100hPa in the vertical. The top panel shows relative vorticity (shaded; warm colors for positive relative vorticity, cold colors for negative relative vorticity), theta-e (θ_e, in black contours), and the horizontal wind at every level (wind barbs in knots); the bottom panel shows relative humidity (shaded) and vertical velocity (contours). These parameters were chosen to help identify the vertical structure of both the composite AEW as well as to provide an idea of the conditions of the environment ahead of the AEW in terms of available moisture and stability, which the feature will encounter further downstream.

In the developing AEW composite the vorticity maximum has increased and is found at around 850hPa (from around 600-700hPa for day -2) and thus suggests that the AEW has obtained a more warm-core structure. In comparison, the relative vorticity of the non-developing AEW composite has not increased as much and has not developed a lower warm-core structure as was seen in the developing AEW composite.

In agreement with the differences in relative vorticity and therefore the intensity of the system, the strongest upward vertical velocities are found within the composited AEWs and are about 30% stronger in the developing case (less than -.32 Pas-1) than in the non-developing case (-0.24 Pas-1). The cross-sections show the presence of moist boundary layers in both the developing and non-developing composite. However, the largest differences in relative humidity are shown to occur in the mid-to-upper levels for the composite AEW as well as for the air column directly downstream from the disturbance. While moisture, as seen in relative humidity values in excess of 80%, is present throughout a deep layer (up to around 300hPa) in the developing AEW composite, the same relative humidity only reaches to around 500hPa in the non-developing AEW composite. Likewise, the mid and upper levels downstream of the developing AEW composite are shown to be somewhat less humid (around 60%), but are typically much drier downstream of the non-developing AEW (relative humidity less than 50% in mid- and upper levels).

Figure 3 shows the histogram of the relative % of the difference of relative vorticity between 850-600hPa for all individual developing (blue) and non-developing (maroon) AEWs on day 0. A sub-panel for the same quantity on day -2 is also provided. This clearly suggests for day 0 that the developing AEWs have larger vorticity at low levels than at mid-level, thus either are tending towards a more warm core or shallower/weaker cold core structure than compared with the AEWs that do not develop further downstream. Also, the developing systems have a stronger mid-level relative vorticity at day -2, indicating stronger baroclinicity.

Final remarks:

The ERA-40 dataset has been used to generate a climatology of AEWs leaving the West African coast. By identifying all AEWs that were associated with tropical storms and hurricanes over the main development region (MDR), a composite view of the structure and characteristics of these AEWs and their large-scale environment was obtained. This was compared to the composite of all AEWs that ultimately failed to develop into named tropical cyclones. Substantial differences exist in the structure for AEWs that become associated with named tropical cyclones and the ones that aren't associated with any further downstream development.

The AEWs under consideration are exhibiting very similar large-scale characteristics as was shown in the observational study of K06. This is seen in the streamfunction contours, which indicate a more baroclinic nature over land and a more barotropic set-up over the ocean, and a shift for convection to preferably occur in northeasterlies over land to southwesterlies over the ocean. For the developing AEW composite the signal is stronger and the sub-synoptic scale features more clearly embedded within the large-scale AEW (highlighting the impact of the Guinea Highland area).

While the high-resolution ERA-40 data for all individual members of the composites is used, the resulting composite shows a smoothed appearance due to slight latitudinal and/or longitudinal shifts in the fields of the individual sample members, variations in translation speeds of the systems, and the different sample sizes of the developing and non-developing AEWs. Nevertheless, the composites show that there exists a significant difference between the developing and non-developing AEWs that is statistically significant (using simple t-test statistics).

Acknowledgement:

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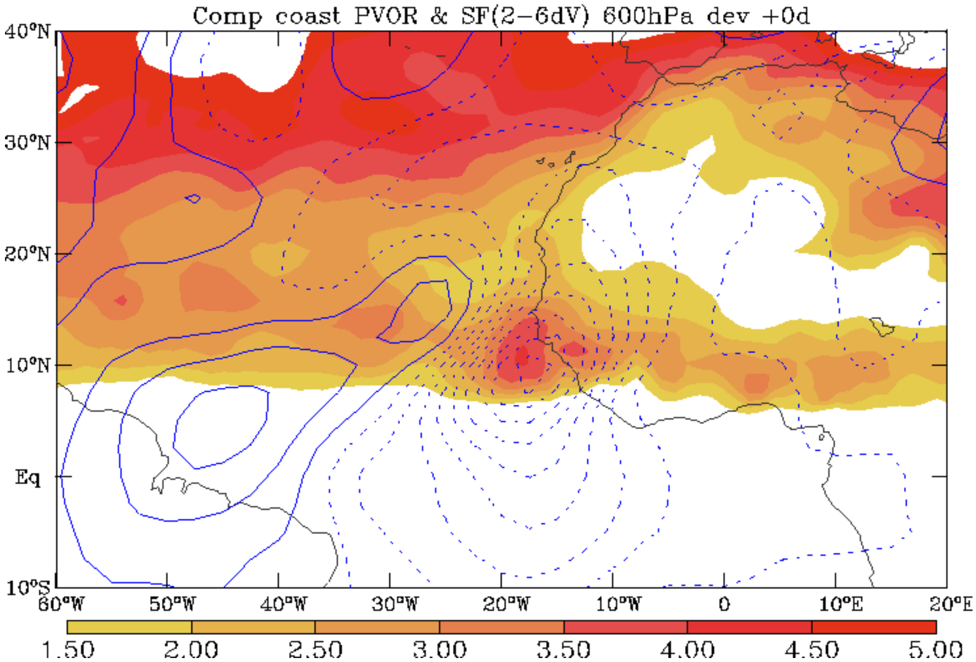
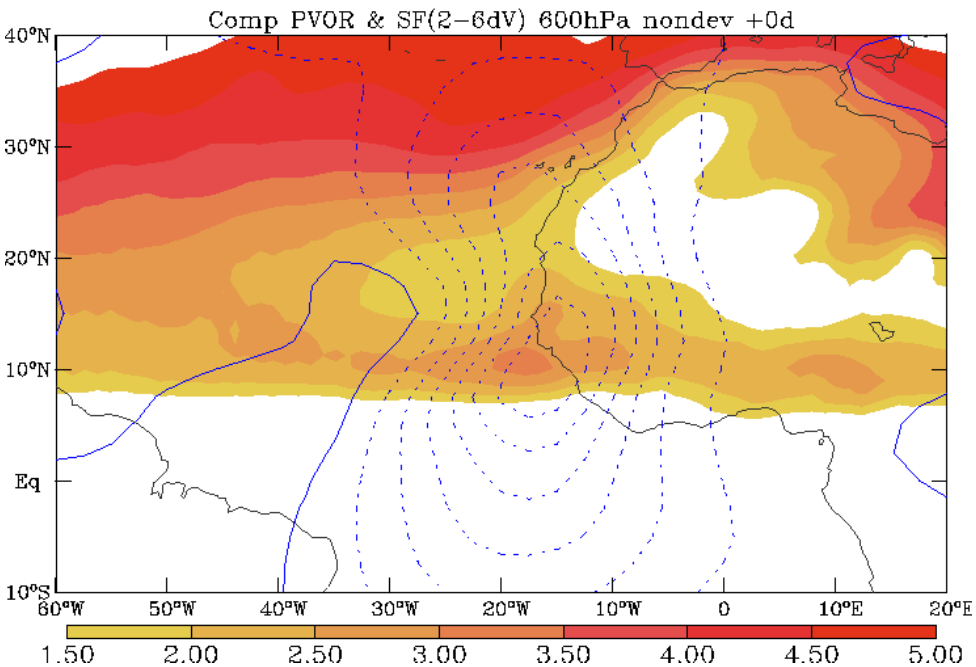
Figures:

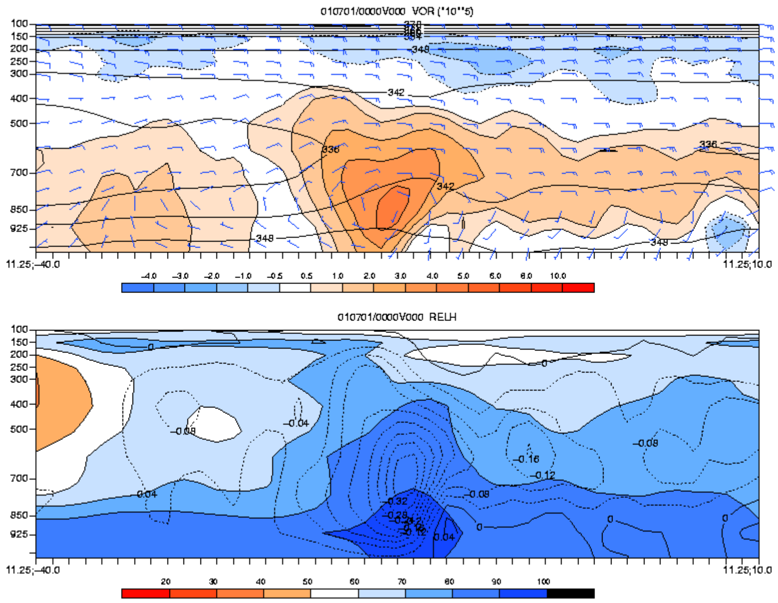


1a

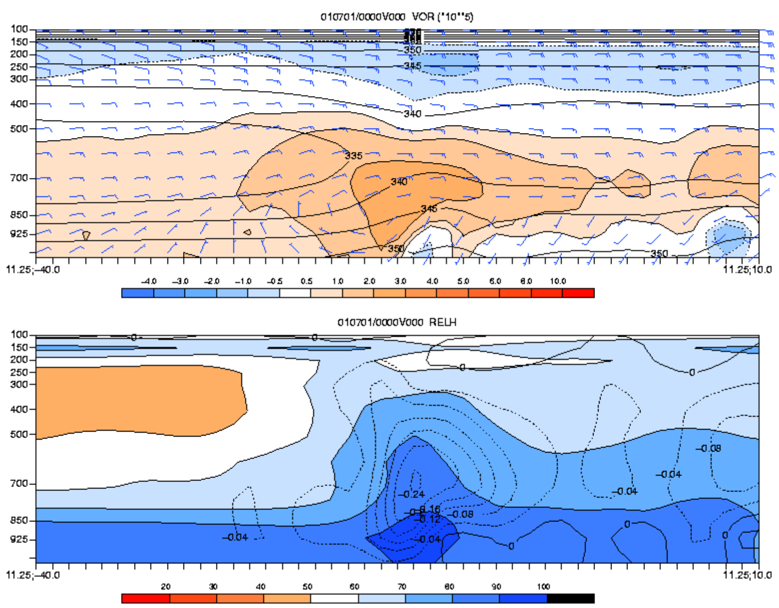


1b

Fig. 1: PV at 600hPa in shading, and the large scale AEW (i.e. the streamfunction of the 2-6day filtered wind) in blue contours. Negative (dashed) contours correspond to AEW troughs. The composite AEW is found around 15°W on day 0 (by definition, the longitude of AEW passage for day 0). Panel 1a shows the composite result for all developing AEWs, panel 1b shows the composite result for all non-developing AEWs.

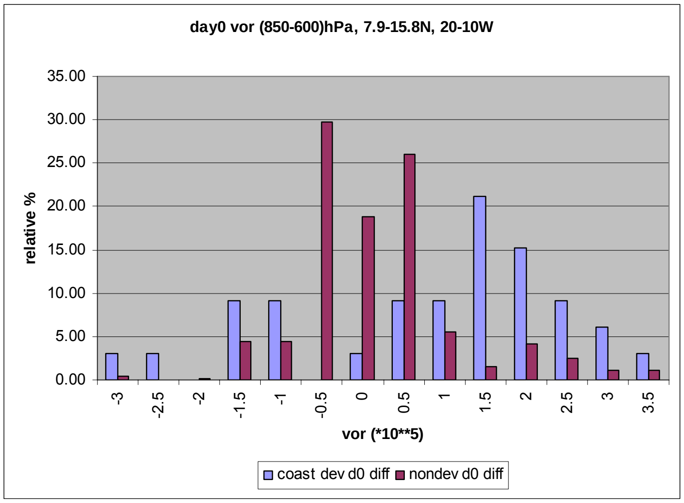


2a



2b

Fig. 2: Cross-section of the generated AEW composite for day 0 using two panels for the developing (2a) and non-developing (2b) AEW composite respectively. The cross sections are taken along 11.25°N and from 40°W to 10° E in the horizontal, and from 1000hPa to 100hPa in the vertical. The top panel shows relative vorticity (shaded; warm colors for positive relative vorticity, cold colors for negative relative vorticity), theta-e (θ_e, in black contours), and the horizontal wind at every level (wind barbs in knots); the bottom panel shows relative humidity (shaded) and vertical velocity (contours).



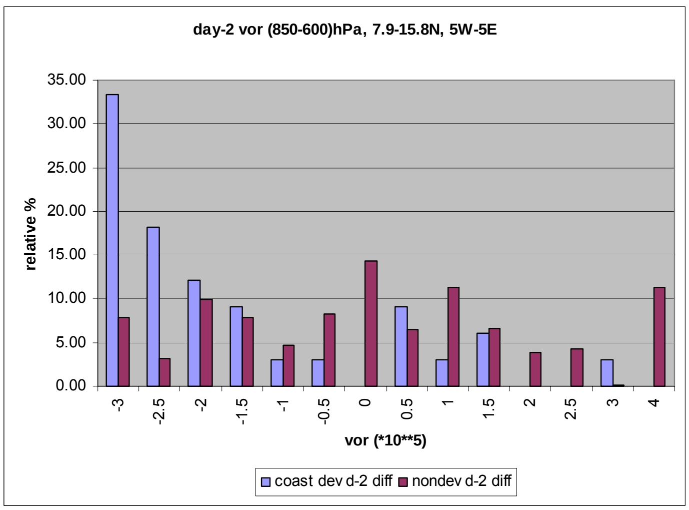


Fig. 3: The histograms show the vertical difference of relative vorticity between 850-600hPa – suggesting for day 0 that the developing AEWs have larger vorticity at low levels than at mid-level (thus either are tending towards a more warm core or shallower/weaker cold core structure than compared with the AEWs that do not develop further downstream). Curiously, the developing systems have a stronger mid-level relative vorticity at day -2 (see lower panel), indicating stronger baroclinicity.