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DIABATIC ROSSBY WAVES AS A MODEL FOR CONVECTIVELY COUPLED AFRICAN EASTERLY WAVES

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1. INTRODUCTION

African easterly waves (AEWs) are synoptic-scale disturbances associated with the African Easterly Jet (AEJ) that move westward across the Sahel region of Africa during the West African Monsoon season. It has been shown that the barotropic and baroclinic extraction of energy from the AEJ is not sufficient to sustain AEWs (Hall et al., 2006), and that moist convection may have an important role in their maintenance (Berry and Thorncroft, 2012). It is, however, not clear how the synoptic scale waves and mesoscale convection interact.

This study examines the hypothesis that convection and AEWs may interact through the Diabatic Rossby Wave (DRW) mechanism proposed first by Moore and Montgomery (2005). In the DRW framework, downstream diabatic generation of Potential Vorticity (PV) plays a similar role to advection of background PV by the meridional perturbation flow (e.g. Raymond and Jiang 1990; Snyder and Lindzen 1991; Parker and Thorpe 1995). The applicability of the DRW mechanism to AEWs, however, is yet to be rigorously tested. This provides the motivation for our study. We examine whether a key condition for DRW genesis; the generation of potential vorticity (PV) due to the vertical gradient of diabatic heating produced by convection (Moore et al., 2013), occurs in AEWs and how it helps in wave propagation and sustenance.

2. METHODS

The impact of diabatic PV generation on the maintenance, propagation, and evolution of AEWs is examined through a PV budget calculated using the ERA-Interim reanalysis and satellite derived TRMM 3B42 rainfall. Here, diabatic heating is calculated following Hagos et al. (2010) using the residual of the thermodynamic equation in pressure coordinates:

$$Q = \frac{c_p T}{\theta}\left(\frac{\partial\theta}{\partial t} + u\frac{\partial\theta}{\partial x} + v\frac{\partial\theta}{\partial y} + \omega\frac{\partial\theta}{\partial p}\right)$$

Diabatic and advective tendencies of PV are then calculated using a form of the Ertel PV budget equation in pressure coordinates following Zhang and Ling (2012):

$$\frac{\partial P}{\partial t} = -\boldsymbol{V}\cdot\boldsymbol{\nabla}_p P - g\left(f + \varsigma_p\right)\frac{\partial Q}{\partial p} + residual$$

where horizontal differential diabatic heating and frictional terms are accounted for in the residual. In this equation the first term on the right hand side represents the contribution to the total PV from advective processes and the second term represents the contribution from diabatic processes (primarily convective). We compare these two terms to examine where diabatic PV generation is important for AEWs.

A composite mean of all AEWs (defined as a 1 standard deviation maxima in the 2-10 day bandpass filtered meridional winds) during the period where the TRMM satellite was operational (1999 through 2013) is used to represent a typical AEW. This composite is taken at various locations along the northern and southern tracks defined by an eddy kinetic energy (EKE) climatology. Anomalies associated with AEWs are isolated by subtracting a climatological mean. Statistical significance of the AEW anomalies is obtained using a student t-test, with all values significant at the 10% level shown in the figures.

3. NORTHERN TRACK AEWS

Figure 1a shows the 900hPa mean PV anomaly associated with a composite of northern track AEWs at 10W, with horizontal wind anomalies overlaid. There is a strong positive PV anomaly in association with the inverted trough of the AEW and a weaker negative anomaly upstream in association with the inverted ridge of the AEW. The total PV generation at the same time, in Figure 1b, is downstream, in the northerlies and southerlies respectively, as expected given the typical westward propagation of AEWs. As discussed in the methods, the total PV tendency is then divided up into diabatic (Figure 1c), advective (Figure 1d) and residual (e.g. frictional, not shown) components. Significant diabatic PV tendencies occur both downstream in the northerlies, and upstream in the southerlies and ridge.

The diabatic PV tendency of most interest for the DRW mechanism is the downstream component, since a downstream component is required to generate new PV ahead of the wave. Although the advective PV accounts for a large proportion of the approximate 0.2 PVU/day total PV tendency maxima in this region, the diabatic tendency is significant and accounts for around 0.1 PVU/day of the total PV tendency further downstream of

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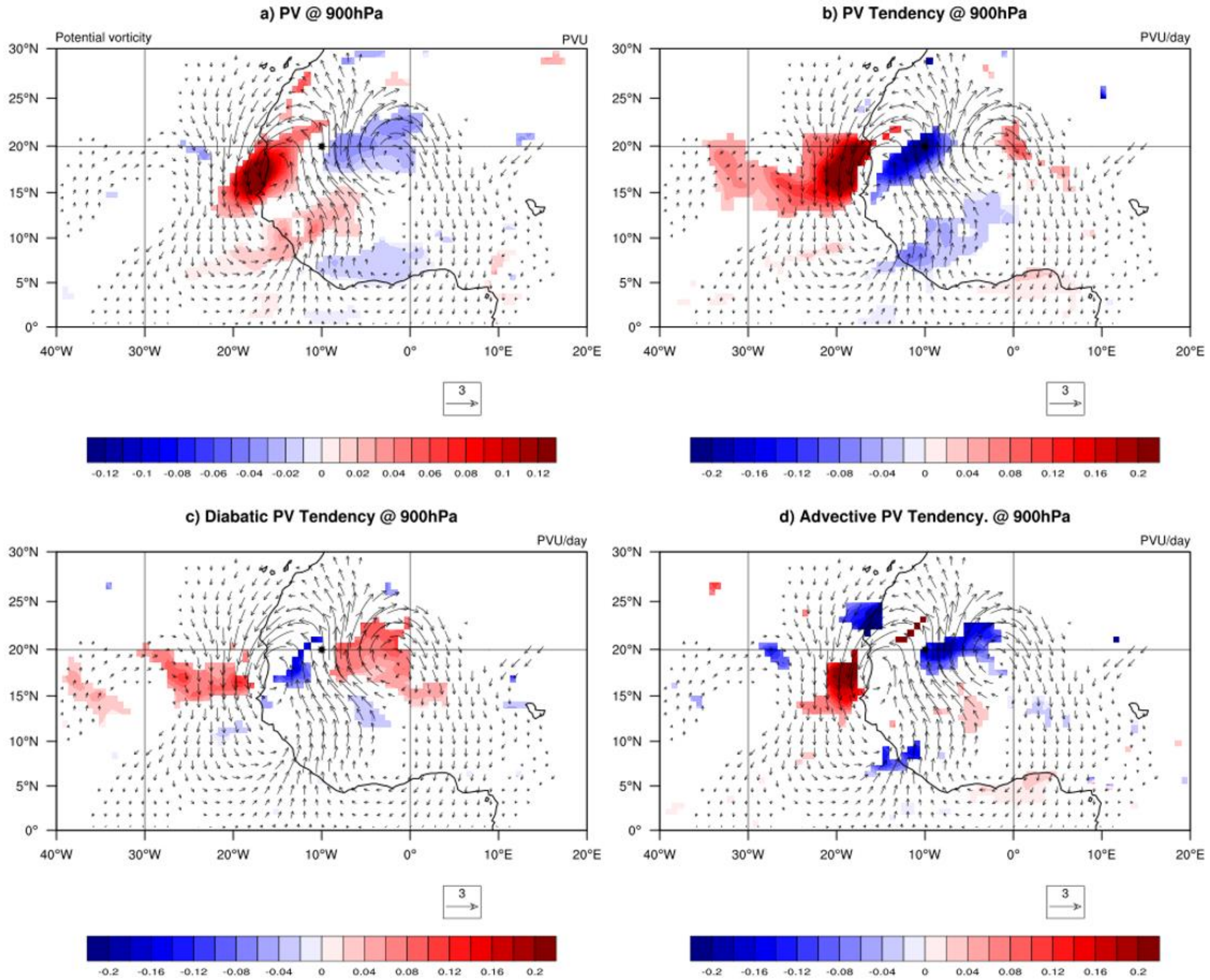

Figure 1: 900hPa anomalies associated with a composite of northern track (900hPa, 20N) AEWs centered at 10W. Anomalies are of a) PV (PVU), b) total PV tendency (PVU/day), c) diabatic PV tendency (PVU/day), and d) advective PV tendency (PVU/day). Anomalous AEW winds (m/s) are overlaid as vectors.

the maxima in total PV tendency. This provides evidence that the DRW process is occurring to some extent in the northern track AEWs, even if advective processes are more dominant.

4. SOUTHERN TRACK AEWS

The picture for southern track AEWs appears a little more complicated. The 650hPa mean PV tendency anomalies associated with a composite of southern track AEWs at various longitudes (not shown), show that positive PV tendencies occur in the northerlies downstream of the trough and the strong positive PV. However, in this case the majority of the PV tendency can be accounted for by advective processes, and there is no significant diabatic PV tendency. This is somewhat expected since PV is generated by the gradient in diabatic heating, and there is unlikely to be a strong gradient in the mid-levels where convective heating profiles are maximized.

Figure 2 shows the 900hPa anomalies associated with the 650hPa southern track AEW at the Greenwich Meridian. Here there is a weak PV anomaly with a maxima of 0.05 PVU, a weak positive total PV tendency downstream, and a weak negative total PV tendency upstream. In this case the total PV tendency occurs from mostly diabatic sources and the positive and negative anomalies are co-located with the 650hPa trough and ridge respectively. Therefore convection in the AEW trough may be acting to deepen or lower the PV structure of the wave.

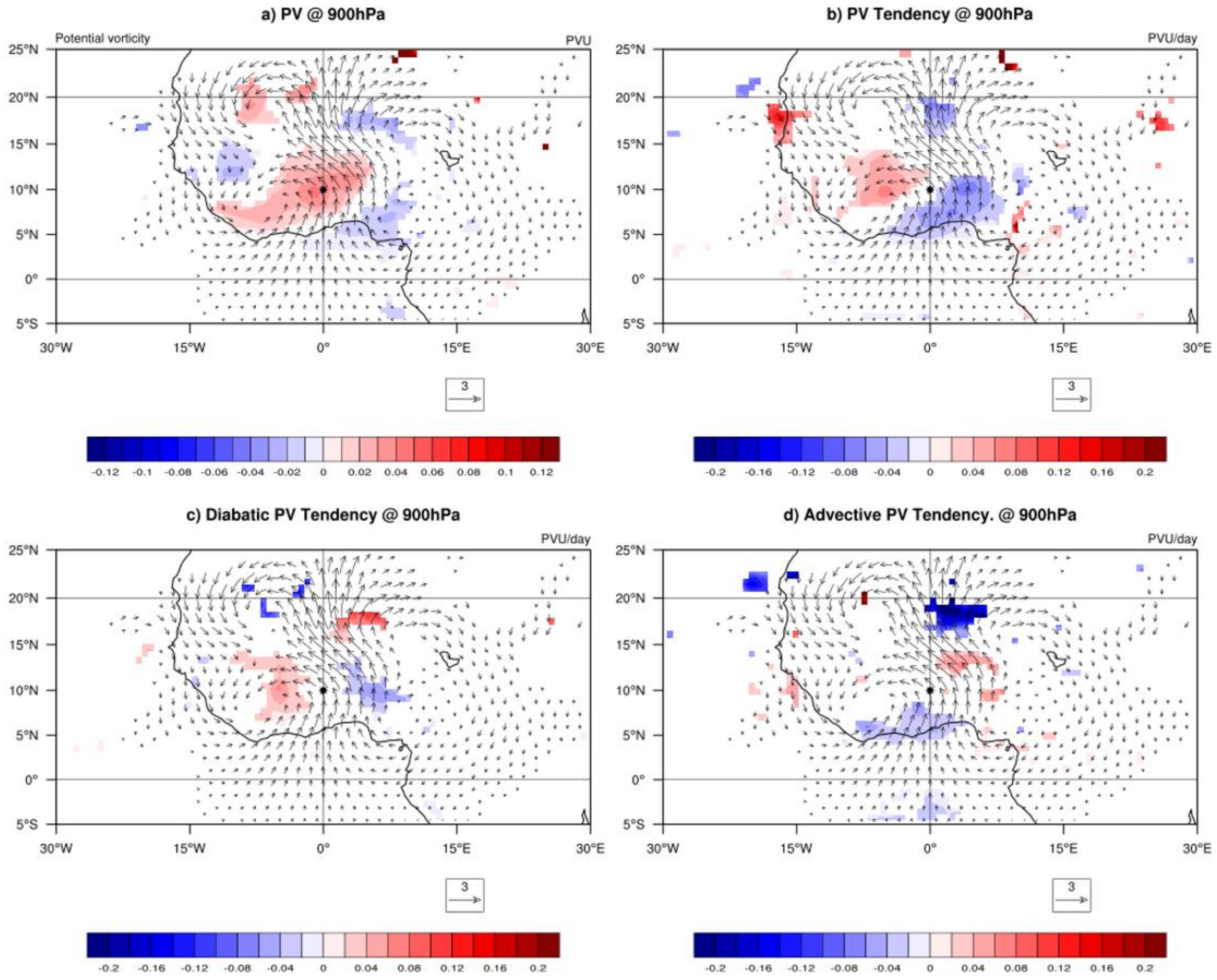

Figure 2: 900hPa anomalies associated with a composite of southern track (650hPa, 10N) AEWs centered at the Greenwich Meridian. Anomalies are as in Figure 1.

5. CONCLUSIONS

By combining a composite analysis and PV budget this study has shown that there is evidence for the theory that the DRW mechanism plays a role in the maintenance and propagation of the low-level northern track AEWs. It is also shown that for the mid-level, southern track AEWs, significant diabatic PV generation occurs not at the level of peak wave amplitude but at lower levels. This suggests that diabatic generation deepens the PV structure of the Southern Track AEW.

Future work will focus on expanding this composite analysis to analyze whether there is any difference between different wavelength and magnitude AEWs. Further, this study motivates numerical simulations using the weather research and forecasting (WRF) model to further examine the sensitivity of AEWs to the DRW mechanism.

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