11D.7 A convectively coupled equatorial Kelvin wave's impact on African easterly wave activity

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1. Introduction

The impact of African easterly waves (AEWs) on African rainfall variability during boreal summer is a well established and heavily studied topic in literature. Given the large body of work on these waves, there is still a lack of knowledge regarding when and how these waves originate. This lack of knowledge might be due to the sparse observations east of 10˚E and the relatively small number of papers that investigate AEW initiation (e.g., Albignat and Reed 1980; Berry and Thorncroft 2005; Thorncroft et al. 2008).

In the 1970s, most believed that AEWs formed via a mixed barotropic and baroclinic instability mechanism, which was backed by several idealized modeling studies showing that AEWs could grow from small amplitudes on an unstable African easterly jet (AEJ; e.g., Rennick 1976; Simmons 1977; Thorncroft and Hoskins 1994a,b). But recent work (e.g., Mekonnen et al. 2006; Kiladis et al. 2006; Hall et al. 2006; and Thorncroft et al. 2008) has challenged this hypothesis and formulated another hypothesis stating that AEWs are triggered by some localized forcing, which can be in the form of latent heating in the entrance region of the AEJ.

Thorncroft et al. (2008) suggest that AEWs rely on the presence of significant upstream convective triggers that are linked to topography. It is argued here that one source of this upstream latent heating could be from the presence of a convectively-coupled equatorial atmospheric Kelvin wave (CCKW). This concept provides new insight on a topic that is not yet fully understood and could be used to support prediction of AEW initiation and intensity changes.

2. The role of CCKWs on convection over the tropical Atlantic and Africa

The convective envelope of the CCKW (dashed black contours) significantly increases convection over the tropical Atlantic and tropical Africa during boreal summer (Fig. 1). Anomalies of unfiltered OLR, Kelvin filtered outgoing longwave radiation (OLR), and 200 hPa winds are averaged over each lag using a CCKW index. The CCKW index is derived by selecting all days between July-September (JJAS) 1989 and 2009 where the minimum Kelvin filtered OLR anomaly was less than -1.5 standard deviations in magnitude over a grid point (10°N, 15°W). Kelvin waves are identified by filtering OLR data in wavenumber and frequency following the methodology of Wheeler and Kiladis (1999). We objectively identify 142 CCKWs using this methodology. Daily lags are used on this time series in order to develop propagating characteristics. For clarification, "Day 0" is when the minimum Kelvin filtered OLR anomaly moves over the selected base point.

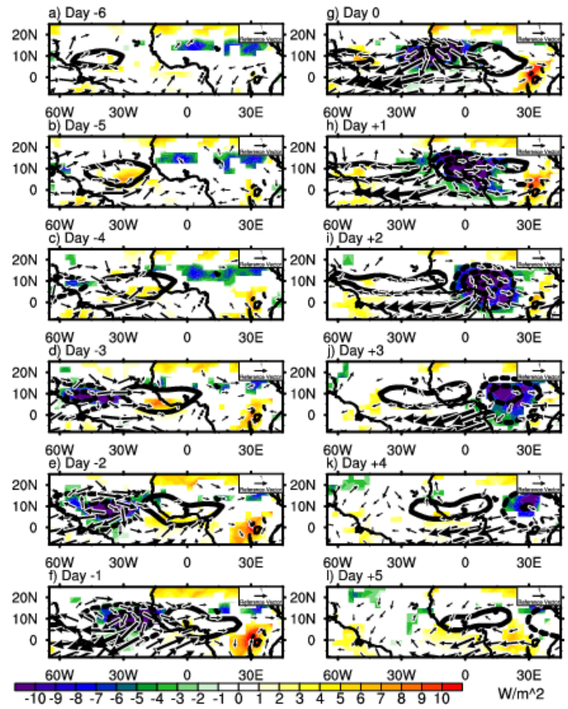

FIG. 1. NOAA daily averaged interpolated unfiltered OLR anomalies averaged over each CCKW lag. OLR anomalies statistically different than zero at the 95% level are shaded. Kelvin filtered OLR anomalies are contoured if statistically different than zero at the 95% level. Negative Kelvin filtered OLR anomalies are dashed. Vectors represent 200 hPa wind anomalies only showing magnitudes greater than 0.5 ms^{-1}. Shade interval is 1 Wm^{-2}; contours begin at (+/-) 3 Wm^{-2} and the contour interval is 6 Wm^{-2}; reference wind vector is 1 ms^{-1}**.** (Fig. 5 in Ventrice et al. 2012)

3. The pre-Alberto African easterly wave (2000)

Berry and Thorncroft (2005) discuss the lifecycle of the AEW associated with the genesis of Hurricane Alberto in 2000. They suggest that the strong AEW that developed into Hurricane Alberto (2000) was the result of an outburst of convection over the Darfur Mountains (~25˚E). To investigate the initiation of this AEW, TRMM 3B42 unfiltered rain rate anomalies, overlaid with Kelvin filtered TRMM anomalies show that the convective burst over the

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Darfur Mountains on July 30-31, 2000 occurred during the passage of the convectively active phase of a strong CCKW (Fig. 2). Two strong CCKWs appear to have modulated the intensity of the pre-Alberto AEW while over Africa. With respect to the rainfall associated with the pre-Alberto AEW, the superposition with the convectively active phases of both CCKWs were associated with increased rainfall, whereas the superposition of the convectively-suppressed phase was associated with a brief weakening of rainfall. This figure provides strong evidence that CCKWs influence the intensity of AEWs and MCSs over Africa and motivates the idea first posed by Mekonnen et al. (2008) that CCKWs might act as convective triggers for AEW genesis.

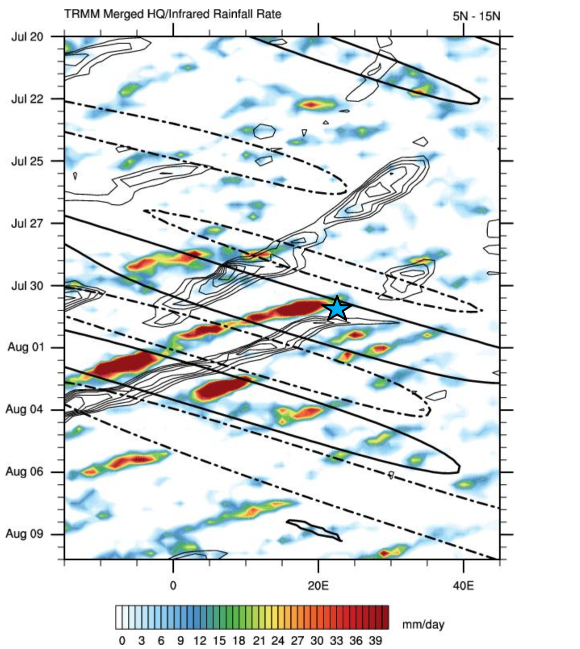

FIG. 2. Time-longitude plot of unfiltered TRMM 3B42 rain rate anomalies (positive -shaded) and Kelvin filtered TRMM anomalies (contours) averaged over 5-15˚N for July 20 through August 10, 2000. Negative Kelvin filtered TRMM anomalies (dashed) represent the convectively suppressed phase of the CCKW. The +/- 2 mm day^{-1} Kelvin filtered TRMM anomaly is only contoured. Positive values of ECWMF-interim total meridional wind is contoured (black); contouring begins at 2 ms^{-1}; contour interval is 1 ms^{-1}. The blue star represents the location where the pre-Alberto AEW first initiated.

In order to investigate the initiation of the pre-Alberto AEW in greater detail, maps of CPC-merged IR (shaded) overlaid with Kelvin filtered TRMM anomalies (black contours) and ERA-interim 850 hPa wind anomalies (vectors) are constructed every six hours for the period beginning at 00Z July 30 and ending 06Z July 31 (Fig. 3). The domain of Fig. 3 is focused over eastern Africa, where the northeastern extent of the Gulf of Guinea is located in the lower left corner. At 00Z July 30, the convectively active phase of the leading CCKW is located between 0-20˚E, while its convectively-suppressed phase is located between 25-35˚E. Note that scattered MCSs were present across eastern Africa at this time, consistent with a time of day when convection is found frequently there (Yang and Slingo 2001; Laing et al. 2008, 2010).

These diurnal-cycle linked MCSs over eastern Africa are observed to weaken by 06Z July 30, consistent with the diurnal cycle of convection there. However, a single MCS associated with a brightness temperature less than 200˚K is observed over 11˚N, 24˚E, which formed in between the convectively suppressed and convectively active phases of the CCKW. Note that at this time, the maximum positive Kelvin filtered TRMM rain rate anomaly (convectively active phase) was located roughly 15˚ of longitude to the west of this convective feature. Takayabu and Murakami (1991) and Straub and Kiladis (2003a,b) find that the greatest low-level zonal convergence occurs 15˚ of longitude to the east of the minimum negative Kelvin filtered OLR anomaly (convectively active phase). Therefore, this MCS formed in a region relative to the CCKW that is preferable for initiating convection. Further, this MCS formed during a time of day when convection is on average suppressed, suggesting that the forcing of the CCKW was able to overcome that of the diurnal cycle. This MCS is found to be the leading convective disturbance associated with the pre-Alberto AEW.

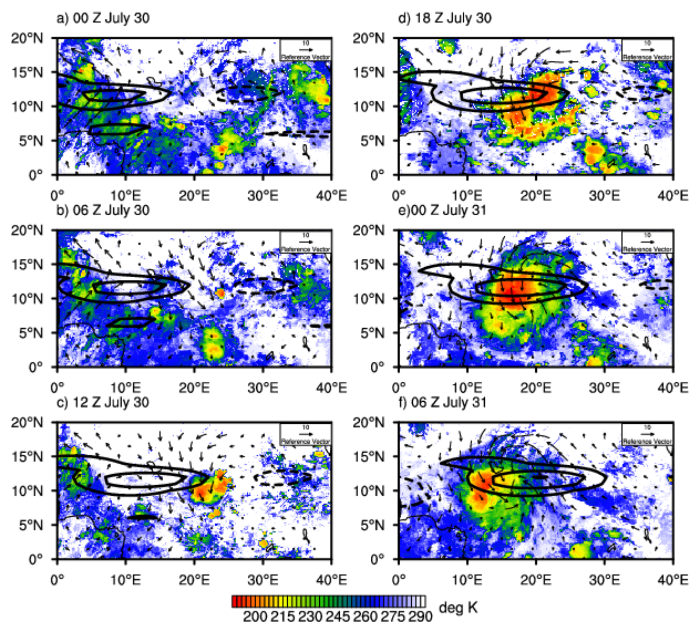

FIG. 3. CPC-merged IR (shaded) overlaid with Kelvin filtered TRMM rain rate anomalies (black contours) and ERA-Interim 850 hPa wind anomalies (vectors) for the period beginning at 00Z July 30, 2000 and ending 06Z July 31, 2000. Shade interval is 2.5˚K; contours interval is 0.2 mm day^{-1}; reference vector is 10 ms^{-1}.

4. The Relationship between convectively coupled Kelvin waves and African easterly wave activity

It will be shown that in addition to increasing convection over tropical Africa, which sometimes is in the form of vigorous and long-lived mesoscale convective systems (Mounier et al. 2007; Laing et al. 2010), CCKWs alter the synoptic background state over tropical Africa that favors the genesis and intensity of AEWs. This modulation occurs via the CCKW impacting the characteristics of the AEJ, along with increasing the low-level (925-700 hPa) vertical wind shear over Africa (not shown). Fig. 4 represents a time-longitude composite of 2-10d filtered 700 hPa eddy kinetic energy (EKE) anomalies averaged over each lag of the CCKW index. Prior to the passage of the convectively active phase of the CCKW over Africa, there are negative EKE anomalies over the tropical Atlantic. After the convectively active phase of the CCKW moves over western Africa, anomalous AEW activity develops over the eastern tropical Atlantic and western tropical Africa.

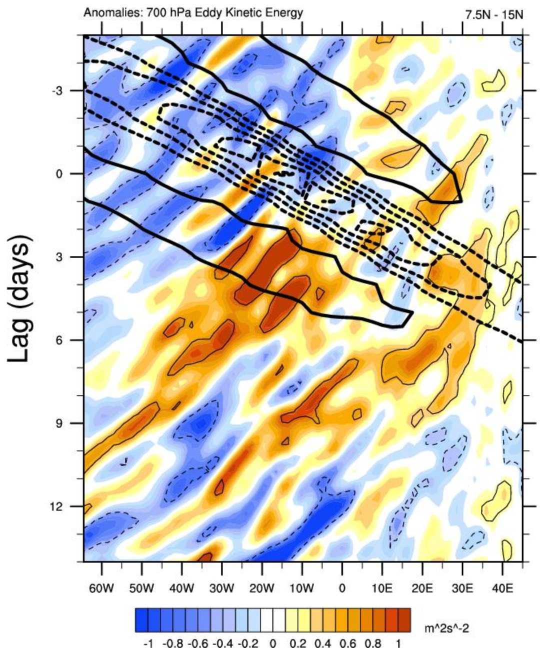

FIG. 4. A time-longitude composite of 2-10 day filtered 700 hPa eddy kinetic energy (shaded) averaged and over each lag of the CCKW index between the 7.5-15˚N band. Positive (Negative) eddy kinetic energy anomalies statistically different than zero at the 90% level are within the solid (dashed) contour. Kelvin filtered OLR anomalies are averaged over the 5-10˚N latitude band and are boldly contoured. Negative Kelvin filtered OLR anomalies are dashed. Shade interval is 0.1 m^2s^{-2}; contour interval is 3 Wm^{-2}.

This area of positive EKE anomalies progresses westward with time over the tropical Atlantic. At a later time (Day +3), positive EKE anomalies develop within the convective envelope of the CCKW over eastern tropical Africa, including the Darfur Mountains. This area of positive EKE anomalies remains stationary over eastern Africa for roughly one day and then progresses westward with time. This time-longitude composite of EKE anomalies reveals that after the passage of the CCKW, AEW activity increases over preferable topographic features in Africa.

Fig. 4 infers that the Guinea Highlands region is a preferable region for the development of AEWs, indicated by the positive EKE anomalies that develop over the Guinea Highlands region after the passage of the convective envelope of the CCKW. The increased AEW activity over the Guinea Highlands region might be interpreted as an area where pre-existing AEWs become stronger due to a coherent diurnal cycle of convection, consistent with the hypothesis of Berry and Thorncroft (2005) and Ventrice et al. (2012). It might be that the CCKW modulates the diurnal cycle of convection there, as well as over the rest of tropical Africa (e.g., Nguyen and Duvel 2008).

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