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East African lightning as a precursor of Atlantic hurricane activity

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[1] Recent years have shown the tremendous damage and loss of life that can be caused by Atlantic Basin hurricanes. The majority of these hurricanes start as African easterly waves (AEWs) over the African continent. In this paper we provide evidence showing the connection between lightning activity over eastern Africa, and the AEWs that leave the west coast of Africa, some of which develop into hurricanes. We have analyzed the 2005 and 2006 hurricane seasons, one a very active hurricane year (2005), and the other a very quiet year (2006). More than 90% of the tropical storms and hurricanes during these 2 years were preceded by periods of above average thunderstorm activity in eastern Africa. During the 2006 season not only was the east African lightning activity 23% lower than during 2005, but there was 36% less lightning activity over the entire African continent during 2006. We suggest the possibility that lightning activity in tropical Africa may represent an important precursor of Atlantic hurricane formation. **Citation:** Price, C., Y. Yair, and M. Asfur (2007), East African lightning as a precursor of Atlantic hurricane activity, *Geophys. Res. Lett.*, *34*, L09805, doi:10.1029/2006GL028884.

1. Introduction

[2] The recent northern hemisphere summers have once again brought to the world's attention the destructive nature of hurricanes. Furthermore, there is evidence that the intensity and number of intense hurricanes may have increased in recent decades [*Emanuel*, 2005; *Webster et al.*, 2005]. However, there is great variability in hurricane activity from year to year. During the 2005 season there were 28 named storms, while in 2006 there were only 10 named storms.

[3] In the Atlantic Basin hurricanes often start as continental tropical disturbances (regions of low pressure) over west Africa [*Dunn*, 1940], and grow into tropical depressions, tropical storms and eventually hurricanes as these disturbances move westward over the warm Atlantic Ocean [*Avila and Pasch*, 1992]. However, not all tropical disturbances will grow into hurricanes. Annually, only approximately 10% of all disturbances develop into tropical storms [*Frank*, 1970]. But during the summer months of July, August and September nearly 50% of disturbances generate tropical storms [*Berry et al.*, 2007].

[4] These disturbances, now known as African easterly waves (AEWs), originate over continental Africa [*Riehl*, 1945]. While a variety of mechanisms for the generating mechanisms of these waves have been proposed, it is generally accepted that the waves are caused by instabilities in the African easterly jet [*Burpee*, 1972]. The jet arises from the reversed latitudinal lower-tropospheric temperature gradient over western and central North Africa resulting from the contrast between the hot air over the Saharan Desert and the substantially cooler air along the Gulf of Guinea coast. For this reason the wave has a strong seasonal dependence, being prominent from late June to September (Figure 1), when the temperature difference peaks.

[5] The AEWs propagate westward in the lower tropospheric trade wind flow across Africa and later over the Atlantic Ocean. They are first seen usually in April or May and continue until October or November. The waves have a period of about 4 or 5 days and a wavelength of 2000 to 2500 km [*Burpee*, 1974], traveling at phase speeds of $\sim$10 ms^{-1} [*Reed et al.*, 1977]. On average, about 60 waves are generated over North Africa each year, but it appears that the number of events has no relationship to how many tropical cyclones develop over the Atlantic each year [*Thorncroft and Hodges*, 2001]. However, while about 60% of the Atlantic tropical storms and minor hurricanes originate from AEWs, nearly 85% of the intense (or major) hurricanes have their origins as easterly waves [*Landsea*, 1993].

[6] The AEWs are associated with deep convection and intense thunderstorms over tropical Africa. The thunderstorms and mesoscale convective systems (MCSs) normally appear where the cooler, moister equatorial air penetrates north into the trough of the westward moving AEW. Hence, MCSs are clustered into regions separated by the AEW wavelength of approximately 2000 km. One of the key questions relating to these tropical waves is whether the waves trigger the convection, or whether the convection triggers the waves. *Carlson* [1969] first suggested the possible role of east African convection triggering AEWs. Recent analysis of satellite data [*Mekonnen et al.*, 2006] has concluded that this is true. Thunderstorms in central and eastern Africa act as precursors to AEW activity. The thunderstorms act as "boulders in a stream" producing downstream turbulence that can grow into instabilities, generating tropical depressions and hence tropical storms and hurricanes. However, *Hall et al.* [2006] has shown that the AEJ is stable to small perturbations. In this paper we investigate whether the intensity of the convection, measured by lightning activity, is related to the AEW intensification.

[7] There are a number of explanations how thunderstorms and convection can trigger instabilities in the AEWs that can then grow into tropical depressions. It has been suggested that a positive feedback may exist between the mesoscale convection (diabatically generated potential vorticity maxima) and the AEJ baroclinic structure [*Berry and Thorncroft*, 2005]. The ability of MCSs to generate

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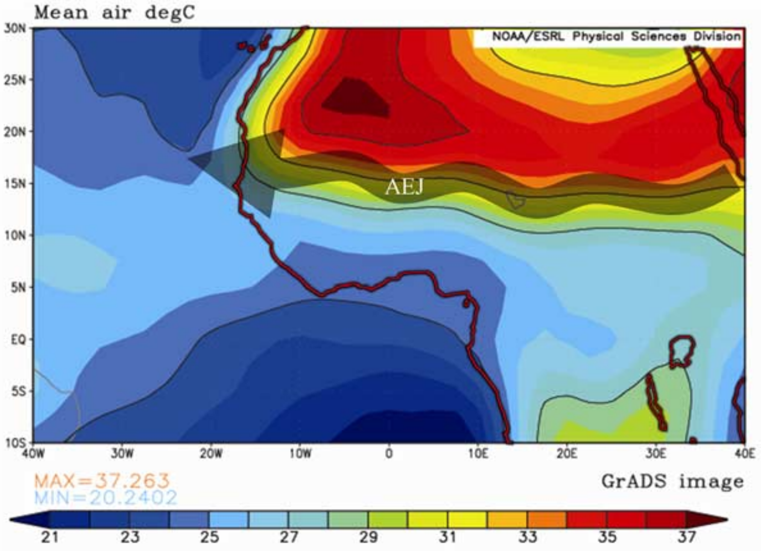

Figure 1. July–September 2005 mean surface temperatures over tropical Africa (from the NCEP/NCAR reanalysis) showing the reverse meridional temperature gradient, with temperatures increasing from the equator northward into the Sahara region. The region with the strongest gradient is where the African Easterly Jet (AEJ) is located, with disturbances along the AEJ resulting in the African Easterly Waves (AEWs) that propagate from east Africa westwards to the Atlantic Ocean.

midlevel potential vorticity anomalies is connected to the heating profile in stratiform rainfall regions, and there are various mechanisms for the amplification of vorticity in AEWs [*Fritsch et al.*, 1994; *Ritchie and Holland*, 1997; *Montgomery and Enagonio*, 1998; *Rogers and Fritsch*, 2001].

2. Data

[8] The MCSs over tropical Africa generate intense lightning activity [*Christian et al.*, 2003], with tropical Africa being the hotspot of lightning activity on a global basis. This lightning activity can be continuously monitored from great distances using very low frequency (VLF) electromagnetic networks on the ground. Such networks exist on local scales in many countries, while more recently effort has been put into developing global networks, such as the World Wide Lightning Location Network (WWLLN, available at http://webflash.ess.washington.edu/) [*Dowden et al.*, 2002; *Lay et al.*, 2004]. The lightning activity over tropical Africa observed by this network, for July–September 2005 and 2006 is shown in Figure 2.

[9] The WWLLN presently consists of 26 stations around the globe that continuously receive the VLF pulses emitted by lightning discharges within a range of a few thousand kilometers. Due to the different time-of-arrival of the pulses at different stations, the distance to each flash can be calculated using 4–5 stations. Due to the data processing limitations, together with the demand that numerous stations detect the same lightning flash, the network detects only a small fraction of the total lightning. Nevertheless, the temporal and spatial coverage is far better than satellite detectors that detect only a few storms per orbit, and only for a fraction of the storm's lifetime [*Christian et al.*, 2003]. The big advantage of the WWLLN is that it is continuous in time and space, even though the network only detects the most intense flashes around the globe.

[10] To investigate the connection between African lightning activity, AEWs and hurricane cyclogenesis, we use two primary data sets. The first is the daily lightning activity over tropical east Africa as detected by the WWLLN (Figure 2). We define east Africa as the box 10–20 N and 30–40 E, in the region of the Ethiopian Highlands, following *Mekonnen et al.* [2006]. The second data set for studying the AEWs is the NCEP/NCAR reanalysis product [*Kistler et al.*, 2001] that supplies the 6-hourly meteorological parameters over Africa. The AEWs result in the north-south perturbation of the zonal flow in the AEJ (Figure 1). In order to visualize these waves over extended periods of time, the data are normally plotted using a Hovmoller diagram [*Hovmoller*, 1949] where the westward propagation of the waves can be observed over time (Figure 3). The figure shows the daily mean north-south (v-wind) velocity component at 700 hPa between 10–20 N (see box in Figure 2), as a function of longitude (x-axis) and time/date (y-axis).

[11] Note that the longitude in Figure 3 extends to 40 W, further than indicated in Figure 2, in order to include the wave propagation into the Atlantic. The sloping horizontal shaded bands show the time and place of the maximum northerly winds (positive values) and southerly winds (negative values). The slope of these lines gives the phase velocity of the waves (~30 km/hr or ~10 m/sec) across Africa and the Atlantic, with these waves passing through a particular longitude every 3–5 days during the summer months [*Burpee*, 1972].

[12] As has been observed in the past, the AEWs are most prominent in West Africa (west of the Greenwich meridian). However, most AEWs can be tracked back to East Africa (30 E). It is for this reason we were interested in comparing

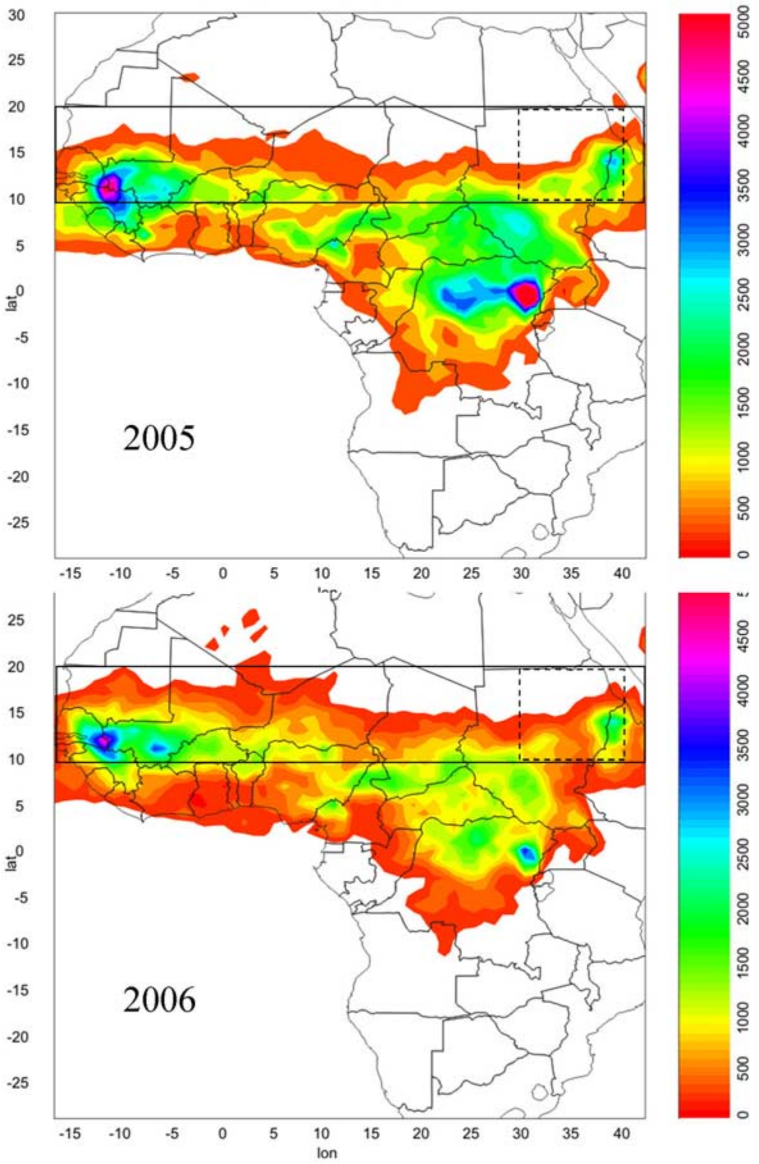

Figure 2. July, August, and September (top) 2005 and (bottom) 2006 lightning activity over Africa (flashes/2.5° × 2.5° grid box) as detected by the WWLLN VLF array. The solid box 10–20N is used in Figure 3 for the v-wind data, and the dashed box for the lightning data.

the AEWs with the lightning data from the WWLLN in East Africa.

3. Results

[13] The lightning flashes detected by the network in eastern Africa (10–20 N; 30–40 E, see Figure 2) were counted each day. The mean daily flash count during this 4-month period was 486 flashes/day for 2005, and 374 flashes/day for 2006, a 23% decrease from 2005 to 2006. Over the entire African continent 2006 had 36% less lightning than during 2005. The daily histogram of the lightning counts in east Africa is shown in the right hand panel of Figure 3. The red bars represent days with lightning activity above a defined threshold (mean+standard error) for the 4-month average. This threshold (526 flashes/day for 2005, and 407 flashes/day for 2006) is indicated by the dashed line on the histogram plot. (Standard Error = Standard Deviation/$\sqrt{N}$)

[14] During the 4-month periods, 30 AEWs were observed leaving the west coast of Africa during 2005, while 28 were observed during the same time-frame in 2006. We have counted only the waves that start and end within June–September. This implies that the number of AEWs was not significantly different between the two seasons. In order to relate the lightning activity in east Africa to the AEWs, we define the date that the AEWs leave Africa as the day when the north-south wind at 700 mb (averaged over 10–20 N, at 17.5–20 W) reaches its maximum positive value, while exceeding the average v-wind for this period in this location ($0.75\ \mathrm{ms}^{-1}$).

[15] Of the 30 AEWs in 2005, 22 (73%) were preceded by above average lightning activity in east Africa ~7 days prior to the AEWs leaving the African continent (the west

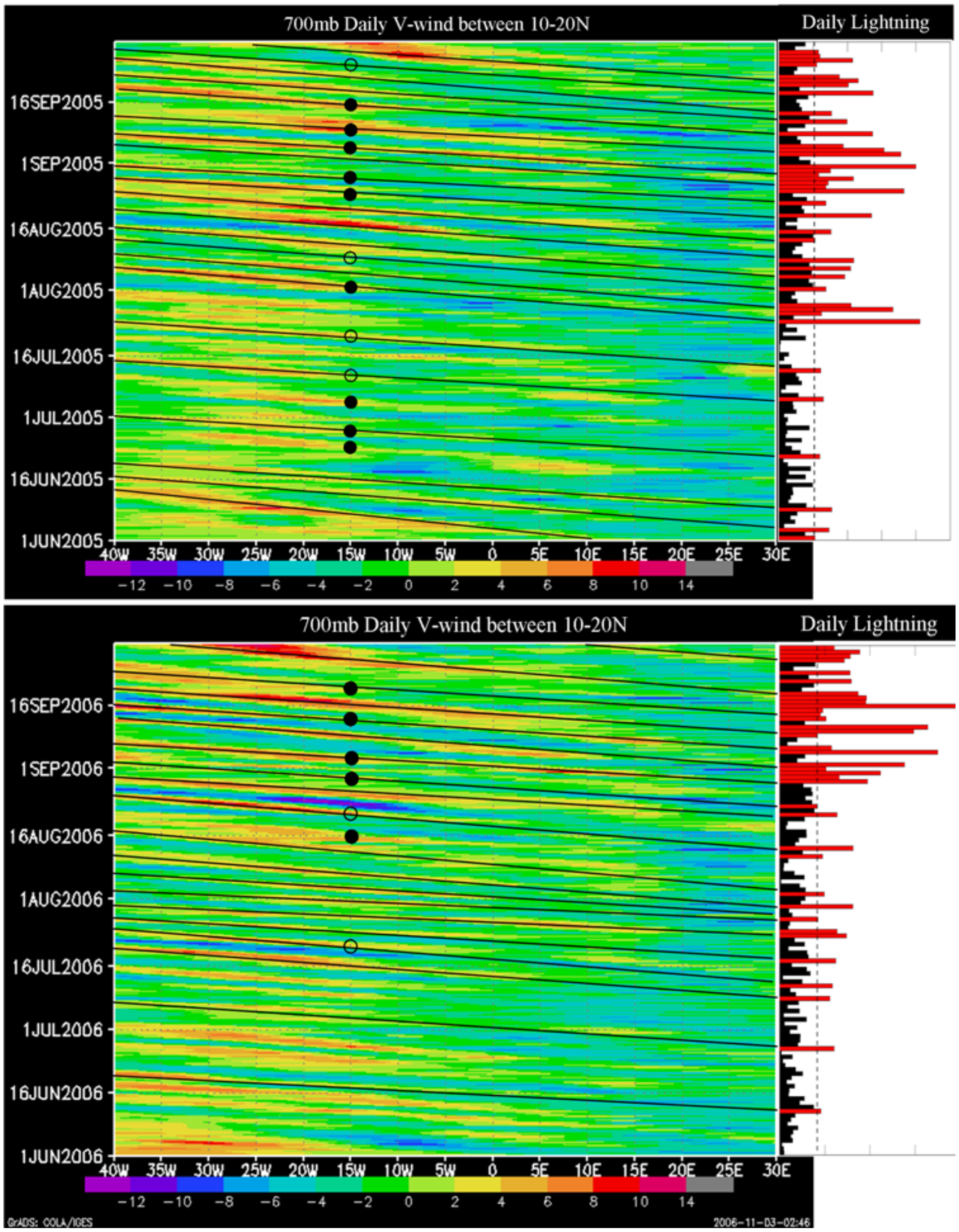

Figure 3. Hovmoller diagram of the daily mean v-wind at 700 hPa between 10–20 N (see solid box in Figure 2) as a function of day and longitude (40 W–30 E), for June to September (top) 2005 and (bottom) 2006. Positive values (yellow/red) represent northerly winds, while the negative values (green/blue) represent southerly winds. In addition, the histogram shows the daily lightning activity over Eastern Africa (10–20 N, 30–40 E). Black lines show AEWs preceded by intense lightning activity (red bars) in East Africa, and circles show the waves that later formed into tropical cyclones (open circles) and hurricanes (solid circles). The longitude of the circles represents the western cost of Africa.

coast of Africa is located at approximately 15 W in Figure 3). Of the 28 AEWs in 2006, 19 (68%) were preceded by above average lightning activity (Table 1). The waves preceded by intense lightning activity are shown with black lines on Figure 3. The lines (constant slope) are fitted to the AEW data over the Atlantic Ocean, and extrapolated eastward over the African continent. It should be noted that the travel-time for these waves across Africa ranged from 3–12 days (mean ± standard deviation = 6.8 ± 2.3), and is not always constant over the lifetime of individual waves. Of the 22 periods with intense lightning activity in eastern Africa during 2005, and the 19 active periods in 2006, all of these active periods were followed by AEWs entering the Atlantic approximately one week later. However, not only was there 23% less lightning in east Africa during 2006, but the seasonal lightning threshold was also 23% lower in 2006. This implies that the 2006 season had less intense lightning days than 2005, and may supply some insight into the differences in the AEW development between the two years, and account for the significant difference in hurricane activity between the two years.

[16] In addition, during the June–September 2005 period, 15 tropical storms and hurricanes formed as a result of these AEWs, while only 7 storms formed in June–September

Table 1. Summary of Statistics From the 2005 and 2006 Hurricane Seasons

	2005	2006
Total number of named Atlantic tropical storms and hurricanes	28	10
Number of storms during 4 months JJAS	15	7
Number of AEWs during JJAS	30	28
Total African lightning measured by WWLLN during JJAS (flashes)	1,256,103	800,227
Total East African lightning measured by WWLLN during JJAS (flashes)	59,328	45,637
Daily threshold (seasonal mean + standard error) used to determine intense lightning days (flashes/day)	526	407
Number (%) of Atlantic AEWs preceded by intense lightning in East Africa	22 (73%)	19 (68%)
Time delay between East African lightning activity and AEW entering Atlantic	$\sim$7 days (4–10)	$\sim$7 days (3–12)
Number (%) of intense lightning periods followed by AEWs	24/24 (100%)	19/19 (100%)
Number (%) of named tropical cyclones and hurricanes associated with intense lightning activity in East Africa	13/15 (87%)	6/7 (86%)

2006 (available at http://www.nhc.noaa.gov/pastall.shtml). The MCSs embedded within the waves that developed into tropical storms/hurricanes are shown on Figure 3 with an open circle representing tropical storms, and a solid circle indicating hurricanes (two waves produced two storms each in 2005, and hence only 13 circles appear in Figure 3a). Of these storms, 13/15 ($\sim$87%) were preceded by intense lightning activity in east Africa in 2005, while during 2006 6/7 ($\sim$86%) were preceded by above average lightning activity in the east (Table 1).

4. Conclusions and Discussion

[17] The results from this initial study show an interesting link between east African lightning activity, the generation of AEWs, and consequent hurricane formation. We have shown that intense lightning activity in eastern Africa occurs on average 7 days prior to the departure of the AEWs from the west coast of Africa, and up to 3 weeks before hurricanes reach the coast of Central and North America. In addition, approximately 90% of all tropical storms and hurricanes during the 2005 and 2006 seasons were preceded by days with intense lightning activity in east Africa. Since lightning activity in African thunderstorms can now be continuously monitored using VLF ground networks, lightning may provide an additional tool to study hurricane genesis.

[18] In addition to the development of AEWs, other important factors that influence both hurricane development and intensity are related to sea surface temperatures and the vertical wind structure (wind shear) above the Atlantic. Hence, not all AEWs will develop into tropical storms or hurricanes. A combination of factors is necessary to generate these massive storms. But lightning monitoring in tropical Africa may provide a new tool for understanding the birth of these damaging storms.

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