S3.3 THE DIURNAL CYCLE OF THE WEST AFRICAN MONSOON AND ITS RELATIONSHIP TO AFRICAN EASTERLY WAVES

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1. INTRODUCTION

The diurnal cycle of convection and winds is particularly strong over tropical land regions (e.g. Yang and Slingo 2001). Diurnal variations in surface heating have a significant impact on vertical atmospheric motions and deep cloud formation.

The West African monsoon occurs in the boreal summer months and is the only rainy season for the normally arid Sahel region. During this time, most of the rainfall in the Sahel comes from large thunderstorms. These storms are influenced by both local temperature and moisture profiles as well as large scale synoptic stability.

African Easterly Waves (AEWs) are a major dynamical component of the West African monsoon. The interaction of AEWs with the diurnal cycle has implications for weather forecasting in the region. By inspecting dynamical (i.e. AEW) coupling to rainfall versus diurnal influences we gain better insight into the relative balance of the large scale and local scale impacts on convection. This could lead to improvements in our understanding of weather processes and ultimately could improve how we model weather systems over West Africa.

2. DIURNAL CYCLE OF THE WEST AFRICAN MONSOON

In boreal spring time the sea surface temperatures (SSTs) in the Gulf of Guinea are at their maximum and the nearby land also increases temperature. At this time ITCZ convection is centered near the West African southern coastline (April-June). As the sun reaches its maximum northward location in June, the Sahara heats up and pressure near the surface decreases: the ‘Saharan Heat Low’ is established. At the same time the SSTs in the Guinea coastal region reduce causing higher pressure in the south. These changes create a large scale pressure gradient between the Sahara and the southern coast, which alters the large scale circulation (beginning of July is monsoon onset). The low level northward inflow is generally referred to as the monsoon wind - moisture penetrates further north and can supply convection in the normally arid Sahel region. The monsoon onset and pre-onset phases are described in detail by Sultan and Janicot (2003), and further illustration of the monsoon is given in Lafore et al. (2011). Figure 1 shows a schematic of monsoon pre-onset and mature phase.

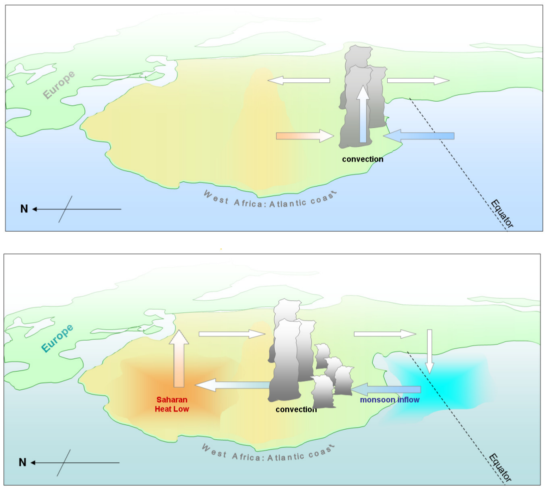

Figure 1: Top panel: pre-onset, convection is centered in southern zone. Lower panel: The West African monsoon mature phase.

The West African monsoon has a distinct diurnal cycle of convection and winds, as described by Parker et al. (2005), and Sultan et al. (2007) among others. During the day convection increases and storm activity peaks in the late afternoon/ evening. At this time the large scale flow is broken up by vertical movements associated with moist and dry convection. At night, the convection dies out and horizontal wind speeds increase. This can be seen in the boundary layer winds, where a nocturnal low level jet forms a few hundred metres above ground (Washington et al. 2006; Abdou et al. 2010; Bain et al. 2010; Pospichal et al. 2010).

3. INFLUENCE OF AEWS ON DIURNAL CYCLE OF WINDS AND CONVECTION

African Easterly Waves are capable of modulating winds and convection on the synoptic scale. Tethered balloon data from

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Agoufou, Mali (Bain et al. 2010) showed that the passage of AEWs can have influence on boundary layer winds in certain conditions. SODAR data from Niamey in 2006 supports this preposition (Bain et al. 2011). Fink and Reiner (2003) showed the tendency for convection to be enhanced in AEW troughs and suppressed in AEW ridge regions and this is often observed in satellite images such as figure 2.

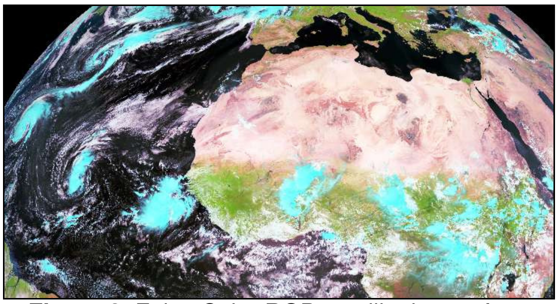

Figure 2: False Color RGB satellite image from 1200 UTC on 26 August 2010 showing MCSs over West Africa and tropical storms in the Atlantic in blue, modulated by AEWs.

3.1. Evidence of AEWs modulating convection

ERA-Interim reanalysis data were used to construct hovmollers of curvature vorticity at 700hPa. Westward moving peaks in vorticity (i.e. AEWs) were then tracked using a new tracking algorithm which used derivatives of the hovmoller and object-orientated post processing. Figure 3 shows an example of the tracked waves in a vorticity hovmoller for August-September 2010 (same period as satellite image in Fig. 2).

The location of the tracked waves in space and time were then matched up with corresponding maps of daily rainfall from GPCP (satellite plus surface station data) for May to September 1997-2008. Composite plots were produced showing the mean state of rainfall when an AEW trough was passing and when it was not passing (i.e. AEW ridge or neutral conditions). Figure 4 shows the two composite plots followed by a third plot which shows the relative enhancement of rainfall in an AEW trough versus rainfall in a ridge. Low rainfall regions have been masked out in the enhancement (bottom) plot.

The plots demonstrate that rainfall is enhanced in AEW troughs. Rainfall does occur in ridge conditions, but total amounts are lower. The experiment was repeated with multiple data sets: GridSat cloud brightness temperatures (primarily geostationary satellite, Knapp et al. 2011), TRMM rainfall data (primarily polar orbiting satellites) and Arrival Time Difference (ATD) lightning strikes from remote land sensors. All data showed the same enhancement of rainfall/ convection/ lightning in trough regions.

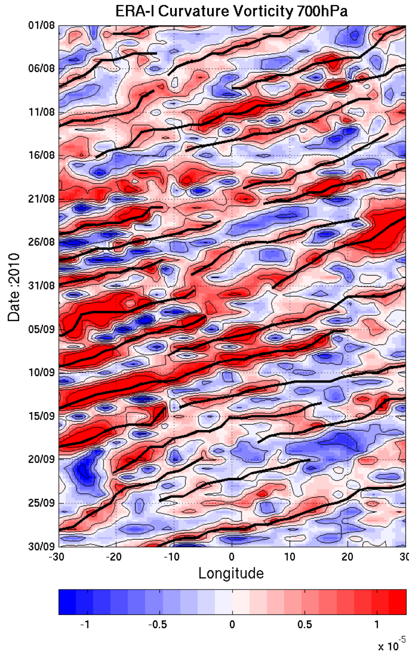

Figure 3: Example of tracked AEWs in 700hPa (averaged 5-15^{o}N) ERA-Interim curvature vorticity hovmoller for Aug-Sept 2010.

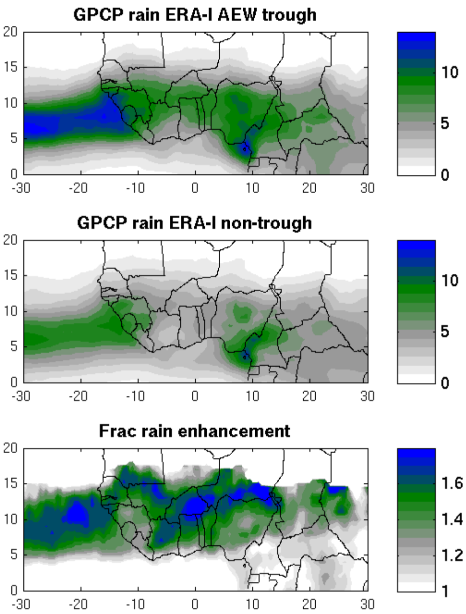

Figure 4: Composite map of mean rainfall (mm/day) in [TOP]: AEW trough; [MID]: AEW ridge, [BOTTOM]: Fraction enhancement of rain in trough or (Trough composite)/(Ridge composite).

Initial inspection of Met Office climate, seasonal and weather forecasting models (not shown) shows that the observed rainfall coupling with AEW trough passage is currently underestimated. Ongoing work is looking into the relative impacts of model resolution and different parameterisation packages to try to improve coupling.

3.2. Evidence of the diurnal cycle modulating convection

Figure 5 shows the diurnal cycle of high top cloud. The data are from the GridSat IR brightness temperature satellite dataset (Knapp et al. 2011). A temperature threshold of 220K was used to isolate deep cold cloud. Fig. 5 shows the percentage of time that cold cloud is present at each hour throughout July-September (JAS) 2005.

The diurnal cycle of convection can clearly be seen in figure 5. Deep convection increases during daytime hours and is maximum in the late afternoon to evening (15 – 00 UTC). During the night and early morning the amount of deep convection is considerably reduced.

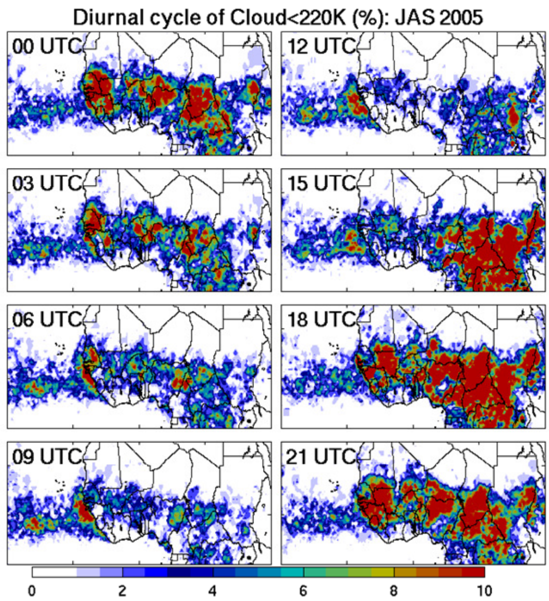

Figure 5: Diurnal cycle of deep convection. Percentage of time that cloud top temperature < 220K for each time for JAS 2005 over West Africa. Time of day is shown in upper right corners.

3.3. Evidence of AEWs enhancing the diurnal cycle of convection

Figure 6 shows the diurnal cycle of convection in AEW troughs and ridges using three 3-hourly independent data sets. The top row shows ATD lightning data from 2010, middle is GridSat cold cloud from 2005 and the lower row is TRMM rainfall from 2009. Different years were chosen mainly for data availability reasons, but also to see if there was an impact of AEWs in different seasons. Green lines represent a composite between 12^{o}W to 10^{o}E, 0-20^{o}N of each field during AEW trough passage. Red lines represent each field during ridge (or more accurately, non-trough) conditions.

Approximately 20 AEWs each JAS season pass the study region; this does mean that few observations are included in each 3-hour time window. Despite this, the data still show an increase in convective activity in AEW troughs, in agreement with the longer GPCP dataset composites in Fig. 4, and published literature.

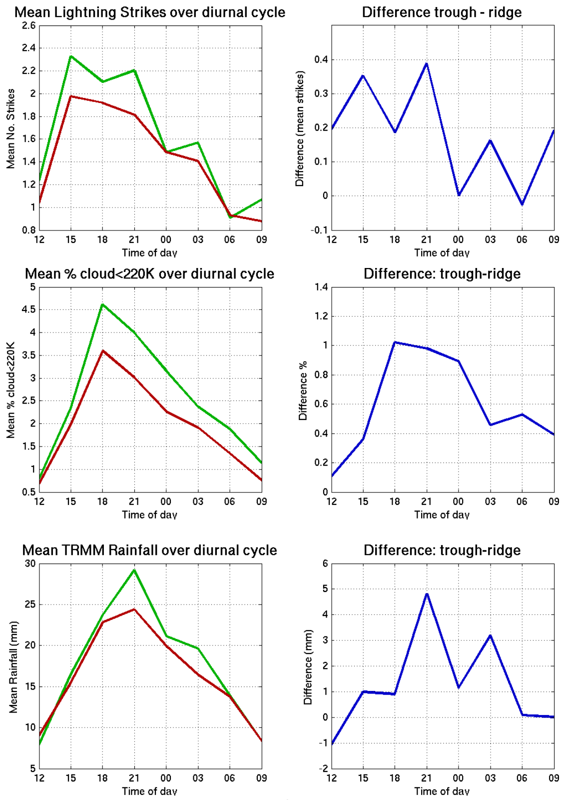

Figure 6: Diurnal cycle of [Top row] ATD lightning strikes [Mid row] GridSat cloud < 220K, [Bottom row] TRMM rainfall. [Left] **Mean AEW trough (green)** and an **AEW ridge conditions (red)**. [Right] Difference between the diurnal cycles of AEW trough and ridge.

The significant finding in the plots is that the diurnal cycle appears enhanced in AEW troughs (green) compared to AEW ridges (red): more convection occurs in the late afternoon/ evening in AEW troughs, but little or no enhancement in convection is found in the early morning.

A secondary finding is a diurnal time lag in the data sets. Lightning peaks first at 15-21 UTC, Cold cloud peaks at 18 UTC, Rainfall peaks at 18-00 UTC. This might suggest that lightning is most active in the growth stage of West African thunderstorms, the anvil then spreads out during mature phase, causing a drop in cloud top temperature, and rainfall peaks when storms reach full maturity later in the evening.

5. SUMMARY

The West African monsoon occurs during boreal summertime. Thunderstorms typically bring the majority of rainfall to the normally-arid Sahel region. The storms have a distinct diurnal cycle and are maximum in late afternoon/ evening time. Convection influences the winds by reducing horizontal motions, therefore the low level geostrophic monsoon flow peaks in intensity in the early hours of the morning, when convection is at a minimum.

Figures 4 and 5 have confirmed that both African Easterly Waves and the diurnal cycle have an impact on rainfall and convection modulation.

New research (Figure 6) with three independent data sets has indicated that the diurnal cycle is particularly enhanced in AEW trough regions – where more convection takes place during diurnal peak hours (15-00 UTC) and little or no enhancement is seen during diurnal minimum.

These findings will be used to improve understanding and representation of the relative convection coupling to diurnal cycle and tropical synoptic systems, which are both currently poor in numerical models.

6. REFERENCES

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