

# Variability of Lightning Activity as a Function of Tropical Easterly Wave Phase

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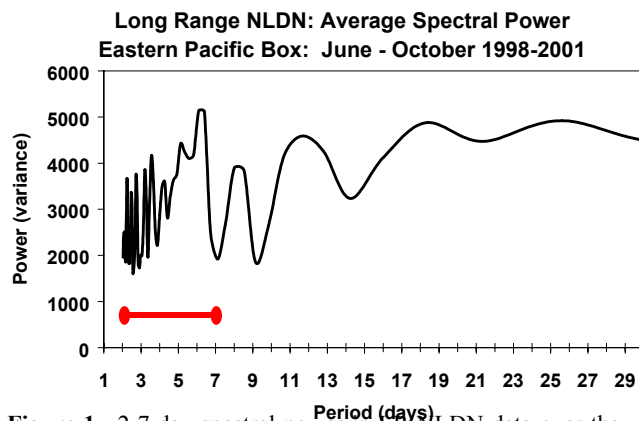
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**ABSTRACT:** 3-5 day Tropical Easterly Waves (TEWs) significantly modulate tropical convection, which in turn influences tropical cyclogenesis. Geostationary satellite imagery provides a robust tool for tracking these disturbances in data sparse regions of the globe; however, the satellite imagery provides little information on TEW convective vertical structure- a key parameter in both the understanding and prediction of TEW evolution. Hence we pose the following question: *Can lightning data be used to reliably indicate changes in mean convective vertical structure, and as a result, latent heating as a function of easterly wave-phase?* To answer this question, we present a combined analysis of ship, space, and ground based radar and lightning data (TRMM-LIS, long range NLDN) for regions of prolific TEW activity (tropical eastern Pacific Ocean and tropical western Africa). By compositing lightning and radar data based on the phase of TEWs at 700 hPa (ridge, northerly, trough and southerly wind phases) we find that the lightning data can be used as a reliable metric of changes in convective vertical structure across different synoptic phases of TEWs. Since changes in convective vertical structure are indicative of related changes in the vertical profiles of cloud mass flux and latent heating, it may be possible to use lightning data to infer changes in latent heating profile across TEWs.

## 1. INTRODUCTION

Tropical 3-5 day Easterly Waves (TEWs) represent a fundamental mode of convective variability in the Tropics. These disturbances provide a synoptic-scale regulation of convection and the tropical hydrologic cycle, and through various feedbacks influence phenomena ranging from “bursts” in monsoon rains, to the spin up tropical cyclones. Since TEWs are a primary source of forcing for tropical deep convection, we should also see TEW signal in time series spectra of lightning flash density. To verify this, a spectral analysis was performed on



**Figure 1.** 2-7 day spectral power in LR-NLDN data over the tropical eastern Pacific. Periods of 2-7 days indicated by line.

several time series of Long Range National Lightning Detection Network (LRNLDN) data. These data were collected over four boreal-summer seasons (June-October; 1998-2001) for areas located in a  $10^{\circ} \times 10^{\circ}$  box over the tropical eastern Pacific- a region of prolific TEW activity. As indicated in Fig. 1, significant spectral power exists in the 2-7 day band of LRNLDN flash counts. This result is consistent with similar spectral peaks noted in time series of Schumann resonance data (Price, 2002).

Having demonstrated the existence of spectral peaks in lightning activity on TEW time scales, we are motivated to ask the following question: *to what extent can we use lightning information to discern specific characteristics of the convection in TEWs?*

## 2. DATA AND METHODOLOGY

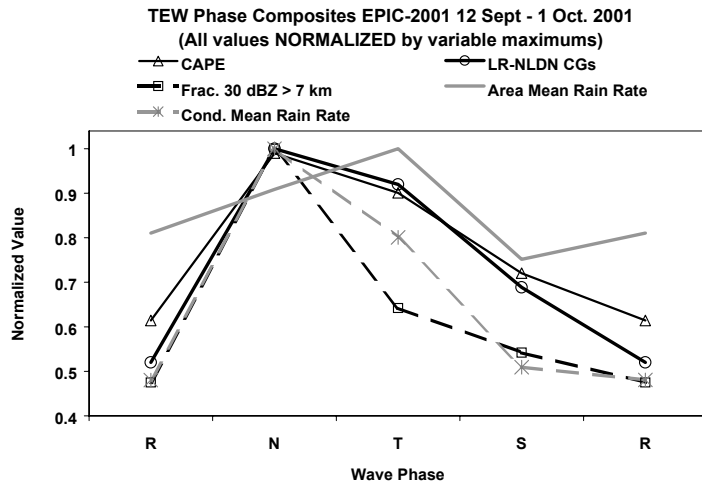
A variety of data sources and analysis techniques were used in this study. Initially, ship-based sounding and volumetric radar data collected during the 21-day tropical eastern Pacific EPIC-2001 field campaign (Petersen et al., 2003) were combined and analyzed with LR-NLDN CG lightning data (Cramer and Cummins, 1999). Following Thompson et al. (1979), sounding meridional winds at 700-hPa were used as a proxy for partitioning TEWs into four wave phases; *ridge, northerly, trough, or southerly*. After partitioning the lightning, radar and sounding datasets into their respective easterly wave phases, the data were averaged in each phase category to provide a composite description of the lightning, convective vertical structure and environment variables (e.g., CAPE) associated with each TEW phase. Based on the success of this methodology (discussed below), we subsequently expanded the temporal and spatial scope of the analysis by using NCEP Reanalysis winds together with TRMM Lightning Imaging Sensor (LIS; Christian et al, 1999) data, and TRMM Precipitation Radar (PR) diagnostics from the University of Utah TRMM precipitation feature database (Nesbitt et al., 2000). We then examined lightning and convective structure in TEWs over regions of the eastern Pacific Ocean and tropical West Africa (both associated with prolific TEW activity). The analysis was performed for warm seasons in the

years 1998-2000. Lastly, we compared the diurnal cycles of lightning and convective structure between the wave-phases, especially over West Africa where the lightning signal was so strong.

### 3. RESULTS

#### a) Eastern Pacific

Initial results for three TEWs sampled during the EPIC-2001 campaign (Petersen et al., 2003) revealed that CG lightning activity, CAPE, vertical convective development, and mean conditional rain rates (e.g., rain rate averages computed only for raining grid boxes) over the eastern Pacific Ocean all peak during the pre-trough northerly wind phase of the TEWs (Fig. 2). Importantly, area-mean rain rates were largest in widespread convective and stratiform precipitation found in the trough regime (Petersen et al., 2003), but these rain amounts differed by only 10% from those of the northerly regime. When considered with trends in the convective vertical structure (fraction of 30 dBZ at heights  $\leq 7$ km), CG flash count, CAPE, and conditional mean rain rate (Fig. 2) suggests that a significant change in convective structure, precipitation process (more ice), and perhaps *latent heating profile* occurs across E. Pacific TEW phases.



**Figure 2.** Normalized values of TEW CAPE, LR-NLDN CG flash count, conditional mean rain rates, area mean rain rates and fraction of 30 dBZ coverage at heights  $\geq 7$  km as a function of wave phase (R=ridge, N=northerly, T=trough, S=southerly).

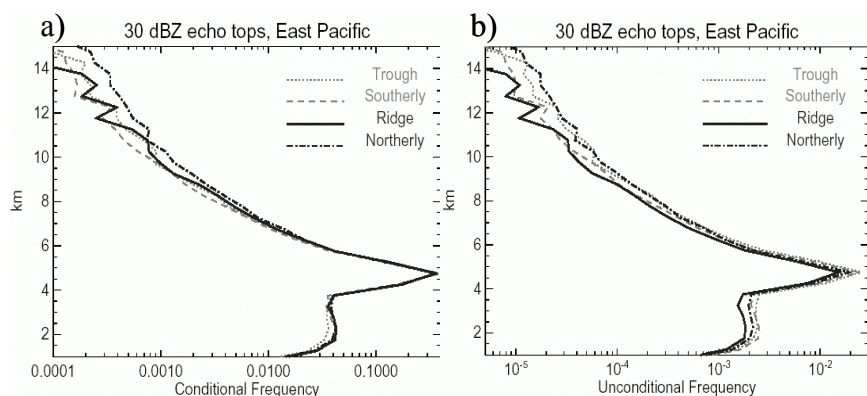
Multi-year analysis of eastern Pacific TEW-phase convective vertical structure and lightning flash counts using LR-NLDN (subdivided by local time to account for nocturnal/diurnal detection efficiency differences), TRMM PR, and LIS data yields similar results (Table 1; Fig. 3). For example, in Table 1 both LR-NLDN and LIS data suggest that lightning flash counts are largest in the northerly and trough phases of eastern Pacific TEWs. Note that while the trend in the LIS data is consistent with that of the LR-NLDN, less frequent TRMM sampling convolved with higher variance in the lightning signal over the ocean makes interpretation of the flash count differences in the LIS data more tenuous. However, we can examine distributions of TRMM PR 30 dBZ echo tops (used here as a proxy for the presence of deep convective cores; Fig. 3) to further support the interpretation of the LIS and LR-NLDN lightning trends.

**Table 1: Flash rates for E. Pacific and W. Africa sample domains by TEW phase**

Wave Phase	East Pacific FI/Hr (LR-NLDN) [18-06 Local] / [06-18 Local]	East Pacific FI/Hr (LIS)	West Africa FI/hr (LIS)
Ridge	24.5 / 6.7	303	1265
North	47.5 / 12.2	320	1338
Trough	40.2 / 9.4	331	761
South	20.3 / 7.4	308	856

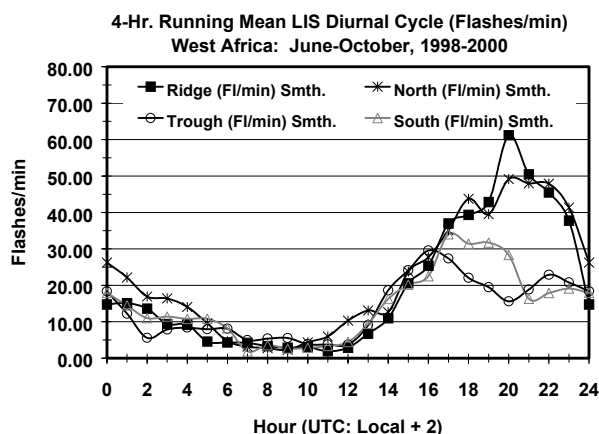
For example, the “conditional” frequency distribution of 30 dBZ echo tops is shown in Fig. 3a, and represents the frequency of 30 dBZ tops taken from the sub-sample of all TRMM PR pixels identified with precipitation features. Alternatively, the unconditional sample (Fig. 3b) represents all PR pixels from each orbit in the domain, regardless of the presence of precipitation features. Comparison of these different statistical samples enables a discernment of both vertical development and coverage information to be made from the precipitation feature population as it relates to the area fraction of deep convective cores. The resultant trends exhibited in Figs. 3a-b are consistent with the EPIC-2001 results and the multi-year lightning flash counts presented in Table 1. When convection is present in E. Pacific TEWs (Fig. 3a), it is statistically more vertically developed in the northerly phase and to a slightly lesser degree in the trough phase. Vertical development is weakest during the ridge and southerly phases. Overall, the unconditional sample (Fig. 3b) suggests that the northerly TEW phase is associated with more vertically robust convection; however, as area coverage of

convection increases in the trough phase, a greater fraction of the TRMM orbit area is covered by 30 dBZ echo at any given height, resulting in a trough 30 dBZ echo top unconditional frequency profile that approaches that of the northerly regime. Combined with the EPIC-2001 results, Table 1 and Figs. 3a-b suggest that in *E. Pacific TEWs northerly phases are associated with a smaller number of deeper, more electrically active storms (and attendant robust ice phase), while trough phases are associated with weaker, but more widespread thunderstorms.*

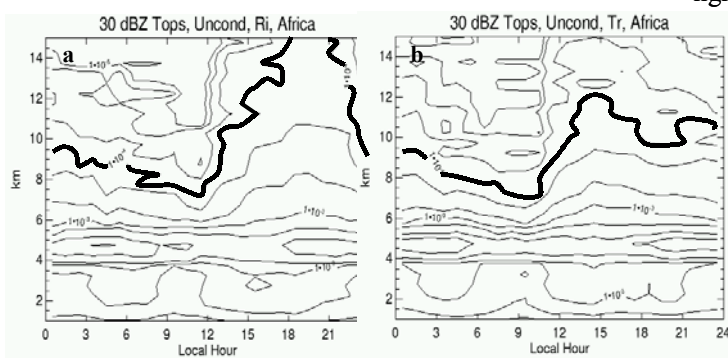


**Figure 3.** Convective vertical structure in eastern Pacific TEWs as a function of wave phase: a) Conditional relative frequency of TRMM-PR 30 dBZ echo tops as a function of height; b) as in (a) but for unconditional frequency.

*b) Tropical West Africa*



**Figure 4.** Diurnal cycles of 4-hr running mean TRMM-LIS lightning flash counts (flashes/minute) for West African TEW phases.



**Figure 5.** W. Africa diurnal cycle of TRMM-PR 30 dBZ echo top frequency distributions as a function of height (ordinate; km). Contours values at 1, 2, 5 x 10<sup>2</sup> (10<sup>3</sup> bold). a) Ridge and b) Trough phases.

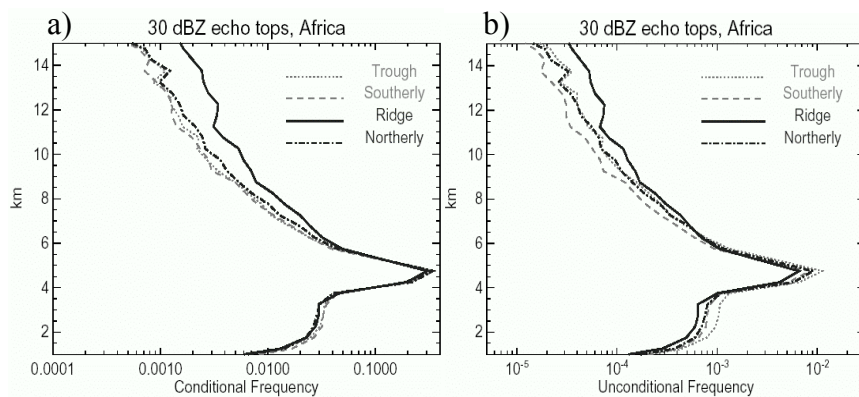
evident when the mean diurnal cycles of TRMM-PR convective vertical structure in the ridge and trough regimes are contrasted (Fig. 5). Note that in both regimes the width of the convective vertical structure distribution deepens (height-broadening of the frequency distribution; Figs. 5a-b) approximately in phase with the diurnal cycle of lighting flash rate (Fig. 4). However, the convective structure distribution of the ridge phase (Fig. 5a) is broader than that of the trough phase (Fig. 5b), possessing a tail that extends much higher into the troposphere coincident with the diurnal peak in lightning flash rate (Fig. 4). That is, similar to the diurnal cycle of lightning, the ridge convective structure distribution is “more amplified” in the evening hours (Fig. 5b).

To examine the lightning and convective structure in West African TEWs, we relied exclusively on TRMM LIS (Table 1; Fig. 4) and PR data (Figs. 5-6). The mean LIS flash rates (computed by dividing total warm-season flash counts by total view-time in each 1-hr bin for each phase) shown in Table 1 and the diurnal cycles shown in Fig. 4 clearly indicate greater total lightning activity in African TEW ridge and northerly phases, with major differences in flash rate occurring in the afternoon and early evening hours when the diurnal cycles of the northerly and ridge regimes are most amplified. Conversely, the trough and southerly regimes exhibit substantially less lightning, a less amplified diurnal cycle, and maximums in lightning activity that occur approximately 2-3

hours earlier than the northerly and ridge regimes. The robust LIS signal in the TEW phases over Africa is likely due an effective increase in the “signal to noise ratio”, a result of the climatologically higher lightning flash densities typically observed over this particular tropical landmass (Christian et al, 2002).

Based on the trends in lightning activity present in Fig. 4, we expect vertical convective structure in the northerly and ridge phases of African TEWs to exhibit markedly different characteristics relative to the trough and southerly phases. These differences are

Finally, if we consider the conditional and unconditional distributions of convective core depth vs. height (Figs. 6a-b) as done for the E. Pacific region, we find that the combined frequency distributions suggest more



(less) intense, but less (more) widespread convection during African TEW ridge (trough) phases. The aforementioned trends in African TEW convective structure and lightning activity are almost certainly accompanied by similar changes in microphysical processes, mass flux, and latent heat profiles, as suggested in the recent cloud-resolving model simulations of African TEWs by Xu and Randal (2002).

**Figure 6.** As in Fig. 3 but for West Africa.

#### 4. CONCLUSIONS

We have demonstrated that *lightning can be used as a tool to identify features of tropical 3-5 day easterly wave convective vertical structure as a function of wave phase for regions of the tropical eastern Pacific and West Africa.* In both W. Africa and the E. Pacific more (less) lightning and more (less) vertically developed convection tended to precede (follow) wave trough passages. Within the trough phase, slightly less lightning but more widespread convection occurred. In the east Pacific, along with increased (decreased) lightning activity, mean conditional rain rates were larger (smaller) in the pre-trough northerly (trough) phase, with area mean rainfall that was only 10% less (more) than that produced by the more (less) widespread but less (more) intense convection of the trough (northerly) phase. These results are important because large-scale changes in convective vertical structure evident in lightning data trends likely reflect significant changes in the cloud mass flux, latent heating and water budget profiles (supported by cloud-resolving modeling studies). Since easterly waves are a dominant mode of variability in the tropical hydrological cycle and often force the spin-up of tropical cyclones (where feedbacks from convective heating are likely to be important, but are poorly understood), any information pertaining to easterly wave development, and in particular convective structure, should be of predictive value. In the future we plan to extend the easterly wave studies to other regions of the tropics using TRMM LIS, PR and microwave imager data together with NCEP Reanalyses in an effort to optimize “data mining” of predictive information as it relates to TRMM-LIS and other lightning datasets.

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