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Characteristics of Lightning Activity in Tropical Cyclones based on WWLLN*

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***Abstract*—Lightning data from the World Wide Lightning Location Network along with tropical cyclone track and intensity data from the National Hurricane Center and China Meteorological Administration are used to study lightning activity in tropical cyclones over the Atlantic, East Pacific and West Pacific from 2005 to 2011, and to investigate the relationship between lightning and environmental parameters. Lightning in tropical cyclones over the three basins is more likely to occur in weak storms at tropical depression and tropical storm intensity levels. The greatest lightning density appears in storms undergoing an intensity change of -5–15 m s^{-1} during the next 24 h. Lightning density was higest in the inner core with a preference for the right-front quadrant of the storm motion. High lightning flash counts falls between 28ºC and 30ºC, with the maximum counts at SST of 30ºC. There is a nonlinear relationship between lightning and vertical shear.**

***Keywords*—lightning; tropical cyclone; Atlantic; Pacific; WWLLN**

I. INTRODUCTION

Lightning data have been successfully used as a proxy for convection activity within tropical cyclones (TC) [Molinari et al. 1999, Squires and Businger 2008]. Recent work have also shown the use of lightning data for rapid intensity change in TC forecasting [Abarca et al. 2011, DeMaria et al. 2012, Zhang et al. 2015]. Physical processes leading to TC intensification rely not only on large-scale dynamics but also on small-scale convection bursts within the inner core. Since lightning activity is significantly associated with the microphysics and dynamics of this small-scale convection, there is potential for using lightning data to provide some in situ information and to help improve forecasts of TC intensification. Therefore, lightning combined with other observational data can contribute to a more comprehensive understanding of the structure of the internal convection and TC intensity change.

In this work, we use lightning data from the World Wide Lightning Location Network (WWLLN) [Rodger et al., 2005], along with storm track and intensity data from the National Hurricane Center and China Meteorological Administration, to study the characteristics of lightning activity in TCs over the most three active regions, i.e., the Atlantic, the East Pacific and the West Pacific and to investigate its relationship to TC environmental factors.

II. DATA AND METHORD

A. Lightning data

Lightning data from 2005 to 2011 of the WWLLN are analyzed in this study. As detection efficiency of WWLLN has varied considerably over the period of this study, a method of data calibration is used. The WWLLN data were multiplied by adjustment factors that make the annual average lightning density (LD) equal to that from the TRMM LIS/OTD climatology. The mean annual flash rate climatology data, with units of flashes km^{-2} yr^{-1}, on a 0.5° latitude–longitude grid from the LIS/OTD are used as ground truth. The ratios between the mean annual lightning climatology from the LIS/OTD and the annual average LD from the WWLLN are calculated as adjustment factors. Thus, for each year of the study, LDs measured from the WWLLN are multiplied by the adjustment factor for that year to give the total lightning. Table 1 lists the adjustment factors for WWLLN annual LD over the three basins.

TABLE I. ADJUSTMENT FACTORS FOR WWLLN LD BASED ON THE LIS/OTD CLIMATOLOGY

Year	**Atlantic 0-60ºN, 100-0ºW**		**East Pacific 0–50°N, 180–100°W**		**West Pacific 0-60ºN, 100-180ºE**	
	Factor	***DE(%)***	***Factor***	***DE(%)***	***Factor***	***DE(%)***
2005	24.7	4.1	113.0	0.9	17.6	5.7

Year	**Atlantic 0-60ºN, 100-0ºW**		**East Pacific 0–50°N, 180–100°W**		**West Pacific 0-60ºN, 100-180ºE**	
	Factor	***DE(%)***	***Factor***	***DE(%)***	***Factor***	***DE(%)***
2006	14.9	6.7	27.9	3.6	13.0	7.7
2007	15.1	6.6	29.0	3.4	14.4	7.0
2008	11.2	8.9	12.3	8.1	10.4	9.6
2009	6.8	14.8	6.4	15.6	7.8	12.8
2010	5.7	17.7	6.6	15.0	6.4	15.5
2011	5.1	19.7	5.2	19.1	6.7	14.9

B. *Tropical cyclone data*

There were 114 TCs in the Atlantic, 96 in the East Pacific and 151 in the West Pacific from 2005 to 2011 (Fig. 1). The data on TC track and intensity are obtained from the National Hurricane Center and China Meteorological Administration best-track dataset, which gives data at six-hourly intervals for the center latitude and longitude, the maximum sustained surface wind speed, and the minimum central pressure of the storms.

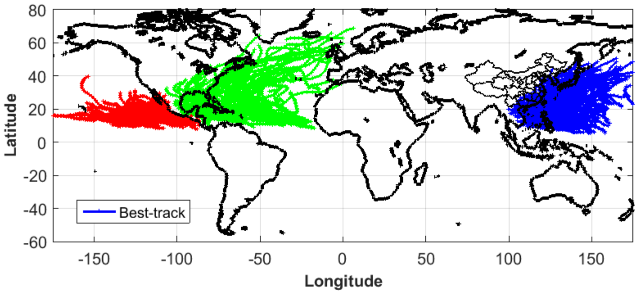

Fig. 1. Best-track of TCs examined in this paper.

The National Centers for Environmental Prediction (NCEP) global final (FNL) analysis dataset at 1° resolution and six-hourly intervals are used to compute environmental vertical wind shear. Vertical wind shear is calculated by averaging the 850 and 200 hPa 6-h horizontal wind vectors over a radius of 500 km from the TC center, and then computing the magnitude in difference. Microwave sea surface temperature (SST) data at 0.25 degree resolution are from the Remote Sensing Systems' Database.

III. RESULTS

The average LD as a function of radius for the Atlantic, east Pacific and west Pacific (Fig. 2) show a decrease in LD with radius for all TC categories in all basins. The inner core region (0-100 km form the storm center) has larger LD than the inner rainbands (100-200 km) and outer rainbands (200-500 km). Average LDs in the Atlantic and west Pacific are twice as large as that for the east Pacific. LDs is much larger for tropical stroms (TS) and tropical depressions (TD) than for hurricanes, which is consistent with the previous studies. Fraction of lightning counts as a function of storm intensity shows that lightning occurs most often (80%) in weak storms (TD and TS) than for intensity level of hurricane.

Lightning is observed in all storm intensity change categories: rapid intensification, average intensity change, and rapid weakening. The greatest lightning density appears in storms undergoing an intensity change of -5–15 m s^{-1} during the next 24 h.

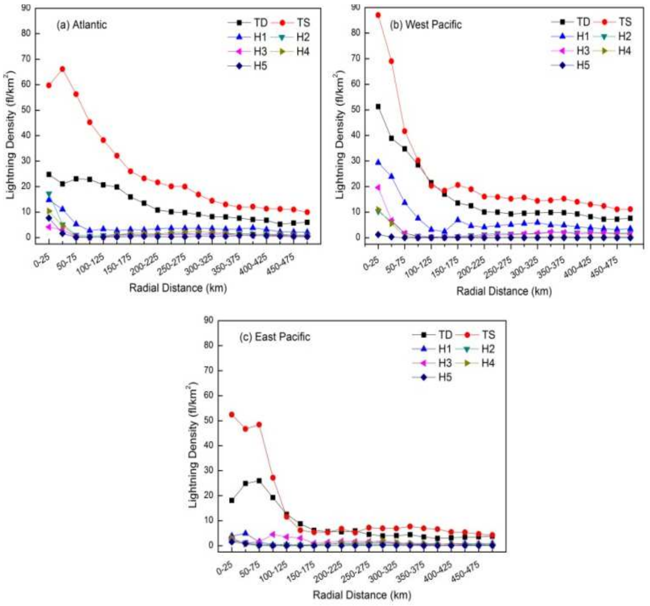

Fig. 2. Mean LD as a function of radius from the storm center for (a) Atlantic, (b) West Pacific and (c) East Pacific.

The effect of storm motion on the distribution of lightning was examined. Fig 3 gives the LD relative to storm montion vector for both Atlantic and west Pacific TCs. High LDs are found in the right-front quadrant which is the down-motion direction. LD was higest in the inner core region in each motion-ratoted quadrant for both basins, with a preference for the right-front quadrant.

The relationship of lightning flashes to environmental parameters, such as SST and vertical wind shear were examined. The results showed that TC lightning occur over warmer SSTs (26~30ºC) for all basins. High lightning flash counts falls between 28ºC and 30ºC, with the maximum counts at SST of 30ºC.

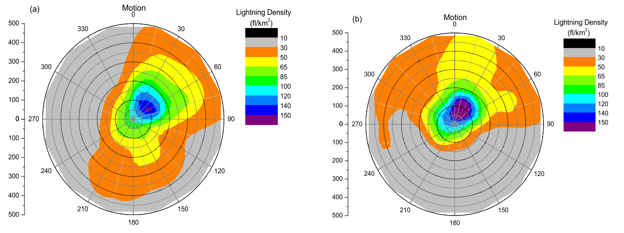

Fig. 3. Lightning density relative to storm motion vector (fl/km^2) for (a) Atlantic (b) west Pacific.

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Figure 4 shows a scatterplot of LD and vertical wind shear for Atlantic and west Pacific. There is a nonlinear relationship between LD and vertical shear. As the shear increases from low (3 m/s) to moderate (10 m/s) values, the LD increases. When the shear is larger then 10 m/s, the LD generally decreases with values of shear.

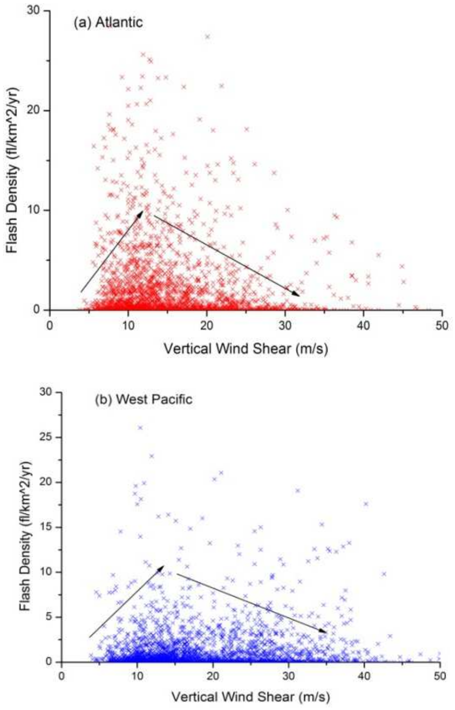

Fig. 4. Scatterplot of the vertical wind shear and LD for (a) Atlantic (b) west Pacific.

The results are consists with the “two shear regimes” suggested by DeMaria et al. [2012] and Corbosiero and Molinari [2003]. The moderate shear may enhance updrafts near the storm while very large shear may disrupt the storm structure and the organized convection.

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