1.4 GLOBAL STUDIES OF TROPICAL CYCLONES USING THE WORLD WIDE LIGHTNING LOCATION NETWORK

Natalia N. Solorzano[1]*, Jeremy N. Thomas[2,3], and Robert H. Holzworth[2]
[1]Digipen Institute of Technology, Redmond, WA, USA
[2]University of Washington, Seattle, WA, USA
[3]USGS, Denver, CO, USA

(Final Version: 29 Feb. 2008)

1. INTRODUCTION

The lightning activity generated by tropical cyclones is not well understood. This mainly because these storms spend most of their lifetimes over the ocean, away from land-based regional lightning networks. Recent studies have used satellite-based lightning detection and an extended regional network to investigate lightning activity in tropical cyclones before landfall. Cecil and Zipser (1999) used lightning data from the Tropical Rainfall Measurement Mission (TRMM) satellite to compare lightning activity and tropical cyclone intensity. With data from the Vaisala Long-range Lightning Detection Network (LLDN), Demetriades and Holle (2006) and Squires (2006) studied lightning activity in Atlantic and eastern Pacific hurricanes. However, these satellites can only detect lightning from a particular storm for a few minutes each day and these extended networks only cover a limited global region.

We use the World Wide Lightning Location Network (WWLLN), the only real-time network that covers the entire globe, to analyze the change in lightning activity during the evolution of tropical cyclones. We examine the spatial and temporal aspects of lightning activity in the eyewall and rainband regions of two Atlantic hurricanes (Rita and Katrina) and three western Pacific typhoons (Durian, Chanchu, and Yagi). To our knowledge, these are the first results concerning the lightning activity in which the entire life span of the western Pacific typhoons is observed.

We find a maximum in lightning activity in the rainbands and a secondary maximum in the eyewall. Moreover, we observe eyewall lightning outbreaks correlated with storm intensity change for all five case study storms and, for at least one case, an eyewall outbreak prior to an eyewall replacement cycle. Additionally, we find that eyewall lightning activity usually increases as the storms approach and reach land. Our results generally agree with previous lightning observations of Atlantic basin hurricanes reported by Molinari et al. (1999) and highlight the need for additional studies of lightning activity in tropical cyclones.

*Corresponding author address: Natalia N. Solorzano, Physics Dept., Digipen Institute of Technology, Redmond, WA 98052; e-mail: nataliansolo@gmail.com

2. THE WORLD WIDE LIGHTNING LOCATION NETWORK

The World Wide Lightning Location Network (WWLLN; http://wwlln.net/) allows us to investigate lightning activity driven by tropical cyclones that occur anywhere on earth. Hence, this work is unique from any past studies of tropical cyclones that were limited to regions within a few hundred kilometers of ground-based sensors or utilized a few minutes of satellite-based data each day.

The WWLLN provides real time lightning locations globally by measuring the very low frequency (VLF) radiation (3-30 kHz) emanating from lightning discharges. For a lightning stroke to be accurately detected with error analysis, the VLF radiation from the stroke must be detected at a minimum of 5 of the network's 26 receivers around the world. Each receiving station consists of a whip antenna to measure the VLF electric field, a GPS antenna for accurate timing, preamplifying electronics, and an internet-connected processing computer. Each receiver locally processes the lightning-driven VLF waveforms and sends the time of group arrival (TOGA) to the central processing station for location (Dowden et al., 2002). In this manner, WWLLN provides continuous lightning detection coverage of the entire globe.

The location accuracy and efficiency of WWLLN have been estimated for certain regions of the globe by comparison to regional, ground-based lightning detection systems (Lay et al. 2004; Rodger et al. 2005, 2006; Jacobson et al. 2006). Rodger et al. (2005) compared WWLLN data in Australia to the local lightning location network, Kattron, and found a detection efficiency of ~26% for cloud-to-ground (CG) strokes and ~10% for intracloud (IC) strokes. Additionally, Rodger et al. (2005) estimated the mean location accuracy for the entire globe to be about 3.4 km with a range of 1.9 – 19 km, which is adequate to resolve regions of convective activity in tropical cyclones. These comparisons with other lightning networks also suggested that most WWLLN located lightning had peak currents greater than about 30 kA.

A subsequent study (Rodger et al. 2006) showed that the WWLLN detection efficiency was spatially dependent and ranged from 2-18% for CG lightning (see their Fig. 16). Importantly, in a particular tropical cyclone basin (e.g. Atlantic or western Pacific) the efficiency varied spatially only by a few percent. For our tropical cyclone analysis, we have reprocessed the WWLLN data with a new location algorithm that increases the detection efficiency by 100 to 200% over these previous studies. Work is currently underway to better quantify this improved efficiency.

Rodger et al. 2006 also estimated the temporal variation of the network. Their Figs. 13 and 14 show detection efficiency differences due to diurnal modulation of ionospheric conditions. Due to the large number of WWLLN receivers spread throughout the globe and the TOGA timing technique that is employed, these day-night differences are relatively low in most regions and will not significantly affect the case studies presented here. For future statistical studies, we will incorporate these diurnal differences into our temporal lightning analyzes.

3. CASE STUDIES

In this work, we present results concerning the spatial and temporal distributions for two Atlantic hurricanes and three western Pacific typhoons. To our knowledge, this is the first investigation of lightning activity over the entire life span of western Pacific typhoons.

In order to test if our results obtained from WWLLN data are representative of the lightning distribution, we plot the lightning spatial and temporal distributions for Hurricane Rita (Figure 1) and compare our results to previous studies. Rita was a category 5 hurricane and the most intense storm ever recorded in the Gulf of Mexico. Figure 1 (top) shows WWLLN data for September 21, 2005 when Rita rapidly intensified from a category 2 to 5 storm. The WWLLN data show the radial pattern previously observed by Molinari et al. (1999) during other Atlantic basin hurricanes. There are three distinct regions: a weak density maximum for the eyewall (region within ~40 km of the center), a distinct area of minimum activity at approximately 80 – 200 km from the eyewall, and the main, broader maximum on the rainband region, outside the 200 km radius.

The spatial distribution of lightning activity for Rita's eyewall is shown in Figure 1 (middle). The lightning frequency is integrated over the period of 14:00 - 15:00 UT of September 21, 2005, which was during very rapid strengthening. A ring of lightning activity clearly identifies the eyewall. Our results are in good agreement with observations from the Los Alamos Sferic Array (LASA) lightning network as reported by Shao et al. (2005).

According to Molinari et al. (1994 and 1999), eyewall lightning is episodic, and outbreaks may accompany the eyewall replacement cycles. We now examine the temporal evolution of eyewall lighting in Rita. Figure 1 (bottom) shows the time histogram of Hurricane Rita eyewall lightning obtained by WWLLN for September 18-27, 2005, which is binned in 30-minute intervals. To indicate storm intensity, we also include the maximum sustained wind and minimum pressure data[1] in Figure 1. For Rita and our other case studies, we define eyewall lightning to be within 100 km of the storm center. We

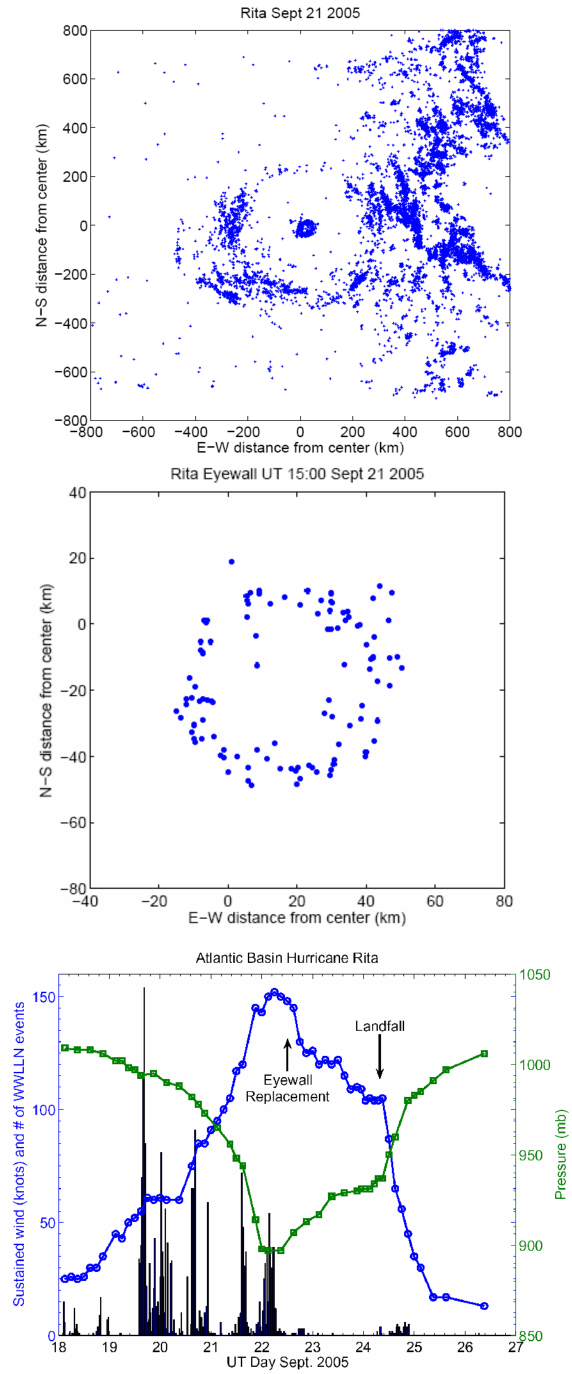

Figure 1: (top) WWLLN lightning in storm centered coordinates during Hurricane Rita for UT day Sept. 21, 2005. (middle) A zoom of the eyewall lightning for 14:00 – 15:00 UT Sept. 21. (bottom) Time histogram of eyewall lightning (within 100 km of the storm center) for Sept. 18-27, 2005 along with maximum sustained wind and minimum pressure.

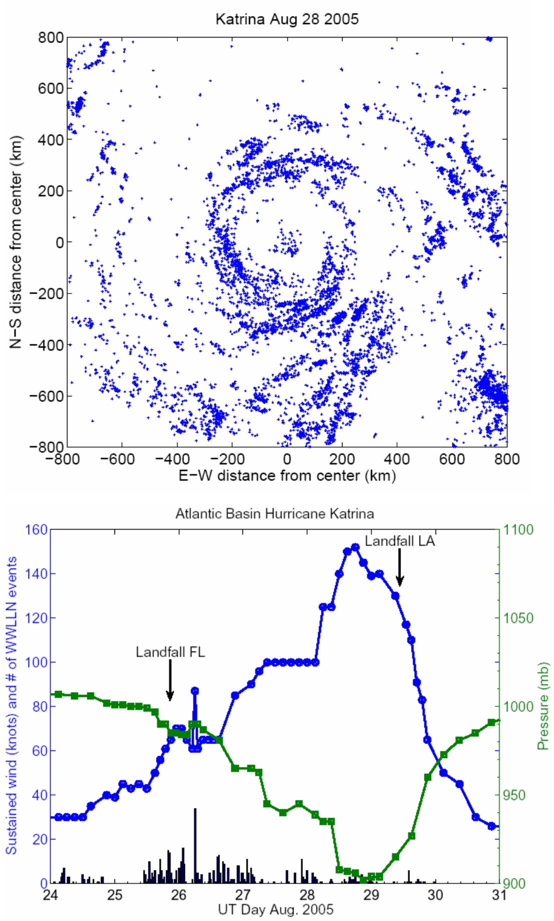

Figure 2: (top) WWLLN lightning in storm centered coordinates during Hurricane Katrina for UT day Aug 28, 2005. (bottom) Time histogram of Hurricane Katrina eyewall lightning (within 100 km of the storm center) observed by WWLLN for Aug 24-31, 2005 along with maximum sustained wind and minimum pressure.

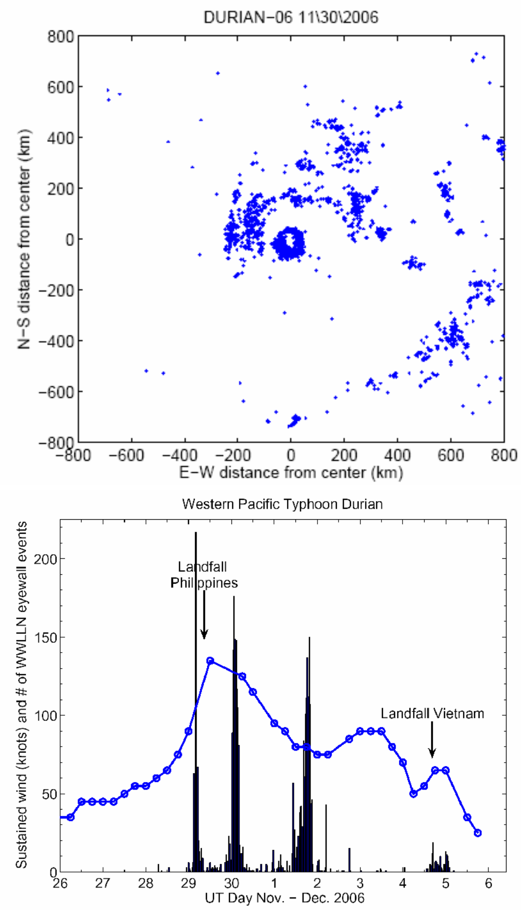

Figure 3: (top) WWLLN lightning in storm centered coordinates during Typhoon Durian for Nov. 30 2006. (bottom) Time histogram of Typhoon Durian eyewall lightning (within 100 km of the storm center) observed by WWLLN for Nov. 26 – Dec 6, 2006 along with maximum sustained wind.

find that eyewall lightning outbreaks occurred prior to, or during, most intensity changes, indicated by the change in the slope on the maximum sustained wind (or the minimum pressure). Squires (2006) using LLDN also reported these peaks in eyewall lightning accompanying intensity changes in Rita. Figure 1 also indicates a large increase in eyewall lightning preceding the eyewall replacement that occurred on September 22 as reported by Houze et al. (2007). Additionally, just prior to and during landfall on September 24 there was a weak eyewall lightning outbreak.

The results presented in Figure 1 show that the data from WWLLN are in good agreement with previous works. Hence, although WWLLN is most sensitive to large peak current strokes above about 30 kA, the data set provides the information we need to study the lightning activity in tropical cyclones.

Figure 2 (top) shows the WWLLN lightning locations Hurricane Katrina on August 28, 2005 during peak intensity. Katrina was a category 5 storm and the sixth most intense Atlantic basin storm on record. Again, the same radial pattern with two maxima and one minimum in lighting density is observed. Figure 2 (bottom) shows the time evolution of Katrina eyewall lightning observed by WWLLN for August 24-31, 2005 along with maximum sustained wind and minimum pressure. The first landfall occurred on August 25 in Florida, when Katrina was a category 1 storm. Interestingly, just after landfall, the storm intensified, which was accompanied by a peak in lightning activity. A second and a third landfall occurred on August 29 in Louisiana, when Katrina was a category 3 hurricane. After these landfalls, the storm weakened, but no change in the lightning activity is observed.

Next, we apply the same techniques as employed for the Rita and Katrin to examine the lightning activity in three western Pacific super typhoons (equivalent to category 4-5 hurricanes): Durian, Chanchu, and Yagi.

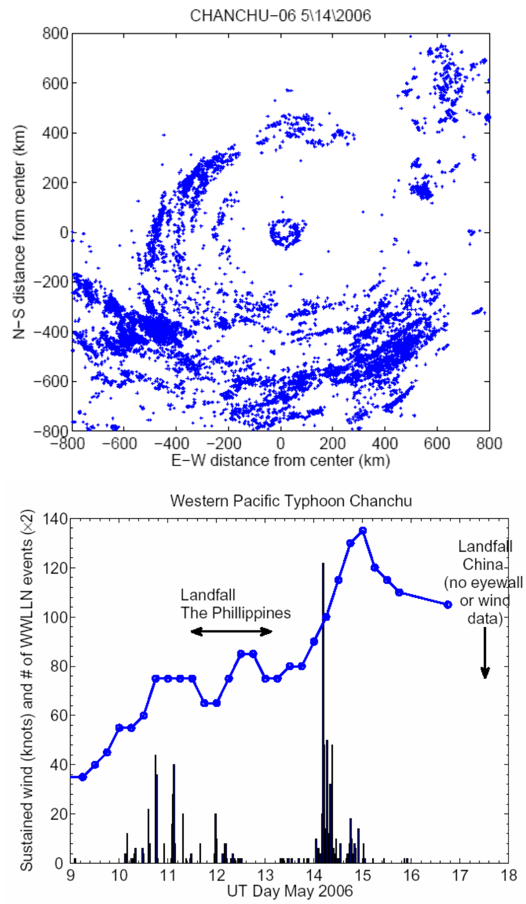

Figure 4: (top) WWLLN lightning in storm centered coordinates during Typhoon Chanchu for May 14, 2006. (bottom) Time histogram of Typhoon Chanchu eyewall lightning (within 100 km of the storm center) observed by WWLLN for May 9-18, 2006 along with maximum sustained wind.

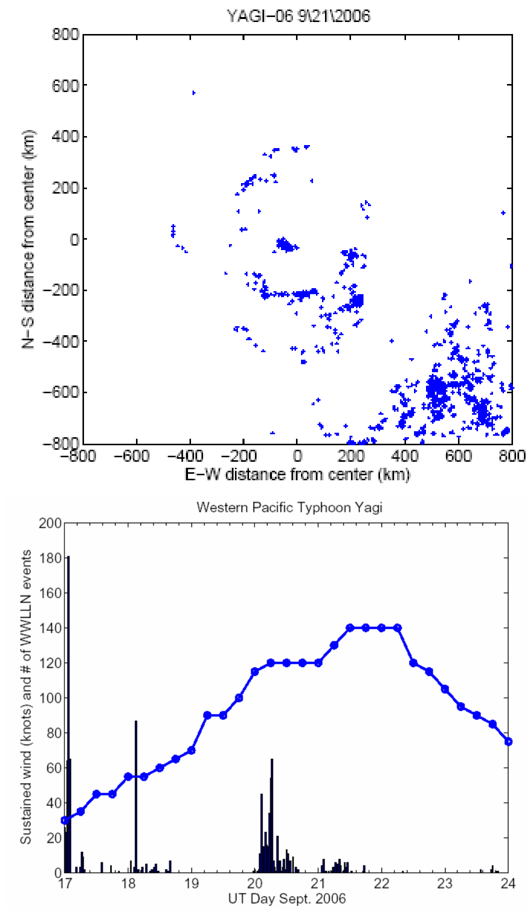

Figure 5: (top) WWLLN lightning in storm centered coordinates during Typhoon Yagi for Sept. 21, 2006. (bottom) Time histogram of Typhoon Yagi eyewall lightning (within 100 km of the storm center) observed by WWLLN for Sept. 17 - 24, 2006 along with maximum sustained wind.

Durian was a super typhoon that made landfall in the Philippines and Vietnam. Figure 3 (top) shows WWLLN lightning for Durian during a period of rapid weakening from a category 4 to 2 storm on November 30, 2006 with clear maxima in lightning activity in the rainbands and eyewall regions. Figure 3 (bottom) shows the eyewall lightning activity for Durian, along with maximum sustained wind. Peaks in activity are observed before or during most major intensity changes. The largest peak in eyewall lighting occurs during rapid intensification from a category 2 to 5 storm on November 29, which was just prior to the first landfall.

Typhoon Chanchu struck the Philippines twice, upgraded to a super typhoon while over the South China Sea, and hit China after weakening. Figure 4 (top) shows the spatial lightning distribution for Chanchu during rapid intensification on May 14, 2006 with dense lightning activity in the rainbands and eyewall regions. At the bottom of Figure 4, the eyewall lightning temporal distribution is depicted along with wind data. Peaks in the eyewall lightning activity accompany most of the intensity changes, including a major outbreak on May 14 when Chanchu intensified from a category 1 to 4 storm.

Yagi was a super typhoon that did not make landfall. Figure 5 (top) shows WWLLN lightning data for Yagi on September 21, 2006 during peak intensity. A similar pattern for lightning density as observed during our other case studies is seen here, with maxima in the rainbands and eyewall regions. Figure 5 (bottom) shows the eyewall lightning time histogram plotted with wind data for Yagi. Peaks in lightning activity are observed during most of the intensity changes, including intensity increases on September 20 and 21.

4. CONCLUSIONS AND FUTURE WORK

We use WWLLN data to study spatial and temporal distributions of lightning for two Atlantic hurricanes (Rita and Katrina) and three western Pacific typhoons (Durian, Chanchu and Yagi). Our observations of lightning activity in Rita are generally in agreement with previous studies (Shao, 2005; Squires 2006). This includes an outbreak in eyewall lightning prior to an eyewall replacement cycle. Moreover, lightning activity during the complete lifetime of western Pacific tropical cyclones is studied for the first time. For all storms observed, we find three regions of distinct spatial behavior for lightning density with maxima in the rainband and eyewall regions. Also, eyewall lightning outbreaks occur prior or during most major intensity changes for all storms examined. This suggests that eyewall lightning activity might be used to identify convection intensification in strong tropical cyclones. Peaks in eyewall lightning activity are also observed before most landfalls.

Since Rita and Katrina were Atlantic basin storms that made landfall in the US, they are well studied and numerous observations are available, including in situ aircraft measurements, ground-based and satellite-based radar, and satellite imagery. We plan to compare the WWLLN lightning observed during Rita and Katrina to these measurements to establish lightning activity as a proxy for convection evolution in tropical cyclones. We also plan investigate the eyewall lightning location with respect to the vertical wind shear vector to compare with the observations of Molinari et al. (2004; 2006). Finally, to develop a more robust, statistically significant relation between lightning activity and storm evolution, we will examine all of the tropical cyclones that occurred globally since 2004, when WWLLN became fully operational.

5. ACKNOWLEDGMENTS

This work was partially supported by a grant from the Mindlin Foundation to the University of Washington. We are grateful to Craig Rodger and Erin Lay for assisting us with WWLLN data processing. We thank the many WWLLN hosts throughout the globe for housing and maintaining the VLF receivers.

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