UNDERSTANDING THE RELATIONSHIP BETWEEN LIGHTNING OUTBREAKS AND TROPICAL CYCLONE INTENSITY CHANGE

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1. INTRODUCTION

Detection of lightning flashes in tropical cyclones (TCs) has improved greatly over the past decade with the advent of global lightning detection networks. Unlike satellite lightning detection platforms, ground-based networks provide continuous coverage of lightning in TCs. Many studies have found an association between increased inner core (IC; 0-100 km) lightning flash counts, or flash density, and TC intensity change 24 h later; however, the results are contradictory.

Pan et al. (2010, 2014) examined northwest Pacific TCs and found increased IC lightning activity 24 h prior to intensification. In contrast, DeMaria et al. (2012) examined eastern North Pacific (ENP) and northern Atlantic (NA) TCs and found increased IC lightning activity 24 h prior to weakening, leading to the conclusion that large amounts of lightning (a "burst") in the IC are indicative of the end of intensification. Stevenson et al. (2014)'s case study of a NA TC, Hurricane Earl (2010), demonstrated that not all TCs with an IC lightning burst weaken; in fact, Hurricane Earl rapidly intensified. They hypothesized Earl's rapid intensification was due to the location of the IC burst upshear and inside the radius of maximum wind (RMW). Although lightning rarely peaks upshear (Corbosiero and Molinari 2002, 2003), perhaps it can aid in intensification by increasing TC symmetry. Radially, intensification efficiency has been shown to increase with convection inside the RMW (Vigh and Schubert 2009; Rogers et al. 2013). Molinari et al. (1999) hypothesized that perhaps the sign of the intensity change was instead dependent on the prior intensity change, where weakening or slowly intensifying TCs are likely to intensify after an IC lightning burst.

This study aims to reconcile the discrepancies in the previous literature by examining three other factors, besides the presence of IC lightning activity, which we hypothesize may contribute to the observed relationship with future intensity change: 1) prior intensity change, 2) azimuthal burst location, and 3) radial burst location.

2. DATA AND METHODS

All NA and ENP basin TCs from 2005–2014 were examined for IC lightning bursts. The World Wide Lightning Location Network (WWLLN), a global, groundbased network, provided locations of lightning flashes in these TCs. An adjustment factor was applied to WWLLN data using the Lightning Imaging Sensor (LIS) climatology for each basin to account for increasing

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Stephanie N. Stevenson, University at Albany, State University of New York, 1400 Washington Ave., Albany, NY 12222. Email: sstevenson@albany.edu detection efficiencies as the number of sensors in the network has grown.

The six-hourly National Hurricane Center (NHC) best track locations were linearly interpolated to oneminute intervals to calculate the radial and azimuthal location of flashes relative to the TC center. For this study, an IC lightning burst was defined as the maximum hourly 8 km x 8 km flash density within 175 km of the TC center that exceeded two standard deviations of the entire data set. Although the inner 100 km is typically used to define the IC, an extended radius of 175 km accounts for weaker TCs that may have a broader circulation (Moyer et al. 2007), and typically have more lightning (Abarca et al. 2011). Additionally, IC bursts within 75 km of the previous hour's burst were removed to reduce long-lived bursts skewing the results. TCs that made landfall within 24 h were also removed.

The NHC best track wind intensities were linearly interpolated to each hour to test the prior intensity change hypothesis. The Statistical Hurricane Intensity Prediction Scheme (SHIPS) provided the deep-layer (850–200 hPa) vertical wind shear vector to determine the azimuthal burst location. Azimuthally averaged tangential wind profiles from flight level reconnaissance were utilized to identify the RMW for the radial burst location analysis.

3. RESULTS

A total of 302 (279) IC bursts were identified in the NA (ENP) using this methodology. Most of the TCs with



Fig. 1 Box plots of the intensity change 24 h prior to and after an IC burst in the NA (top) and ENP (bottom). Future intensity changes are stratified as follows: weaken $(\Delta v_T \le -10 \text{ kt})$, steady $(-10 \text{ kt} < \Delta v_T < 10 \text{ kt})$, and intensify $(\Delta v_T \ge 10 \text{ kt})$.

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an IC burst remained steady $(-10 kt < \Delta v_T < 10 kt)$ 24 h after the burst occurred; however, more TCs experienced intensification $(\Delta v_T \ge 10 kt)$ than weakening $(\Delta v_T \le -10 kt)$ in both basins, contradicting the results of DeMaria et al. (2012).

The intensity change 24 h before and after the IC burst was examined to test the hypothesis put forth by Molinari et al. (1999). Figure 1 shows that each distribution of TCs weakening, remaining steady, or intensifying after the burst had both weakening and intensifying tendencies prior to the burst, suggesting no clear association between prior and future intensity change. Although not all TCs that slowly intensified before the burst intensified after, most of the TCs that did intensify were intensifying before (~75% in NA and ~90% in the ENP; see Fig. 1).

Consistent with previous work, 80% of the IC bursts identified in our study occurred in the downshear quadrants, as expected by TC vortex dynamics in a sheared environment (Reasor et al. 2004). The TCs in this study weakened and intensified 24 h after the IC burst independent of the shear quadrant in which the burst occurred (Fig. 2). Stevenson et al. (2014) hypothesized that upshear bursts were perhaps more likely to intensify; however, about an equal number of cases with IC bursts occurring upshear weakened or intensified 24 h after.



Fig. 2 The 24 h intensity change associated with IC bursts in various shear quadrants (DL: downshear left, DR: downshear right, UR: upshear right, and UL: upshear left).

The radial location of the IC bursts relative to the RMW had a strong relationship for the 11 cases examined (Fig. 3). TCs with an IC lightning burst near or

inside the RMW intensified, while bursts near or outside the RMW weakened. This result is consistent with previous studies, and suggests that convective heating confined within the high inertial stability core promotes intensification.



Fig. 3 The radial location of IC bursts relative to the RMW and the associated 24 h intensity change. Letters and numbers correspond to the storm name and year.

4. CONCLUSIONS

The analysis of IC lightning bursts in TCs presented here tested whether other factors contributed to the signaled intensity change 24 h after the burst first occurred. Of the three hypotheses tested, the radial burst location relative to the RMW was the most important factor. If diabatic heating was confined to the high inertial stability region in the IC, TCs were more likely intensify. The results of this study provide additional guidance for the utility of lightning in TC intensity forecasts.

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