OBSERVED RELATIONSHIPS BETWEEN TOTAL LIGHTNING INFORMATION AND DOPPLER RADAR DATA DURING TWO RECENT TROPICAL CYCLONE TORNADO EVENTS IN FLORIDA

Scott M. Spratt, David W. Sharp, and Stephen J. Hodanish
NOAA/NWS Melbourne, Florida

1. **INTRODUCTION**

The presence of a unique *(total)* lightning detection network and a nearby WSR-88D radar within east central Florida has afforded many opportunities to investigate the structure and life cycle of convective cells in great detail. Until now, these studies have focused on two main areas: the apparent relationships between excessive lightning and subsequent severe weather during "warm season" pulse storms (e.g. Hodanish et al., 1998) and the more dynamic storms of the "cool season" (e.g. Williams et al., 1998), and the identification of signatures prior to cloud to ground lightning initiation and cessation (Forbes et al., 1996).

This paper will delve into a new topic by providing an initial examination of observed relationships between *total* lightning signatures and Doppler radar data of tornadic cells within tropical cyclone (TC) outer rainbands. While research of cloud to ground (CG) lightning within tropical cyclones can be considered relatively unexplored (Samsury et al., 1997), examination of the *total* lightning signal within tropical cyclone rainbands has never been studied, until now.

Previous TC CG lightning studies have shown that the amount of discharges to the surface vary considerably from TC to TC, but contain very little CG lightning overall relative to mid latitude mesoscale convective systems (Samsury and Orville, 1994). The literature also agrees that most observed CG lightning occurred within outer convective bands, rather than within inner bands and stratiform precipitation regions. This is not surprising since a greater coverage of deep convective cells typically occur within the outer TC bands where updrafts penetrate far enough aloft to generate mixed phase precipitation (supercooled water and wet graupel) to initiate electrification (Saunders, 1993). The threshold for the production of enough mixed phase particles is generally denoted when a 30 dBZ reflectivity echo reaches or exceeds a height of 8 km AGL or the level of the -15 to -20 deg C isotherms (Forbes et al., 1996).

The remainder of this paper will examine *total* lightning information (TLI) and radar reflectivity and storm relative velocity signatures associated with several known TC tornadic cells. Characteristics of observed lightning will be shown for comparison to those discovered in the CG studies. Lastly, the significance of this unique lightning data set will be highlighted, as both a real-time forecast and warning tool, and for the post event study of electrical rainband structure and microphysical processes.

2. **TOTAL LIGHTNING INFORMATION**

Total Lightning Information (TLI), as the title implies, encompasses all forms of lightning; cloud to ground (CG), cloud to cloud (CC), in cloud (IC), and cloud to air (CA). The National Aviation and Space Administration (NASA) developed a lightning sensor network and display workstation in 1990 to provide increased lead time for the lightning sensitive operations performed throughout the Kennedy Space Center (KSC). The system, called LDAR (Lightning Detection And Ranging), detects volumetric discharges and displays individual discharges or "points" of lightning in realtime in a 3 dimensional (X, Y, Z) format (Hodanish, 1996). The LDAR system detects TLI by using an array of 6 antennae, located at the KSC, to detect lightning induced "disturbances" at the 66 MHZ frequency. The system uses a time of arrival approach via Global Positioning System (GPS) technology. A total of 5 minutes of data is displayed, with continuous realtime updates. It has been found that an individual lightning flash within a distance of 20 km can generate over 10 000 discharge points (Hodanish, 1996). For a detailed description of LDAR, see Lennon and Maier (1991).

In 1995, the Massachusetts Institute of Technology (MIT)/Lincoln Laboratories developed a second workstation to display TLI (LDAR) data. This workstation, designated LISDAD (Lightning Imaging Sensor Data Applications Display), converts all TLI "points" from a discharge into a single "point" (flash) and plots the result on a plan view map containing WSR-88D composite reflectivity data. Trend tables (time sections) of TLI, CG lightning, maximum reflectivity, and echo tops are also available for each identified cell. The TLI data are updated continuously in realtime and radar data are refreshed every volume scan (5 minute intervals). For additional information concerning LISDAD, refer to Boldi et al. (1998).

Both the original LDAR workstation and the prototype LISDAD workstation are located side-by-side and used operationally at the Melbourne (MLB) National Weather Service Office (NWSO). In this posture LDAR is exploited for its 3 dimensional display capabilities, while LISDAD provides total lightning trends for each cell from initial development to the current time. Data displays from the LDAR workstation will be used below to illustrate electrical discharges occurring in the vicinity of a TC Gordon tornadic cell and output from LISDAD will highlight lightning activity associated with the TC Josephine tornado event.

3. **TROPICAL CYCLONE GORDON (1994)**

After initial classification as a tropical depression on 8 November 1994 near the coast of Nicaragua, the system followed a slow, erratic path across the western Caribbean Sea and the eastern Gulf of Mexico while slowly strengthening to moderate tropical storm intensity. Tropical Storm Gordon made landfall along the southwest Florida coast on 16 November with maximum sustained winds of 22.5 m s^{-1} and a central pressure of 995 hPa. For a complete discussion of TC Gordon, see Avila and Rappaport (1996).

When the TC center reached a position between Key West and Sarasota on 15 November, several tornadoes occurred across east-central and southeast portions of the Florida peninsula. The first and strongest of six confirmed tornadoes occurred far from the TC center and in the favored right front quadrant of circulation at an azimuth/range of 36 deg/340 km (Spratt et al., 1997). This tornado and the last of the six tornadoes occurred well within range of the TLI and MLB radar networks, and will be discussed further below.

3.1 Radar and Total Lightning Comparisons

At approximately 2300 UTC 15 November 1994, WSR-88D storm relative velocity products first began to indicate weak rotation within an isolated cell over the Atlantic, 75 km southeast of the radar site (KMLB). This cell traveled steadily northwest and reached the immediate coast at 2340 UTC (Fig. 1).

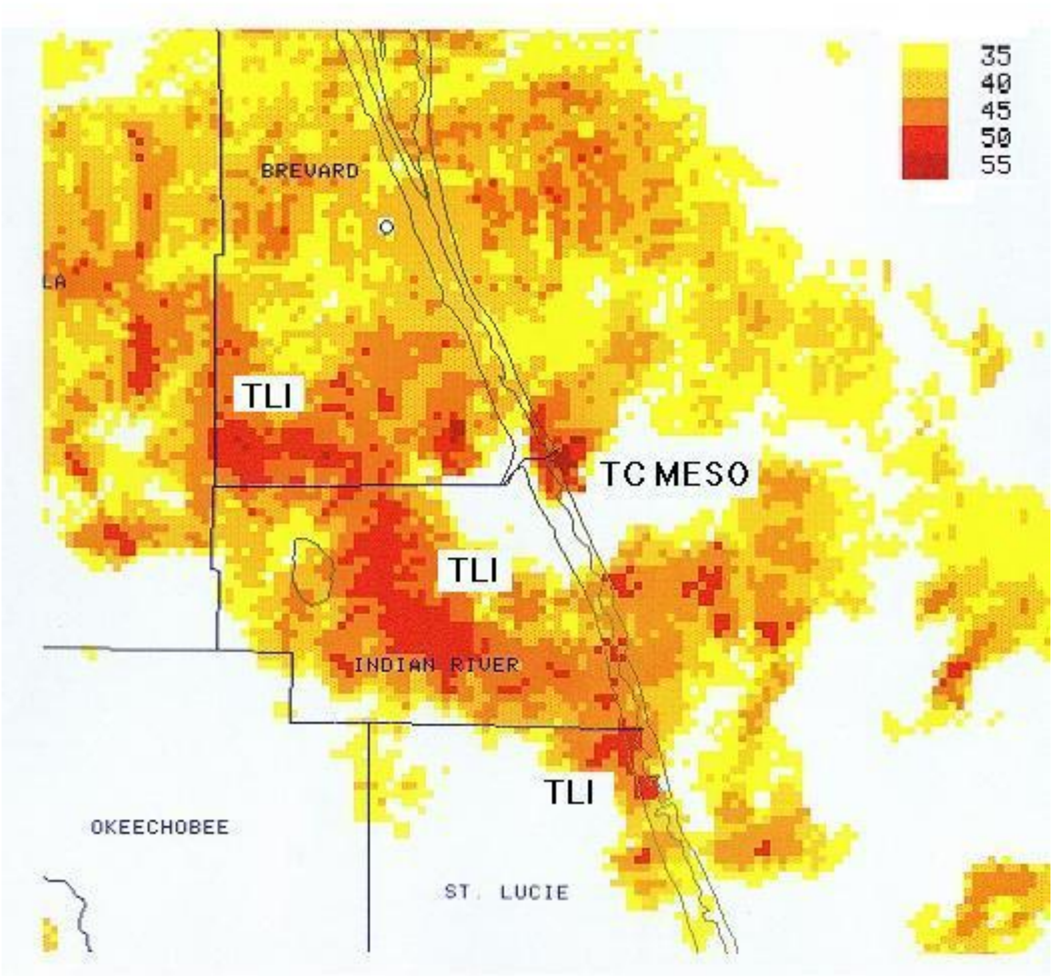

Fig. 1. WSR-88D composite reflectivity product at 2340 UTC 15 November 1994. Note the three areas of active lightning (indicated by TLI) and the location of the cell containing the mesocyclone (indicated by TC meso).

Throughout this time, echo tops remained near 35 kft and the maximum reflectivity held between 55 and 59 dBZ. Shortly after 2340 UTC, the cell likely spawned a tornadic waterspout over the intracoastal waterway (Spratt et al., 1997). Minutes later the waterspout made landfall along the mainland coast, then moved through a mobile home community causing F2 damage and numerous casualties (including one fatality). By 2355 UTC the tornado had lifted. During the time the waterspout/tornado was occurring, low level rotation and shear peaked at 15 m s^{-1} and .016 s^{-1}, respectively. Maximum reflectivities remained between 55 and 59 dBZ and echo tops decreased to around 34 kft (likely underestimated due to close-range radar sampling).

Unfortunately, TLI was not available during the first half of the TC mesocyclone's life time (prior to 2330 UTC). TLI examined between 2330 and 2359 UTC revealed nearly 1000 "points" of lightning within the vicinity of the TC mesocyclone (Fig. 2).

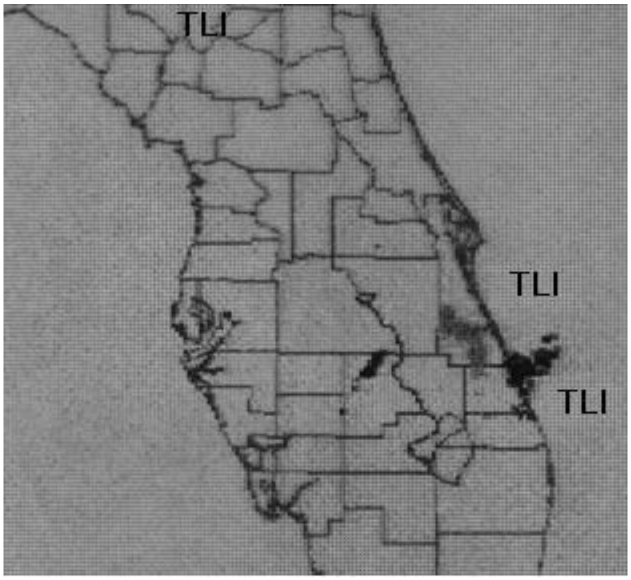

Fig. 2. LDAR display indicating "points" of total lightning between 2330 and 2359 UTC. The northernmost TLI area (gray shading) occurred between 2332 and 2345 UTC, while the southernmost TLI area (black shading) occurred at 2334 UTC. Another area of TLI occurred well inland at 2341 UTC.

A detailed analysis of the times of LDAR "point" occurrence indicated that the 1000 points resulted from approximately 6 individual strikes (all non CG) which occurred between 2332 and 2345 UTC. Interestingly, no TLI occurred within the TC mesocyclone cell, but instead was associated with surrounding deeper convection to the west, southwest and south (Fig. 1). While the maximum reflectivities of the cells which produced the lightning were less (50-54 dBZ) than that of the tornadic cell, the echo tops were generally greater (40-50 kft).

Throughout the life cycle of the TC mesocyclonic cell, it exhibited the greatest maximum reflectivity value of any cell within at least 80 km. Although the TC meso cell remained more shallow than the surrounding convection which produced limited TLI, it remained isolated and exhibited persistent rotation throughout its existence.

Over six hours after the demise of the cell described above, another long-lived supercell developed approximately 40 km inland from the coast and eventually produced a brief F0 tornado. No TLI accompanied this cell throughout its lifetime.

4. TROPICAL CYCLONE JOSEPHINE (1996)

Tropical Storm Josephine moved steadily northeast-ward across the Gulf of Mexico on 7 October 1996, making landfall over extreme northwest Florida with maximum sustained winds of 30 m s^{-1} and a central pressure of 983 hPa (Pasch et al., 1998). This path allowed outer rainbands to rotate onshore into a weakly buoyant, yet highly sheared environment - one notably conducive to tornado formation. In fact, Josephines' outer circulation was largely responsible for spawning 20 confirmed tornadoes, making it the most prolific tornado-producing TC in Florida history (Hagemeyer, 1997).

Three individual mini-supercells (Cammarata et al., 1996) responsible for a total of thirteen tornadoes, traveled across the central Florida peninsula. The portions of these cells which traversed the combined coverage area of the TLI and radar networks will be discussed below.

4.1 Radar and Total Lightning Comparisons

Shortly after 1830 UTC 7 October 1996 an isolated cell developed rapidly and acquired weak rotation well southwest of the TLI and radar networks. This mini-supercell produced four brief F0 tornado touchdowns between 1845 and 1920 UTC. From this point until 2140 UTC, the cell remained within range of the lightning network and the KMLB radar. Maximum reflectivities throughout this period remained between 54 and 59 dBZ, and echo tops were generally between 30 and 40 kft. Lowest elevation storm relative velocity and shear values steadily increased early in the period, and displayed relative peaks of 20+ m s^{-1} and .020+ s^{-1}, respectively, at 2000 UTC. At this time, a brief tornado touchdown was reported.

The 1957 UTC LISDAD image (Fig. 3) revealed a large number of lightning flashes in the five minute period surrounding the tornado, mainly northeast of the reflectivity core, and likely associated with the anvil (i.e. downstream shear).

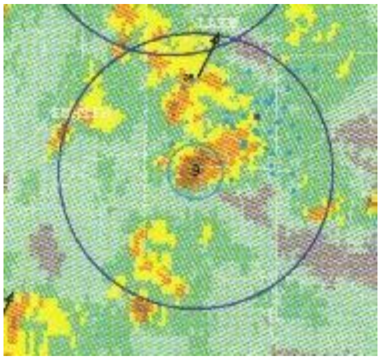

Fig.3. LISDAD image at 1957 UTC centered on a tornadic cell (cell "9"). Cell reflectivity is indicated by shading (darkest red/orange reveal highest dBZ values) and TLI flashes which occurred between 1955 and 2000 UTC are overlaid (small light blue dots, mainly northeast of the core of cell "9").

A peak rate of 10-12 flashes per minute occurred from approximately 1954 to 2004 UTC (-40 to -50 min period) according to a LISDAD trend table (Fig. 4). Additional tornado touchdowns occurred at 2033 and 2042 UTC, and were also accompanied by increased TLI rates (Fig. 4).

Note that single CG flashes occurred on five occasions during the period (Fig. 4), usually during times of additional TLI, however were not associated with tornado times. During the 2033 UTC touchdown, radar-detected storm relative velocity and shear again temporarily peaked. However, little change was indicated in Doppler velocity or shear at 2042 UTC, although both values remained relatively high at the time. A final touchdown was documented at 2130 UTC as the echo passed beyond efficient sampling range of the TLI and radar networks ranges.

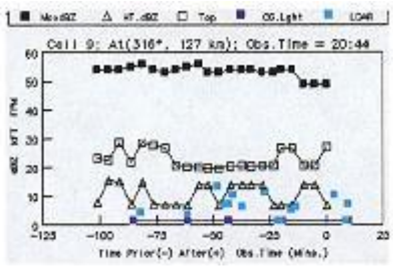

Fig. 4. LISDAD trend table of maximum reflectivity (Max dBZ), height of the maximum reflectivity (HT dBZ), echo top (Top), number of CG flashes (CG Lght), and number of TLI flashes (LDAR) for cell which produced multiple tornadoes. Time zero "0" is 2044 UTC, and time "-100" represents 1904 UTC. Note that "Tops" were underestimated because of downstream displacement due to excessive shear aloft.

A second long lived mini-supercell followed closely behind the first cell (described above), and along nearly the same track, while producing three F0 tornadoes. Radar characteristics of the cell were similar to the earlier cell, however only minimal TLI (all non-CG) were detected near the times of the first two touchdowns and no lightning was observed with the third tornado.

A third mini-supercell developed during the mid point of the previous cells' life cycle and produced a waterspout, followed nearly 20 min later by an F2 tornado (Spratt and Sharp, 1997). TLI was not observed during either tornadic phase of this cell, with only a very brief period of minimal non-CG activity midway between the demise of the waterspout and onset of the strong tornado.

5. DISCUSSION AND CONCLUSIONS

Five individual (tornadic) mini-supercells, embedded within the far outer rainbands of TC's Gordon and Josephine were tracked by the KMLB WSR-88D radar and a NASA total lightning network as they traversed east central Florida. TLI signals associated with the tornadic cells varied considerably from one event to the next, but were minimal for all cases.

CG flashes were extremely rare. In fact, only one of the five cells examined produced any ground strikes. This particular cell exhibited two periods of CG activity during a 3.5 h observation period. The first period lasted 100 min with single CG strikes detected approximately every 25 min. Following a 50 min period of CG inactivity, ground strikes resumed for 40 min with a frequency of one every 3-5 min. During the times of CG activity, four F0 tornadoes occurred; however, four additional touchdowns occurred during times when no CG activity was detected. This same cell was the most proficient producer of TLI (i.e. mainly non CG), with lightning observed nearly throughout the observation period, often with rates of 10-12 flashes per minute. TLI occurred prior to and during all except one of the tornadic periods. Interestingly, the two greatest flash rates coincided with the times of highest detected rotational velocity (and shear), and occurrence of two of the eight F0 tornadoes.

Two of the remaining long-lived supercells possessed very limited TLI, with only two (one minute) periods of lightning detected with each. Two of the TLI periods preceded F0 tornadoes by a few minutes; however, the remaining bursts of activity were not associated with touchdowns. A significant peak of rotational velocity (and shear) occurred over a 10 min period, coincident with two of the tornadoes, but not within a period of TLI.

An important discovery was documentation that two cells which produced relatively long-tracked, strong tornadoes (F2) were totally devoid of TLI. Only two brief bursts of lightning preceded one of the tornadoes by 10 min, while the other was not accompanied by TLI for at least 25 min prior to touchdown. With relatively strong detected rotational velocities (>15 m s-1) and shears ($>.016\ s^{-1}$), implied strong updrafts, and echo tops well above the height of the -20 deg isotherm during both tornadoes, the total lack of lightning (CG or other) proved intriguing. Willoughby et al. (1985) and others have theorized that microphysical conditions (lack of supercooled water) in tropical cyclones due to relatively weak updrafts may not be sufficient to produce large amounts of CG lightning. From the current study, it appears that this theory can be extended to include total lightning, even within some tornadic TC supercells.

Although it has been shown that strong TC tornadoes can occur in the absence of total lightning, the presence of TLI, even when infrequent, can be important to operational forecast and warning operations (especially when associated with an isolated cell). Cells which exhibit TLI appear to imply the presence of stronger updrafts than within adjacent cells which lack lightning. Therefore, in the presence of sustained storm scale rotation, TLI can be used as a proxy for locations of enhanced updrafts to highlight where vortex stretching could lead to tornadogenesis. The presence of lightning may also help provide early indication of a developing dominant band. It is possible that a lightning "signal" may be more apparent within tropical-extratropical (hybrid) cyclones due to lower melting levels and a greater likelihood of mixed phase precipitation aloft.

Results from this study suggest that much additional research involving (TC rainband) cloud electrification within the marine zone is necessary and that LDAR data sets should be exploited for such a purpose. Furthermore, additional research into the relationships between TLI and tornadic mesocyclones (both TC and non TC) are planned by the authors.

6. ACKNOWLEDGMENTS

The authors wish to thank John Madura of NASA/KSC for access to LDAR data, Ann Matlin, Earle Williams, and Bob Boldi of MIT/LL for access to and assistance with LISDAD data, and Tom Crawford and Humberto Caratagena of Command Technologies Inc. for LDAR data processing assistance.

7. REFERENCES

Avila, L.A., and E.N. Rappaport, 1996: Atlantic Hurricane Season of 1994. *Mon. Wea. Rev*., **124**, 1558-1578.

Boldi, R., S. Hodanish, D. Sharp, E. Williams, S. Goodman, R. Raghavan, A. Matlin, and M. Weber, 1998: The Design and Evaluation of the Lightning Imaging Sensor Data Applications Display (LISDAD), Preprints, *19th Conf. on Severe Local Storms*, Minneapolis, MN, Amer. Meteor. Soc., this volume.

Cammarata, M., E.W. McCaul, and D. Buechler, 1996: Observations of Shallow Supercells During a Major Tornado Outbreak Spawned by Tropical Storm Beryl. Preprints, *18th Conf. on Severe Local Storms*, San Francisco, CA, Amer. Meteor. Soc., 340-343.

Forbes, G.S., S.G. Hoffert, M.L. Pierce, 1996: Lightning Forecasting Studies at Kennedy Space Center Using WSR-88D and Companion Data Sets. Preprints, *15th Conf. On Weather Analysis and Forecasting*, Norfolk, VA, Amer. Meteor. Soc., 447-449.

Hagemeyer, B.H., 1997: Peninsular Florida Tornado Outbreaks. *Wea. Forecasting*, **12**, 399-427.

Hodanish, S.J., 1996: Integration of Lightning Detection Systems in a Modernized National Weather Service Office. Preprints, *18th Conf. on Severe Local Storms*, San Francisco, CA, Amer. Meteor. Soc., 428-432.

Hodanish, S.J., D. Sharp, E. Williams, R. Boldi, S. Goodman, R. Raghavan, A. Matlin, and M. Weber, 1998: Observations of Total Lightning Associated with Severe Convection During the Wet Season in Central Florida, Preprints, *19th Conf. on Severe Local Storms*, Minneapolis, MN, Amer. Meteor. Soc., this volume.

Lennon, C. and L. Maier, 1991: Lightning mapping system. NASA CP-3106, Vol. II, 1991 International Aerospace and Ground Conf. on Lightning and Static Electricity, pp. 89-1 to 89-10.

Pasch et al., 1998: Atlantic Hurricane Season of 1996. *Mon. Wea. Rev*., in print.

Samsury, C.E. and R.E. Orville, 1994: Cloud-to-Ground Lightning in Tropical Cyclones: A Study of Hurricanes Hugo (1989) and Jerry (1989). *Mon. Wea. Rev*., **122**, 1887-1896.

Samsury, C.E., M.L. Black, P.P. Dodge, and R.E. Orville, 1997: Utilization of Airborne and NEXRAD Data in the Analysis of Cloud-to-Ground Lightning in 1995 and 1996 Tropical Cyclones. Preprints, *22nd Conf. on Hurricanes and Tropical Meteorology.*, Ft. Collins, CO, Amer. Meteor. Soc., 125-126.

Saunders, C.P., 1993: A Review of Thunderstorm Electrification Processes. *J. Applied Meteor*., **32**, 642-655.

Spratt, S.M. and D.W. Sharp, 1997: Hurricane Operations at NWSO Melbourne: Applied Research and Real-time Forecasts/Warnings. Preprints, *22nd Conf. on Hurricanes and Tropical Meteorology*, Ft. Collins, CO, Amer. Meteor. Soc., 659-660.

Spratt, S.M., D.W. Sharp, P. Welsh, A. Sandrik, F. Alsheimer, and C. Paxton, 1997: A WSR-88D Assessment of Tropical Cyclone Outer Rainband Tornadoes. *Wea. Forecasting*, **12**, 479-501.

Williams, E., R. Boldi, A. Matlin, M. Weber, S. Hodanish, D. Sharp, S. Goodman, R. Raghavan, and D. Buechler, 1998: Total Lightning as a Severe Weather Diagnostic in Strongly Baroclinic Systems in Central Florida. Preprints, *19th Conf. on Severe Local Storms*, Minneapolis, MN, Amer. Meteor. Soc., this volume.

Willoughby, H.E., D.P. Jorgensen, R.A. Black, and S.L. Rosenthal, 1985: Project Stormfury: A scientific chronicle 1962-1983. *Bull. Amer. Meteor. Soc.*, **66**, 505-514.