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TOTAL LIGHTNING AS A SEVERE WEATHER DIAGNOSTIC IN STRONGLY BAROCLINIC SYSTEMS IN CENTRAL FLORIDA*

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1. INTRODUCTION

Severe weather is defined by specific thresholds in wind, hail size and vorticity. All of these phenomena have close physical connections with vertical drafts in deep convection, which are themselves not directly measured with scanning Doppler radars of the NEXRAD type. Cloud electrification and lightning are particularly sensitive to these drafts because they modulate the supply of supercooled water which is the growth agent for the ice particles (ice crystals, graupel and hail) believed essential for electrical charge separation. For these reasons, one can expect correlations at the outset between total lightning activity and the development of severe weather which may aid in the understanding and prediction of these extreme weather conditions. The exploration of these ideas has historically been impeded by lack of good quantitative observations. A recent review of results on severe storm electrification (Williams, 1998) indicates a general absence of cases for which total lightning activity is documented over the lifetime of a severe storm. The recent development of LISDAD (Lightning Imaging Sensor Data Application Display) (Boldi, et al., 1998) has largely remedied this problem. This paper is concerned with the use of LISDAD to quantify the behavior of total lightning in all types of severe weather, with a focus on a pair of extraordinarily electrified supercells in the Florida dry season.

2. METHODOLOGY

The observational mainstay of this study is the LISDAD system in central Florida. The original intent of LISDAD was a ground-truthing system for optically-detected lightning flashes from space using the Optical Transient Detector and the Lightning Imaging Sensor. The flurry of severe weather in Florida in the spring and summer of 1997 soon made clear LISDAD's effectiveness as a tool to study severe thunderstorms (Weber, et al., 1998).

The development and operation of the LISDAD system is described in a companion paper by Boldi, et al., 1998). LISDAD offers substantial improvements over the traditional short term field experiment in the investigation of thunderstorms. The real-time round-the-clock operation virtually guarantees the capture of all interesting events. Furthermore, the direct exposure and use by operational NWS forecasters provides insights about systematic features of the observations as they occur. Finally, the different data sets which were rather laboriously assembled in the traditional field experiment after the fact are now available for integrated replay and inspection immediately following the events of interest.

The emphasis on total lightning as a diagnostic for severe weather in all the LISDAD results at this conference gives the LDAR radiation data special importance (Lennon and Maier, 1991). The viability of LDAR for accurately detecting and mapping both intracloud and cloud-to-ground lightning flashes has been verified through more than 25 years of operation at the NASA Kennedy Space Center (KSC). Its successful use during the TRIP (Thunderstorm Research International Program) in the 1970's (Lhermitte and Krehbiel, 1979; Lhermitte and Williams, 1985) demonstrated 50-100 meter rms errors in source locations for storms directly over KSC based on observations from two independent arrays of radio receivers. More recent studies in Orlando with the ONERA (Office National d'Etudes and de Recherches Aerospatiale) 3D lightning interferometer (Mazur, et al., 1997) demonstrate reliable detection of lightning at a range of 50 km, though with an attendant degradation of location accuracy. Some LDAR radiation is detected from storms on Florida's west coast at distances from KSC exceeding 200 km. For the rapidly migrating mesocyclones of interest in this study, analysis to distances up to about 100 km from KSC will be considered.

The LDAR data stream currently ingested by LISDAD consists of individual radio source locations (x,y,z,t) which have been independently verified by the two independent arrays of receivers at KSC. The data stream is used to create an LDAR flash rate, a measure of the total flash rate for individual thunderstorm cells. The details of the source-to-flash algorithm are found in Boldi, et al., 1998.

For more detailed analysis of supercell vertical structure beyond the real-time processing capability of LISDAD, the original Melbourne Doppler radar data have been analyzed after the fact. This includes the hand-extraction of maximum reflectivity and mesocylonic velocity on a tilt-by-tilt basis.

All truth on severe weather otherwise documented with LISDAD remote sensing is based on surface observer reports. This aspect of the study is judged to be the least quantitative and most susceptible to sampling limitations.

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3. GENERAL RESULTS

Althought the focus of this study is on the Florida dry season results in which supercell tornadoes are most prevalent, it is useful to begin with some more general results from LISDAD that pertain to ordinary (nonsevere) thunderstorms and to the broader spectrum of severe weather in all seasons. The use of the same rules to compute total flash rates in all storms regardless of their size and severity helps to place the results for extreme instability and shear in context.

The pop-up box feature in LISDAD (Boldi, et al., 1998) has been used to study the lightning histories of numerous Florida thunderstorms of all types. Severe thunderstorms have been identified on the basis of surface observer reports of hail (dime size or greater), strong wind (trees blown down), or the occurrence of a tornado. Figure 1 summarizes the peak flash rates (LDAR for total lightning) for all cases. The most likely maximum flash rate, associated with small thunderstorms in great abundance, is in the range of 1-10 per minute.

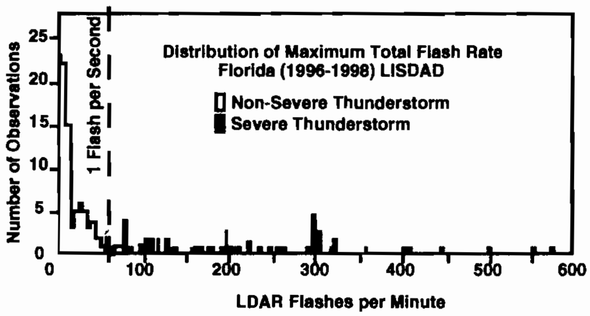

Figure 1. Peak flash rates for FL thunderstorms.

A vertical dashed line is indicated at a flash rate of 60 fpm (1 flash per second). To a large extent, the storms are organized into nonsevere and severe categories on the basis of peak flash rate alone (with one important caveat to be discussed presently). No severe cases were found with a peak flash rate less than 60 fpm. For higher flash rates, the majority of cases were identified as severe. However, numerous cases with high flash rates (one as high as 500 fpm) were found with no confirmation of severe conditions. Some of these high flash rate cases occurred over sparsely populated areas where hail (for example) may have been missed. A few cases of high flash rate storms over heavily populated areas suggest that severe storm status was not attained.

The most extreme LDAR flash rates observed are in the vicinity of 500-600 fpm. The two dry season supercells discussed in Section 4 both lie in this tail of the flash rate distribution in Figure 1.

The fraction of thunderstorms found to be severe in Figure 1 is surely larger than one might find climatologically in Florida. This disproportionality is the result of the emphasis given to severe weather cases when a systematic behavior in the flash rate evolution became apparent in the early LISDAD observations.

The most obvious and systematic characteristic of severe thunderstorms is the rapid increase in intracloud flash rate 1-15 minutes in advance of the severe weather manifestation at the ground. These increases, termed lightning 'jumps,' vary in magnitude from about 20 to over 100 fpm per minute. Specific examples of jumps in supercell thunderstorms are illustrated in Section 4. The existence of lightning jumps is perhaps the most obvious departure from steady state behavior for the severe thunderstorms studied. The noted association between enhanced electrification and the growth of ice particles aloft in the mixed phase environment would suggest that the jumps are an accompaniment of strong upsurges in air motion aloft. Figure 2 shows the magnitude of the lightning jump versus the maximum hailstone diameter reported on the ground for all hail cases observed so far with LISDAD. The positive correlation here supports a physical connection with stronger electrification associated with stronger upsurges and larger hail. The precursory nature of the lightning jump appears to pertain not just to hail but to all severe weather, including strong wind and tornadoes.

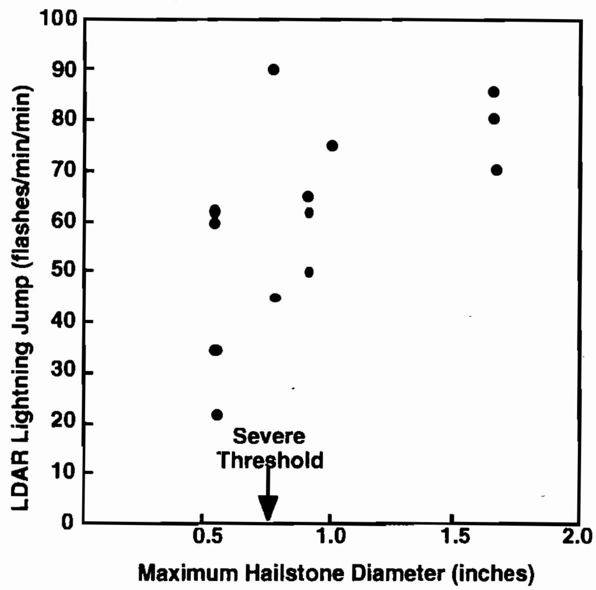

Figure 2. Lightning jump vs maximum hailstone size.

4. SUPERCELL COMPARISON

Improved Doppler radar observations (Burgess, et al., 1993) have led to the realization that the majority of supercell mesocyclones do not evolve to tornadoes. A challenging issue both scientifically and operationally is the identification of physical conditions which make the difference. With this challenge in mind, two electrically extreme supercell mesocyclones in the Florida dry season were selected from the LISDAD archive to compare–one on Oct 31, 1997 (for which wind damage was reported but no tornado) and another on Feb 23, 1998 (that made an F3 tornado). Selected parameters for comparisons of these two cases are shown in Table 1. The numbers are generally quite similar, thereby emphasizing the subtlety of the distinction. For example, the peak LDAR flash rates agree to within 5 percent, and are both extraordinarily high. It is possible that the use of the same (nonsevere) storm rules leads to an overcounting of flashes. Both estimates are less than the value for stroke rate estimated by Vonnegut and Moore (1958) for the Worcester, MA tornadic storm (600-1200 strokes/minute).

Table 1. Comparison of Selected Parameters for Two Florida Supercells

Parameter	31 Oct 97	23 Feb 98
Pseudoadiabatic CAPE	1540 j/kg	2140 j/kg
tropopause height	12.9 km	12.7 km
melting level height	4.0km	3.8 km
maximum LDAR flash rate	554 fpm	567 fpm
maximum NLDN flash rate	14 fpm	17 fpm
lightning 'jump'	60 fpm/min	160 fpm/min
maximum IC/CG ratio	~230	~200
maximum radar cloud top	16-17 km	17-18 km
tropopause overshoot	3-4 km	4-5 km
inferred max. updraft speed	60-80 m/s	80-100 m/s
diameter of 30 dBZ core at 7 km	22 km	30 km
mesocyclone max. rotational velocity	19 m/s	28 m/s
typical midlevel meso. diameter	5-9 km	5-8 km
translational speed	50-80 km/hr	90-100 km/hr
hail (?)	no hail reported	3/4"hail
tornado (?)	no (wind damage only)	yes (F3)

Histories of radar reflectivity and mesocyclonic rotational velocity in time-height format, together with the lightning (LDAR and NLDN ground flashes) evolutions for the two cases side-by-side are shown in Figure 3. The storm intervals containing the largest lightning jump, maximum flash rate, and most intense vertical development are included in both cases, and the overall storm tracks are also shown. Neither storm was sufficiently close to the Melbourne radar to enable observation of concentrated low level vorticity (i.e., the tornado). These time-height comparisons reveal more about the differences between the two cases than the parameter comparisons in Table 1.

In comparison with ordinary airmass thunderstorms (Lhermitte and Krehbiel, 1979; Lhermitte and Williams, 1985; Goodman, et al., 1988; Williams, et al., 1989) these supercells are far closer to a dynamical steady state in their vertical development. And yet the observations show in both cases that the unsteady features are of central importance in signaling severe conditions on the ground. The total lightning is perhaps the least steady feature of supercell evolution, with substantial lightning jumps (in the LDAR flash rate) coinciding with explosive vertical development (2020-2040 UT on Oct 31 and 0305-0320 UT on Feb 23) that are once again precursory to severe weather (at 2045 UT on Oct 31 and at 0355 UT on Feb 23). The upward growth at mid-levels (and in particular in the mixed phase region where the strongest charge separation is expected) clearly coincides with the enhancement in mid-level rotation, presumably by stretching of vertical vorticity in the updraft at mid- and upper levels. In both cases the maximum in rotational velocity aloft is sustained to the time of maximim LDAR flash rate (2045 UT on Oct 31 and 0324 UT on Feb 23). Unlike the behavior of many nonsevere thunderstorms (Byers and Braham, 1949; Williams, 1985), the peak flash rate does not coincide with the maximum radar cloud top height. Agreement is better between the vertical extent of radar reflectivity in the mixed phase region at lower levels, consistent with the idea that supercooled water is a fundamental ingredient in the electrification process. In both cases, an abrupt drop in total flash rate occurs, suggesting a reduction in updraft strength, with an attendant reduction in rotational velocity. Severe wind is reported at the surface for the Oct 31 case, but no severe report was logged for Feb 23 at this time.

Shortly thereafter, in both cases, a secondary maximum in rotational velocity is observed (2057 UT on Oct 31 and 0337 UT on Feb 23) associated with the most strongly descending reflectivity contours (and declining reflectivity within the respective mesocyclonic cores), indicative of possible restretching of the vorticity, but this time by a downdraft rather than an updraft.

At this juncture, the behavior of the two cases diverges. The flash rate for Oct 31 rebuilds after its short term decline, whereas the flash rate for Feb 23, which has dropped to a lower relative level, does not rebuild. The midlevel reflectivity for Oct 31 is sustained whereas for Feb 23, midlevel reflectivity contours continue the descent that began near the time of cloud top apogee (0310 UT). An F3 tornado is first observed at 0355 UT (with a notable diminishment of rotational velocity aloft) in the latter case, but no further severe weather is observed in the time frame shown for the Oct 31 supercell.

The lightning discussion has thus far centered on the LDAR information on account of the demonstrated connection with storm vertical development. The sustained lightning jumps which stand out clearly in the LDAR history are hardly present in the NLDN ground flash history, and the general level of activity is less than the inferred intracloud development, often by more than tenfold. These findings corroborate earlier results on the limitations of CG information in diagnosing severe weather (Perez, et al., 1997; Williams, 1998).

Some tendency is noted for supressed ground flash activity at times of elevated intracloud activity (2040 UT on Oct 31 and 0330 UT on Feb 23), suggesting a competition between lightning types for a shared reservoir of charge (Williams, 1998).

5. CONCLUSIONS

The LISDAD system has revealed a remarkably consistent pattern of total lightning behavior for severe Florida thunderstorms, with strong upsurges prior to severe weather in all categories (wind, hail and tornadoes) in both the wet and the dry seasons as shown by this and other papers (Goodman, et al., 1998; Hodanish, et al., 1998).

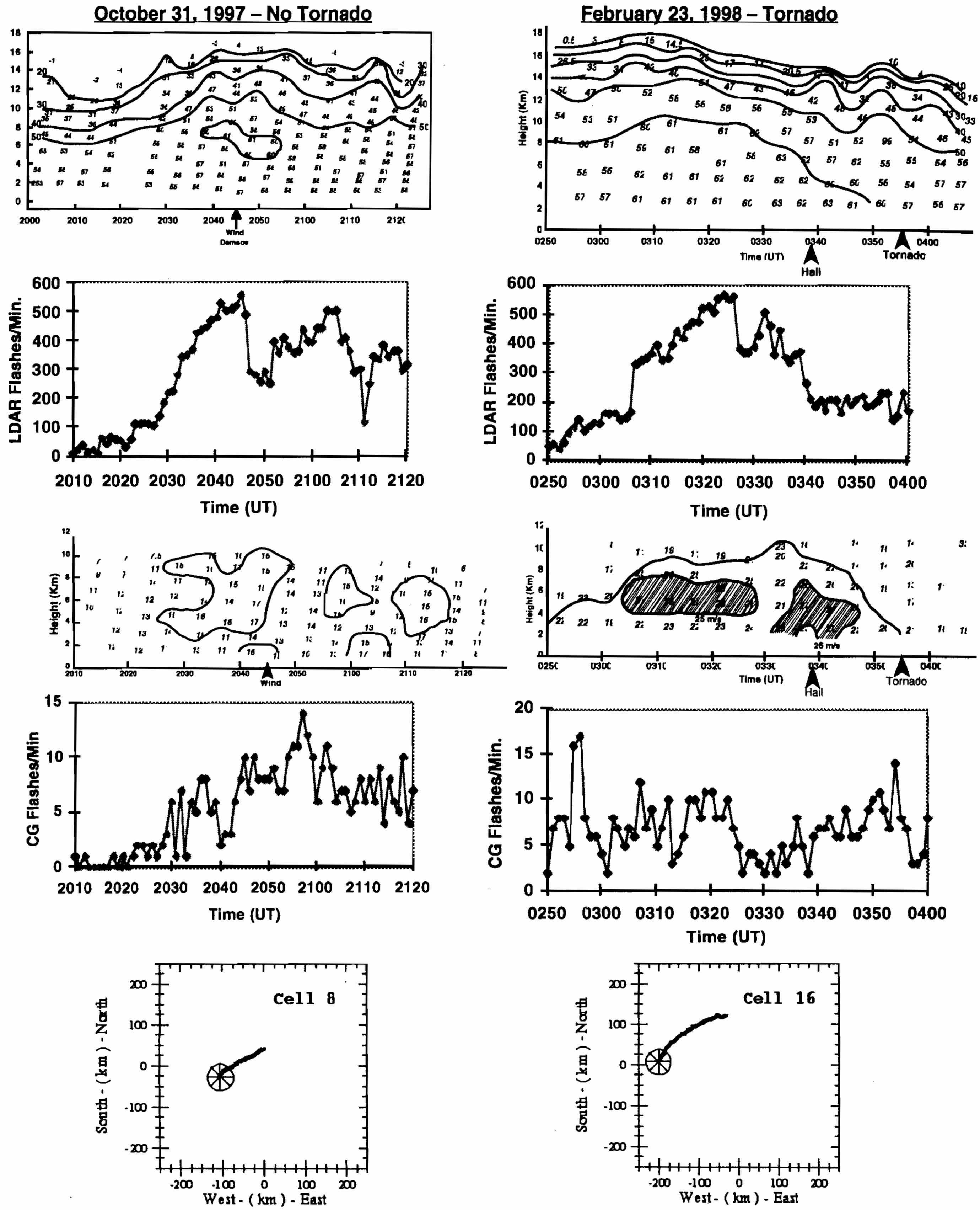

Figure 3. History of (a) maximum radar reflectivity (dBZ); (b) total lightning flash rate (LDAR); (c) maximum mesocyclonic rotational velocity (m/s); and (d) NLDN ground flash rate for October 31 and February 23 supercells. The storm tracks are shown on the maps at the bottom.

The supercell comparison has disclosed deep reservoirs of vertical mesocyclonic angular momentum (to 10 km altitude) with indications of vortex stretching by both updrafts initially and by downdrafts at later stages. These cases and additional tornado/waterspout cases considered by Goodman, et al. (1998) and Hodanish, et al.. (1998) are consistent in showing that pronounced departures in dynamical steady state are needed for tornadogenesis. In particular, a slumping of the cloud and attendant diminishment in total flash rate after the initial lightning jump appear to be related to the concentration of vorticity near the surface. Continued examination of Florida null cases (i.e., mesocyclones without tornadoes) with the LISDAD are needed for further clarification of mechanisms.

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