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10.1 THE 29 JULY 1994 MERRITT ISLAND, FL MICROBURST: A CASE STUDY INTERCOMPARING KENNEDY SPACE CENTER THREE-DIMENSIONAL LIGHTNING DATA (LDAR) AND WSR-88D RADAR DATA

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I. Introduction

Many researchers have shown that the development and evolution of electrical discharges within convective clouds is fundamentally related to the growth and dynamics of precipitation particles aloft. In the presence of strong updrafts above the freezing level, collisions among mixed-phase particles (i.e., hail, ice, supercooled water) promote the necessary charge separation needed to initiate intra-cloud lightning (Saunders 1993). A precipitation core that descends below the freezing level is often accompanied by a change in the electrical structure of the cloud. Consequently, more cloud-to-ground (CG) than intra-cloud (IC) lightning flashes appear (Williams et al., 1989).

Descending precipitation cores can also play a significant role in the evolution of mesoscale features at the surface (e.g. microbursts, downbursts) because of latent heat and mass loading effects of water and ice (Fujita 1985). For this reason, some believe that lightning and microbursts are fundamentally linked by the presence of ice particles in thunderstorms (Williams et al. 1989). Several radar and lightning studies of microburst thunderstorms from COHMEX in 1986 (Williams et al. 1987) showed that the peak IC lightning systematically occurred ten minutes before the onset of a microburst. In contrast, most CG lightning occurred at the time of the microburst.

Many of the preceding studies have been done using high-resolution research radars and experimental lightning detection systems in focused field projects. In addition, these studies could only determine the vertical origin or occurrence of IC lightning, and not a true three-dimensional representation.

Currently, the WSR-88D radar system and a real-time, state-of-the-art lightning system (LDAR) at the Kennedy Space Center (KSC) in Florida provide an opportunity to extend these kinds of studies in a more meaningful operational setting. Because the lightning detection system at KSC is three-dimensional, additional insight can be gained into the spatial development and evolution of IC lightning relating to radar reflectivities and precipitation in thunderstorms. This paper represents the first time that 3-d lightning data has been directly intercompared with WSR-88D data for a severe, microburst producing storm. This storm occurred near KSC during the summer of 1994. Section 2 of the paper describes in more detail the nature of the lightning and radar data used for this case. Section 3 presents the temporal and spatial evolution of reflectivity and lightning patterns within the microburst storm. A brief overview of the microburst damage is also presented in Section 3. The paper concludes in Section 4 with a discussion of the case and what it potentially means in the context of developing future lightning and microburst forecast rules.

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2. Data description and methodology

The IC lightning discharges were detected using the Lightning Detection and Ranging (LDAR) system (Lennon and Maier, 1991) at the Kennedy Space Center (KSC) in east-Central Florida. The LDAR system detects lightning-induced electromagnetic disturbances at 66 MHz frequency using a time of arrival (TOA) approach with seven separate receiving antennae. The spatial position of each discharge is determined by converting time offsets at the different antenna to distance differences and then performing a triangulation to a point in three-dimensional space (x,y,z). One individual IC lightning flash may consist of hundreds of unique LDAR point discharges. The LDAR system detects stepped-leader type processes in the cloud. The Lightning Location and Protection (LLP) system identifies the discharges for return strokes. The LLP system detects return strokes in CG lightning by determining the point of intersection of electromagnetic impulses from a network of magnetic direction finders (Krider et al. 1980). The accuracy of the LLP system at KSC is roughly 1 km, while the accuracy of the LDAR system is around 200 m at horizontal ranges of 30 km or less. For the case study presented in this paper, the microburst storm is within the LDAR system's region of high accuracy.

WSR-88D archive Level II data from the Melbourne, FL site is used to intercompare reflectivity data with the lightning data in this case. The resolution of the reflectivity data is 1 km x 1 degree. The WSR-88D archive Level II data is explained in detail in Crum et al (1993). During the time of this case study, the WSR-88D radar was operating in severe weather mode, scanning through 14 elevations every five minutes. The WSR-88D radar is located roughly 50 km south of the lightning detection systems at KSC.

We wrote a sophisticated software package to intercompare horizontal and vertical cross-sections of LDAR, LLP, and WSR-88D data. To numerically integrate the three data sets over time and space, a storm-identification algorithm was written to identify individual thunderstorms from the WSR-88D base reflectivity data. LDAR and LLP events are assigned to a given storm if the events occur within the radius of the radar-defined storm (>30 dBZ). Time series, vertical profiles, and vertical cross-sections of reflectivity and lightning data are examined throughout the life-cycle of the microburst storm.

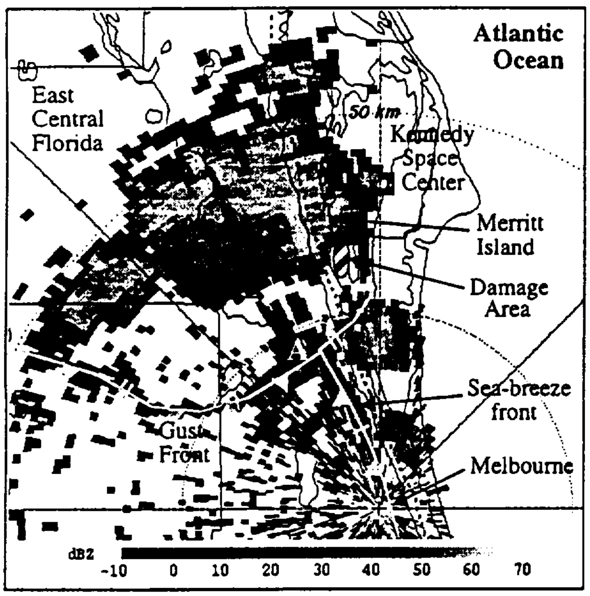

Figure 1. *Analysis domain near Kennedy Space Center, FL. The Melbourne, FL WSR-88D radar is located at "+". Base reflectivity (dBZ) for 1953 UTC on 29 July, 1994 is shown.*

3. 29 July 1994 Merritt Island, FL microburst case

3.1 Overview

At approximately 2030 UTC 29 July 1994, a damaging microburst touched down on Merritt Island (Fig. 1), just to the south-southwest of KSC. In a ground survey conducted by Hoffert and advisor Greg Forbes, a swath of damage was evident from south-southwest to north-northeast, aligned with the movement of the storm. Damage mostly consisted of downed trees, broken signs, toppled, unsupported walls, minor roof damage. The swath of estimated 25 ms^{-1} (50 kts) winds was approximately 2 km wide, with a narrow zone of stronger winds estimated upwards of 35 ms^{-1} (70 kts) in the immediate core. Quarter-dollar sized hail was also reported during the time of the microburst, along with a possible (although unconfirmed) small tornado.

The synoptic environment on 29 July 1994 was anomalous for Florida in that winds aloft were slightly stronger than usual while the temperature and dew point at mid-levels were slightly colder and drier than normal for late July. The primary reason for this was a huge summertime trough (not shown) that was located to the west over the lower Mississippi Valley, which was responsible for spawning severe weather up and down the East Coast of the U.S. in the preceding days. Mesoscale frontal convergence lines were affiliated with the initiation of the cell which produced the microburst (Fig. 1).

3.2 Convective initiation and lightning development

The microburst thunderstorm was initiated along an intersection point of the Florida east-coast sea breeze front and a southward propagating gust front generated by an earlier line of storms moving northward (point "A", Fig 1). The first detectable radar-defined cell occurred during the 1953 UTC volume scan near point 'A', approximately 40 minutes before the onset of the microburst. This developing cell initially contained no lightning. At 2008 UTC, radar reflectivities (> 30 dBZ) grew tall enough to extend above the freezing level where the necessary mixed phase processes could initiate lightning (Fig. 2). The first LDAR discharges occurred at 2008 UTC between 9-10 km AGL. The reflectivities at the 8 km level were approximately 30 dBZ. Forbes and Hoffert (1995) recently found that an approximate reflectivity of 30 dBZ or higher is required at a level of 7-8 km for a summertime Florida cloud to become electrically active. The initial LDAR discharges occurred just above the top of the radar-inferred hail core of 58 dBZ at 5.8 km, in a region where mixed phase processes are likely generating charge separation between the "classic" lower negative (~ -15°C) and upper positive (~ -30°C) charge layers (Saunders, 1993). We have modified the 1500 UTC Cape Canaveral temperature sounding (not shown) in the developing thunderstorm cell to reflect latent heat release (white dashed lines, Fig. 2b). Simple parcel theory was invoked following a parcel having mean mixing ratio in the lowest kilometer, and using the observed surface potential temperature at 2000 UTC. Cloud-ground lightning at this time was infrequent.

3.3 Lightning evolution and microburst initiation

Fig. 3 depicts a time-series evolution of the reflectivity core height and the number of LLP and LDAR events summed over each volume scan. During the mature stage of the thunderstorm, radar reflectivity reached a peak of 68 dBZ at 6.7 km AGL, at 2018 UTC. The LDAR activity was also a maximum at this time, with relatively few LLP events. At 2023 UTC, LDAR and LLP changed significantly as the reflectivity core descended. LDAR has decreased while the number LLP events have more than doubled. Five minutes later, the reflectivity core reached the surface marking the onset of the microburst at 2028 UTC. Coincidentally, LLP activity reached a maximum while the number of LDAR events continued to decrease.

The time evolution of the microburst that struck Merritt Island, FL is further illustrated by three vertical cross-sections in Fig. 4. This microburst occurred near the cone-of-silence of the Melbourne, FL WSR-88D radar. Therefore, a detailed comparison of radar and LDAR at cloud-top is not possible. Nevertheless, changes in radar reflectivity and LDAR took place during this 10 minute period. The main cluster of LDAR activity (Fig. 4a, 9-10 km) separated into two distinct regions (dashed lines, Fig. 4b,c) as the reflectivity core descended. The main area of LDAR activity around 8 km lowered slightly while a second cluster formed aloft at 14 km (Fig. 4b). In addition, strands of IC lightning occurred between the two regions (Fig 4b,c). The lower region indicated IC lightning as well as discharge patterns extending laterally and downward toward the surface indicative of CG flashes (Fig. 4a,c). The upper region showed IC lightning extending laterally and (possibly) upward towards the stratosphere (Fig. 4c).

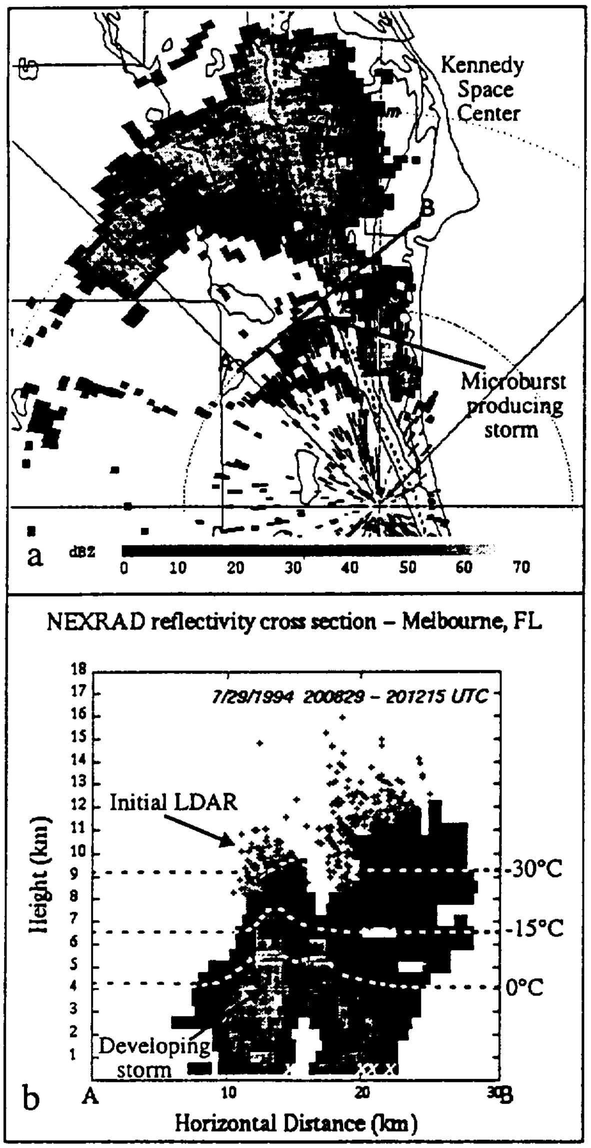

Figure 2. *(a) Base reflectivity image at 0.4° from the WSR-88D at Melbourne, FL, at 2008 UTC, 29 July 1994. A vertical cross section from points A to B is shown in (b), with LDAR points (+) and LLP cloud-to-ground flashes (X's at ground). The reflectivity image is displayed for the period 2008-2012 UTC, while the LLP and LDAR data is valid for the first minute in the scan. Black dashed lines indicate environmental temperature from Cape Canaveral 1500 UTC sounding; white dashed lines are estimated in-cloud temperature from latent heat release. Values in both images are >10 dBZ. The radar scan sequence did not go high enough to reach storm top.*

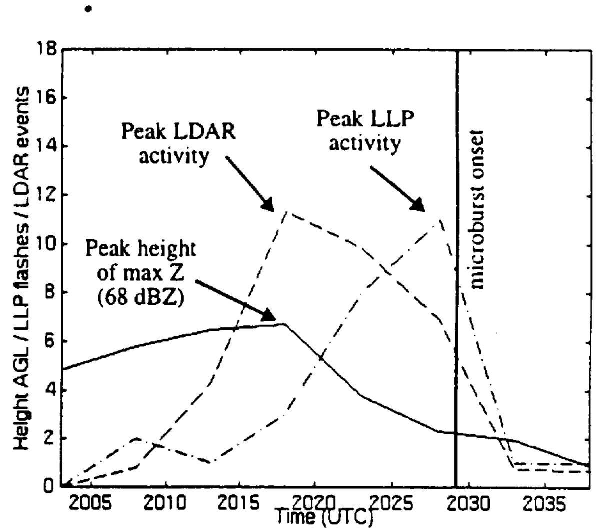

Figure 3. *Time series of height of maximum reflectivity (Z) in km (solid curve), number of LDAR events (in 1000's, dashed curve), and number of LLP events (dash-dot curve). LDAR and LLP events are summed over the time of one volume scan and the volume encompassed by storm reflectivities greater than 30 dBZ.*

4. Discussion and Conclusions

The microburst case at Merritt Island, FL has some very interesting elements. During early storm development, most of the LDAR activity, which occurs between the positions of the "classic" positive and negative charge centers, is limited to the region above the radar reflectivity core. The differing regions of LDAR activity during storm collapse could be attributed to changes in the structure of the thunderstorm cell (i.e., anvil growth, formation of a strong downdraft). The upper region reflects an increase in quasi-horizontal anvil lightning. Storm debris and associated charge spreads laterally aloft. The main lower region of LDAR is still associated with vertical IC lightning, but also with an increase in CG lightning during the development of the storm downdraft.

The peak IC lightning occurred at the time of maximum reflectivity aloft, while the peak in CG lightning lagged both of these by 10 minutes. Clarence and Malan (1957) and Williams et al. (1989) suggest that a lower positive charge center develops underneath the main negative region as the hail core descends. The additional positive charge below the freezing level helps initiate more frequent CG lightning. This theory implies that a lag must exist between peak CG lightning and elevated reflectivity cores. In our case, the rapid increase in LLP events after the descent of the reflectivity core supports this theory. The microburst lag is also expected from a dynamic standpoint because it is driven by the collapse of the hail core. Consequently, the microburst also lagged the peak

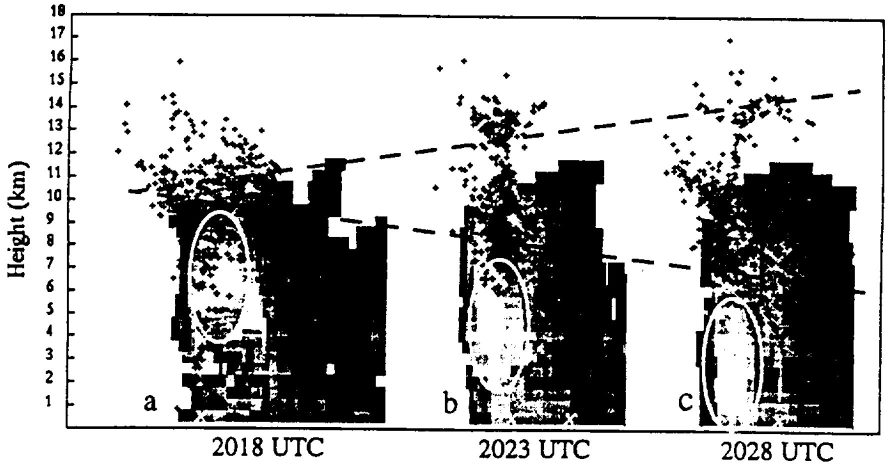

Figure 4. *Same as 2b, except a time series showing the evolution of the wet microburst. The white oval represents the maximum reflectivity core. The dashed lines represent the trend of distinct areas of clustered LDAR activity.*

LDAR and reflectivity aloft by 10 minutes.

The goal of this paper was to describe the evolution of a microburst-producing thunderstorm by integrating some unique, real-time datasets (i.e., IC/CG lightning, WSR-88D Doppler radar). Studies in the past have shown some potential for using IC lightning data as a short-term predictor of microbursts (Lhermitte and Williams, 1984; Fujita and Black, 1988; Goodman et al., 1988; Williams et. al, 1989). In our case, a well-defined peak in IC lightning prior to the microburst is consistent with these studies. However, this may not be unique to all microburst-producing thunderstorms.

While the sequence of events involving LDAR, radar reflectivity core and microburst was well-defined in this case, that does not necessarily mean that the problem of forecasting microbursts has been solved. One note of caution is that not all microbursts are associated with hail, high reflectivity aloft, or even precipitation reaching the surface (Fujita, 1985). Furthermore, we have examined *many* vigorous Florida thunderstorms which undergo a similar sequence of LDAR evolution without producing any reported microbursts. It seems likely that any operational forecasting scheme for predicting microbursts using these observational tools will need to be based on *subtle* variations between microburst and non-microburst thunderstorms. Therefore, additional studies comparing microburst and non-microburst producing storms using LDAR and Doppler radar data will be needed in order to possibly develop a general set of microburst forecasting rules.

5. Acknowledgments

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