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AIRBORNE OBSERVATIONS OF MICROPHYSICS AND ELECTRIC FIELDS IN ANVILS OF FLORIDA THUNDERSTORMS

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1. INTRODUCTION

Numerous studies have been conducted to examine the microphysical conditions that are present in convective clouds when charge separation is occurring and electric fields are intensifying. There also have been some studies that use multi-parameter radar to examine particle types in relationship to lightning frequency and storm type. But few studies have been conducted to examine the changes in microphysics when electric fields are decaying after lightning has ceased. At NASA Kennedy Space Center (KSC) Florida triggered lightning is a significant hazard to the launch of the shuttle and other space vehicles. In the case of anvils, an important question is: "How much time must elapse after the last lightning before a vehicle can be launched safely through different locations in an anvil." During June 2000 and 2001 the Airborne Field Mill (ABFM) project was conducted at KSC to investigate the relationships in anvils between microphysics, radar reflectivity and the decay of electric fields spatially and temporally. In-situ observations of electric field, particle concentrations, types and sizes and standard thermodynamic and flight measurements were made from the Citation II jet aircraft of the Univ. of North Dakota. The aircraft measurements were coordinated with radar measurements from the Patrick Air Force Base WSR74C, 5 cm, radar and the Melbourne, Florida NEXRAD, 10 cm radar. Measurements of total lightning (IC and CG) were made using the KSC Lightning Detection and Ranging (LDAR) and the Cloud to Ground Lightning Sensing systems. In this paper we present an example of observations for one anvil case and some results from the project.

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2. THE ANVIL OF JUNE 4, 2001

The storm of June 4, 2001, one of our best anvil cases, first formed NE of Lake Okechobee around 1900 with first anvil formation around 1915. The anvil tip moved towards 110 degrees at about 18 m/s. The Citation investigated this anvil for over 3 hours, first with a NS pass very near the storm core at 2010. An example of measurements for one E to W pass almost 2 hrs after anvil formation is shown in Fig. 1. In this figure the eastern edge of this anvil is roughly 150 km from the convective core and the Citation is 100 to 125 km downwind of the core. Lightning was still occurring in the core and sporadically extended out as much as 75 km into the anvil.

The radar structure shown in Fig. 1 is the curtain of reflectivity along the Citation track. Until ~2108 the aircraft was flying north across the eastern part of the anvil but after 2108 was heading ~290 degrees along the center of the anvil at a temperature of –36C. From 2108 to 2116 there is a gradual increase of particle concentration in all size ranges, but the increase is slightly larger for the smaller particles. The electric field is weak (<2 kV/m) until after 2110 but rapidly increases to >10 kV/m by 2111 with lots of variability. Note that the abrupt increase in electric field occurs as the aircraft flies into reflectivities of 10 to 15 dBZ. We often, but not always, found that electric field rapidly increased when the aircraft entered reflectivities ~>10 dBZ.

The microphysical observations were made with the PMS FSSP, 1D-C, 2D-C and the SPEC Cloud Particle Imager and High Volume Particle Spectrometer, thus spanning particle sizes from a few microns to about five centimeters, i.e. frozen cloud droplets to very large aggregates. A Rosemont icing detector showed no evidence of supercooled water in any of the anvils investigated. All particles discussed herein are ice. The 3-dimensional vector electric fields were measured using a set of 6 field mills as described in Mach and Koshak, 2003 and had a range from <0.1 to >100 kV/m.

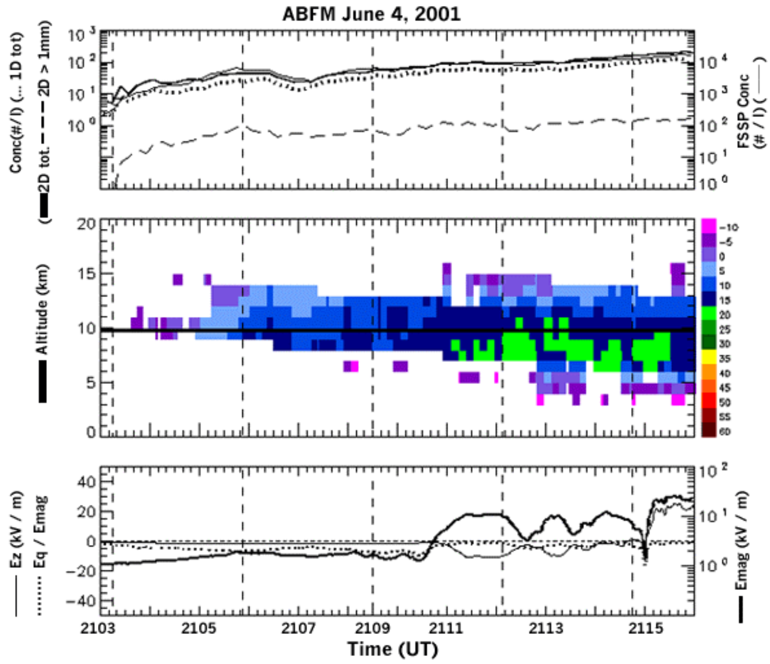

Figure 1.

Top Panel: Time history of Particle concentrations:
FSSP: light, solid line = total conc. On right
2D-C: bold line = total conc., dashed line = conc. >1 mm on left
1D-C: dotted line = total conc. on left

Middle Panel: Radar reflectivity curtain above and below the aircraft from WSR74C radar at Patrick AFB FL, bold line = aircraft altitude

Bottom Panel: Vertical electric field, Ez, light line on left, linear scale, and the resultant vector field, Emag, bold line on right, log scale.

The measurements in this and other anvils show that when electric fields are strong (> 10 kV/m) the concentration of particles in all sizes is significantly greater than when electric fields are weak (< 1 kV/m). In regions with strong electric fields the microphysical observations showed a surprising consistency of concentrations of all sizes from one storm to another. As the aircraft flew from downwind edges of anvils towards the convective cores, concentrations in all size ranges gradually increased. Normally, the electric fields increased more abruptly and showed much greater variability.

Figure 2 shows number and particle area size distributions for 4 separate 30 s averages along the flight track. The first three are for selected times from Figure 1 to illustrate changes in distribution as the aircraft flies towards the storm core. Images from the CPI show the smaller particles to be frozen cloud droplets, particles from ~0.1 to roughly 0.4mm were mostly irregular or small aggregates, but those larger than ~0.4 mm and the larger ones are aggregates some of which were nearly 1 cm. We want to emphasize that even at this eastern extent of the anvil ~125 km downwind of the core there are aggregates >1 mm size. Either the aggregates have not fallen out, or more likely, aggregation is continuing to occur. Given the strength of the electric fields in some parts of this anvil, it is probable that they enhanced aggregation. There was normally little evidence of riming except close to the convective cores.

3. **THE ROLE OF MICROPHYSICS IN THE DECAY OF THE ELECTRIC FIELD IN ANVILS**

An estimate of the decay of electric field with time has been calculated using a simple model (Willett and Dye, 2003). The mechanism for field decay in the model is that ions produced by incoming cosmic rays attach to cloud hydrometeors by electrical drift and diffusion, thereby decreasing the bulk conductivity inside the cloud. Bulk current flow to the surfaces of the anvil reduces the charge contained in its interior. The model assumes no turbulent mixing, no sedimentation of particles and the absence of active charge separation in the anvil. The model calculates electric-field decay times based on observed particle size distributions and assumes that a given size distribution is uniform and constant everywhere in the model anvil during the decay of electric field. The assumptions provide lower bounds on the rate of decay of electric field and upper bounds on the time to decay. A "high-field limit" is identified, for ambient field intensities greater than about 1 kV/m, in which the model field decays linearly with time; and a decay time scale, τ_E, is defined as the time required for the cloud field to decay to zero from an arbitrary initial value of 50 kV/m. τ_E is found to be proportional to the particle effective electrical cross section (area), integrated over the size distribution. See Willett and Dye for more details.

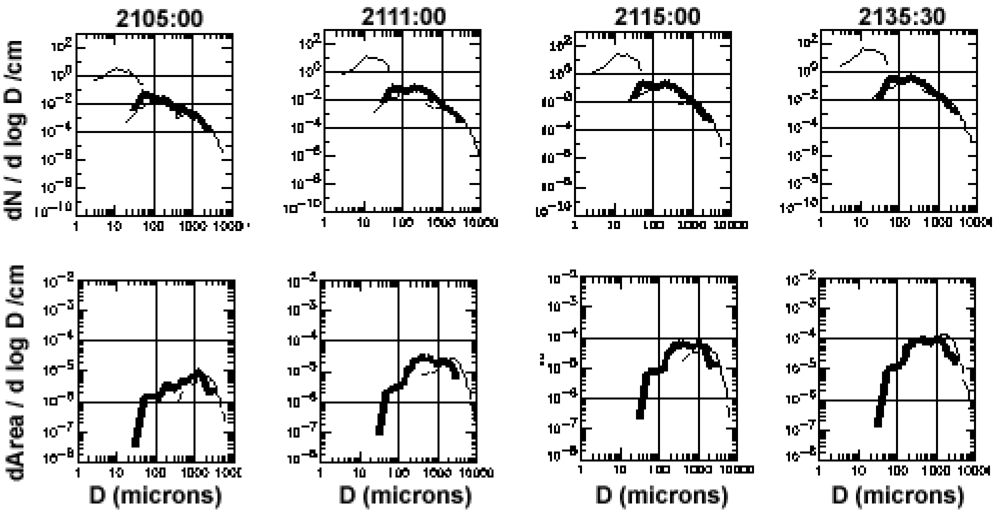

Figure 2. Top: Number size distributions (30 sec averages) for times as indicated. Bottom: Particle area size distribution for the same periods. Light line on the left of each plot -- FSSP (off scale for area); Bold line – 2D-C; light line on right -- SPEC High Volume Particle Spectrometer.

Particle area distributions in Figure 2 show a peak near 1 mm in the edge of the anvil, but as the aircraft moves more centrally into the anvil, the area distributions have a broad mode from 0.2 to 2 mm and show the dramatic increase of almost two orders of magnitude in integrated area. This dramatic change in area from 0.2 to 2 mm was found for all anvils that contained strong fields. The observations coupled with model results show that this part of the size distribution largely controls the rate of field decay in these anvils. τ_E for the first 3 time periods of Figure 2 is 351, 2105, 3037 s, respectively. τ_E increases by a factor of 10 from the edge to the central part of the anvil. Thus on the edge of the anvil the decay of electric field is very rapid (<10 min) while in regions with greater concentrations, particularly in the range of 0.2 – 2mm the decay will be much, much slower.

4. **SECONDARY DEVELOPMENT OF A STRATIFORM-LIKE AREA**

During the first 1 ½ hr of the growth of this anvil, it had the structure of a classic anvil with blow-off and translation down wind of material ejected from the core of the storm. But beginning around 2045 an area of reflectivity >20 dBZ began to appear, particularly at 7 - 8 km. This was not sedimentation alone because a N-S penetration at 2040 to 2045 in the same drifted locale as Fig. 1 shows reflectivity at all altitudes to be <20 dBZ. The radar curtain in Fig. 1 is during the early stage of this "secondary development". By 2130 the area of reflectivity >20 dBZ at 7 km had grown considerably both horizontally and somewhat vertically. Fig. 3 shows the vertical curtain of reflectivity, particle and electric field measurements along the Citation track for 2130 to 2140 in this secondary development.

This pass, just as that in Fig. 1, was toward the WNW and along the main axis of the anvil. Compared to Fig. 1. the increase in reflectivity is readily apparent as is the relatively uniform structure. Similarly, the particle concentrations were relatively uniform and the electric field was uncharacteristically uniform, unlike those in Fig. 1, with strong electric fields of 25 to 30 kV/m. At the 120 m/s flight speed of the Citation this is a distance of ~70 km. At its largest extent near ~2200 this feature had a length of 50 to 75 km and was 40 to 50 km across. Even though the vertical structure such as that in Fig. 3 looks like an anvil, this anvil has evolved into a stratiform-like area. This stratiform area persisted until at least ~2245. By this time it was at the limit of the radar range.

Between 2045 to 2200 reflectivity has grown in area and magnitude. Electric fields have

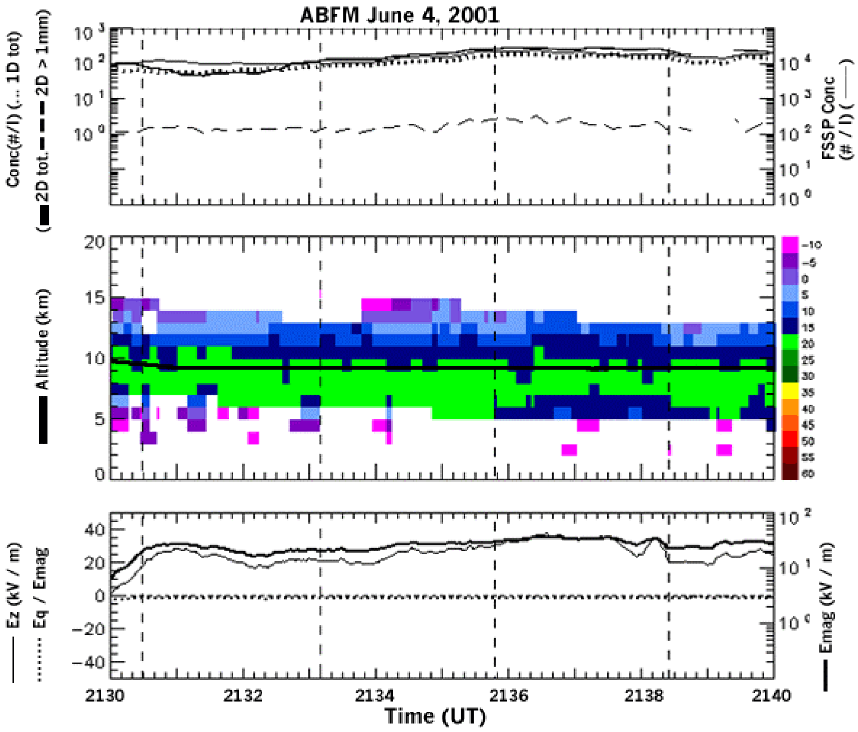

Fig 3. As in Figure 1 except for time period 2130 to 2140

maintained themselves and grown in area and uniformity. Similarly particle concentrations and sizes of the largest particles have grown (Fig. 2, 2115 compared to 2135:30). The cross sectional area size distribution has also increased causing the electrical decay time, τ_E, to increase from 3037 to 5662 s (46 to 94 min) between 2115 and 2135:30.

There were probably several reasons for this development. First, the base of the anvil started to drop below the melting level near 2100. Charge separation in melting zones has been well documented by others (Shephard et al., 1996). Electric fields grew strong enough to enhance the aggregation process, leading to larger particles and reflectivity. But if reflectivity growth was due to aggregation alone we would expect a decrease in the concentration of the small and intermediate particles. But Fig. 2 clearly shows increases rather than decreases in this range. The area of this anvil and secondary development was ~100 km east of the coast and probably over the gulf stream, a source of moisture and warmer temperatures, possibly inducing additional dynamical circulation. This seems to be fairly common off the coast east of KSC, and warrants further investigation. We observed at least 3 cases for which stratiform-like development occurred from an anvil.

ACKNOWLEDGEMENT

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REFERENCES

Dye, J.E. et al., 2003: The Decay of Electric Field in Anvils: Observations and Comparison with Model Calculations, Proc. Internat. Conf. on Atmospheric Electricity, Versailles, France, June 2003.

Mach, D. M. and W. J. Koshak, 2003: General Matrix Inversion Technique For The Calibration Of Electric Field Sensor Arrays On Aircraft Platforms, Proc. Internat. Conf. on Atmospheric Electricity, Versailles, France, June 2003.

Willett, J.C. and J.E. Dye, 2003: A Simple Model to Estimate Electrical Decay Times in Anvil Clouds, Proc. Internat. Conf. on Atmospheric Electricity, Versailles, France, June 2003.

Shephard et al., 1996: Electric Fields and Charges near 0C in Stratiform Clouds, Month. Weath. Rev., **124**, 919-938.