THE MICROPHYSICAL AND ELECTRICAL STRUCTURE OF CONVECTIVE ANVILS

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1. INTRODUCTION

The airborne field mill project (ABFM) was carried out over central Florida during the early summers of 2000 and 2001 with an overall objective of improving, and quantifying, the basis for triggered lightning safety rules for spacecraft launches from Cape Kennedy. Numerous convective anvils were sampled with the University of North Dakota Citation aircraft. Detailed electric field measurements and rather complete concomitant cloud and hydrometeor microphysical measurements were obtained from the single airborne platform. Most of the sampling was done at anvil levels, nominally 10 km altitude and -35 deg C. The aim was to document the conditions as the fields decayed in anvils. But, in many cases the sampling was done as the anvils were being fed by flux of hydrometeors from active convective cells and updrafts. In this study we examine the microphysics in the vicinity of locations where the fields change significantly, but perhaps more generally, these measurements serve to characterize the microphysical characteristics of Florida convective anvil clouds. In this brief summary we use one case to illustrate the typical cloud microphysics.

2. CONCEPTUAL CONVECTIVE ANVIL MODEL

A conceptual model of the morphology of these convective anvils can provide a framework for interpretation of the myriad of complex varied observations. The framework outlined here is very preliminary. Anvils over East Central Florida typically are the result of convective cells (updrafts) initiated on the sea breeze front. At stochastically favored locations these smaller cells organize into a significant cloud system with strong updrafts (20 – 40 m/s). These updrafts shed non-buoyant elements and then detrain at their level of zero buoyancy, which is often near the tropopause. The divergence as the updrafts detrain, will build the anvil slightly upwind, but transport the bulk of the volume down the environmental flow, sometimes accelerated slightly. Some of the updraft flux is also incorporated into developing downdrafts. These cloud systems typically are multi-cellular, with new updraft cells developing on the upshear side of the cloud system. Decaying cells move mostly downshear, and develop into stratiform precipitation cloud regions, characterized by bright band and a melting layer, and rain extending to, or near, the surface. The cloud system evolves towards varying degrees of mesoscale organization, and these mesocale circulations may then control the movement of decaying cells, the anvil transport, and the location of new growth. In the convective cells below the 0 C isotherm, warm rain processes play an active role, and in fact influence the ice development at higher levels in the cloud. The bulk of the microphysical charge separation probably occurs in the active convective elements (updrafts). The subsequent spatial separation of charge, i.e. the evolution of charge centers, is driven by the differing cloud particle and hydrometeor trajectories. The trajectories of graupel remain in close proximity to the active convective cells, and fairly large, but less dense ice hydrometeors are lofted into the anvils. The observed anvils are characterized by a very broad range of particle sizes, including particles of quite large dimension, but of fairly low density and terminal velocities. These large hydrometeors coexist with high concentrations of small near spherical frozen cloud droplets.

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The case of 13 June 2000 illustrates the aspects of the conceptual model, as well as the microphysical characteristics of the anvil clouds. The sounding taken at the Cape (XMR) at 2200 UTC. , and the shows environmental flow at anvil levels is from the SW, and upshear is to the S thru West. A series of high resolution visible satellite images clearly illustrate the system, but only one at 2115 UTC can be shown here (Fig. 1). The Melbourne WSR-88D Cappi's for 4km, 7 km and 10 km show that CG lightning is occurring in the main convective cell to the SSW of the flight track, that the anvil is building to the NE. New cells are developing to the SW, W, and NW of the primary cell, and the system has not yet built a stratiform precipitation area.

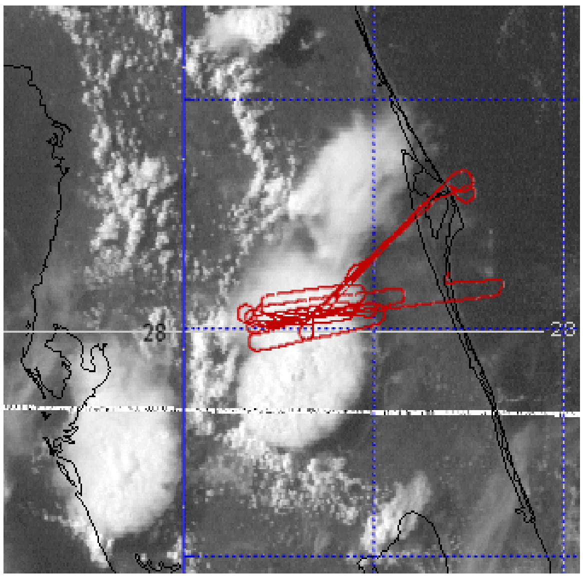

Fig. 1 Visible image and flight track 61300 2115 UTC

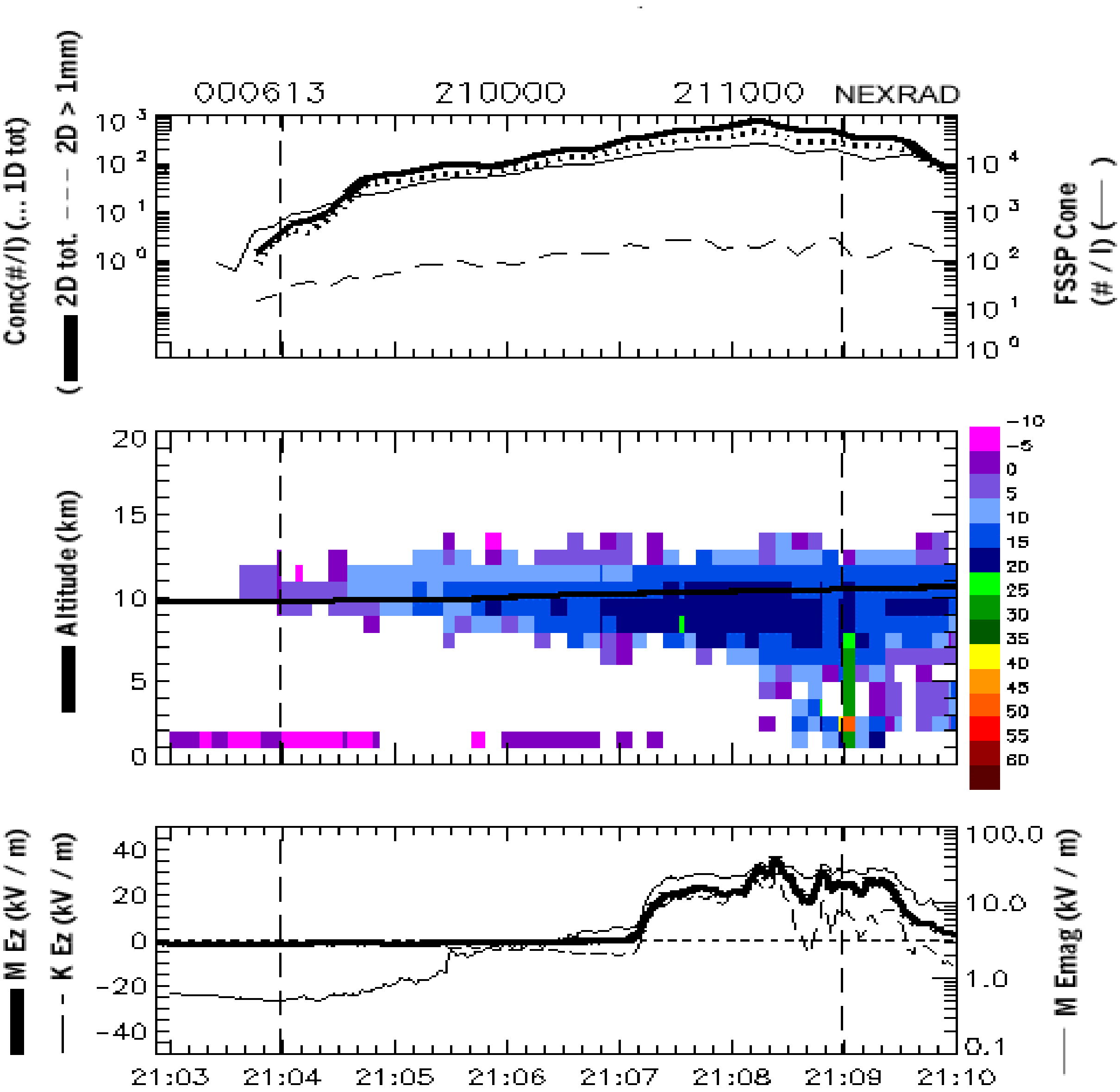

Fig. 2 Merged Summary Plot – track 3 Top Panel: Time history of particle concentrations; Center Panel: vertical MLB WSR-88D curtain of reflectivity columns along flight track; Bottom Panel: two retrievals of vertical electric field–linear, left; and resultant vector field Emag–log, right

3. CONVECTIVE ANVIL MICROPHYSICS

The microphysical measurements were made using multiple instruments spanning the size range from about 3 um (cloud droplets), to about 5 cm (ice hydrometeors), with adequate sample volume in each size range. The instruments are described in Dye, et al. (2004). The Rosemount icing detector did not find any evidence of supercooled liquid water in any of the anvils sampled during the project. Fig. 2 presents data along a typical flight track. The top panel summarizes the particle concentrations in several size ranges. The second a vertical curtain of reflectivity along the aircraft flight track. The bottom panel shows the electric field measured by the aircraft. Note that the field increases gradually from anvil entry to 210710, where there is a significant, almost step increase, to 20 kV/m.

As noted in Dye, et al. (2004) the particle concentrations of small ice, and medium to large size ice hydrometeors nearly always increase in concert. Regions of high concentrations of 2mm ice particles are also regions of high concentrations of small ice (3 – 60 um). Fig. 3 displays a series of 30s composite size spectra along the anvil flight track of fig. 2. In general as shown for this case the concentrations of all sizes increases along the track from the anvil edge into the dense portions of the anvil. Where there are fields significantly elevated above ambient, high concentrations over the full range of sizes appears to

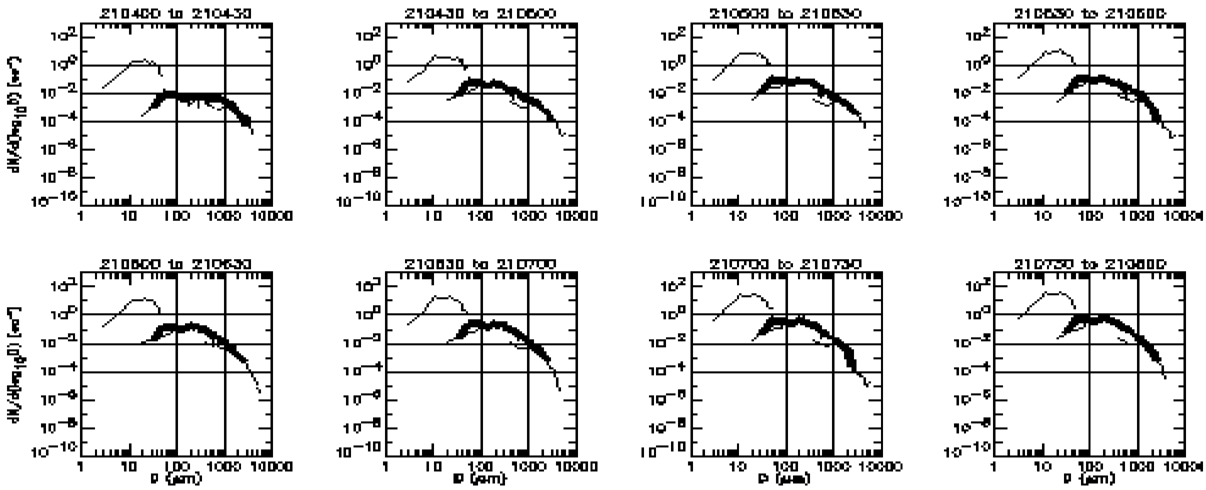

Fig. 3 Number size distributions–30s averages; FSSP light line, 2DC bold line, med line HVPS

be a necessary condition, but, there is no outstanding concentration inflection at the location of the immediate strong increase in field strength near 2107/10. There are often regions of significantly high concentrations of particles over a broad range of sizes, where the fields are not particularly elevated.

Fig. 4 shows detailed typical composite size distribution in two formats. Illustrated is the transition from a small size, low concentration distribution (2056), to a distribution with high concentrations at all sizes (dense anvil) (2059). In the second panel the same data are shown in a semi-log plot. It appears that a two exponential function fit may be appropriate for these distributions. This small sample series of distributions shown here is often repeated throughout this rather large sample of anvil microphysics.

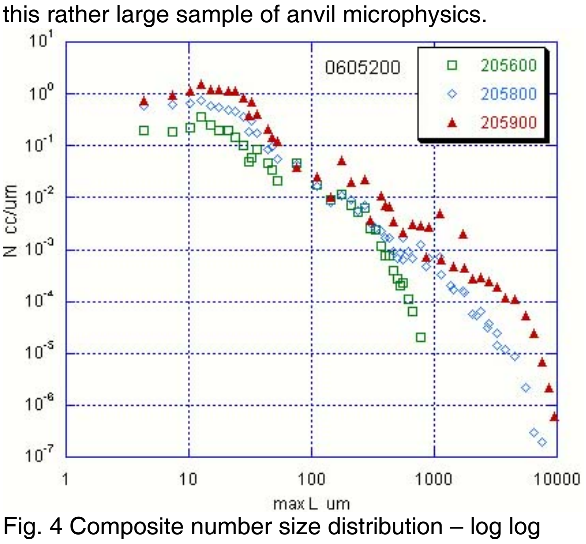

Fig. 4 Composite number size distribution – log log

The CPI images, with 3 um resolution, provide a detailed look at the characteristics (form and structure) of a wide range of particle sizes The sample volume is not adequate for obtaining concentrations of large hydrometeors, but concentrations can be derived for small particles of dimension < 100 um. The morphology of the particles, as with the size distributions, repeats throughout entire sample of

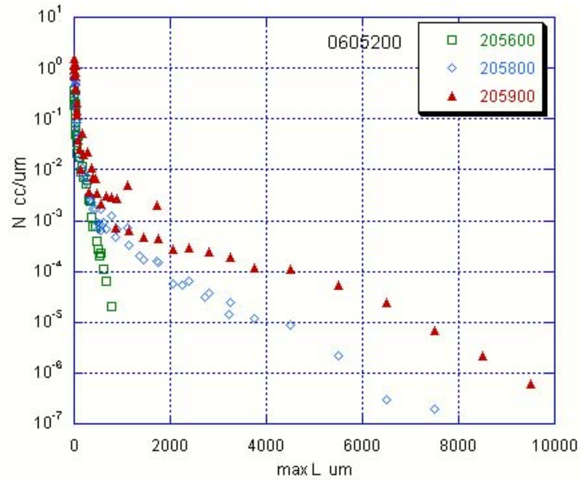

Fig. 5 Composite number size distribution – semi log

convective anvils. There are subtle differences, but the similarities are quite astounding. Only a very small sample of images can be shown here, but, even this very small sample illustrates the salient recurring features of the images. In Fig. 6 two half frames are shown that have been sorted by particle size, but not edited otherwise. The large particles shown here are ~ 1mm, but the data from the HVPS instrument show that hydrometeors to cm size do exist in these anvils, and probably have a very similar morphology to the images shown in Fig. 6a. Although some riming is present, these large hydrometeors do not appear to be heavily rimed. This is consistent with graupel being formed in the strong updrafts and having particle trajectories that fall out before these anvil samples. Aggregation was probably involved, to some degree, in the evolution of these particles, but for the most part they do not look like strictly like aggregates. Instead they appear to have a polycrystaline structure indicative of their tortuous growth history, as they were formed, and grown, in strong updrafts before being detrained at anvil levels. Along their trajectory the growth history in strong updrafts undoubtedly spanned a wide range of temperature and supersaturation conditions, and growth was probably forced at multiple sites and at multiple habits on each particle. It is surprising how the same general structure of large hydrometeors recurs through the sample. These particles are microphysically very different from cirrus formed in the same geographical area by large scale gentle uplift. The formers convoluted particle morphology is in stark contrast to elegant bullet rosettes found in the latter.

In Fig. 7b an unedited sample of particles < 100um is shown. The very striking feature is that every thing smaller than about 40 um is an almost perfectly spherical frozen droplet. This is typical of nearly all of the anvils observed throughout the course of the project. This is consistent with the observation that regions of high concentrations of medium to large particles almost universally coexist with regions of high concentration small particles. These small particles are ubiquitous even in quite aged anvil parcels. They undoubtedly do collide with the larger hydrometeors of higher terminal fall velocities, but do not aggregate, so they can coexist. These small spherical ice particles are probably formed at some level in the strong updrafts through a condensation freezing nucleation mechanism. Also, the near sphericity of these small ice particles augers well for the trustworthiness of the FSSP data sample.

The fairly abrupt increase in Ez field strength, i.e. inflection in the field data in Fig. 4, occurs quite often. At these inflections along sampling flight tracks, the observed field strengths quickly increase from near a kV/m to tens of kV/m, often in an area where the bulk microphysical conditions (concentrations) appear to be either constant, or slowly monotonically increasing. We examine the relative concentrations in each of four size intervals from the CPI images for three field inflection points. The CPI sample area and actual sampling time was assumed to be constant for 30s periods. Microphysically the only difference from the low field side of the field increase to the high field side of the inflection. appears to be an increase in the concentration of small size cloud particles (<80 um). The situation is complex and this is a very small preliminary sample, but this may indicate that in the charge center responsible for the high fields, the charge may reside on the small particles (approx < 80 um). Of course, much more needs to be done to substantiate, or refute, this very preliminary result.

This result is consistent with the anvil charge decay model of Willett and Dye (2003), where the decay of anvil charge is due to a reduction of the bulk conductivity in parcels with significant particle area. These particles are smaller than the particles that contribute to the bulk of summed particle area cross section (> 100 um).

The microphysical conditions, size distributions and particle morphology, are generally quite repeatable throughout this anvil cloud sample. Surprisingly, there are more similarities than differences. Small near spherical frozen cloud droplets (< 60 um) are ubiquitous in this large sample of convective anvils. These small particles may be important keys to aspects of cloud and anvil electrification, and warrant further examination

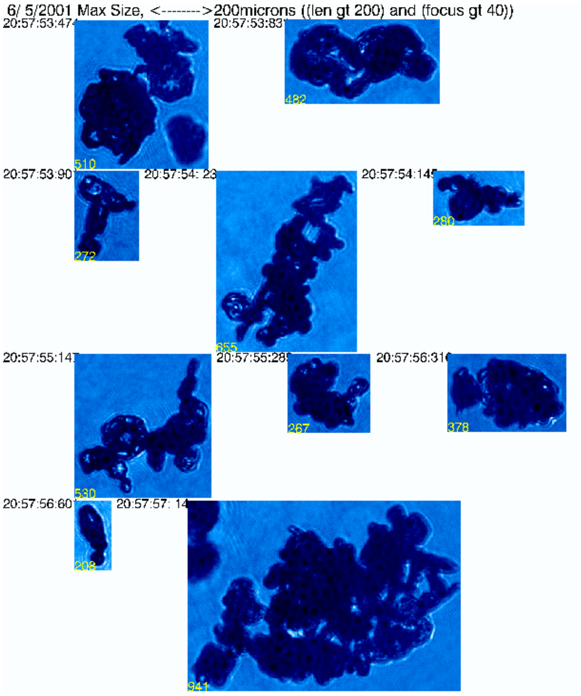

Fig. 6A typical large CPI images L > 400 um

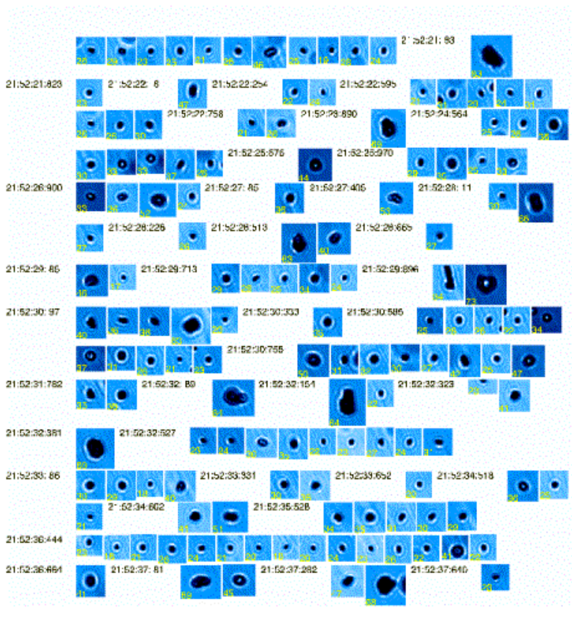

Fig. 6B typical small CPI images L< 100 um

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