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Microphysical Properties and the Decay of Electric Fields in Florida Anvils

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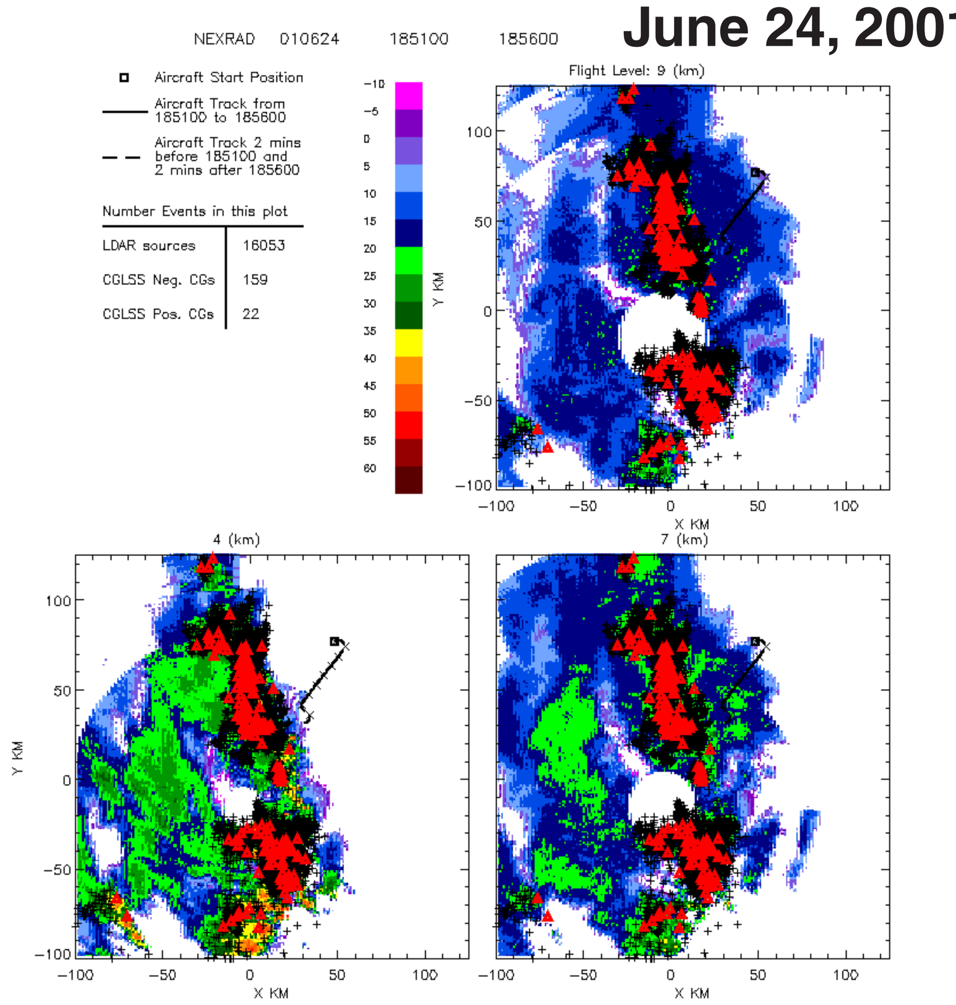
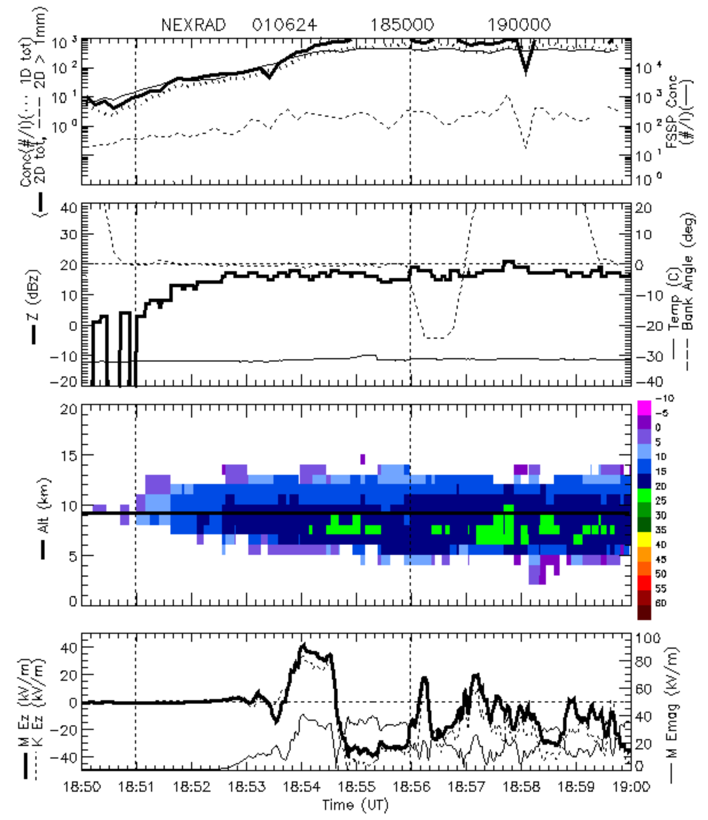
PURPOSE OF STUDY: Investigate the decay of electric field and associated particle concentrations and sizes in time and space in anvils and storm debris near Kennedy Space Center in June 2000 and 2001 (44 cases in 30 flights), using the

* Univ. No. Dakota Citation Aircraft with 6 field mills, an array of microphysical sensors and state parameter measurements.
* Patrick AFB WSR74C 5 cm and NWS NEXRAD 10 cm Melborne Florida radars.
* KSC Lightning Detection and Ranging (LDAR); Cloud to Ground Lightning Sensing (CGLSS); and ground based Field Mill Systems.

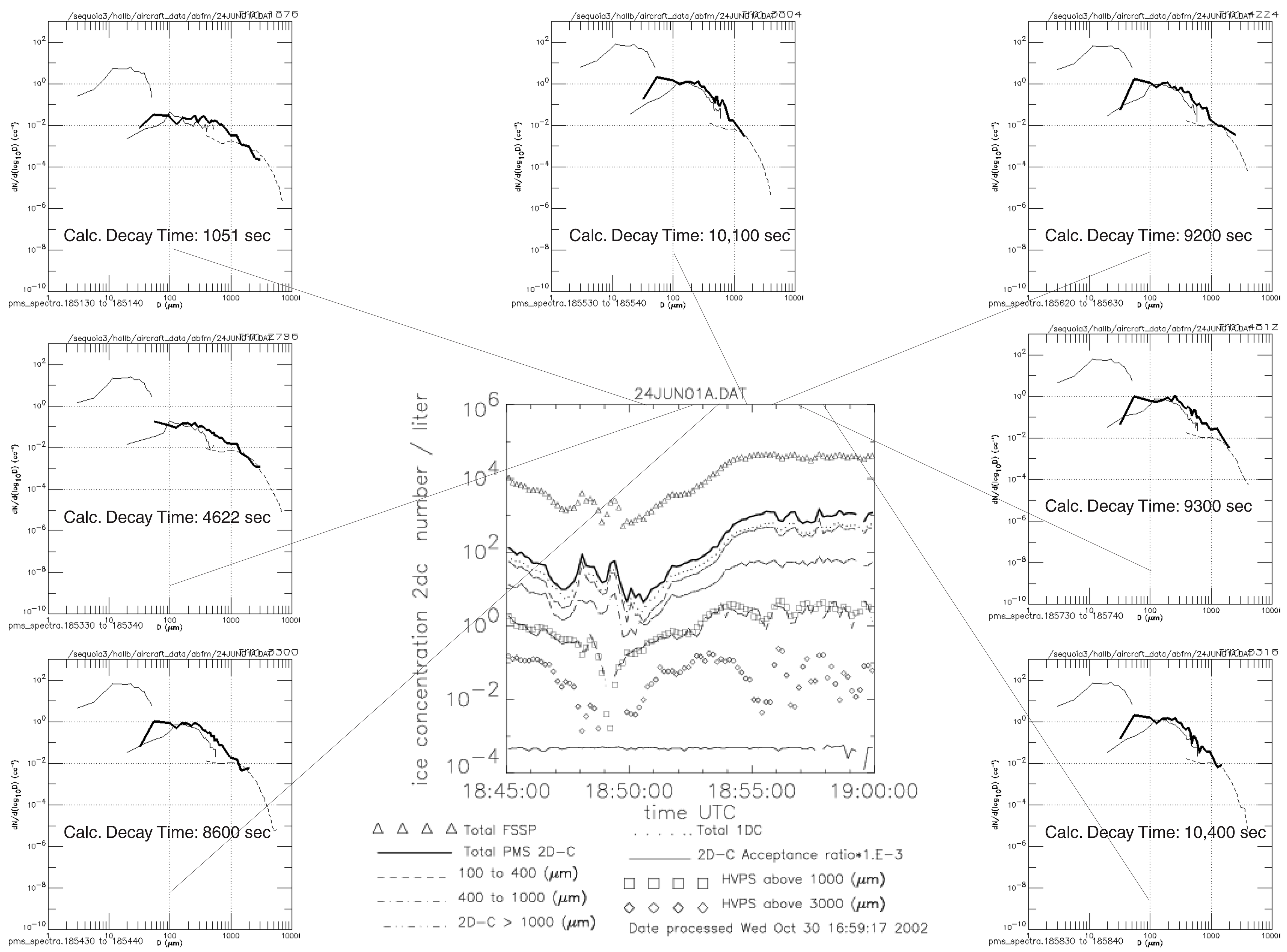
June 24, 2001: A tornadic storm case



Radar CAPPIs at 4, 7, 9 (aircraft level) km. X's are locations of LDAR sources and red triangles are locations of CG flashes. Lightning is shown for period 1851-1856.



Panel 1: Concentrations for total 1D, total 2D, 2D>1mm, FSSP
Panel 2: Reflectivity at the aircraft, temperature, and bank angle
Panel 3: Curtain of reflectivity above and below the aircraft
Panel 4: Vertical Electric Field as measured at the aircraft, Magnitude of the Electric Field



FINDINGS TO DATE

* Strong Electric Fields (>~10 kV/m) are associated with regions of reflectivity >~10 dBZ above the freezing level, but reflectivity >10 dBZ does not necessarily indicate strong electric field.
* In regions with strong Electric Fields, particle concentrations are high in all size ranges from 10 microns to several mm.
* Smallest particles are frozen cloud droplets while intermediate and largest particles are aggregates and other highly irregular shapes.
* There is considerable day to day consistency of observed particle concentrations in all size ranges in regions with strong Electric Fields.
* There is no evidence of supercooled liquid water in these anvils or debris.
* Calculated Electric Field decay times in anvils and ice cloud debris are mostly contolled by particle concentrations in the size range 0.2 to a few mm.
* Calculated Electric Field decay times using constant but observed particle size distributions ranged from almost 3 hours (near the core of active storms) to only several minutes toward the edge of anvils.
* Comparisons of the calculated decay times with those observed suggest the calculated decay times are upper limits.

Model for Electrical-Decay Time Scale in Anvil Clouds

For motionless, uncharged, conducting cloud particles of electrical cross section, A_e, capacitance, C, and number concentration, N, the steady-state, small-ion budget equation becomes,

$$q \sim A_e\, Nn(t)\, kE(t) + [C/\varepsilon_0]\, Nn(t)\, [kKT/e],$$

where q is ionization rate, k and $n(t)$ are the mobility and concentration of small ions (assumed identical for both polarities), ε_0 is the dielectric permittivity, K is Boltzmann's constant, T is absolute temperature, e is the electronic charge, and $E(t)$ is the ambient electric-field intensity. (Recombination and attachment to non-cloud aerosol particles are neglected.)

High-Field (non-Ohmic) Limit: At sufficiently high fields the first ion-loss term (electrically driven attachment) dominates, and the second term (diffusive attachment) may be neglected. The resulting conduction-current density becomes,

$$J = 2e\, kn(t)\, E(t) = 2eq/[A_e N],$$

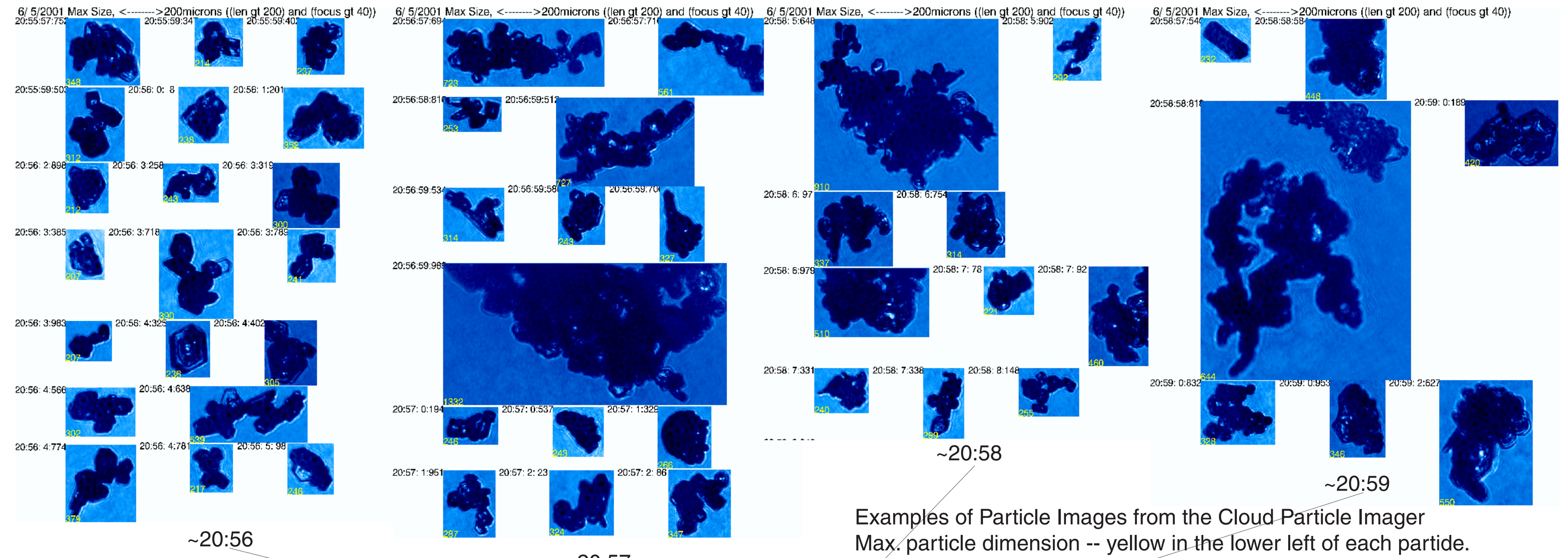
which is independent of time [Krehbiel, 1967]]! Our calculations using observed particle size distributions show that this limit is relevant in observed anvil clouds down to fields of a few kV/m.

Anvil Cloud: Imagine a stratified cloud (constant, uniform microphysics w/o sedimentation; no turbulence nor convection) containing a thin layer of charge (the only source of field inside the cloud). Constant J causes this charge layer, hence $E(t)$ throughout the cloud, to decay linearly! Define an electrical-decay time scale,

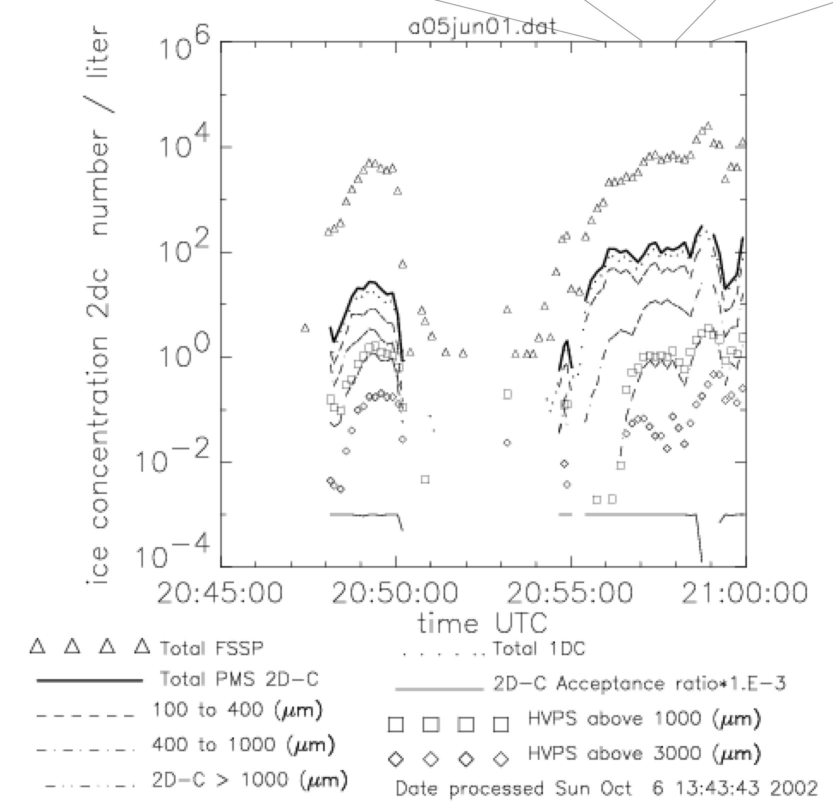
$$t_{(DE)} = \varepsilon_0(\Delta E)/J = A_e N\, \varepsilon_0(\Delta E)/[2eq].$$

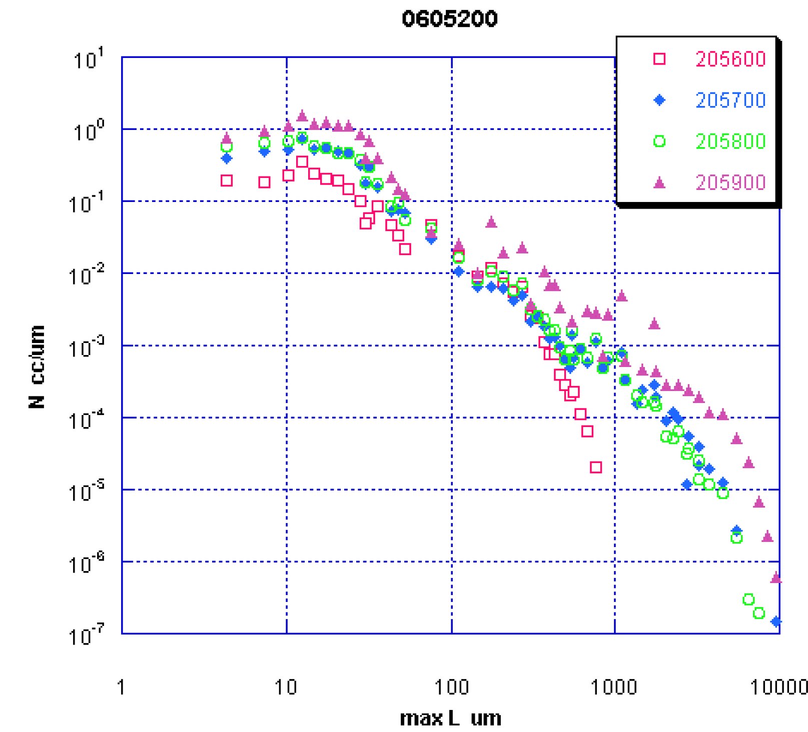
All decay-time estimates in this paper were obtained by setting (ΔE) = 50 kV/m and integrating $A_e N$ over particle diameter, d, for the observed size distribution (assuming spherical cloud particles, $A_e(d) = 3\pi d^2/4$, as a worst case) to get the total electrically-driven attachment loss.

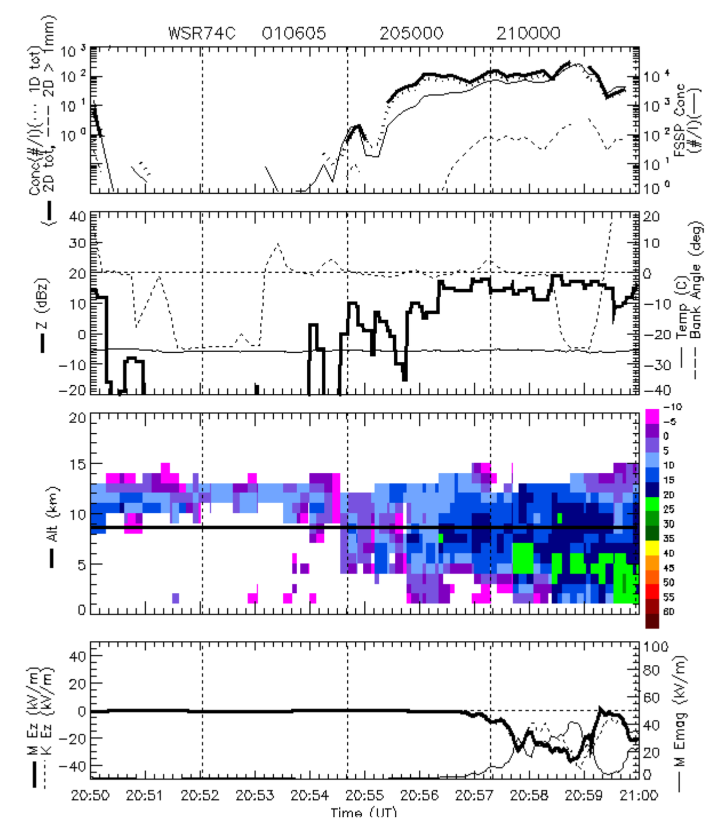
June 05, 2001: Decay of debris from deep convection



Examples of Particle Images from the Cloud Particle Imager
Max. particle dimension -- yellow in the lower left of each partide.







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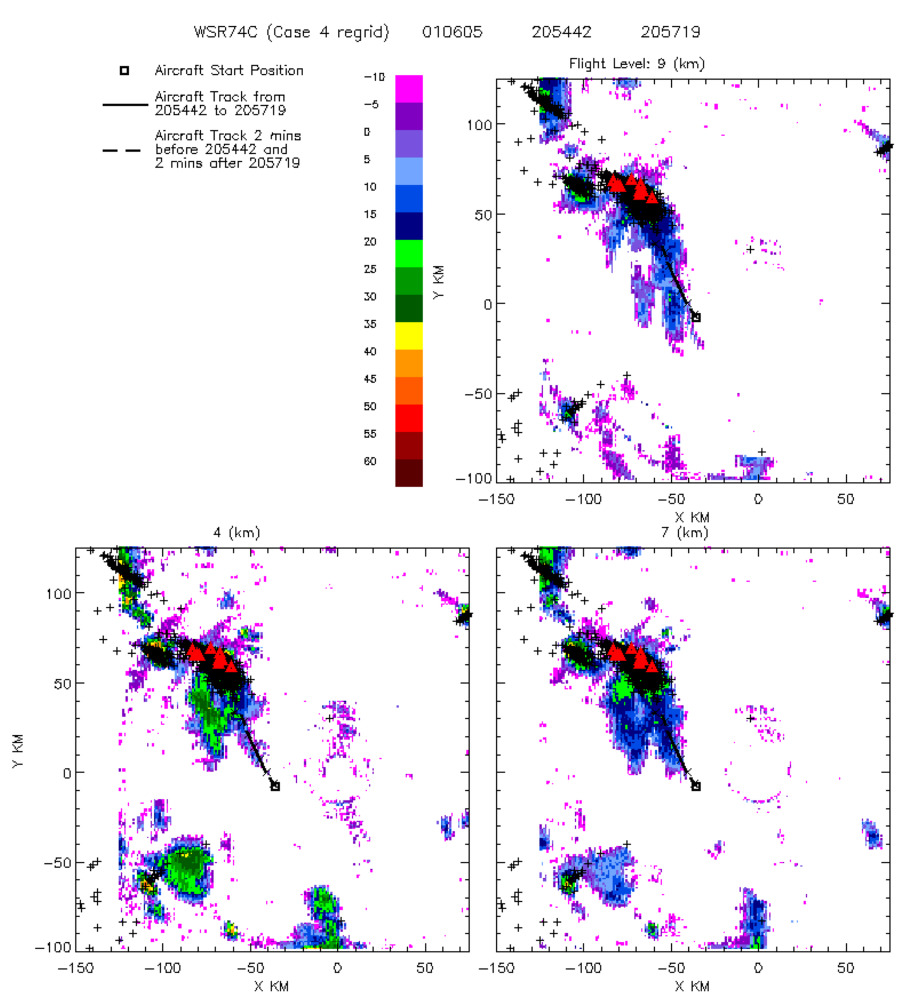

Radar CAPPIs at 4, 7, 9 (aircraft level) km. X's are locations of LDAR sources and red triangles are locations of CG strokes. Lightning is shown for period 2053-2057.