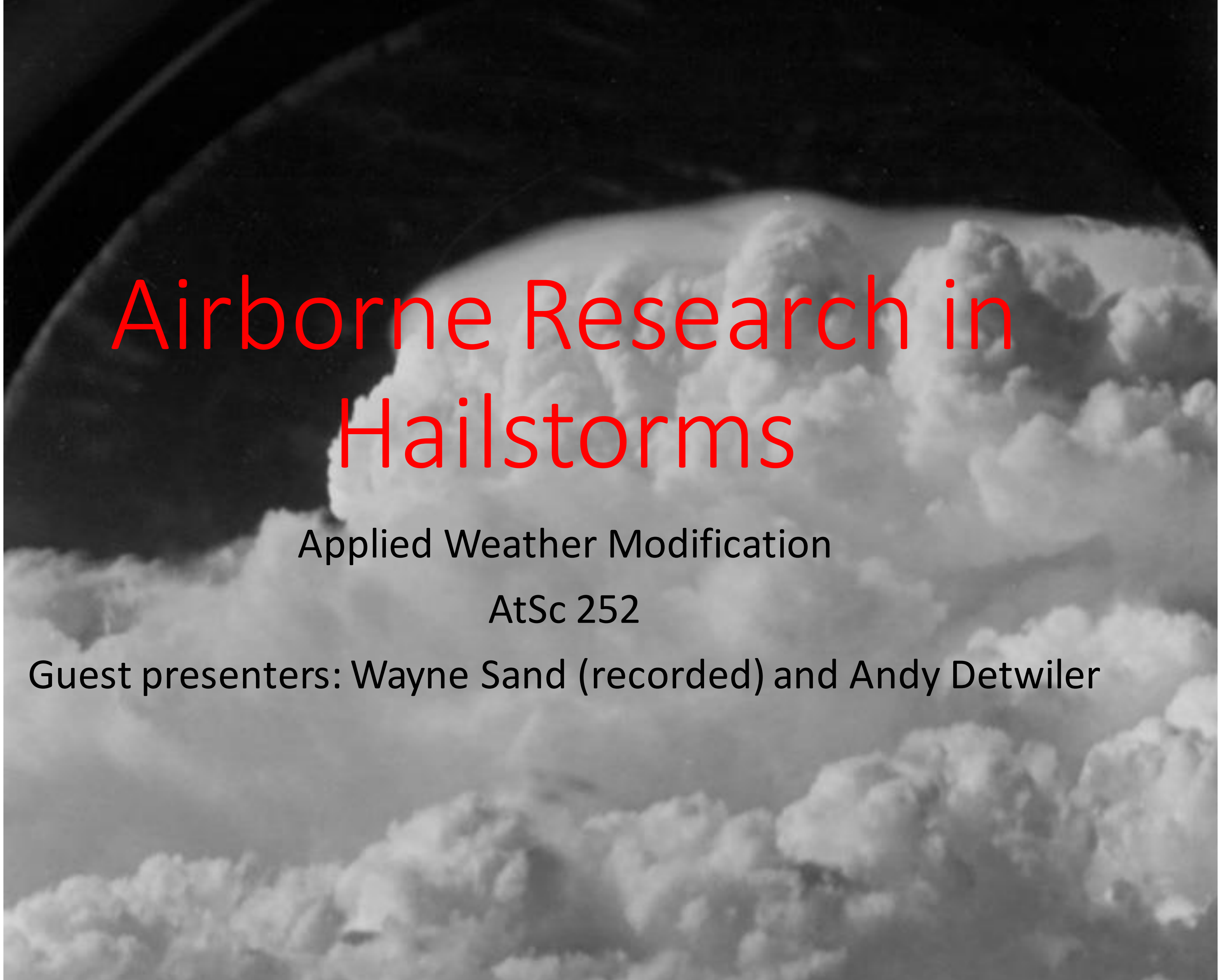

Airborne Research in Hailstorms
Applied Weather Modification
AtSc 252
Guest presenters: Wayne Sand (recorded) and Andy Detwiler

Flying through a Hailstorm– presented by Wayne Sand

- Day 3 - 2022 North American Workshop on Hail & Hailstorms (youtube.com) (scroll ahead to 3:41:40 to position at start of the presentation by Wayne Sand)

The concept of “cells” in convective clouds and storms

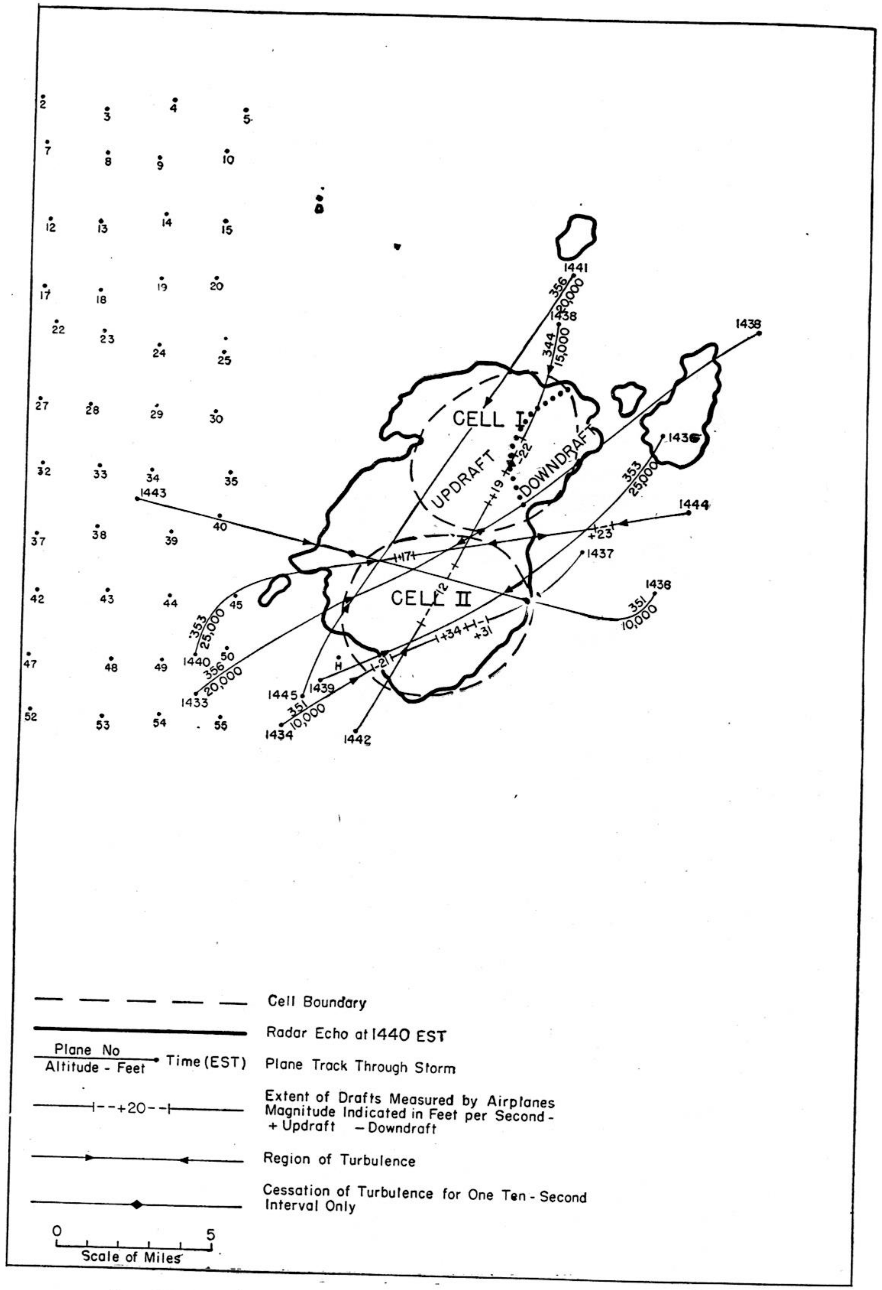


FIGURE 211.—PPI radar echo at 1440 E.S.T., and airplane paths from 1435 to 1445 E.S.T., August 17, 1947.

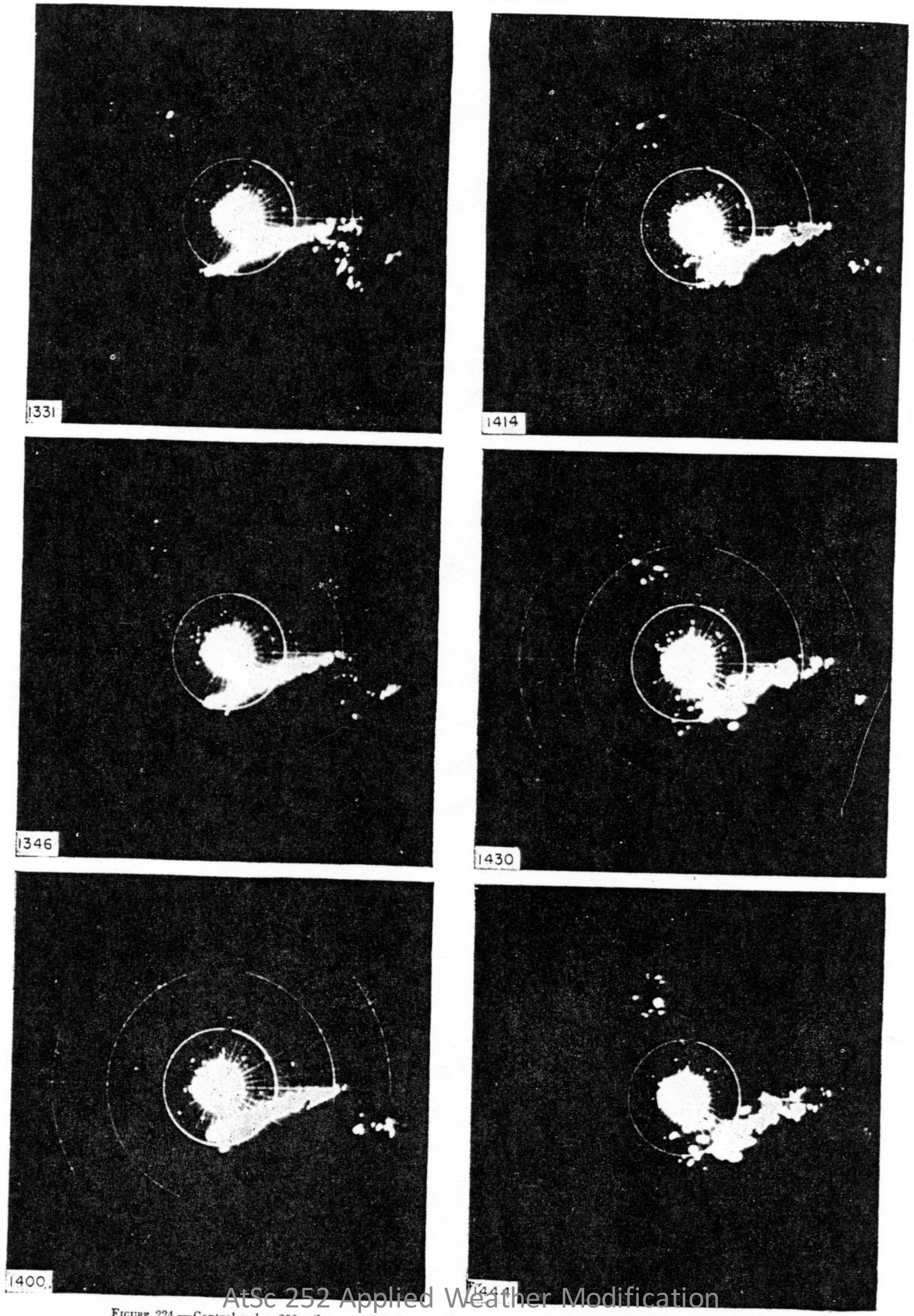


FIGURE 224.—Control-radar 200-mile-range PPI 'scope photographs, 1331-1444 E.S.T., September 5, 1947.

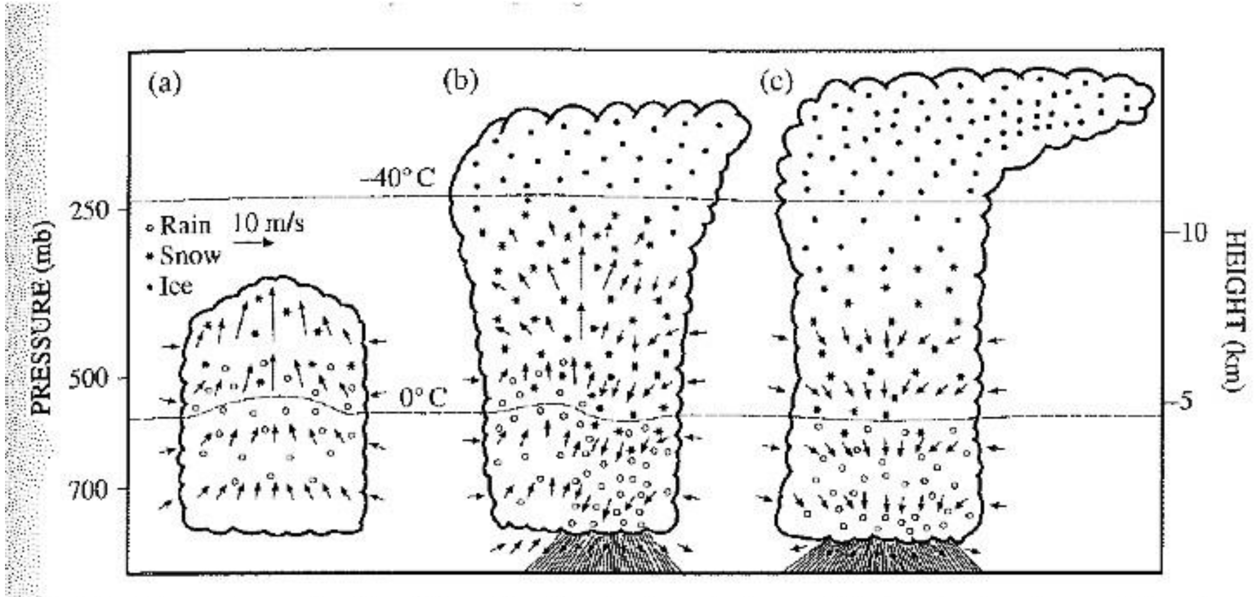


Fig. 8.1 Three stages for the life cycle of a single-cell storm: (a) developing stage, (b) mature stage, and (c) dissipation stage. (Adapted after Byers and Braham 1949.)

- *air mass* thunderstorm
- stages of development
- weak vertical wind shear
- entrainment at low levels, detrainment aloft (idealized)

- Thunderstorm Project in field in 1946 – 1947 in Florida and Ohio
- led by Horace Byers and Roscoe Braham

Graupel and Hail – insights from NHRE

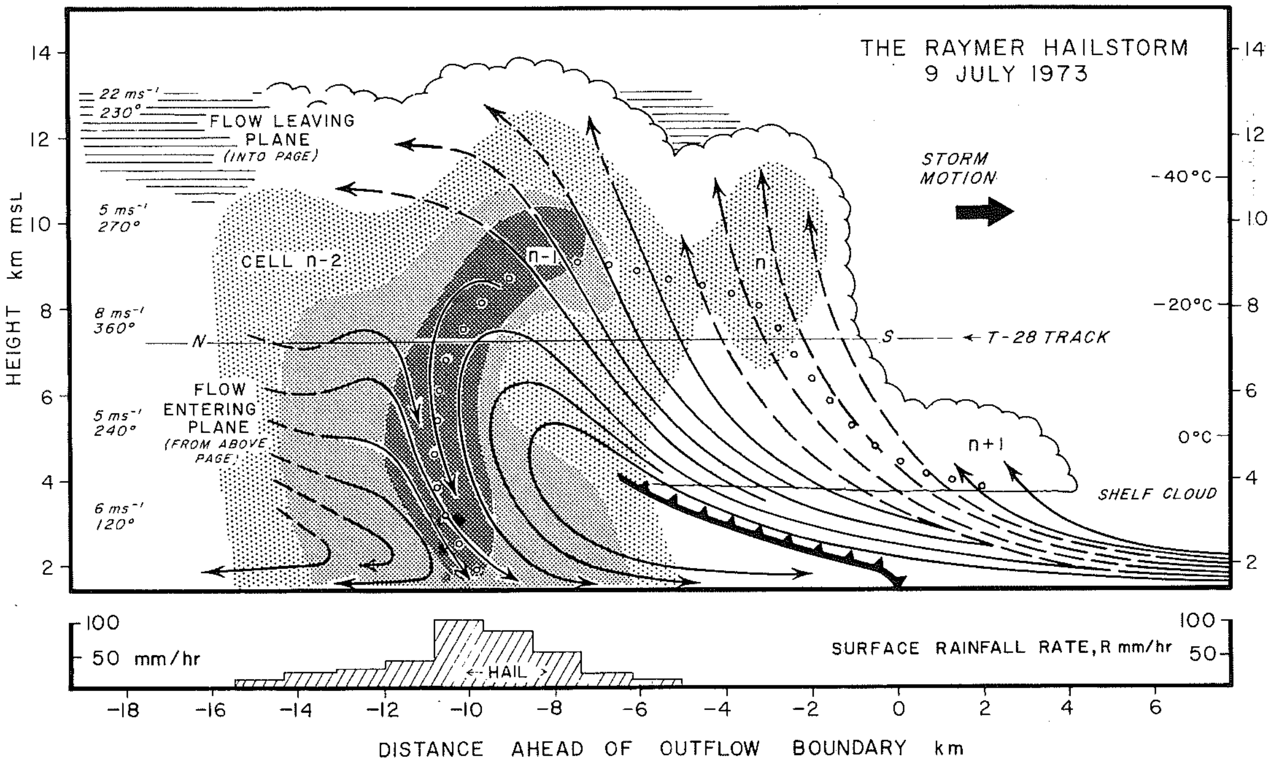


Fig. 9.21. Schematic model from a northeastern Colorado storm case study. Storm relative airflow is composited from aircraft, Doppler radar, and surface mesonet measurements. Light stippling represents cloud; successively darker stippling denotes radar reflectivity of 35, 45, and 50 dBZ. Measurements of rain, θ_e, and wind (the component in the plane of the figure), from a surface station over which the storm passed, are shown in the lower portion. The maximum wind vector is 11 m s^{-1}. [Adapted from Browning *et al.* (1976) and Fankhauser (1976).]

Multicell storm

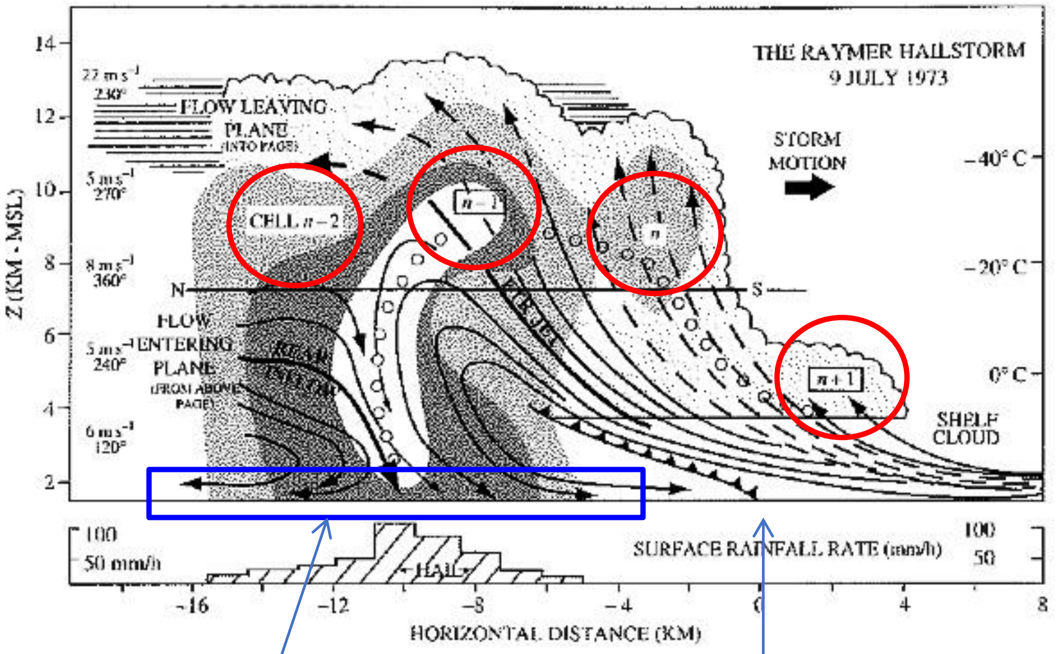


Fig. 8.4 A schematic diagram for a multicell storm in the vertical plane along the direction of the storm's movement. This storm has been referred to as the Raymer hailstorm. A series of convective cells, denoted as $n-2$, $n-1$, n, and $n+1$, were generated at the gust front and moved to the left as they developed. The solid lines represent storm-relative streamlines on the vertical plane; the broken lines on the left and right sides of the figure represent flow into and out of the plane and flow remaining within a plane a few kilometers closer to the reader, respectively. FTR JET and RTF JET stand for front-to-rear jet and rear-to-front jet (rear inflow), respectively, and are denoted by thick streamlines. The open circles represent the trajectory of a hailstone during its growth from a small droplet at cloud base. (Adapted after Browning *et al.* 1976.)

cold pool *gust front*

- new cells form as air lifted at gust front (become buoyant)
- multicell system can last several hours
- moderate-strong shear
- *front-to-rear jet*: ascending air, above cold pool
- *rear-to-front jet*: low-θ_e air from rear part of storm brought into cold pool

(jets part of more mature multicell system)

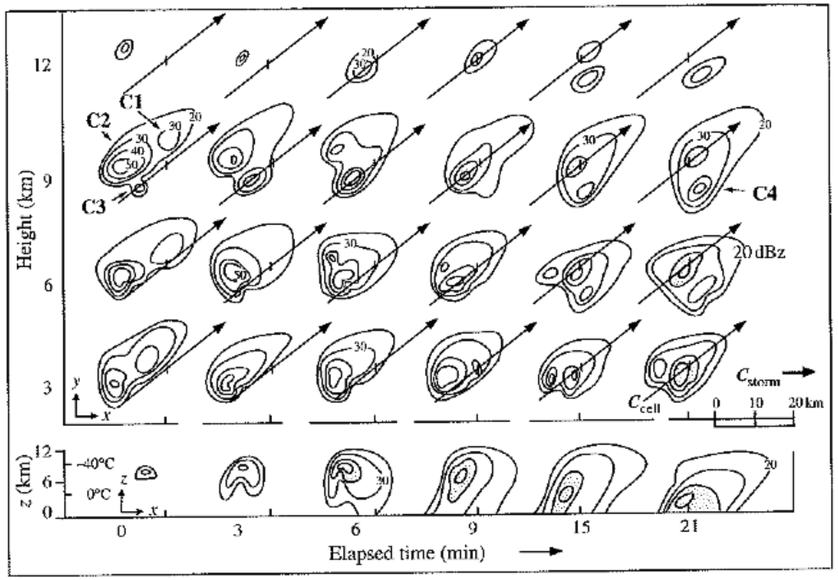
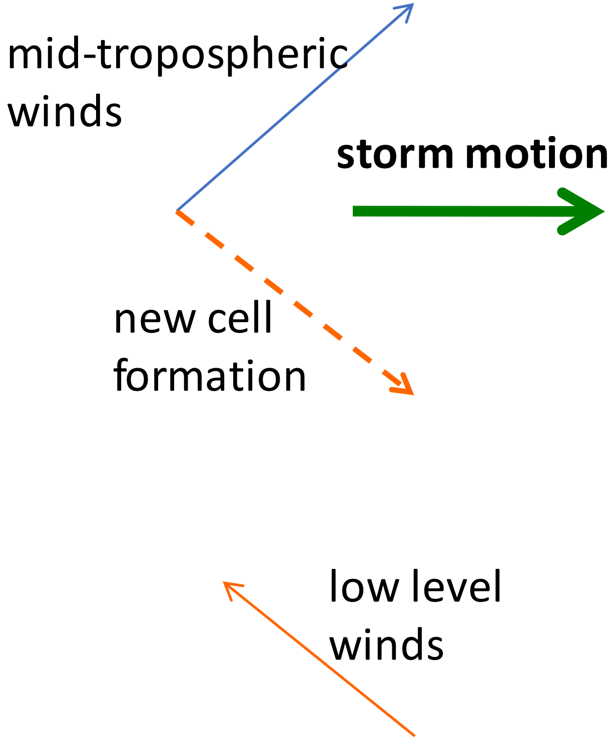
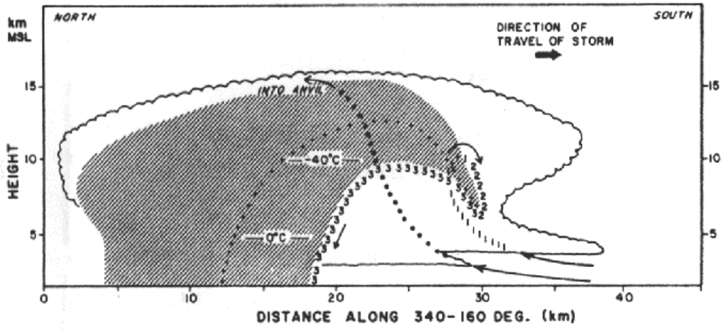


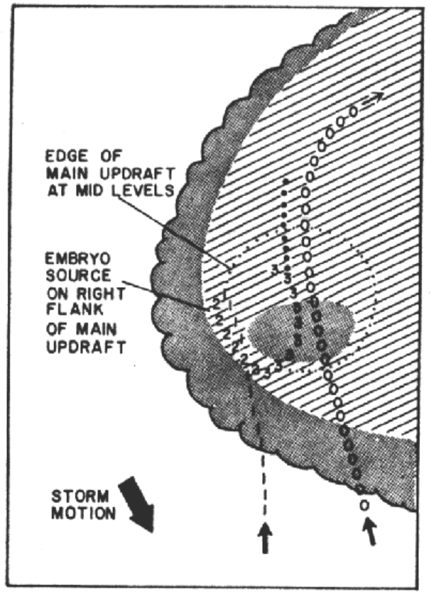
Fig. 8.5 Schematic diagram for the propagation and evolution of an ordinary multicell storm (Raymer hailstorm, Fig. 8.4). Both the horizontal and vertical radar reflectivity contours (at 10 dBZ intervals) are sketched. Horizontal cross sections are illustrated for four altitudes at six different times. Individual cell motions are steered by a midlevel wind toward the northeast (denoted by c_{cell}), while the entire storm moves towards the east (denoted by c_{storm}). New convective cells, such as cells 3 and 4 (denoted as C3 and C4), are generated to the south of the storm against the low-level wind. (After Chisholm and Renick 1972.)



Graupel and Hail – insights from NHRE

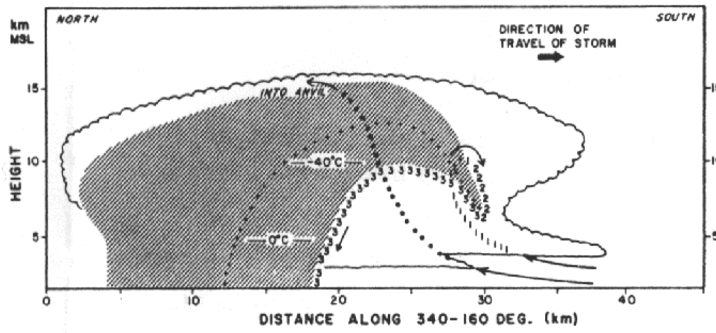
- Stage 1—Hailstone Embryo Stage.
    - Embryos (of a finite size) are needed because otherwise they would be ejected out of the top of the storm upon traveling into the updraft.

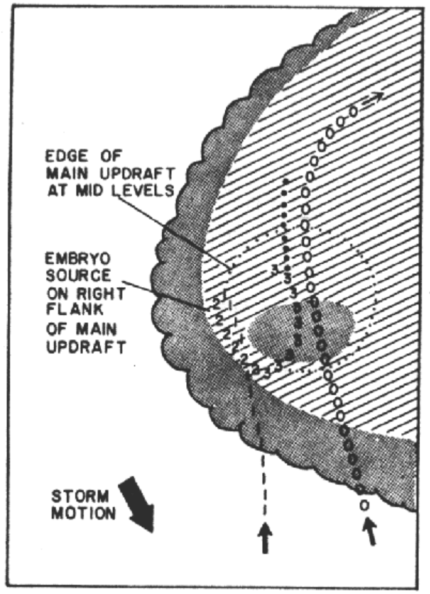




Graupel and Hail – insights from NHRE

- Stage 2—Translation Stage.
  - Hailstone embryos become positioned so that they may be injected into and traverse the main updraft of the storm.
- Stage 3—Accretional Growth Stage.
  - Hailstone embryos are injected into the main updraft and grow through *accretion of supercooled cloud drops*.
  - Hailstones grow to large sizes in 10-30 minutes.





Graupel and Hail – insights from NHRE

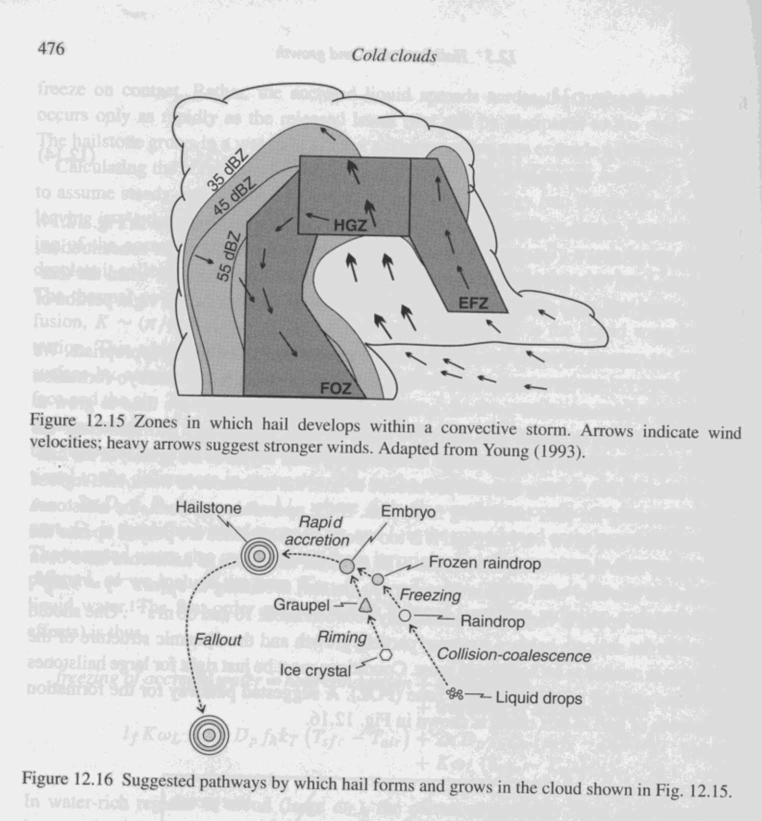


Figure 12.15 Zones in which hail develops within a convective storm. Arrows indicate wind velocities; heavy arrows suggest stronger winds. Adapted from Young (1993).

Figure 12.16 Suggested pathways by which hail forms and grows in the cloud shown in Fig. 12.15.

Graupel and Hail – insights from NHRE

From Knight and Knupp, 1986

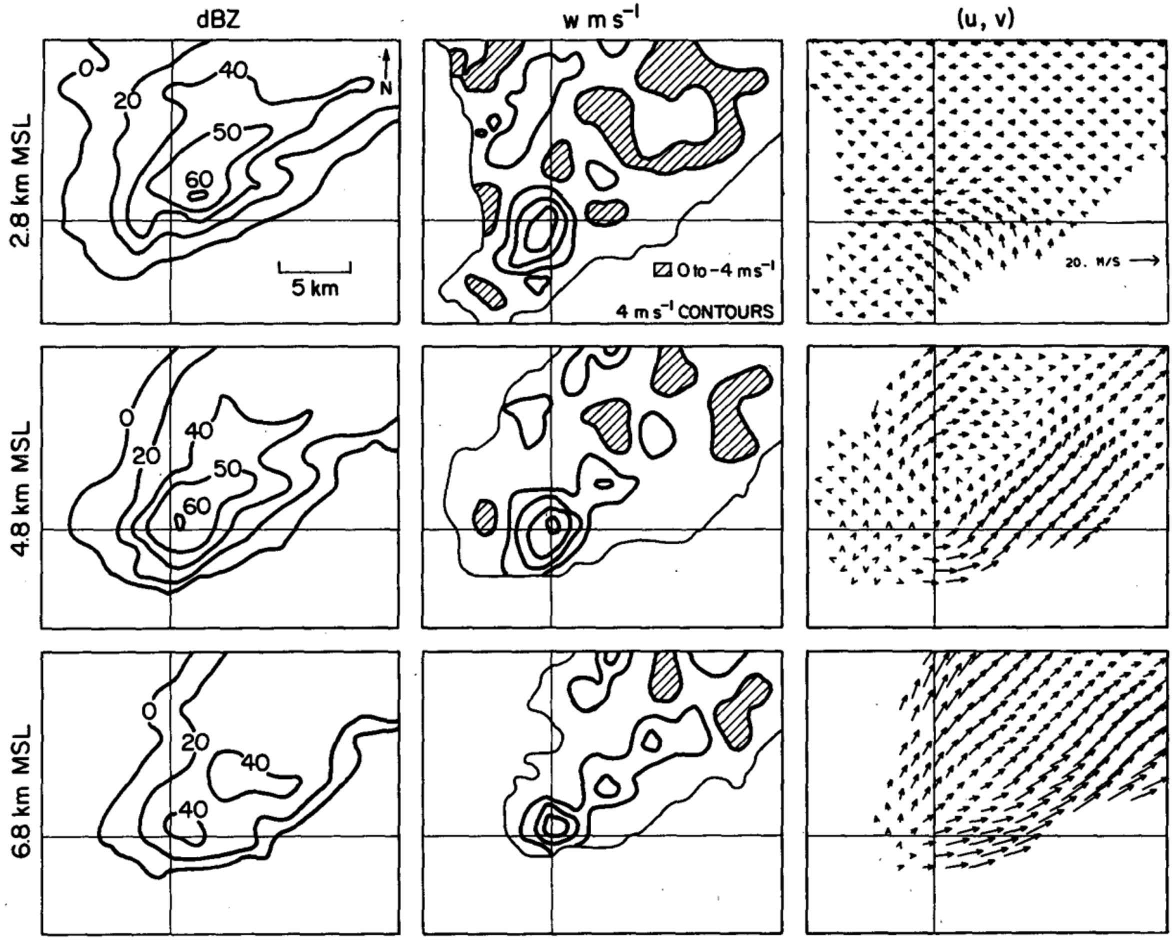


FIG. 2. Radar echo, updraft and the horizontal wind field shown at 2.8, 4.8 and 6.8 km MSL (2, 4 and 6 km AGL), 1655 LDT scan. Note the rapid decrease of the maximum equivalent reflectivity factor with height and the downwind extensions of the updraft with height. The horizontal winds are storm-relative, using a storm speed $(u, v) = (8.9, 3.6)$ m s^{-1}. In the vertical velocity plots, the contour between the blank and cross-hatched regions is 0 m s^{-1}. The 2.8 km level is a little above cloud base.

Graupel and Hail – insights from NHRE

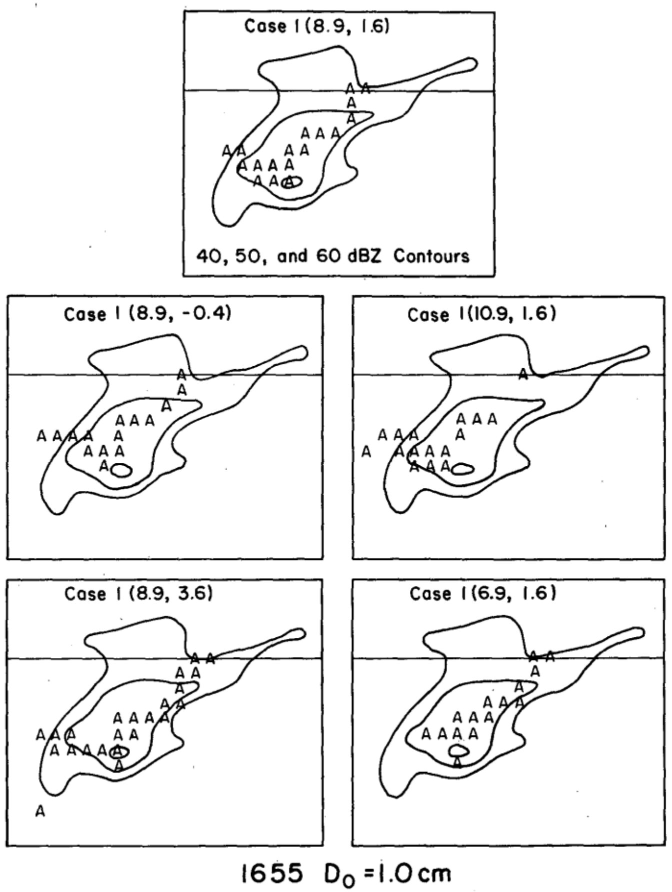


FIG. 4. The locations at 2.8 km MSL of particles 1.0 cm in diameter, grown in the wind field using microphysics case 1 (see text), for the five storm motions including and bracketing $(u, v) = (8.9, 1.6)$ m s^{-1}. The 40, 50, and 60 dBZ_e contours are shown in each case, and the scale is indicated by the 1-km spacing of the A's. Only the 1-km grid points on and to the south of the horizontal line were tested. At grid points not marked with A, growth trajectories leading to 1.0 cm particles were rejected—judged impossible—according to one of the rejection criteria in the text. The patterns and locations of the A's are fairly sensitive to storm motion. Their correspondence with the high radar reflectivity is a test of the scheme.

Graupel and Hail Summary

- Large damaging ice hydrometeors can develop in thunderstorms with persistent strong updrafts
  - Main growth process is accretion/riming on mm-diameter “embryos” formed in less vigorous regions of storms, then transported to the vicinity of a strong updraft where there is a high concentration of supercooled liquid water. Rapid growth then occurs.

Graupel and Hail Summary

- Hail growth has mainly been studied in long-lived supercellular storms where a steady-state circulation persists for 10’s of minutes.
- Less is known or predictable about hail formation in multicellular and “air mass” thunderstorms.
  - Many scenarios proposed….

Hail Suppression Concepts (from Bruce Boe, Weather Modification International)