Cloud physics

Growth of large hailstones

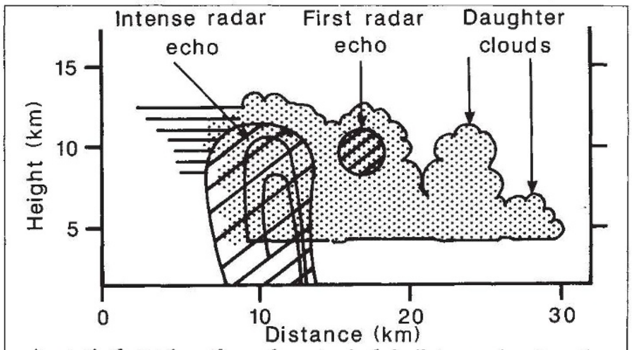
Anthony Illingworth

HAIL causes considerable damage to agriculture: for example, in France losses are estimated at £100 million per annum and in Italy the damage in the Po valley alone is even greater. Although hail storms originate in cumulonimbus clouds, not all large thunderstorms produce hail, and a cloud has to perform a delicate balancing act if it is to grow hailstones more than 1 centimetre in size. Many people have been tempted to try to upset this balance and suppress the hail by firing cannon or rockets into the clouds. But our knowledge of hail growth is incomplete and because we cannot precisely predict what would have happened to the storm without any interference, these hail-control techniques are untested. L. Cheng and D.C. Rogers (*J. atmos. Sci.* **45,** 3533–3545; 1988) report observations of radar data, time-resolved surface collections of hail and cloud photographs of a storm in Alberta, Canada, which confirm earlier suggestions that the growth of large hail is a two-stage process.

The main problem is to explain how the embryo of a hailstone can be confined in a region dense with liquid cloud droplets for sufficient time to grow to a hailstone. A falling hailstone grows by sweeping out these droplets which freeze as soon as they hit the hailstone. The maximum amount of cloud water produced by cooling and condensation of moist, warm surface air as it is lifted to −20 °C is about 4 g m^{-3}, and a hailstone needs to spend about 20 min in such a cloud if it is to grow to 1–2 cm in size.

Such hailstones have a terminal velocity of about 20 m s^{-1} or so, but updraught velocities of this magnitude occur in thunderstorms, and so the final stage of growth to the larger size can occur as the hailstone is balanced against the updraught within the cloud and then descends to the ground. The difficulty arises in the early stages of growth. It takes several minutes to achieve a size of a few millimetres, and during this time the embryonic hailstone will have a low terminal velocity, and if it finds itself in a 20-m s^{-1} updraught, it will pass straight through the cloud.

In Alberta, three vehicles chased the storm and collected hailstones underneath the regions of high radar reflectivity. At any one place the large fall lasted only a few minutes. The maxima in the radar reflectivity of the cloud could be traced backwards in time for 20 minutes to the new growth regions of the storm 30 km away from the main hail-producing updraught. Airborne photography confirms the existence of a series of these small but rapidly growing cumulus clouds, called daughter or feeder clouds, in the form of a staircase (see figure).



A vertical section through a typical hailstorm showing the daughter clouds on the storm's right flank. Stippled shading represents cloud, hatching the highest radar reflectivity. (After Dennis, A.S. *et al. J. appl. Met.* 9, 127–135; 1970.)

The picture emerges, then, of hail embryos which can be in the form of raindrops or small ice pellets, growing to about 5 mm while suspended in the weak updraughts of the growing daughter cells. The daughter cell then grows to become the principal updraught, or merges with the main storm, and the final growth stage occurs in a region of much higher vertical air velocity.

Problems do remain. First, why does the succession of daughter cells form with a separation of about 3 km? Cheng and Rogers note that the line of daughter cells was oriented along a line approximately parallel to the environmental wind shear, consistent with the resonance-mode theory of shear-induced instability proposed by D.P. Lalas and F. Einaudi (*J. atmos. Sci.* **33,** 1248–1259; 1976).

Second, why are so few embryos introduced into the main updraught? The concentration of raindrops in mature clouds is several thousand per cubic metre, and if they all found their way into the main updraught they would collect cloud droplets so quickly that the supply of cloud water in the updraught would soon be exhausted. Instead of a few large hailstones, many more smaller hail pellets would be produced.

My recent polarization radar measurements of developing cumulus clouds (*Nature* **336,** 754–756; 1988) suggest that the first detectable radar echo consists of just a few large raindrops in concentrations of less than one per cubic metre. If this is so, then these raindrops would form natural embryos for large hailstones without invoking any elaborate mechanism for size sorting. But we still cannot predict whether any attempt to introduce artificial nuclei such as silver iodide into daughter cells would enhance or diminish the hail risk, or whether such efforts at modification are futile. □

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Oceanography

Are rising and falling particles microbial elevators?

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A CASUAL survey of sediments from the deep-sea floor reveals that most of the sedimentary material consists of the remains of tiny plants and animals that once lived near the surface. Not long ago it was widely assumed in oceanography that particulate material sinking from the 'euphotic' upper layers of the ocean was composed of fairly indigestible organic particles and mineral precipitates, like $CaCO_3$, which slowly settled through a dark and largely lifeless abyss. Since sediment traps were developed in the late 1970s to catch the sinking material in mid-water, it has become apparent that material sinking through the abyss is composed not of inert, slow-settling particles, bur rather of fast-sinking, nutritious material which can feed a rich assortment of deep-dwelling animals, both in the water column and at the sea floor. Now we learn that the flow of particulate organic material goes both ways: K.L. Smith Jr, P.M. Williams and E.R.M. Druffel report elsewhere in this issue (*Nature* **337**, 724–726; 1989) that the deep-dwellers of the abyss are generating buoyant organic particles which ascend toward the surface. Their data show that the upward flux may be 15–20 per cent of the sinking flux on average.

Smith *et al.* hung moored sediment traps, both in the usual upward-facing mode and upside down, at 600 m and 1,600 m above the sea floor at two locations in the Pacific Ocean. Besides finding