NOTES AND CORRESPONDENCE

Comments on "Hail Growth Mechanisms in a Colorado Hailstorm: Parts I and II."

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A recent pair of papers, Jameson and Heymsfield (1980) and Heymsfield, Jameson and Frank (1980), henceforth JH and HJF, reported on the use of dual-wavelength radar hail-signal data for determining the locations of hail and graupel within a storm. The distinction between hail and graupel made from the dual-wavelength data was based on having a positive hail signal greater than +3 dB or a negative hail signal less than −3 dB.

Earlier studies (Eccles and Atlas, 1973; Jameson, 1977; and Eccles, 1979) suggested that hail signals could be as large as +45 dB or so for monodisperse hail size distributions and as large as 16–18 dB for exponentially-distributed hail. Negative hail signals occur only for small, wet hail and only to about −4 dB. Eccles (1979) shows that for exponential hail distributions with any reasonable water coating, the hail signal is essentially zero or positive even for small hail. Thus, it was somewhat surprising to see JH and HJF attempting to impart meteorological interpretations to large negative hail signals when existing theory says that they should not exist (or occur only rarely at most). Their use of these negative hail signals was supported to some extent by data from a penetrating T-28 aircraft equipped to make microphysical measurements. It detected graupel in some locations where the dual-wavelength radar gave negative hail signals. JH and HJF postulated that their large negative hail signals were caused by small, low-density graupel particles through some as-yet-to-be-defined resonance process. Since the theoretical backscattering cross sections of ice particles has only been worked out for sphere and oblate spheroids (Humphries and Barge, 1980), there is a void in our knowledge as to what might happen with irregularly-shaped particles. However, Humphries and Barge concluded that shape effects could not be used to explain the unusually large negative hail signal values reported earlier by Jameson and Srivastava (1978), Wilson (1978) and Barge and Humphries (1980).

A common assumption in most previously published dual-wavelength work is that the antennas are sampling identically the same volume in the storm (Srivastava and Carbone, 1971; Eccles and Atlas, 1973; Jameson, 1977; Jameson and Srivastava, 1978; Eccles, 1979; JH and HJF). The NCAR CP-2/M33 dual-wavelength radar was designed to have antenna beam patterns of the same mainlobe size (i.e., nominally 1°). In an examination of the actual beam patterns of the CP-2/M33 dual-wavelength system, however, we found that the beamwidths are not well matched (Rinehart and Tuttle, 1982). The CP-2 S-band beamwidth is 0.96° while that for the M33 X-band is 1.3°. Furthermore, the sidelobe patterns are distinctly different. The first sidelobe on the CP-2 system is nearly 30 dB down (one way) from the peak gain on the axis of the mainlobe while the M33's first sidelobe is only about 16 dB down.

Using the actual beam patterns determined for the CP-2/M33 dual-wavelength system, Rinehart and Tuttle (1982; hereafter, RT) showed that the mismatched antenna beam patterns on that radar can generate large negative hail signals (i.e., erroneous hail signals) in many parts of a strong storm; further, in some locations, mismatched beam patterns can also generate some weak positive erroneous hail signals. The effects of mismatched antenna beam patterns were studied by using analytical representations of the S and X band beam patterns to "resample" one of the same volumes of storm data studied by JH and HJF. This simulation was done in such a way that the only source of hail signal at a given location was the mismatched antenna beam pattern; the results are then totally unaffected by attenuation effects and any non-Rayleigh, wavelength-dependent backscattering phenomena which may be present in the real situation, as well as pointing errors, range errors, averaging differences or any other instrument- or processing-induced differences.

A major result of this simulation study was that many large, negative hail signal regions were produced entirely by the effect of mismatched antenna beam patterns. The meteorology of the storm was totally irrelevant to the production of these negative hail signals. Further, the locations of the negative hail signal regions generally agreed with the corresponding locations of negative hail signals found in the dual-wavelength data shown by JH and HJF. The relative abundance of these negative hail signals and their positions in the simulated dual-wavelength data suggest that virtually all negative hail signals can and probably are produced by the mismatched antenna beam patterns

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of the CP-2 and M33 radars. Even if the restrictive conditions needed to produce negative hail signals would occur in nature, there would be no way to separate the real from the erroneous hail signals in the data of JH and HJF. Thus, we must dismiss all the negative hail signals considered by JH and HJF as artifacts produced by the radar.

Are the positive hail signals of JH and HJF also suspect? Generally, we think not. By virtue of the fact that they used a 3 dB threshold to filter out potentially noisy positive hail signals, the hail signals which exceeded this threshold very likely are due to meteorological causes. However, as shown in RT, both attenuation and antenna beam patterns can produce positive hail signals in some parts of the storm. Erroneous positive hail signals from the beam patterns were found to be less than 2 dB. Thus, the antenna beam patterns could at worst inflate the magnitudes of positive hail signals (and probably do) but should not produce them in the absence of hail. Attenuation can also produce positive hail signals. The claim by JH that attenuation above the melting level is negligible does not seem to be correct. Rinehart and Tuttle found attenuation in excess of 3 or 4 dB at quite high levels in the storm (see Figs. 7 and 8 of RT). It appears that thorough dual-wavelength analyses should account for attenuation.

Finally, we feel compelled to make some other comments on the pair of papers by JH and HJF. These authors are to be commended on their attempt to piece together data from such diverse systems as the dual-wavelength radar, penetrating aircraft and the triple-Doppler radar system and to synthesize them into some kind of coherent picture of what they believed was taking place in this storm. Unfortunately, their reliance upon the dual-wavelength data to determine where the graupel (negative hail signal) was within the storm proved misplaced. In light of what we now know, half of the conclusions of their first paper are no longer correct; the dual-wavelength radar data used by JH and HJF cannot be used to determine the presence of graupel. Similarly, their two-stage hail growth model given in HJF can no longer be considered reliable because of their use of the negative hail signals to indicate locations of graupel. The relatively weak reflectivity in feeder cells and their location adjacent to strong reflectivity cores is precisely the kind of situation which could have produced erroneous negative hail signals with the dual-wavelength radar data JH and HJF used. Some of their physical arguments might have been more convincing had they simply tracked some of their positive hail signal regions through time and space rather than assuming that they followed the winds derived from the Doppler radar system. At any rate, much of their comments and discussion can no longer be accepted as correct even though there are likely some aspects of their work which are, in fact, correct. In particular, the triple-Doppler wind fields and the T-28 aircraft observations and any interpretation based solely upon these should be correct. Nevertheless, the fact that HJF intertwined the results of these with dual-wavelength data so extensively makes it difficult to separate fact from fiction.

The attempts by JH and HJF to synthesize all their observations graphically also needs mention. We found a number of problems with several of their figures but were especially troubled by Figs. 4 and 5 in HJF. These figures contain numerous line segments which are difficult to interpret; it is hard to understand why there should ever be a line segment completely enclosed by a continuous contour—line segments within closed contours are nonsensical. There were also crossing contours which defy interpretation. Fig. 4's caption and legend are contradictory with regard to the lowest displayed downdraft velocity. In one location on Fig. 5 both positive and negative hail signals are shown to occupy the same point. And surely the units on hail signal are decibels and not dBZ.

Perhaps one lesson to be learned from all of this is that with a measuring system as complicated as a meteorological radar, great care must be exercised at each step of the analysis. The fact that the correlation between graupel, as determined by T-28 measurements, and negative hail signals was rather weak and somewhat unimpressive in JH (and now thought to be nonexistent), combined with the absence of a coherent theoretical foundation for expecting negative hail signals should, perhaps, have led the authors to examine their approach more closely.

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