Deduction of Ice Particle Types in the Vicinity of the Melting Layer from Doppler Radar Measurements[1]

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ABSTRACT

A technique is described for deducing, from vertically pointing Doppler radar measurements, whether the predominant ice particles just above the melting layer are graupel or aggregates of ice crystals. Under certain conditions, the type of graupel and the type of ice crystals which comprise the aggregates can be deduced.

1. Introduction

A wealth of information about the microphysics of clouds and precipitation exists in Doppler radar data that are not presently being utilized. In a previous paper (Weiss and Hobbs, 1975) we have shown how some ice particle growth processes can be deduced from Doppler radar measurements. Here we present a method which, under certain situations, permits the types of ice particle just above the melting layer to be deduced from vertically pointing Doppler radar measurements.

2. Description of the technique

If a solid precipitation particle melts to form a raindrop without breakup (as indicated by Ohtake's, 1968, observations), then

$$M_s = M_r,$$

where M_s and M_r are the masses of the solid particle and the raindrop, respectively. The fallspeed of a raindrop is given by (Atlas *et al.*, 1971)

$$V_r = V_{\max}\left\{1-\exp\left[-\beta\left(\frac{6M_r}{\pi\rho}\right)^{\frac{1}{3}}\right]\right\}, \tag{1}$$

where $V_{\max}=9.65$ m s^{-1}, $\beta=6$ cm^{-1} and ρ is the density of water. The fallspeeds V_s of solid precipitation particles of known masses were measured by Locatelli and Hobbs (1974). Values of V_s from Locatelli and Hobbs' data for ten ice particles types [classified using the scheme proposed by Magono and Lee (1966)] are plotted on the ordinates in Figs. 1–3 and the corresponding values of V_r calculated from (1) (assuming $M_r=M_s$) are plotted on the abscissas. It can be seen from the figures that each type of ice particle occupies a certain zone on the V_s-V_r diagram, but not all of these zones are mutually exclusive. By combining the data in Figs. 1–3, as shown in Fig. 4, the following zones can be defined:

ZONE I Lump and conical graupel; graupel-like snow of lump and hexagonal type; hex-

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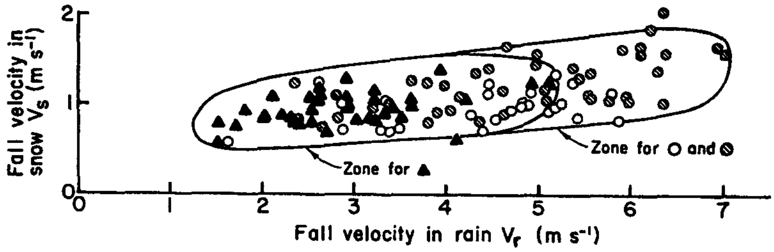

FIG. 1. The relationship of V_s to V_r for aggregates of unrimed sideplanes, bullets and columns (triangles), aggregates of unrimed to moderately rimed dendrites and radiating assemblages of dendrites (unshaded circles) and aggregates of moderately to densely rimed dendrites and radiating assemblages of dendrites (hatched circles).

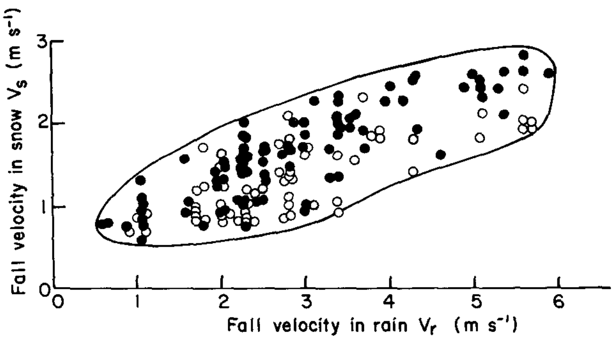

FIG. 2. The relationship of V_s to V_r for lump and conical graupel (shaded circles) and hexagonal graupel and graupel-like snow (unshaded circles).

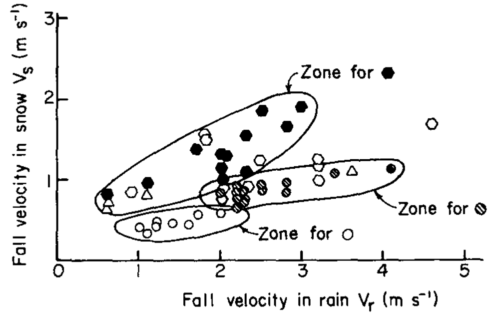

FIG. 3. The relationship of V_s to V_r for unrimed dendrites (unshaded circles), densely rimed dendrites (hatched circles), densely rimed radiating assemblages of dendrites (unshaded hexagon), densely rimed columns (shaded hexagon) and unrimed sideplanes (triangles).

agonal graupel. (Note the lump and conical graupel tend to lie more in the upper portion of this zone than the graupel-like snow or hexagonal graupel.)

ZONE II All 10 ice particle types listed in the captions of Figs. 1–3 except for unrimed dendrites.

ZONE III Aggregates of dendrites and radiating assemblages of dendrites; unrimed aggregates of bullets, sideplanes and columns.

ZONE IV Aggregates of dendrites and radiating assemblages of dendrites. (The unrimed aggregates lie toward the bottom of the zone and the densely rimed aggregates toward the top.)

ZONE V Unrimed dendrites. (This zone and accompanying data points were deduced from the data for densely rimed dendrites using the fact that a densely rimed dendrite falls about twice as fast as an unrimed dendrite.)

During precipitation the spectra of fallspeeds just above and just below the melting layer can be measured with a vertically pointing Doppler radar. (Our range gate spacing was 600 m; since complete melting was generally accomplished in about 400 m of fall, there was no ambiguity in determining the spectra "just above" and "just below" the melting layer.) The spectra just above and just below the melting layer define an area on the V_s-V_r diagram. If the area thus defined falls into zones I, III, IV or V listed above, useful information on the predominant ice particle type just above the melting level can be deduced. In particular, this technique will generally permit the presence of graupel to be determined; also fairly readily distinguishable are the more massive aggregates of dendrites and radiating assemblages of dendrites and unaggregated unrimed dendrites. If, in addition, the cloud-top temperature is known, other ice particle types can be deduced by this technique. For example, if the cloud top temperature is not below −18°C, "cold-type" ice crystals, such as bullets and sideplanes, can be eliminated.

We have used this technique successfully on a number of occasions to deduce the predominant ice particle types just above the melting level in extratropical cyclonic storms (see Section 3). In this case,

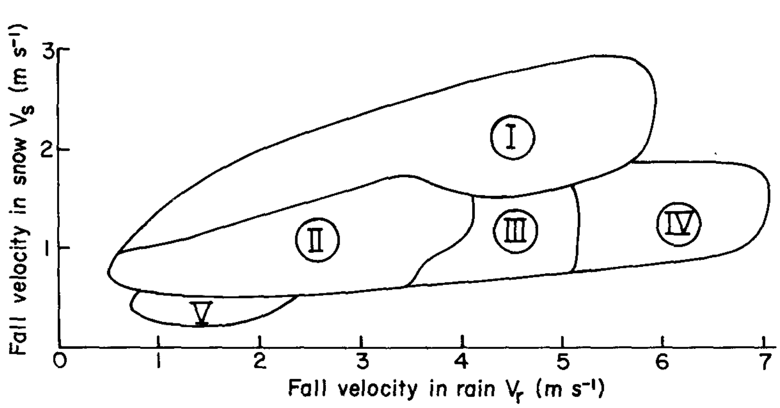

FIG. 4. Zones on the V_s-V_r diagram for various crystal types. See text for definition of the zones.

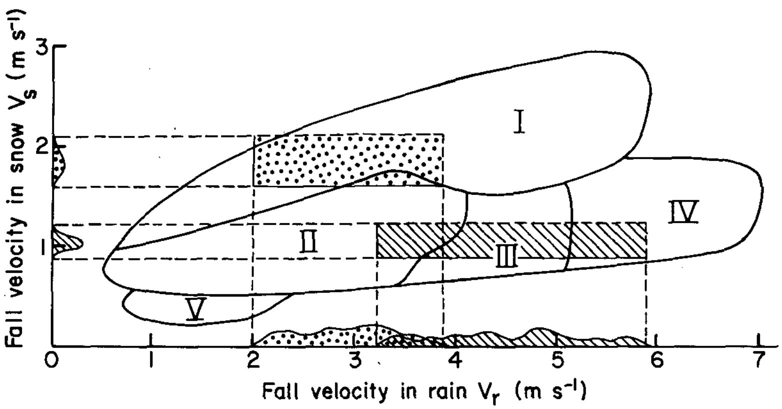

FIG. 5. The spectra of fallspeeds above and below the melting level measured by Doppler radar on 10 January 1976 are shown on the ordinate and abscissa, respectively, by the hatched area and the same shading is used to indicate the area in the body of the V_s-V_r diagram which these spectra define. Similar results for cold frontal precipitation on 10 January 1976 are indicated by the dotted areas. The zones I–V are the same as those shown in Fig. 4.

the magnitudes of the updraft velocities do not appear to cause serious errors in application of this technique. However, independent studies will be required to determine whether the technique can be used in more vigorous convective cloud systems.

3. Illustration of the use of the technique

To illustrate the technique we will consider Doppler radar measurements of fallspeeds obtained on 10 January 1976, as part of the University of Washington's study of cyclonic storms (the CYCLES PROJECT). Two periods were chosen: one during warm-frontal precipitation (1331 PST) and the other during cold-frontal precipitation (1415 PST). The measured fall-speed spectra just above and just below the melting level for these two periods are plotted on the ordinate and the abscissa, respectively, in Fig. 5. It can be seen from the area on the V_s-V_r diagram defined by the two particle spectra measured during the warm frontal precipitation that the ice particles just above the melting layer were predominantly aggregates (since the area falls predominantly in zones III and IV), whereas the area on the V_s-V_r diagram defined by the two spectra measured in the cold-frontal precipitation shows that the particles above the melting level were graupel (since the area falls in zone I). Furthermore, since the cloud-top temperature during the warm frontal precipitation was not below -18°C, bullets and sideplanes could not have been present. Therefore, the aggregates probably consisted of dendrities.

4. Concluding remarks

Under suitable conditions, the technique described here can provide continuous information on the predominant types of ice particles just above the melting level. This information, in turn, can be used to deduce whether the precipitable particles are being formed primarily by riming or by aggregation and how these two growth processes vary with mesoscale and synoptic conditions.

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REFERENCES

Atlas, D., R. C Srivastava and R. S. Sekhon, 1971: Doppler radar characteristics of precipitation at vertical incidence. Tech. Rep. No. 22, Dept. of Geophysical Sciences, University of Chicago, 59 pp.

Locatelli, J. D., and P. V. Hobbs, 1974: Fall speeds and masses of solid precipitation particles. *J. Geophys. Res.*, **79**, 2185–2197.

Magono, C., and C. W. Lee, 1966: Meteorological classification of natural snow crystals. *J. Fac. Sci. Hokkaido Univ., Ser. 7*, **2**, 321–335.

Ohtake, T., 1968: Change of size distribution of hydrometeors through a melting layer. *Preprints 13th Radar Meteor. Conf.*, Montreal, Amer. Meteor. Soc., 148–153.

Weiss, R. R., and P. V. Hobbs, 1975: The use of a vertically-pointing pulsed Doppler radar in cloud physics and weather modification studies. *J. Appl. Meteor.*, **14**, 222–231.