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HYDROMETEOR CLASSIFICATION BASED ON Z_{DP} USING C-BAND RADAR

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1. INTRODUCTION

Discriminating between liquid and solid precipitation is a fundamental, important task in classification of precipitation by polarimetric radar. Many research efforts so far have concentrated on the detection of hail in connection with severe convective storms (e.g. Aydin et al. 1986). Until recently, less emphasis has been placed on the possibility of discriminating between rain and ice hydrometeors (e.g. Ryzhkov and Zrnic, 1998).

In the present study we concentrate on more stratiform precipitation events typical in connection with mid-latitude cyclones. The main goal is to investigate the possibilities of determining the ice fractions in precipitation using the difference reflectivity (Z_{DP}) introduced by Golestani et al. (1989). The study is based on data from the University of Helsinki Research Radar Setup (Puhakka, T., 2005).

2. CLASSIFICATION METHOD BASED ON Z_{DP}

A hydrometeor classification method based on Z_{DP} (Eq. 1) was first introduced by Golestani et al. (1989). As seen in equation 1, Z_{DP} is only defined when horizontal reflectivity (Z_H) has greater values than vertical reflectivity (Z_V). Hence, Z_{DP} is only defined for horizontally oriented particles.

$$Z_{DP}(\mathrm{dB}) = 10\log_{10}(Z_H - Z_V) \qquad Z_H > Z_V \qquad (1)$$

The Z_{DP} method is based on a strong correlation between Z_H and Z_{DP} in rainfall. Scatter plots of these two parameters in rainfall form a line that is called the rain line, which should not depend on changes in drop size distribution (DSD).

Spherical particles in a radar volume do not affect Z_{DP} values but do increase the value of Z_H. This enhancement in reflectivity values causes these data points to deviate from the rain line. If we assume ice hydrometeors to be mainly spherical, this method can be used to discriminate between ice particles and raindrops. The difference between measured and rain line-defined reflectivity ΔZ tells us the amount of Z_H caused by ice particles. With ΔZ we can calculate the ice fraction f (Eq. 2) that defines what portion of the measured total Z_H is caused by ice particles.

$$f = 1 - 10^{-0.1\Delta Z} \qquad 0 \le f \le 1 \qquad (2)$$

3. DATA

Measurements were performed using RHI scans from the klystron-based fully coherent C-band dual-polarimetric Doppler weather radar located at the University of Helsinki. The main characteristics of the radar can be found in Puhakka et al. (2006). Data used for this study are from summer 2005 and spring 2006. In summer 2005, a doppler filter was not in use, which caused some limitations to the data usage at low elevation angles. For spring 2006, the lowest elevations also had to be excluded from calculations even though the doppler filter was in use, because strong ground clutter contamination was still noticeable.

4. RAIN LINE

Rain lines were calculated for three stratiform rain events to investigate if the rain line is constant and independent of DSD variations. All rain events are from June 2005 and have well-defined bright bands. Only one of the events is represented here (Fig. 1), because of the similarity of the characteristics in Z_H and Z_{DP} in all of the cases.

In figure 1 enhanced values caused by the melting layer can be seen in both Z_H and Z_{DP}

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Table 1: Rain line equations, their standard error (SE), and the correlation between Z_{DP} and Z_H calculated from stratiform rain cases (1) 06/11/05 23:44 UTC, (2) 06/12/05 21:44 UTC and (3) 06/27/05 18:50 UTC. The last equation (4) represents the average rain line obtained by combining the data for all three cases.

	Rain line (dB)	SE (dB)	Correlation
1	$Z_{DP} = 1.36Z_H$-18.04	0.74	0.99
2	$Z_{DP} = 1.29Z_H$-18.10	1.03	0.90
3	$Z_{DP} = 1.36Z_H$-17.63	0.69	0.98
4	**$Z_{DP} = 1.26Z_H$-15.86**	**1.20**	**0.95**

at about 2-2.5 km height. In Z_{DP} there is a large area above the bright band where Z_{DP} is not defined. This may be caused by completely spherical particles, or by a sufficient number of vertically oriented particles. Slightly negative values of differential reflectivity were indeed found from the data of this specific case, which indicates that both spherical particles and vertically oriented particles were possible. The area where data are taken for rain line calculations can be seen in figure 1(a) as the area between the dashed black lines. Data points are taken well below the bright band to avoid ice particles contaminating rain line measurements.

According to the first row of Table 1, the linear correlation coefficient between Z_H and Z_{DP} is as high as 0.99 in the rain event of 11 June 2005 at 23:44 UTC. In the scatter plot (Fig. 1(c)) this strong correlation is noticeable. The red line in figure 1(c) represents a rain line fit using the least squares method. The results for three different rain lines are very similar (Table 1) and are in good agreement with results of e.g. Carey and Rutledge (2000). Still, the differences in rain lines indicate that the correlation between Z_H and Z_{DP} is not totally independent of variations in DSD.

5. ICE FRACTIONS

5.1 *STRATIFORM RAIN*

Ice fractions are calculated for 11 June 2005 using data at ranges between 31.5 and 32.5 kilometers. The height of the freezing level is about 2.5 km, according to sounding data obtained in Jokioinen at 00:00 UTC. The time evolution of ice fractions was examined using radar scans every 4 minutes during a 20 minute time interval. During this time period the rainfall event remained quite constant. In figure

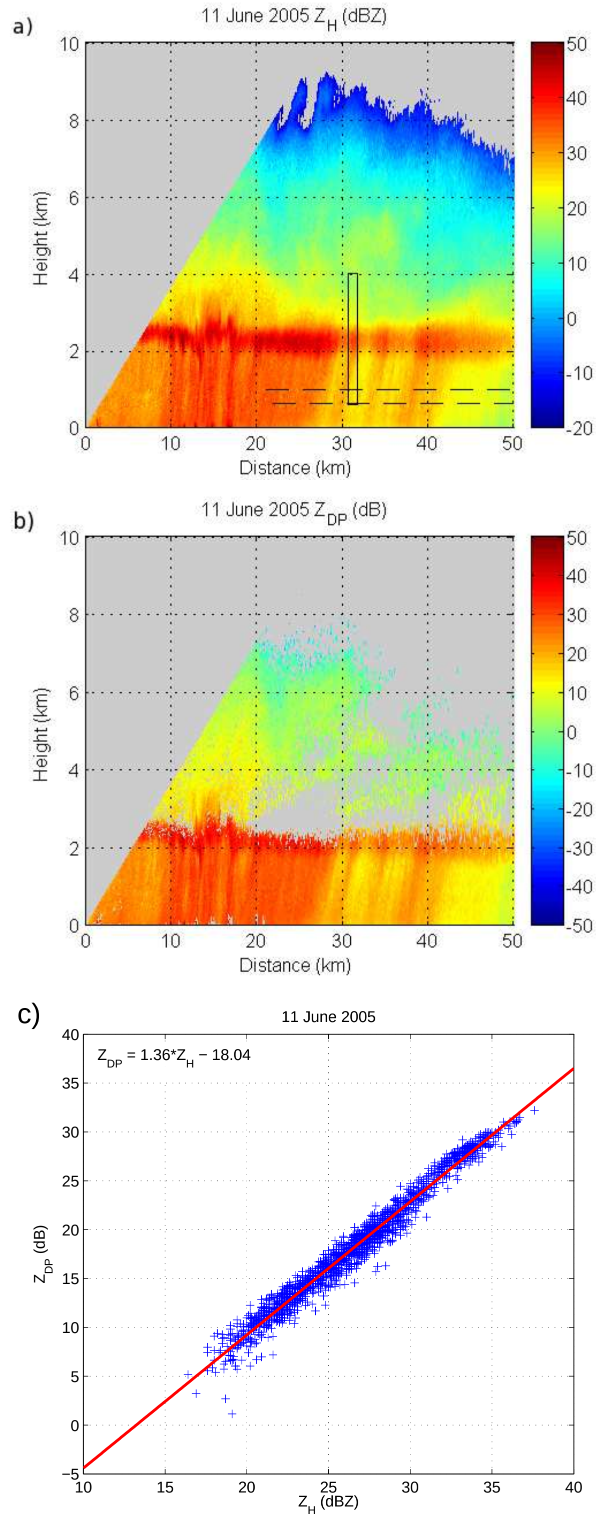

Figure 1: RHI scans of a) Z_H and b) Z_{DP} of the stratiform rain event on 11 June 2005 at 23:44 UTC. Figure c) shows the rain line calculated from the area between dashed lines marked in a). The solid line rectangular in a) represents the area used for ice fraction calculations.

2(a) ice fractions are calculated using a rain line obtained for the same day. As seen in figure 2(a) the vertical profile of most ice fractions is promising: below the melting layer, f is relatively constant, and the largest values are found at the upper part of the bright band. Still, below the melting layer, the ice fraction gets unrealistic negative values. Instead, values should be near zero, because we can assume that there is no ice present. Also ice fractions for the times 23:28 UTC and 23:44 UTC differ from others. During these times, differential reflectivities, as well as horizontal reflectivities (not shown here) below the melting layer, are smaller than in other cases. This indicates a higher relative number of small, and thus more spherical, drops. In such cases, a discrimination between ice particles (assumed to be spherical) and rain drops (assumed to be oblate) does not work properly.

To improve ice fraction calculations, we calculated rain lines on a case by case basis, since even small differences in the rain line have a strong impact on ice fraction calculations. These individual rain lines were calculated for data points well below the bright band and for each time using values from the same range gates mentioned above for the calculations. The results for ice fraction calculations using individual rain lines are presented in figure 2(b). Now the ice fractions are very close to zero below the bright band in all cases.

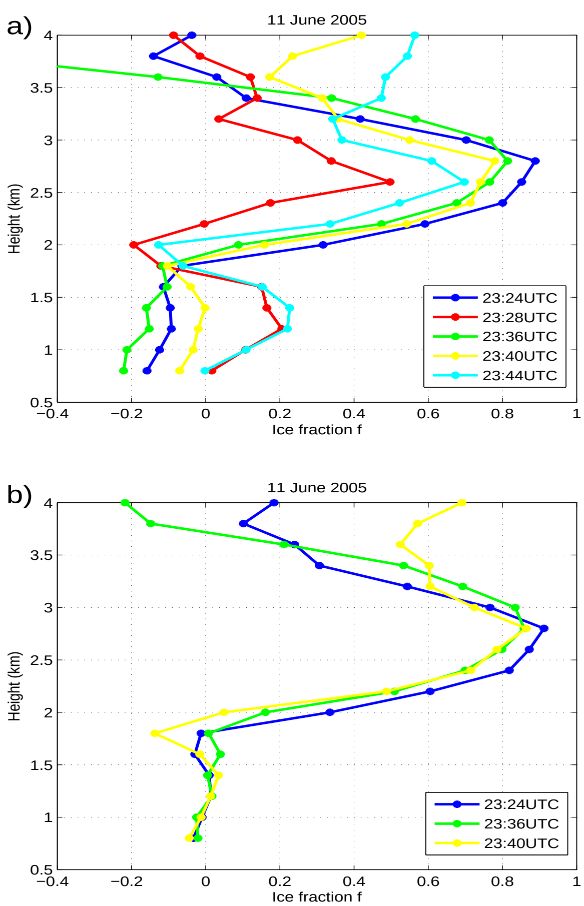

Figure 2: Vertical profiles of ice fractions for 11 June 2005 at ranges between 31.5 and 32.5 km calculated using a) an average rain line defined for that particular day and b) individual rain lines.

Above the melting layer, ice fractions first increase with height as expected, but at higher altitudes decrease again. This decrease has no physical meaning, since above the melting layer the ice fraction should have values near unity in cases with no strong convection and no liquid water. The reason for this conflict is again found in the definition of Z_{DP}. The ice fraction calculations based on Z_{DP} do not work properly above the melting layer, because there is no water present and Z_{DP} is not defined for populations of precipitation particles consisting only of spherical ice particles.

5.2 *CONVECTIVE RAIN*

In weak to moderate convective precipitation a clear bright band is seldom seen. On 15 May 2006 (Fig. 3), the height of the freezing level is about 0.8 km, according to sounding data obtained in Jokioinen at 12:00 UTC. In this convective case a rain line could not be obtained because of the lack of a bright band signature. Also, there seemed to be rain and ice present below the freezing level. The rain line used in this case was an average taken from three previously calculated rain lines (Table 1). The time evolution of this convective case could not be followed because of the rapid changes of the convective cell.

The area where ice fractions were calculated is marked in figure 3(a) as a solid line rectangular. The ice fraction is about 0.6 at a height of 0.8 km. It increases upwards and reaches a maximum at an altitude of 2 km. At a height of 3 km the ice fraction suddenly drops to values near 0.3. This sudden drop can be explained by the fact that the top of the cell is reached at about this height (Fig. 3(a)). Even though the lowest measuring point is at the same height as the freezing layer (0.8 km), it is clearly seen that there is no similar bright band signature in the ice fraction as can be found in the stratiform rain cases. Also, it is very likely that there is ice and water simultaneously present even at the a)

b)

c)

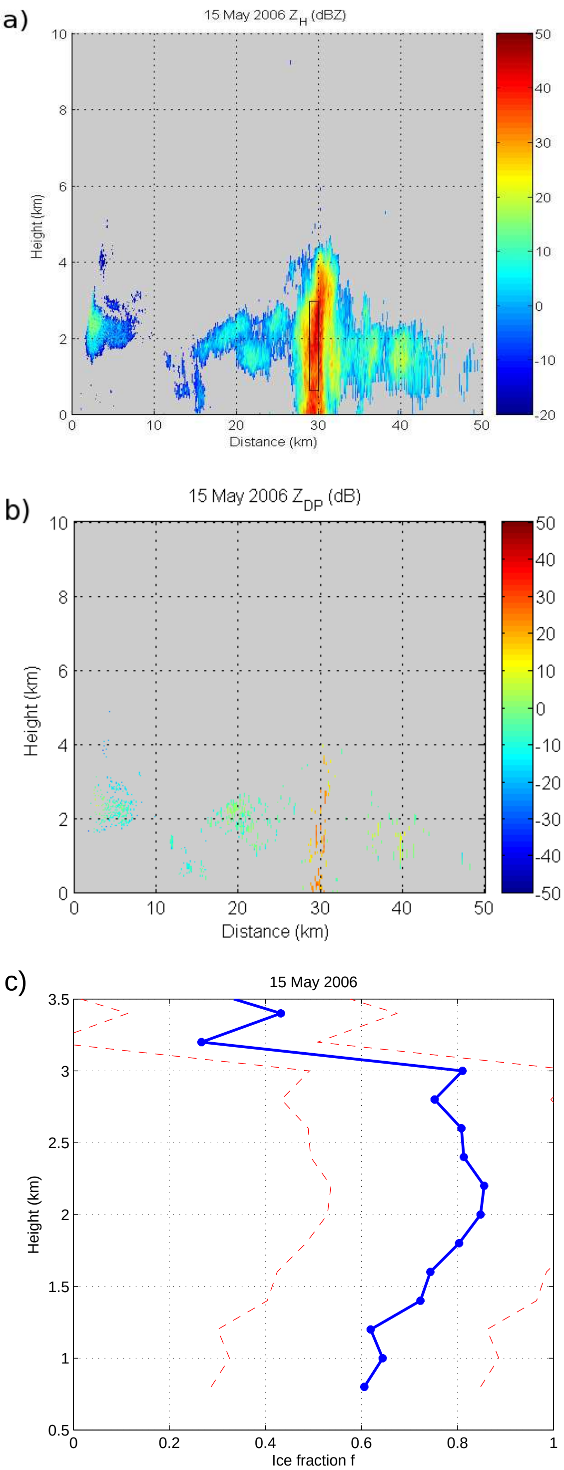

Figure 3: RHI scans of a) Z_H and b) Z_{DP} of a convective case on 15 May 2006 at 11:13 UTC. Figure c) shows vertical profile of ice fraction calculated for the area marked in a) as the solid line rectangular. Red dashed lines represent the error bars.

ground level, because at a height of 0.8 km, the ice fraction is still as high as 0.6.

6. CONCLUSIONS

Our results agreed in general with the results obtained earlier by other authors. The method of dividing the horizontal reflectivity into fractions corresponding to ice and liquid water with the aid of difference reflectivity seemed to work well below and within the bright band in most stratiform cases. However, in weak precipitation and above the melting layer, ice fraction calculations did not work properly. Reasons for these deficiencies are found from the following conditions conflicting with the basic assumptions of the method, namely:

1) Weak rain consists of small and almost spherical water droplets. As Z_{DP} is not defined in cases with spherical particles only, ice fractions cannot be estimated in weak rain events. Small water drops are possible both below and above the melting layer.

2) Precipitation consisting of ice only is assumed to be composed of spherical particles. As Z_{DP} is not defined in cases with spherical particles, Z_{DP} is not defined above the melting layer in stratiform situations without liquid water.

In more convective cases a well-defined bright band cannot be found, as both liquid and solid precipitation particles coexist within a deep layer due to the turbulent convective motions. In these cases, ice fraction calculations are physically meaningfull even above the freezing level. For the same reason supercooled water consisting of large drops may be detected and the ice fraction estimated above the melting level.

However, small, and thus spherical, droplets coexisting with ice particles cannot be discriminated from ice particles using only Z_{DP} with Z_H, as both particle types have non defined difference reflectivity and low horizontal reflectivity.

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