Four-Dimensional Microphysical Data from Darwin

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Introduction

The recently installed Atmosphere Radiation and Cloud Station 3 (ARCS3) site at Darwin benefits from a large network of existing Bureau of Meteorology Research Center (BMRC) and operational observing systems. These are illustrated in Figure 1. In particular, the BMRC C-Pol (C-band Polarimetric) radar (Keenan et al. 1998) is located approximately 20 km from the ARCS site and there are two wind

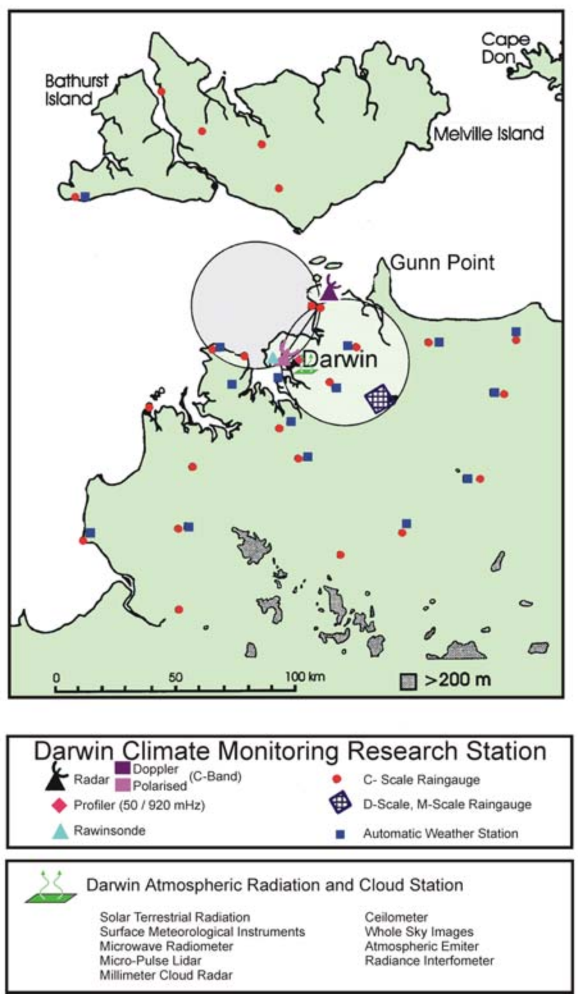

Figure 1. The Darwin observing network.

Profilers (a 50 MHz and a 920 MHz) collocated about 6 km from the ARCS site. These systems operate routinely and form part of the Atmospheric Radiation Measurement (ARM) external data stream. Two sets of C-Pol data are available from the ARM archive. These are Cartesian grids of reflectivity and microphysical classification of the detected hydrometeors. This paper examines some examples of these data and uses the profiler data to provide some ground truth for the microphysical classifications of the radar.

C-Pol Radar

The C-Pol radar runs a “volume scan” once very 10 minutes. These scans consist of a series of conical sweeps at a sequence of increasing elevations. Data is sampled every 300 m out to a range of 150 km. This builds up a three-dimensional picture of cloud systems. Note that at 150 km, the minimum detectable signal with the radar is about 0 dBZ, so the radar does see substantial amounts of non-precipitating cloud although clearly much less than the millimeter wave cloud radar (MMCR). The volume scan data is then interpolated onto a Cartesian grid.

The polarimetric radar alternates between horizontal and vertical polarization on a pulse-to-pulse basis. Thus, in addition to reflectivity, there are a number of additional parameters available. These include the difference in reflectivity between the signals at the two polarizations which is represented as the ratio of the Z_H/Z_V, the Z_{DR}, the correlation between the signals at the two polarizations, the ρ_{HV} (0) and the rate of change of the differential phase on propagation, the K_{DP}. The Z_{DR} is a measure of the mean oblateness of the hydrometeors. For example, large drops are oblate and produce large values of Z_{DR} (>3 dB); whereas snow and large hail tumbles have no preferred orientation, so Z_{DR} is typically near 0 dB. The ρ_{HV} (0) is near 1 for most rain, but drops substantially if the drops are very large (Mie scatter effects become important) or if there is mixed phase precipitation. The K_{DP} can be understood by considering that the two polarizations essentially see different water paths because of the oblateness of rain drops and therefore one polarization is retarded relative to the other (as the refractive index is > 1). In general, different hydrometeors occupy different parts of the four-dimensional phase space so that estimates of hydrometeor type can be obtained from the radar (Table 1). These are not completely unambiguous and a fuzzy logic approach is used to combine the polarimetric estimators. Some environmental information is also used. This approach is described in detail by Straka et al. (2000) and Keenan (2003).

An example of the radar data and the microphysical classification at a height just above the freezing level is shown in Figure 2. For the purposes of these plots, the classification 9 corresponds to wet graupel rather than large hail so that the mixed phase is highlighted in the figures. This figure nicely shows the presence of mixed phase (mainly wet graupel) in the high reflectivity areas of a thunderstorm over the Tiwi islands north of Darwin. This is consistent with the very strong updrafts in these storms and their high level of electrical activity.

In general, the microphysical classifications of the radar seem very reasonable. However, they have not been independently verified. The remainder of this paper deals with using profilers to verify the polarimetric classification and to point out some problem areas.

Table 1. Ranges of polarimetric variables and temperature for various hydrometeor species.

	Z_{HH} (dBZ)	Z_{DR} (dB)	$\rho_{HV}(0)$	K_{DP} (deg km^{-1})	Temperature (°C)	Classification Number in File
Drizzle	10-25	0.2 to 0.7	> 0.97	0 to 0.06	> -10	1
Rain	25 to 60	0.5 to 4	> 0.95	0 to 20	> -10	2
Snow (Dry, Low Density)	-10 to 35	-0.5 to 0.5	> 0.95	-1 to 1	< 0	3
Snow[(a)] (Dry, High Density)	-10 to 35	0.0 to 1	> 0.95	0 to 0.4	< 0	4
Snow (Wet, Melting)	20 to 45	0.5 to 3	0.5 to 0.9	0 to 1	0 to 5	5
Graupel, Dry	20 to 35	-0.5 to 1	> 0.95	0 to 1	< 0	6
Graupel, Wet	30 to 50	-0.5 to 2	> 0.95	0 to 3	-15 to 5	7
Hail, Small < 2cm Wet	50 to 60	-0.5 to 0.5	0.92 to 0.95 -0.95	-1 to 1	-15 to 5	8
Hail, Large > 2 cm Wet	55 to 65	-1 to 0.5	0.90 to 0.92	-1 to 2	-25 to 5	9
Rain and Hail	45 to 80	-1 to 6	> 0.9	0 to 20	-10 to 10	10

(a) Rimed and aggregated snow.

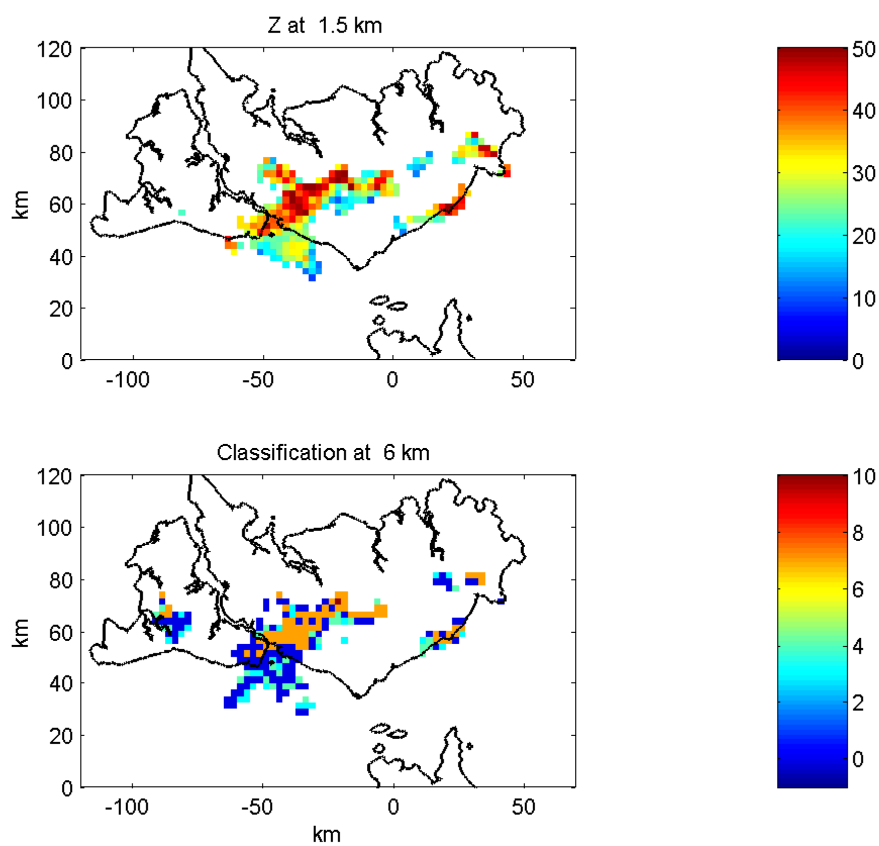

Figure 2. Example of reflectivity and microphysical classification. Note that 9 corresponds to wet graupel here to highlight mixed phase areas.

Profiler Studies of Precipitation

Wind profilers have been used for the study of precipitation for more than a decade. The ability of the profilers to simultaneously observe spectral peaks associated with the clear air vertical motion and peaks associated with hydrometeors has allowed the estimation of raindrop size distributions (e.g., Wakasugi et al. 1986), snow size distributions (Rajopadhyaya et al. 1994), and studies of the radar bright-band (Drummond et al. 1996). More recently, May et al. (2001, 2002) examined several storms where there was significant production of hail and graupel with a combination of wind profiler and the C-Pol data. In particular, the combination of 50-MHz and 920-MHz profilers was used to directly sense particles with fall speeds greater than the asymptotic limit for raindrops. The details of the profiler Doppler spectra and the retrievals of microphysical characteristics can clearly be used to validate the C-Pol estimates.

One of the key tests of the C-Pol classification will be the delineation of areas of mixed phase precipitation, in particular wet graupel and rain/hail mixtures. This is manifested in the profiler data as areas where there is significant signals in the profiler Doppler spectra corresponding to particle fall speeds greater than the asymptotic fall speed for rain (~$9.8/\rho^{0.4}$ ms^{-1} where ρ is the air density). As a guide, fall speed exceeding about 10 ms^{-1} indicates significant dense solid precipitation.

Verification

Figure 3 shows an example of a time height cross section of the profiler reflectivity, vertical motion and reflectivity weighted fall speed relative to the air (i.e., the vertical motion has been subtracted) through a squall line. This example shows a strong updraft on the periphery of the main precipitation core. However, this updraft is within the cloud as demonstrated by a weak increase in the 920-MHz reflectivity. The maximum updrafts exceed 10 ms^{-1} and it is reasonable to expect that super cooled drops are being lofted and significant riming is occurring. This is corroborated by the large fall speeds seen in the downdraft in the high precipitation area. One intriguing feature is the apparent upward moving precipitation next to the top of the main updraft. Detailed examination of the radar Doppler spectra shows that there are two peaks in the 50-MHz spectrum. The one moving at a lower speed is a downdraft and is the larger of the two peaks, but there is also a secondary upward peak and the 920-MHz spectral peak corresponds to this. What appears to be happening is some overturning, which is also indicated in the reflectivity structure, and that the precipitation in the downdraft is evaporated, perhaps intensifying the downdraft and there is small precipitation being carried aloft in the updraft. This kind of feature has now been identified in several cases.

There is also an indirect confirmation of mixed phase and graupel production in the area. Lightning echoes are seen in the profiler data. These are most clearly seen in the 50-MHz data but are also visible as small bright spots at altitudes ~7 km to 8 km just after the main peak of precipitation. This is not the radar seeing the direct radio emission from the lightning as that would appear at random height, but rather is radar reflections off the ionization trail of the lightning as it is advected through the radar beam (and possibly sidelobes, but the fact that it appears in both of the profilers suggest it is the main beam). These lightning echoes typically have very large spectral widths and very high power at 50 MHz.

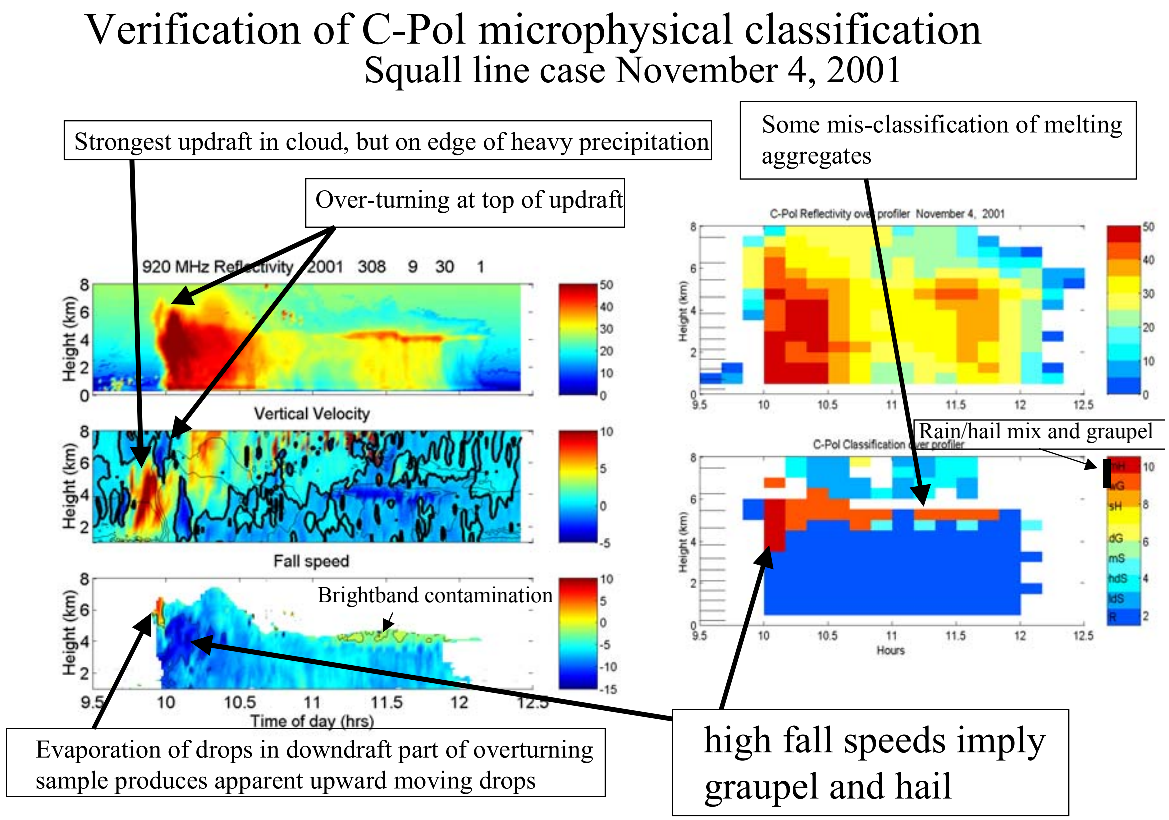

Figure 3. Time height cross sections of the reflectivity, vertical motion, and reflectivity weighted fall speed of the hydrometeors measured with the profilers at Darwin during a squall line passage on November 4, 2001. The corresponding time height cross sections of the reflectivity and microphysical classification measured by the C-Pol radar is shown on the right. Again, wet graupel is given as classification 9 to highlight it in the figures. Note that in the original file, classification 9 corresponds to large hail.

The time height cross section of the C-Pol data above the profiler is broadly consistent with the profiler data (given the 10-minute sampling and the vertical interpolation. The regions where the estimate is we graupel and rain/hail mixtures correspond very closely with the profiler regions of high fall speed and there appears to be consistent estimates of rain and snow. However, the C-Pol classifications are far from perfect. One area is clearly the brightband in the trailing stratiform rain area. Here the dominant precipitation will be melting snow, but this is misidentified as wet graupel. This needs to be examined in more detail, but perhaps the snow consisted of relatively large crystals. It is also highly probable that the ice crystals are heavily rimed and the resulting polarimetric signatures are indeed similar to those of small graupel.

Several more cases have been examined including another squall case, which had its heaviest precipitation in the main updraft. Weaker cases have been examined where there were smaller vertical motions and no indications of graupel were seen in the profiler data or the C-Pol classification. The aim over the next few months will be to examine a sufficient number of cases to make these comparisons more quantitative.

Conclusions

The profiler data is clearly useful in verifying the C-Pol microphysical classifications. Furthermore, the classifications themselves are fairly robust, although they have some problems, particularly in brightband conditions. This verification study is currently limited to just a few cases but is being extended.

The C-Pol dataset will be very useful in placing the ARCS3 data in context with respect to the cloud origin and the characteristics of the parent convection. This gridded data is being made available as an external dataset to the ARM community as is the profiler data.

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