P10.12 RADAR VERTICAL PROFILES AND MELTING LAYER STUDIES FROM AN S-BAND DOPPLER POLARISATION-DIVERSITY RADAR CAMPAIGN IN SINGAPORE

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1. INTRODUCTION

As part of the TRMM and EUROTRMM projects the Radio Communications Research Unit, at Rutherford Appleton Laboratory, designed, built and installed a 3 GHz (S-band) Polarisation Diversity Doppler Radar at Nanyang Technological University (NTU), Singapore. The radar provides information on the vertical structure of precipitation, including the melting layer height and thickness.

The melting layer is the transition region between snow and rain, and its characteristics are vitally important to remote sensing, and in particular to TRMM rainfall retrieval algorithms, because it defines the rain height, and the impact of melting particles on satellite radar profiles. The concept of rain height plays an important role in propagation modelling for satellite communications, because rain significantly attenuates millimetre wave signals, while ice does not. Information on the melting process in the tropics is still very sparse, and radar can play an important part in improving knowledge in this area.

The use of different radar parameters gives rise to specific signatures in the melting layer, due to changes in index of refraction, particle number density, shape and fall speed during the melting process. This paper explores some of these characteristics in detail.

2. INSTRUMENTATION

The 3 GHz S-band Polarisation Diversity Doppler Radar has been gathering data at NTU (lat. 1.34 ^{o}N, long. 103.68 ^{o}E, 49 m above mean sea level (a.m.s.l.), since its installation in April 1998. The radar uses fixed slant and vertically pointing scans, and records four parameters; radar reflectivity (dBZ), linear depolarisation ratio (LDR), Doppler velocity and spectrum width, in 75 m range gates, with a 1.6 s update rate. It was calibrated in the UK using the Chilbolton Radar, and, after installation at NTU, using a co-located Joss distrometer. (Wilson et. al, 1999).

Radiosonde data were made available for 1998, courtesy of the Meteorological Service Singapore. The radiosonde is launched twice daily in the East of Singapore Island (lat. 1.33 deg. N, long. 103.88 deg. E, 14m a.m.s.l.), at 00:00 UTC and 10:00 UTC. Measurements are taken at 50 m intervals from ground level to 5500 m aloft.

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Radar reflectivity from a vertical pointing scan lasting about 1 hour is shown in Figure 1. The scan shows a clear bright band (maximum in reflectivity) at a height of 4.5 km a.m.s.l.

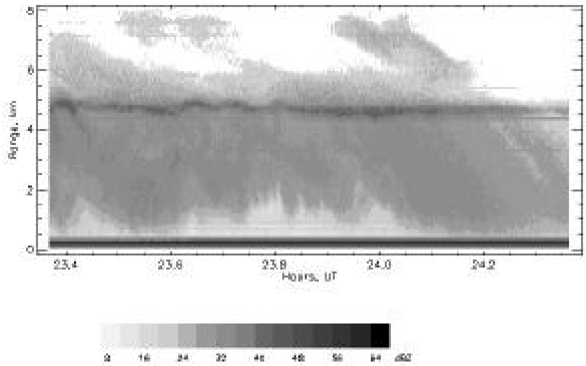

Figure 1. Vertical radar reflectivity scan, 24th September 1998.

Figure 2 shows all 4 radar parameters, reflectivity, LDR, velocity and Doppler width, from a single profile, obtained at the end of the time series in Figure 1, at 24.00 UTC. Also shown is the concurrent radiosonde ascent, which indicates the 0°C height is at 4.6km.

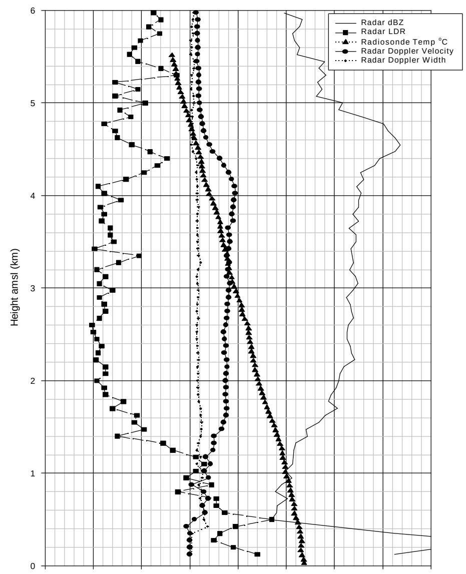

Figure 2. Vertical profiles of radar parameters versus height (a.m.s.l.), compared with radiosonde data, 24:00 24th September 1998.

3. MELTING LAYER STRUCTURE

Previous studies of melting layer characteristics have defined various key points with which to identify the precise top and base heights of the layer. Examples of these points, together with peak values, are defined as follows, and are illustrated schematically in Figure 3.

From the reflectivity profile:

- A - The level above which dBZ begins to increase rapidly, at the bottom of the enhancement.
- B - The position where the peak in dBZ occurs.
- C - The point at the top of the enhancement directly above position A, which, by definition, has the same reflectivity value as that at point A. This is referred to as the 'Freezing level point', (Smyth and Illingworth, 1999).
- D - Location where the gradient rises sharply after the enhancement in dBZ, (Bandera et. al. 1998).

From the LDR profile:

- L - The point where the peak in LDR occurs.

Using radiosonde data, the point O is noted where the temperature reaches 0^{o}C (assuming a monotonic decrease of temperature with height).

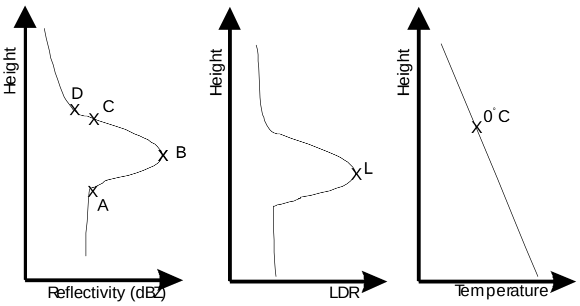

Figure 3. Key heights noted from vertical radar profiles and radiosonde data

3.1. RADAR RESULTS

From fifty-six vertical profiles recorded during the end of the SW monsoon season and throughout the pre NE monsoon season (the last four months of the year) of 1998, we have noted the heights of the points A-D. During this period, the bright band maximum only varied by 500 m, from 4.3 to 4.8 km a.m.s.l.

Clearly, the thickness of the bright band depends on whether point C or point D is considered as the top. Point A is always taken as the bottom. With point C taken as the top, the bright band thickness varies between 400m and 1000m, with a mean thickness of 750m. With point D taken as the top, the thickness varies between 500m and 1300m, a much wider spread, with a mean thickness of 840m.

3.2. RADAR AND RADIOSONDE COMPARISONS

There were ten stratiform events when concurrent vertically pointing radar and radiosonde data were recorded between September and December 1998. Height measurements were compared for points, A-D, L and O obtained from these data sets. The average heights for each of these points calculated from all ten stratiform profiles are shown in Table 1.

It can be seen that the height of the peak in LDR is 209 m lower than the height of the peak in dBZ, on average. This is due to the different effects of the microphysics on reflectivity and LDR. While reflectivity is dependent on the number density, size and dielectric constant of hydrometeors, LDR is also affected by the shape and orientation (canting).

Comparing the radiosonde temperature profiles and the radar data, the 0^{o}C isotherm occurs on average at 4.73 km a.m.s.l., roughly half way between the peak in the bright band and the top of the bright band, and around 450 m above the bottom of the melting layer. The average distance between points O and B is 137 m, considerably less than the 500 m typically assumed

If the top of the melting process is taken as the 0^{o}C isotherm and the process is considered to be complete at point A, an average melting layer thickness of around 450 m, is found, starting at 0^{o}C and finishing at 4-6^{o}C.

Point	Height, km a.m.s.l.
D	4.947
C	4.908
O	4.762
B	4.625
L	4.416
A	4.310

Table 1. Average values of points, A-D, L & O in the melting layer.

The above results clearly illustrate the difference between the 'bright band' height and the 'rain height'. The bright band height is usually associated with the peak/maximum radar reflectivity dBZ, whereas the rain height is the point in the atmosphere at which the process of melting from pure ice to water is complete. While the height of peak dBZ is usually closer to the top of melting layer, the height of peak LDR is closer the bottom of melting layer, and therefore the parameter LDR is a better signature to identify the true rain height.

4. VERTICAL PRECIPITATION STRUCTURE

To study the full vertical structure of both stratiform and convective precipitation in Singapore, radar data from April to December 2000 were used. There was an even spread of events during the time period of data extraction as rain occurs throughout the year in Singapore. The vertically pointing data were averaged over a one minute period. The linear values of reflectivity from these profiles were then averaged to obtain a climatological mean vertical profile of reflectivity. Only strong events for both stratiform and convective regions were utilised. Stratiform events were identified by the presence of a strong bright band, while convective sections of events were identified by their turbulent nature, with the occurrence of up and down drafts indicated in the Doppler signatures.

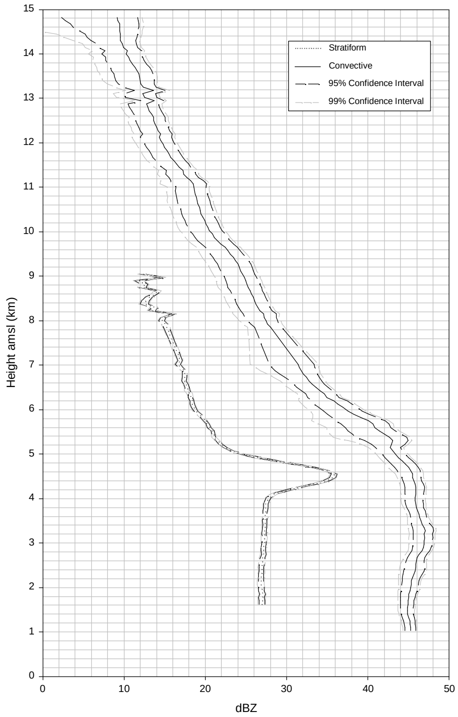

Figure 4. One minute averaged vertical profiles extracted from convective and stratiform events, April-December 2000.

There were nearly three times as many stratiform profiles as convective profiles, because stratiform events tend to last longer than the short, intense convective stages. The average profiles obtained are shown in Figure 4.

Due to the location of the radar, there is a significant degree of ground clutter at short ranges. Therefore data between 0 - 1.5 km range on the stratiform events are not shown in Figure 4. Convective events tend to have much higher reflectivity values, so that clutter is less evident. As a consequence, only data between 0 – 1 km range on the convective events are excluded from Figure 4.

The results show the peak in the bright band to occur around 4.5 km a.m.s.l., in agreement with the results described earlier. The stratiform profile shows that reflectivity in rain, between 1.65 km and 3.6 km, is not constant with height, but decreases at a rate of 0.26 dB/km from below the melting layer to the ground. This is most likely due to evaporation.

As expected the convective profile does not show evidence of a bright band and the values of radar reflectivity are considerable higher than in the stratiform situation. The convective events also extend to much greater heights, often reaching 15 km in height. The confidence intervals also plotted in Figure 4 show that the convective profiles are considerably more variable the stratiform profiles.

5.CONCLUSIONS

From the studies of vertical profiles of radar parameters in Singapore we have seen that peaks in dBZ and LDR are related to different stages of the melting process. The peak in LDR is within 100 m of the bottom of the melting process. The peak in dBZ, found on average at 4.5 km a.m.s.l. in Singapore, lies half way between this peak in LDR and the 0^oC isotherm. The variation in the height of the 0^oC isotherm and the height of the peak in dBZ is no more than 450 m during the year, due to the relatively constant ground temperature in Singapore. The thickness of the melting layer is 450 m.

The averaged profiles of stratiform and convective events show that convective events often extend to heights of 15 km, and that below the bright band there is a decrease in reflectivity as rain falls to the ground, possibly due to evaporation.

Future work will focus on analysing more events and looking into the relationships between rainfall rate, melting layer thickness and enhancement in radar reflectivity.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Bandera, J., Papatsoris, A.D., Watson, P.A., Tan, J., and Goddard, J.W.F.,1998: Method for detecting the extent of the melting layer, *Electronics Letters*, *34*, 22-23.

Smyth, T.J., and Illingworth, A.J., 1997: Estimating rainfall rates at the ground in bright band and non-bright band events, *27th Int'l Conf. On Radar Meteorology*, 125-126.

Wilson, C.L., Goddard, J.W.F., and Ladd, D.N., 1999: Distrometer-derived Z-R relations in Singapore and Papua New Guinea, and implications for the TRMM products, *29th Int'l Conf. On Radar Meteorology*, 647-650.