Radar bright band correction using the linear depolarisation ratio.

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Abstract The enhanced radar return associated with melting snow, 'the bright band', can lead to large overestimates of rain rates. Most correction schemes rely on fitting the radar observations to a vertical profile of reflectivity (VPR) which includes the bright band enhancement. Observations show that the VPR is very variable in space and time; large enhancements occur for melting snow, but none for the melting graupel in embedded convection. Applying a bright band VPR correction to a region of embedded convection will lead to a severe underestimate of rainfall. We revive an earlier suggestion that high values of the linear depolarisation ratio (LDR) are an excellent means of detecting when bright band contamination is occurring and that the value of LDR may be used to correct the value of Z in the bright band.

INTRODUCTION

Errors in precipitation intensity of up to a factor of five can result from the enhanced radar return due to the melting snow (the bright band) if left uncorrected (Joss and Waldwogel, 1990). The challenge is first to identify when bright band contamination is occurring so that any rain rates derived from reflectivity can be flagged as error prone. The second challenge is to derive an accurate rainfall at the ground when the beam is sampling the bright band. The approach generally adopted is to compute a mean vertical profile of reflectivity (VPR) by analysing the operational radar data itself and then use the shape of this mean VPR to predict the rain at the ground. For example, Tabary et al (2007) in France use a correction scheme based on a mean 'daily' VPR with four adjustable parameters which is derived from all observations within 250km over a 24 hour period. The scheme in the UK (Kitchen and Davies, 1994) uses a more constrained 'standard' high resolution VPR; the height of the top of the bright band is fixed to the level of the 0°C isotherm in the operational forecast model, the bright band depth is fixed at 700m, and the enhancement is a prescribed function of the rainrate. The VPR has just one degree of freedom, which is the scaling factor in Z, and this is chosen iteratively so that, when the VPR is multiplied by the appropriate beamwidth of the operational radar, it agrees with the Z observed by the radar. Mittermaier and Illingworth (2003) have shown that the average error in the height of the top of the bright band predicted from the forecast model is less than 150m.The advantage of this scheme is that a local VPR is computed for each radar gate. The performance of this approach is analysed in Harrison et al (2000).

One particular shortcoming of the 'standard' or 'mean' VPR approach is that embedded convection is quite common and has no bright band, so applying a VPR will lead to a drastic underestimate of rainfall at the ground. In practice VPRs are variable in space and time, so mean profiles are not representative. We propose to revive a scheme first proposed by Caylor et al (1990) which uses the value of the linear depolarisation ratio (LDR) to identify the bright band; values of LDR between -14 to -18dB result from the large oblate melting snowflakes which rock from side to side as they fall, and are associated with a value of Z in the bright band about 10dB higher than in the rain below. In contrast to this, embedded convection has an LDR below -18dB, because the melting graupel or soft hail pellets are much more spherical, and the value of Z at the freezing level is very similar to that in the rain below. Caylor et al (1990) noted that the value of the co-polar correlation (ρ_{HV}) between the time series of the returns for the horizontally and vertically polarised transmitted pulses fell to about 0.9 in the bright band because of the variety of hydrometeor shapes present, whereas in rain ρ_{HV} is over 0.98. However, because the difference in

LDR in the bright band and the rain is so much larger than the change in $\rho_{HV,}$ they felt that the LDR method would be more reliable. Modern polarimetric radars transmit V and H pulses simultaneously at 45° and receive the co-polar signals at the same time. This means that LDR has fallen out of favour because dedicated scans are needed for its measurement. Matrosov et al (2007) discuss the use of ρ_{HV} to identify the bright band in more detail.

THE CHILBOLTON DATA SET

Examples of LDR data are displayed in figures one and two which are vertical sections (RHIs) through stratiform rain and embedded convection, respectively. The data were obtained with the S-band Chilbolton radar which has a 300m gate length and 0.25° beamwidth so that the vertical resolution at 57km is just 250m. These RHIs immediately reveal the vertical structure in a way which is not at all evident from the operational radars which scan in azimuth at a low elevation angle with a 1° beam. In figure one, the rain is horizontally rather uniform; the bright band at 2.2km altitude with a depth of about 700m is very obvious as is the large enhancement in Z, which we will call ΔZ, when compared with the rain below. Above the bright band in the ice the Z values drop of very rapidly with height. The LDR signature of the bright band is very clear with values of about -16dB which are 10dB higher than in the rain below or the ice above. Note that clutter in the lowest elevation beam can be identified by its high values of LDR.

A very different picture is evident for the embedded convection in figure 2. The very high values of Z between 32 and 36km range exceed 46dBZ and reach an altitude of 7km without any visible bright band. This region is surrounded by rain with quite a different VPR; Z values in the ice are much lower and there is a significant bright band. The LDR signatures clearly differentiate the embedded convection from the surrounding stratiform rain and bright bands. The bright band has an LDR of -14dB which is only 700m thick, whereas in the convective region there are some high values of LDR but generally at temperatures below freezing; these are associated with wet oblate hail which tumbles as it falls.

The extensive Chilbolton data set of many RHIs can be used to examine how well LDR can identify the presence of bright bands, and if a correlation exists between the value of LDR close to the freezing level and the enhancement of reflectivity, ΔZ, in the bright band compared with the reflectivity in the rain below. The first analysis will involve the original high resolution data, but the data can be degraded to mimic what an operational 1° beamwidth radar would measure. One issue of interest is the behaviour of LDR and ΔZ at larger ranges where both will be reduced because the bright band will not fill the radar beam.

ANALYSIS OF TWO CASE STUDIES

Figure 3 shows a uniform bright band case similar to that in figure 1. Superposed on the two RHIs is a uniform horizontal black line which is the 0°C isotherm. The analysis is performed on vertical profiles using a 0.9km (three gate) running averages; this is to minimise wind shear effects which lead to sloping rather than vertical profiles. The first step, shown in the panels on the LHS of the figure, is to locate the height of the maximum Z in each profile within ±750m of the 0° isotherm, and if this maximum is within ±500m of the isotherm and has a Z > 25dBZ, find the value of Z 750m below this maximum (shown as the two rows of black dots superposed on the RHI), and finally the difference in these two values of Z, which is ΔZ, the bright band enhancement. The ±750m and ±500m limits are to restrict the search to a region where a bright band is expected, and the 25dBZ limit is introduced so that areas of rainfall less than about 1mm/hr are excluded. Such low echo regions are often associated with the ragged edges of clouds where the concept of a VPR is not valid. If no maximum Z is found within ±500m, no bright band has been found, then the 'enhancement' is computed from the Z value 250m and 1km below the 0°C isotherm. Such data points are plotted as a single '*' symbol; there are only three in this case, close to the maximum

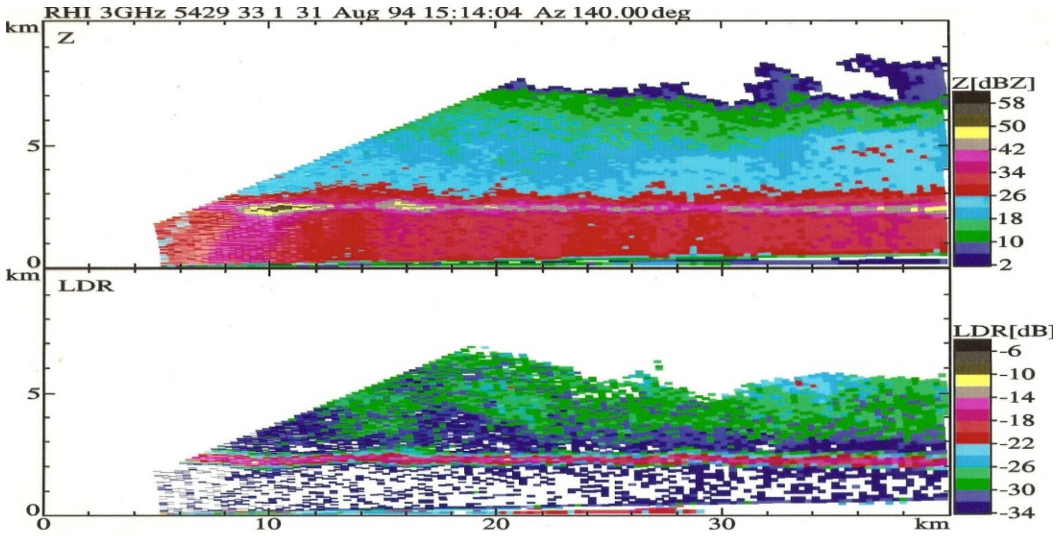

Fig. 1 An RHI through widespread stratifrom rain taken with the 0.25° beamwidth Chilbolton radar. Upper panel. Radar reflectivity; The bright band of enhanced reflectivity at 2.2km height is clearly visible. Lower panel: Linear depolarisation ratio. (LDR). The value is about -16dB in the bright band but 10dB lower in the ice above and the rain below.

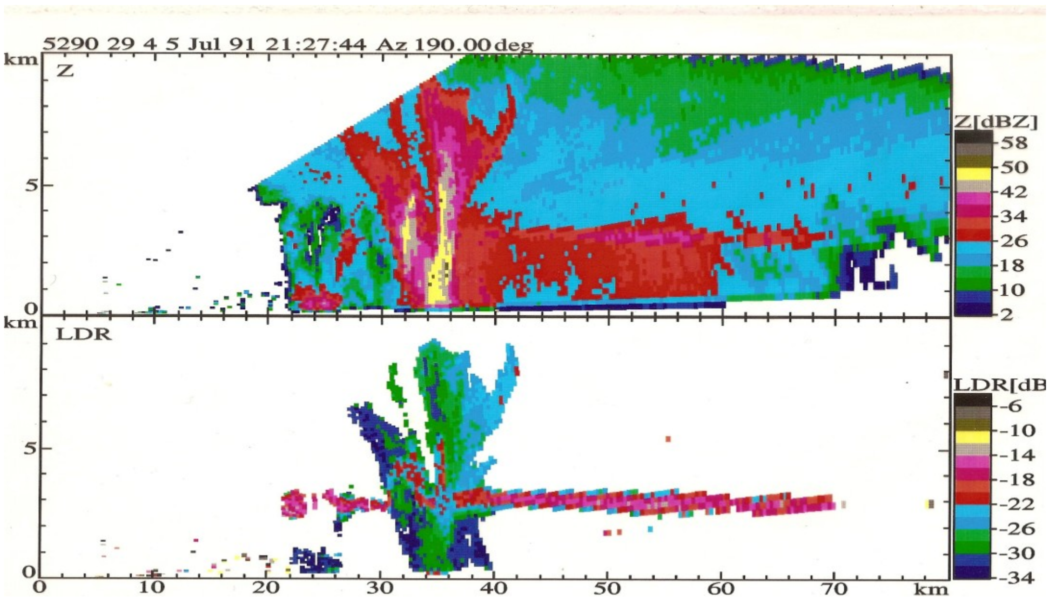

Fig. 2 As for Fig 1 but for a case with embedded convection. Note the high values of LDR coincident with the bright band in the stratiform areas. The LDR accompanying the high Z echo from 32-36km range is generally lower, but some high values are found above the melting layer and are associated with melting hail.

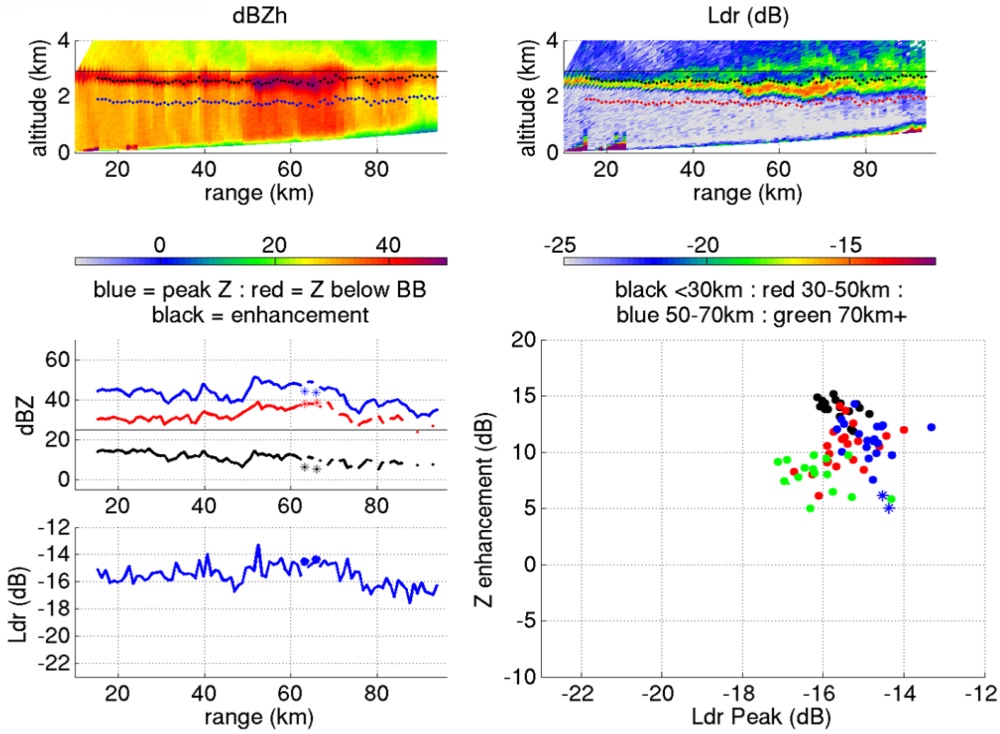

Fig. 3 Stratiform case; 13 Aug 2005 at 1300h. LHS: Upper plot - Straight black line - 0°C isotherm. The two black lines are the where Z peaks and 750m below. Middle plot: peak Z, Z 750m below and the enhancement in Z in blue, red and black respectively. Lowest plot: peak values of LDR. RHS: Upper panel: LDR values. Red line is the position of max Z. Lower panel: Peak LDR versus enhancement for various ranges.

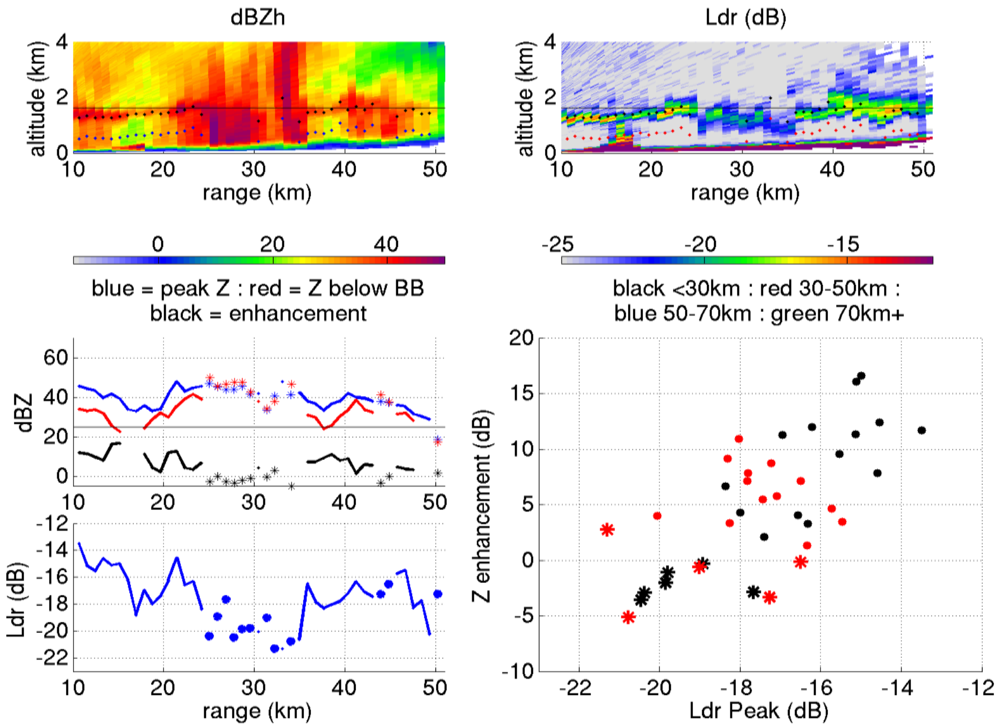

Fig. 4 Embedded convection: 15 March 2010, 1647h. As for Fig 3. The stars indicate gates where no max in Z was found, so Z value 250m below the 0°C isotherm was used.

range of 90km. The lower plot on the LHS is the maximum value of LDR which is found within ±750m of the 0°C isotherm. On the RHS, the top plot is the LDR RHI, with the red dots indicating the position of the maximum Z in each profile The lower plot on the RHS tests the hypothesis that the bright band reflectivity enhancement ΔZ is related to the maximum value of LDR; in the scatter plot the colour indicates the range of the profile. The points lie in a fairly tight cluster with enhancements between 5 and 15dB and LDR ranging from -13 to -17dB. The more distant green points at a range beyond 70km have values of ΔZ and LDR which both average about 5dB lower than for the points at shorter range. This is encouraging for any correction scheme; it suggests that the beamfilling effects at larger ranges affect LDR and ΔZ to the same extent.

Figure 4 shows a more challenging case of embedded convection. Between 25 and 35km where Z values are highest most of the profiles are indicated with a star, indicating that no bright band was identified. These profiles have a maximum LDR of between -18 and -22dB and generally a value of ΔZ which is slightly negative. The scatter plot of ΔZ against LDR for all profiles is very encouraging; Z enhancements range from -5dB to +15dB and are well correlated with LDR which increase from -21dB to -13dB. In this case there are no data beyond 50km so beam filling is not a problem.

FUTURE WORK AND OPERATIONAL IMPLEMENTATION

The correlations between ΔZ and LDR found in figures 3 and 4 indicate that there may be some skill in a bright band correction scheme based on LDR. The next step is to examine the rest of the high resolution data set to provide more robust statistics. The final stage is to model the effects of a 1° beamwidth to see if the beamfilling affects LDR and ΔZ to the same extent so that the same correction algorithm can be used at all ranges. Currently, rainfall estimates are most accurate if the beam is sampling only the rain, so for a 1.7km freezing height, the beam must not be higher than 1km, leading to a 50km maximum range for a 0° elevation scan. If rain rates can also be derived from the bright band, the maximum height of the beam could be 2km and the range could be doubled.

Most polarisation radars transmit V and H simultaneously and cannot detect the cross polar return, so a special LDR scan is needed when either H or V polarisation is transmitted. However, because the LDR signal is so large, the required accuracy for LDR is low and can be achieved with a scan rate three times faster than for the normal scan. A possible implementation would be to have a conventional Z scan at each elevation angle followed by a rapid LDR scan for the VPR correction algorithm.

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