4.6 DIAGNOSING Z-R RELATIONS USING NWP

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1. INTRODUCTION

The use of a single $Z-R$ relation is predominant at most weather services. Some organisations have a summer relation and a winter relation and the switch between the two is performed according to the calendar. In northern Europe, the melting layer can exist even in mid-winter which causes bright bands (BB) in radar data. A given radar image, or even a given pulse, may contain solid, liquid and mixed precipitation phases on an annual basis in this region. This limits the use of static $Z-R$ or Z_e-S relations for quantitative measurements of precipitation rates.

Recent attempts at deriving techniques for dynamically determining the precipitation phase for a given radar pixel, and assigning an appropriate $Z-R$ relation (Saltikoff et al. 2000), have been made to improve the quantitative use of radar observations. In doing so, the relative importance of an accurate $Z-R$ relation was confirmed as being less than effects caused by the vertical reflectivity profile (VRP). Additionally, the inherent sampling errors involved in evaluating such methods using gauges (Kitchen and Blackall 1992) imply difficulties in revealing improvements using such methods.

This abstract presents and briefly discusses a method where information from a numerical weather prediction (NWP) model is used to diagnose the precipitation phase and assign appropriate $Z-R$ relations (DZRs) to radar data.

2. METHODS

Significant work has been performed in the past to derive $Z-R$ relations, mostly for rain but also for snow and hail (Battan 1973). In this approach, well-known relations taken from such previous work are used (figure 1). The procedure becomes twofold: first is the determination of the height and thickness of the BB and those parts of it which are located within the radar beam, and second is the derivation of the appropriate precipitation rate using dynamic $Z-R$ relations.

Input data consists of radar reflectivity (dBZ) composites from the BALTRAD network, static lookup tables containing the top and bottom heights of each pixel in the composite, derived using a digital elevation model and assumed standard beam refraction (Michelson et al. 2000), along with HIRLAM NWP model fields (Källén 1996). This model version provides a horizontal resolution of 22 km, 31 vertical levels, and hourly model states with 6-11 hour forecast lengths.

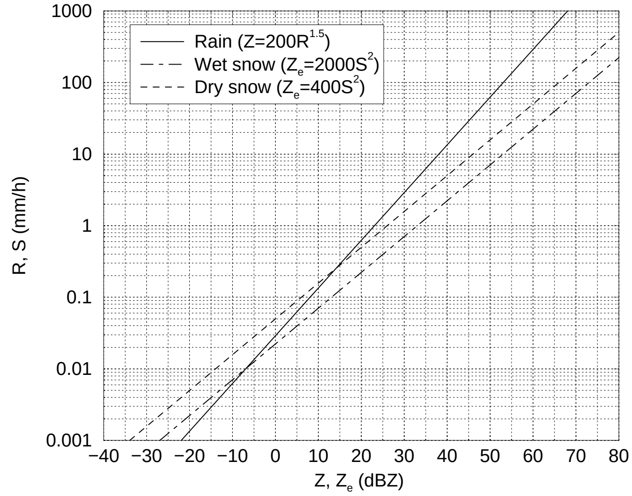

Figure 1: $Z-R$ relations used in this study.

Jonas (1999) and Hansson (1999) both identify the wet-bulb temperature (T_w) as being suitable for identifying the melting layer. Hansson (1999) showed in an experiment that the localization of the melting layer may be 250 m or more higher when using the temperature compared to using T_w. Since model layer thicknesses are often less than this within the planetary boundary layer, T_w is used in this application. A 3-D T_w analysis is performed and the height at which T_w=-0.21°C is defined as the top of the BB. This threshold is based on a relation derived for SMHI's Mesoscale Analysis System (Häggmark et al. 1997) which relates T_w to proportion of snow in precipitation using a large observational dataset; T_w=-0.21°C is the T_w where 99% of precipitation is snow. A static BB thickness of 600 m, with the peak in reflectivity centred, is assumed in this first version.

A standard half-power beamwidth is applied, which means 0.9-1° for those radars in the BALTRAD network (Michelson et al. 2000). The beamwidth relative gain (g) follows a Gaussian distribution defined as

$$g = exp\left(-ln2\left(\frac{\theta}{\theta_0}\right)^2\right) \quad (1)$$

where θ is the offset from the beam's main axis and θ_0 is the angle of half the half-power beamwidth.

Reflectivities with heights above the BB are converted to R using the coefficients for dry snow given in figure 1. Likewise, reflectivities below the bright band use coefficients for rain only.

In pixels with reflectivities originating from mixed-phase precipitation, the $Z-R$ conversion involves inte-

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grating between the pixel's top and bottom heights (z_t and z_b), deriving coefficients A_z and b_z according to their location above, within, or below the BB, and using the relative gain (g_z) from equation 1 as a weight. Schematically, this algorithm can be formulated according to equation 2.

$$Z_{(x,y)} = \sum_{z=z_b}^{z_t} \frac{g_z(A_z R_{(x,y)}^{b_z})}{\Sigma g_z} \quad (2)$$

Coefficent A varies linearly from 200 at the BB base to 2000 at mid-BB, and linearly again to 400 at the BB top. Coefficient b also varies linearly from 1.5 at the BB base to 2 at mid-BB.

A simple check for graupel and/or hail is included in this approach, where hail is diagnosed to occur if the equivalent radar reflectivity value at 1.5 km above the BB top exceeds 30 dBZ, according to Smyth and Illingworth (1998). The equivalent reflectivity is calculated assuming a vertical profile of -2 dBZ/km. Such values are not subject to DZRs since this would imply that a BB were present which would cause enhanced reflectivity which, in turn, would require a correction.

3. DISCUSSION

3.1 Example

The dynamic approach to deriving and applying $Z-R$ relations is illustrated in figure 2. A reflectivity value based on the top of the half-power beamwidth being at 3300 m and its bottom at 2200 m is defined. A 600 m deep BB is centred at 2700 m. A mean reflectivity factor of 27.7 dBZ results from a 1 mm/h precipitation intensity profile starting above the BB and ending below it (solid line). This profile is unweighted with respect to the beamwidth. If this mean value is distributed according to the half-power Gaussian distribution defined by equation 1, the dashed line is the result and the mean reflectivity factor becomes 22.5 dBZ. Then, if DZRs are derived and applied, the effect of the BB is significantly reduced (dot-dashed line) and the mean reflectivity factor is reduced to 18.9 dBZ. This value may then be converted to a precipitation intensity using coefficients A and b for rain and this intensity will be independent of phase.

3.2 Evaluation

The DZR approach is designed to increase the accuracy of measurements aloft. It's results are therefore invalid as surface measurements, which makes their evaluation against gauge observations difficult. The successful use of DZRs could, indeed, manifest itself in radar data having a greater range dependancy, since minimized BB effects would increase the bias between radar and gauges. The effects on a measurement aloft brought about by the VRP must first be treated before a proper evaluation may be conducted.

Gauge adjustment techniques (Michelson and Koistinen 2000) are blunt instruments in this context since they provide only a generalized means of reducing radar

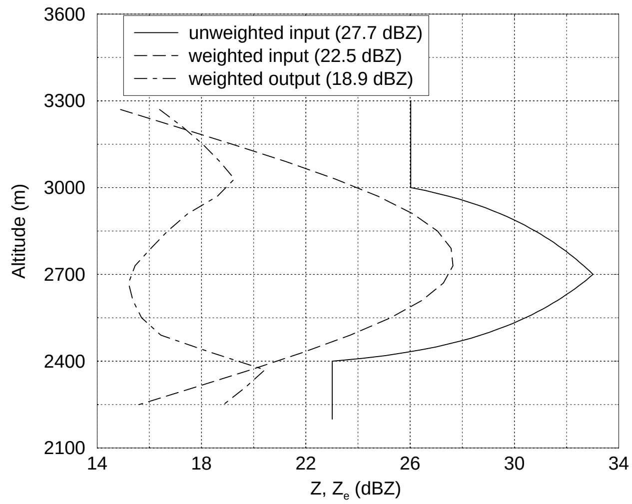

Figure 2: Unweighted equivalent reflectivities required to produce a 1 mm/h precipitation intensity (solid line) profile through a BB, and how this 27.7 dBZ reflectivity mean is convolved to a half-power beamwidth before (dashed line) and after (dot-dashed line) the application of DZRs. The BB is centred at 2700 m.

data's range dependency. A more appropriate strategy would be to apply a VRP correction, either one based on the statistical properties of radar data given different precipitation event types (Germann 2000) or a physically-based one (Hansson and Michelson 2000), before comparison with gauges. A natural requirement is that the VRP correction has already been proven successful at improving the accuracy of radar data.

3.3 Model dependency and use of T_w

The more dependent the DZR approach is on an NWP model, the more the benefits gained using the approach will be sensitive to the model's ability to be in phase, ie. forecast the right weather in the right place at the right time. Spinup is also an issue which must be addressed when using model data in this context. A tradeoff between spinup and phase problems has been attempted by using the 6-11 hour forecast lengths. Saltikoff et al. (2000) argue against using operational NWP models for these purposes since models can be out of phase by 100-200 km and not be able to accurately resolve boundary layer conditions associated with frontal passages. Yet, this approach requires an accurate description of the atmospheric state at the heights where radars make their measurements. It remains to be seen whether surface analyses extrapolated in the vertical, and/or soundings interpolated in the horizontal, are better suited to this purpose.

Kitchen et al. (1994) use the 0°C isotherm from NWP model fields to identify the BB top, which is a similar and more robust approach to the one presented here which uses T_w. In situations where the model may not produce accurate results, it may be safer to rely on fewer thermodynamic variables. Conversely, where the models succeed, the ability to resolve the BB, and thus minimize its effects, may be improved. Such improvements can be expected in dry layers under the cloud base, which implies radar data at relatively proximate ranges and low heights. These areas are where the radar can make its most accurate measurements as they are the areas with the smallest pulse volumes; this makes an accurate resolution of the BB vital if improvements are to be made using DZRs.

3.4 Future developments

The evaluation of the DZR technique will be evaluated, according to the strategy presented in section 3.2, prior to the conference and the results will be presented there.

Since the BB top is derived according to the threshold T_w at which precipitation is 99% snow, the BB base could likewise be defined as the T_w at which precipitation is 1% snow or less, which according to Häggmark et al. (1997) is 2.42°C. Whether this may lead to more accurate resolution of the BB will be investigated.

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