

ASSESSMENT AND TUNING OF THE BEHAVIOR OF A MICROPHYSICAL CHARACTERIZATION SCHEME BASED ON RADAR POLARIMETRIC VARIABLES

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1. INTRODUCTION

Considering the scientific evidence accumulated over the last decade, radar meteorologists made it clear that polarimetry will play a fundamental role in the forthcoming use of weather radars. Polarimetric radar data are relevant and have potential application in many diverse fields from improving quantitative precipitation estimates to identification of scatterers' nature and type, up-to improving initial conditions and constraints in numerical models for short term forecasts. Zrníc and Ryzhkov (1999) give a summary of the state-of-the-art of polarimetry for weather surveillance radar.

A never-ending task such as the best estimation of the rain pattern will benefit from polarimetric information. Indeed, the correct classification of the prevailing bulk hydrometeor type within a radar resolution volume should be a prerequisite of any quantitative rain-retrieving scheme. Further, the classifications is also useful for warning purposes and for validation of non-hydrostatic models where the physical parameterizations are so advanced that major hydrometeor species are represented.

Most of the work in this field is based on the use of S-band data, but the prospects of the deployment of polarimetric radars in Europe motivates the research community to increase work at shorter wavelengths. Radar data taken at C-band or X-band are affected by attenuation and resonance (see among others May et al. 1999, Zrníc et al. 2000). The difficulties in trying to identify the bulk hydrometeor types within a radar resolution volume are amplified by propagation effects at C band. We refer chiefly to incomplete understanding of radar signatures, ambiguities in hydrometeor classes, occurrence of artifacts in the data, and uncertainties in radar calibration.

For this reason particular attention and efforts should be addressed to adapt procedures from S band and validate these at C band. In this paper, we use the scheme developed at the National Severe Storms Laboratory (hereinafter referred to as NSSL scheme), with a reduced set of polarimetric variables (Z, ZDR) collected at C band.

2 HYDROMETEORS CLASSIFICATION SCHEME

The NSSL scheme is based on fuzzy logic and the reader should refer to Straka et al. (2000) and Zrníc et al. (2001) for an exhaustive introduction to it. In brief, let us say that it is based on a combination of weighting (membership) functions associated with a particular hydrometeor type. These are two-dimensional functions, the first argument being one of the polarimetric variables and the other the reflectivity factor Z. The classification is accomplished by taking the highest value of the combination of weighting functions for each image pixel.

The original version of the NSSL scheme uses four different radar variables plus the temperature profile (to remove certain ambiguities). The variables are: reflectivity (Z), differential reflectivity (ZDR), specific differential phase (KDP) and the cross-correlation coefficient between horizontally and vertically polarized waves (ρ_{hv}).

Currently, there are 11 hydrometeor classes that build on the synthesis by Straka et al. (2000):

- Light rain (LR);
- Moderate rain (MR);
- Heavy rain (HR);
- Rain dominated by large drops (LD);
- Rain/hail mixture (RH);
- Graupel and/or small hail (GSH);
- Hail (HA);
- Dry snow (DS);
- Wet snow (WS);
- Horizontally oriented ice crystals (HIC);
- Vertically oriented ice crystals (VIC).

For a fixed Z a trapezoidal membership function over a polarimetric variable describes the valid range associated with each specific bulk hydrometeor type. Finally a weight coefficient defines the relative importance of (confidence in) each variable.

The NSSL scheme is designed to take advantage of the presence of all available polarimetric variables and also to work with a reduced set of these. As discussed in Zrníc et al. (2001), the most discriminating variables are the reflectivity factor and the differential reflectivity. Based on this fact, we expect to obtain reasonable results with our C-band polarimetric radar, which provides the two most significant variables for the classification.

With such a reduced set we are able to study how sensitive the algorithm is to the possible set of the

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temperature weight (W_t), to the threshold value (S), and to their interrelationship.

3. OVERALL DESCRIPTION OF THE BEHAVIOUR

In order to assess the sensitivity of the scheme to small, if not infinitesimal, variations of the temperature weight and the threshold value, we consider a “representative” convective event. The reflectivity and differential reflectivity are displayed in Fig 1 and Fig 2.

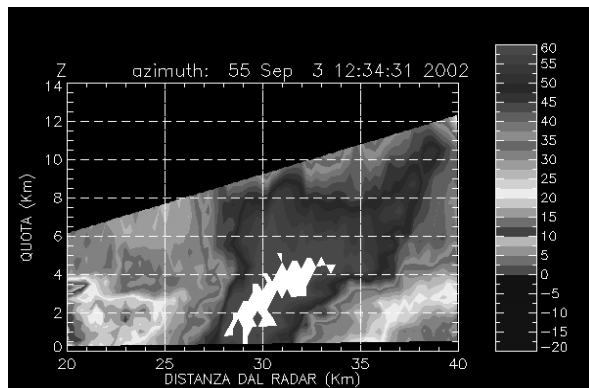


Figure 1 – 3 September, 2002; convective event observed by the SPC radar, the reflectivity is reported in gray scale

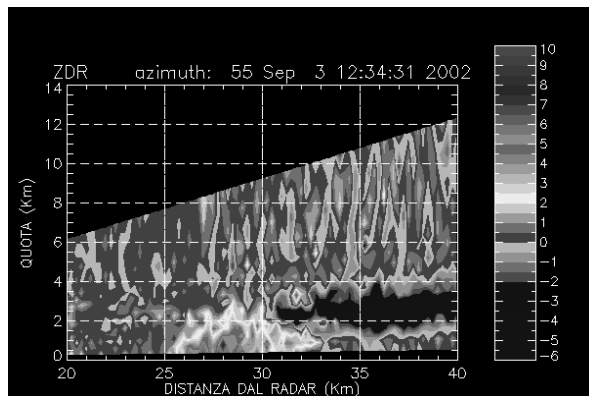


Figure 2 – Same as in Fig. 1, but for the differential reflectivity.

A direct application of the classification scheme with the “natural” values of S ($S=0.5$) and W_t ($W_t=1.0$) reproduces well known problems (see Fig. 3) already documented in other works:

- The attenuation cone behind the main convective core is filled with hail;
- Too many ice crystals identified at the highest levels.

These are, of course, not realistic in terms of cloud microphysics. We refer to this type of image as “spurious image” (SI).

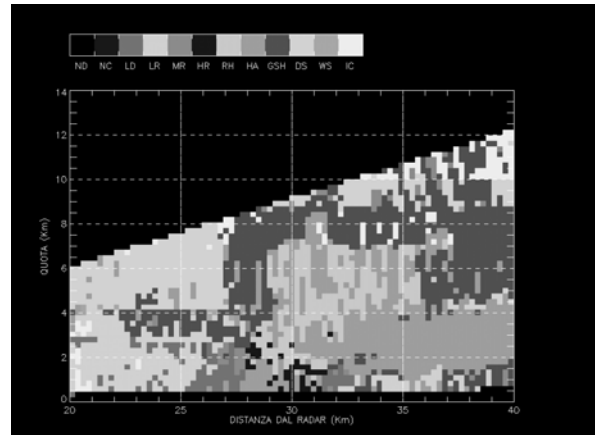


Figure 3 – Hydrometeor classification for the data in Fig. 1 and Fig. 2. ($S=0.5$, $W_t=1.0$)

Further, some pixels are assigned hydrometeors that are in contrast with the environmental temperature. Indeed, we note the presence of ice crystals close to the ground and moderate rain at roughly 8km above ground.

A decreasing of the temperature weight causes a transition in the behavior of the algorithm. The attenuated area is now unclassified and also the ice crystal pixels have diminished (see Fig. 4). Note that the pixels which were wrongly classified are now unclassified. On the same stream, also the area close to the base of the convective core is now partially classified as LD and partially unclassified.

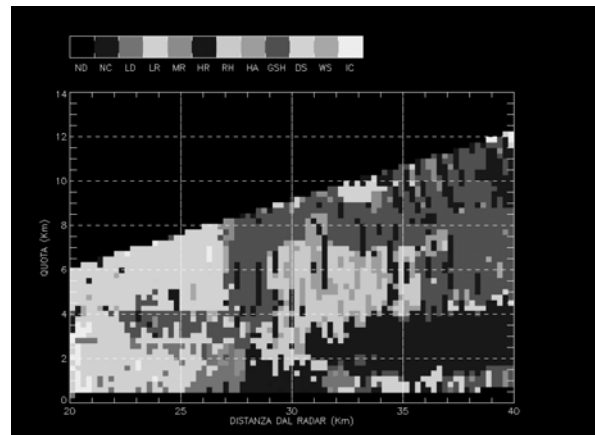


Figure 4 – Hydrometeor classification for the data in Fig. 1 and Fig. 2. ($S=0.5$, $W_t=0.8$)

This transition is very sharp and its effect does not increase even when the temperature weight decreases to very low values ($W_t=0.4$ or lower). If the weight value gets too low the algorithm loses its thermal characterization with obvious negative impact

on the classification itself. We will refer to this behavior as Thermal effect (TE).

These sensitivities and behaviors of the classification algorithm do not depend on the specific image under consideration: similar images for the same couples of S and W_t were reproduced for convective and stratiform events. This suggests that these observed characteristics are intrinsic properties of the scheme.

4. ANALYSIS OF THE TRANSITION TO SI TYPE

From an analysis of the images produced using a variety of couples of the “driving parameters” it is clear that the transition between a reasonable classification and a classification with the SI characteristics takes place over a well defined sharp boundary. Examples of such a boundary are the couples in Table 1.

	S	W_t
Reasonable	0.48	0.92
SI	0.48	0.93
Reasonable	0.46	0.85
SI	0.46	0.86

Table 1 – Results of the classification scheme with different values of the driving parameters.

A close look to the algorithm reveals that the temperature shape functions are such that for each temperature there is at least one hydrometeor type that could exist in such environment.

As a direct consequence of this constraint there is always some hydrometeor type that gains the maximum score from the thermal component of the algorithm. If in such cases the acceptance threshold, which is the combination between the thermal and the polarimetric components of the algorithm, is lower than the thermal one, we will accept as classified some pixels without any polarimetric agreement. This means that, for examples, if $W_t = 1$ then we should have $S > 0.5$.

Such behavior could be deduced from the mathematical expression of the algorithm. In this configuration the acceptance threshold could be simplified as:

$$S > \frac{k_2 \cdot W_t}{1 + W_t}$$

where K_2 is the value of the temperature shape function.

In the range of valid temperature [-40, +40] °C we can invert this equation to extract a function that describes the variation of the critical temperature weight as a function of the selected acceptance threshold:

$$W_c = \frac{S}{1 - S}$$

This function is displayed in Fig. 5.

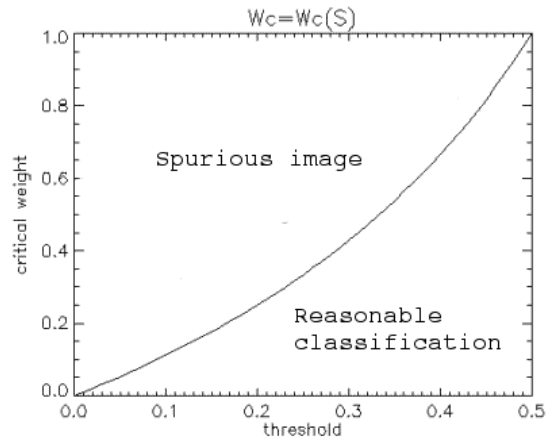


Figure 5 – Boundary of the transition between the SI configuration (upper part of the diagram) and a reasonable classification. The curved boundary represents the variation of the critical temperature weight as a function of the acceptance threshold.

5. ANALYSIS OF THE TRANSITION TO TE TYPE

From the analysis of the images examined so far it can be stated that the TE configuration is always present if the acceptance threshold is below 0.5 regardless of the thermal weight and disappears if we choose a couple like $S=0.51$ and $W_t=1.0$.

We need to understand the basic rules of such behavior and further to analyze the TE transition for values of acceptance threshold above 0.5.

For this reason we focused our attention on a convection case using different couples of parameters. As for the SI transition the TE transition happens across a very sharp boundary. Some examples of such transition are displayed in Fig. 6 and Fig 7.

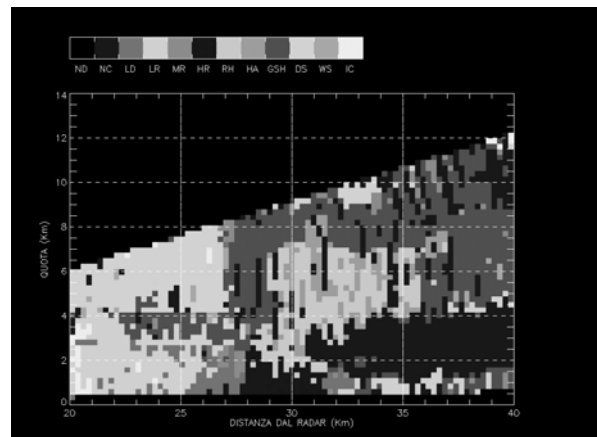


Figure 6 – Hydrometeor classification for the data in Fig. 1 and Fig. 2. ($S=0.55$, $W_t=0.81$).

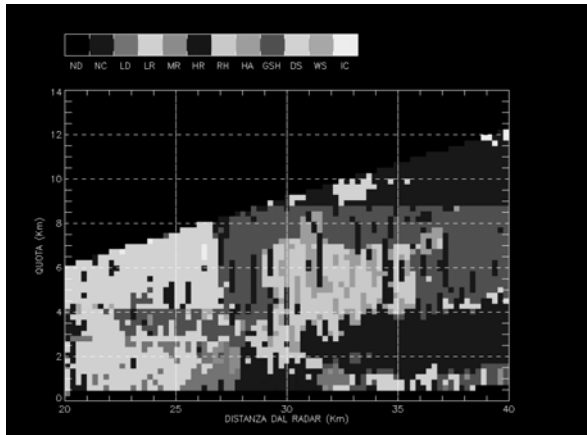


Figure 7 – Hydrometeor classification for the data in Fig. 1 and Fig. 2. ($S=0.55$, $Wt=0.82$)

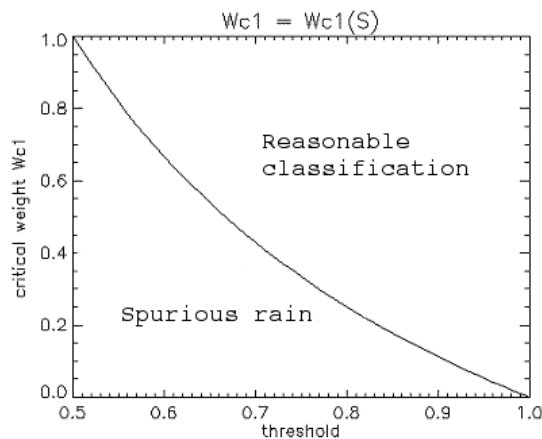


Figure 8 – Boundary of the transition between the TE configuration (lower part of the diagram) and a reasonable classification. The line represents the variation of the critical temperature weight as a function of the acceptance threshold.

In a broad sense the TE configuration is the analog of the SI configuration. In such case some hydrometeors are classified only on the base of the polarimetric component without any contribution from the thermal component. As for the SI case we have to draw upon the mathematical formulation of the algorithm and impose the acceptance threshold be greater than the single polarimetric component. The equation is thus:

$$S > \frac{k_1}{1 + Wt}$$

where K_1 is the value of the polarimetric shape function.

If we invert the equation, we obtain the variation of the critical weight as a function of the acceptance threshold for the TE transition (Fig. 8).

6. CONCLUSION

The classification scheme has proved to be robust enough to be used with a reduced set of polarimetric variables provided a careful choice of the parameters is done.

In this configuration a reasonable classification will be obtained. As a counter effect the number of unclassified pixels will increase. It is clear that the correct choice of parameters depends on the type of application and is in the hand of the analyst.

Any sensitivity to the parameters could be avoided by combining the terms with products of them that automatically guarantee the simultaneous contribution of all the terms to the overall acceptance value. This approach, however, has been less investigated in the literature and operational implementations in the US make use of sums rather than products.

7. ACKNOWLEDGEMENTS

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