Hydrometeor classification using polarimetric radars: intercomparison and hail detection

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1. Introduction

The ability to perform hydrometeor classification (HC) at high space-time resolution (5 minutes – 1 km²) in precipitating systems is one of the main benefits brought by polarimetry. Polarimetric radar measurements of precipitation vary with hydrometeor properties such as shape, size, orientation, phase state and fall speed (Straka et al., 2000).

A new fuzzy logic hydrometeor classification scheme is proposed (Al-Sakka et al., 2011). The algorithm is simpler, more realistic (with respect to actual radar measurements, biases and errors), and more efficient compared to previous approaches, with fewer parameters and without weights. It takes into account the measurement conditions by broadening the membership functions (MBF) when the measurement conditions deteriorate, and it employs a 3D temperature field provided by the French operational high-resolution non-hydrostatic NWP model (AROME).

Currently, the network of radars at Météo France includes 24 radars. Eleven of them are polarimetric, with ten at C-band and one at S-band. In addition, a network of four X-band polarimetric radars will be deployed (2008 - 2013) in the maritime Alps mountainous region during the RHYTMME (Risques Hydrométéorologiques en Territoires de Montagnes et Méditerranéennes) project.

Common volumes observed by different radars can be located at the same altitude but different distance. The hydrometeor classification algorithm is overviewed in Section 2, comparative analysis is discussed in Section 3, the detection of hail, the corresponding membership functions, and an original method of validation of hail measurements are detailed in Section 4. Conclusion and future work are drawn in Section 5.

2. Overview of the hydrometeor classification algorithm

The HC algorithm used in this paper is a fuzzy logic approach similar to Bringi and Chandrasekar (2001) and Zrnic et al. (2001). The input data vectors are reflectivity ($Z_H$), differential reflectivity ($Z_{DR}$), specific differential phase ($K_{DP}$), co-polar correlation coefficient ($\rho_{HV}$), bright band location and temperature. The output data is the dominant precipitation type for each pixel.

The algorithm can be summarized as follows: for each polar pixel, the actual measurement conditions (distance, signal to noise ratio (SNR), signal to clutter ratio (SCR) …) are taken into account to generate modified bivariate MBFs. The resulting values for ($Z_H$, $Z_{DR}$), ($Z_H$, $K_{DP}$) and ($Z_H$, $\rho_{HV}$) are calculated and added for each hydrometeor. The result is multiplied by three 1D MBFs: a $Z_H$-dependent MBF, a temperature-dependent MBF, and a BB dependent MBF. The hydrometeor with the highest score is considered the dominant one. Equation 1 summarizes the calculation of the probability:

$$P_{T} = F_j(Z_H) F_j(T) F_{BB}(BB) [F^{+}(Z_H, Z_{DR}) + F^{+}(Z_H, K_{DP}) + F^{+}(Z_H, \rho_{HV})]$$

Figure 1 represents the result of the hydrometeor classification algorithm for the Nîmes radar (June/04/2011, 1.2° of elevation at 11:15 TU). The transition between liquid and solid precipitation is clearly shown, with yellow representing wet snow. An important cell hail (red color) is detected in Cavaillon (east of Nîmes, 43km), Section 4 detailed this case.

3. Comparison between polarimetric parameters and HC results

3.1 Method of detection of the common areas.

Due to the dense network of Météo France, especially in the south of France, many common volumes are observed by two radars.

For example common volumes from Nîmes (S-Band, 80m antenna altitude, 1.2° tilt) and Montclar (C-Band, 670m, 1°) are illustrated in Figure 1. The distance between these two radars is 153 km. The altitude of the common volume varies from 1800m to 2200m. The method of detection of the common area is manual using expressions for the distance and angles that take into account the curvature of the earth.
Different problems can occur and should be taken into account during the detection of common areas:

1) The partial beam blocking in the common areas.
2) The attenuation and the distance from radar especially for X-band.
3) The presence of the bright band in the common volume. The use of 3D temperature model as described in Al-Sakka et al. (2011) can resolve this problem because the bright band for both radars should occur at the same altitude (due to the use of the same data base).

We try to take a thin interval of altitude in the case where the altitude is close to the bright band. Unfortunately, taking into account the distance from radars, not all the altitude in the scanned volume can be reached.

Figures 2 to 4 show eight curves representative of comparison between a pair of radars. From the top, the first two panels show the percentage of each hydrometeor type (R: rain; WS: wet snow; DS: dry snow; H: hail; I: ice) in the common volume for each radar respectively. The third curve show the average of $Z_H$ (dBZ), then $Z_{DR}$ (dB), $K_{DP}$ (°/km), $\rho_{HV}$, the differential phase $\Phi_{DP}$ (°) and finally the rainfall rate above the radar (to study the effect of wet radome in the measurements).

Polarimetric data used for comparison has been pre-analyzed following these processing steps as described in Figueras et al. (2012): 1) Calibration of $Z_{DR}$, 2) Detection of non meteorological echo (pre-classification of each polar pixel in either clear air, ground clutter or precipitation type using a fuzzy logic scheme, Gourley et al. (2007)), 3) Identification of the bright band, 4) Calculation and correction of system $\Phi_{DP}$, 5) Estimation of $K_{DP}$ (using 25 precipitation range gates linear regression over the filtered $\Phi_{DP}$ curve), 6) Correction of attenuation using a simple linear $\text{PIA} = f(\Phi_{DP})$ relationship.

3.2 Comparison between two C-band radars: Toulouse (C-Band, 160m, 0.8°) and Montclar (C-Band, 670m, 0.4°)

The distance between radars is 109Km, different areas are selected (by choosing different altitude intervals). In Figure 2, an interval between 1000m and 1400m is chosen during June 10, 2010. Since the bright band is above the common area, the classification of rain can be validated by comparing the two first representations.

A good agreement between both radars is evident throughout the day. After 12:00, a percentage of hail classification appears, but not the same in both radars; this difference may be due to the difficulty of localizing the common volume. A similar difference is detected around 20:00 when the radar of Toulouse detects wet snow, but the Montclar radar does not.

A good correlation exist between $Z_H$, $Z_{DR}$, $K_{DP}$ and $\rho_{HV}$, but the detection of hail for Montclar increases the average of $Z_H$ and at the same time decreases $Z_{DR}$ and $K_{DP}$ but always follows the same variation. The curve of $\Phi_{DP}$ gives information about the path between radar and the common area, i.e. the presence of a precipitation cell.

Here the wet radome did not affect the results. The non continuity of the curve is due to the measurement being canceled when the number of pixels is less than 50 in the common area.
3.3 Comparison between the S-band and C-band radars Nîmes (S-Band, 80m, 1.2°) and Montclar (C-Band, 670m, 1°)

The distance between radars is 153Km. In Figure 3, an interval between 1740m and 2200m is chosen on June 04, 2011. This interval is in the bright band for this date. Some difference can clearly be shown between the first and the second representations even though the polarimetric parameters are correlated. This may be due to the difference in the MBF between S and C-band and to the difficulty of the HC in the bright band. However in general, a good coherence in measurements is shown.

Hail is detected by both radars between 9:00 and 11:00 which also increase $Z_H$ and decreases $Z_{DR}$ and $K_{DP}$. $K_{DP}$ for C-band is on average greater than S-band (theoretically, a factor of two between the two $K_{DP}$); this difference can be observed in the 5th curve. The values of $\rho_{HV}$ are around 0.94 in average during the day due to the presence of wet snow (and also $\rho_{HV}$ in the bright band is around this value). $\rho_{HV}$ values can validate the detection of the bright band especially in the case of two radars with different bands showing close results.

3.4 Comparison between the S-band and X-band radars Nîmes (S-Band, 80m, 1.2°) and Maurel (X-band, 1770m, 1.5°)

The distance between radars is 164Km. In Figure 4, an interval between 3000m and 3420m is chosen on November 04, 2011. Here the interval is above the bright band and as a consequence, only solid precipitation type is shown. What should be seen is the coherence between the variation of $Z_H$ and the variation of the percentage of dry snow or ice type where the $Z_H$ alone can make the difference.

A great and similar percentage of hail around 23:00 is seen by both radars. $K_{DP}$ in average is greater in X-band as expected.

Here the effect of wet radome can be shown; around 12:00, the radome of both radars is wet (R = 8 mm/h), by looking to $Z_H$ curve at this time, a difference of 5 dBZ is shown between the two curves. The signal of Maurel radar is attenuated and there is no effect for Nîmes radar. More details of the effects of wet radome are in Frasier et al. (2012).
Fig 3: A comparison between Nîmes and Montclar radars, June 04, 2011.

Fig 4: A comparison between Nîmes and Maurel radars, November 04, 2011.
4. Hail detection: Membership function and validation method

4.1 Membership function and hail detection

During the day of June 06, 2011, a severe hail storm hit the city of Cavaillon after 11:00 causing widespread damage. The size of hail for this episode varies from 1.5 to 5 cm as can be shown in Figure 5. Figure 1 shows the position of Cavaillon city bordered by a white rectangle; the HC algorithm classifies the majority of pixels as hail type.

**Fig 5: Hail in Cavaillon, south east of France, June 04, 2011.**

To study the values of polarimetric variables, Figure 6 represents the scatterplots of $Z_{DR}$, $K_{DP}$ and $\rho_{HV}$ in function of $Z_{HI}$ for pixels that the HC algorithm has classified as hail. $Z_{DR}$ values can be large when $Z_{HI}$ is less than 60 dBZ, then values decrease to be less than 2 dBZ (the majority of points). In the first interval ($Z_{HI}$<60 dBZ), these values are found of hail sizes of 2.5 and 4.4 cm. In the second interval, larger hail is dominant.

For $K_{DP}$ and $\rho_{HV}$, two distributions can be observed, a wide distribution when $Z_{HI}$<60 dBZ, and for large hail $K_{DP}$ and $\rho_{HV}$ tend to decrease.

To understand the wide values in the first interval ($Z_{HI}$<60 dBZ), large hail is overwhelmed by the presence of small hail and a significant probability of the presence of melting hailstones or even large raindrops. This nonhomogeneity of the size of drops can explain the wide values of $Z_{DR}$, $K_{DP}$ and $\rho_{HV}$. More details about hail study are described in Picca et al. (2012).

**Fig 5: the values of $Z_{DR}$, $K_{DP}$ and $\rho_{HV}$ in function of $Z_{HI}$ for pixels that the HC algorithm has classified as hail. Nîmes rada, June 04, 2011.**

We should mention here that the study of scatter plot is important to reduce the false alarm, i.e. when the HC algorithm classifies pixels as hail and when in truth they are not. These scatterplots can help to improve the MBF of hail and large rain.
4.2 Method of validation of hail detection

Different hail validation methods exist in order to identify dates, time, hail size, and the damage. For example, a hail pad network is used in areas that statistically have more probability of hail and that are close to radars. These methods require human and financial resources. Elsewhere, use of online sites that collect information from witnesses is possible.

An easier (and free) method for validation is to use the popular online search engines to find dates and localize areas, and then use video sharing sites, where one can see the events, specify the size and know the exact time of falling. The most important point of this method the detection of differentiation between hail and large drops, because if there are large values of \( Z_H \) especially above the main cities and there are not any journal reports or videos found in research engines for the same date, one can say there is no hail. Using this method, we collect different dates and episodes as shown in Table 1.

<table>
<thead>
<tr>
<th>City</th>
<th>Date</th>
<th>Time (LT)</th>
<th>Size</th>
<th>Radar 1</th>
<th>Radar 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavaillon (84)</td>
<td>04 June 2011</td>
<td>13h-14h</td>
<td>1.5–5 cm</td>
<td>Nimes</td>
<td>Montclar</td>
</tr>
<tr>
<td>Limours (91)</td>
<td>05 May 2012</td>
<td>18h-19h</td>
<td>1–2 cm</td>
<td>Trappes</td>
<td>Montclar</td>
</tr>
<tr>
<td>Martiel (12)</td>
<td>29 April 2012</td>
<td>15h-16h</td>
<td>1–2 cm</td>
<td>Toulouse</td>
<td>Trappes</td>
</tr>
<tr>
<td>Dreux (28)</td>
<td>05 May 2012</td>
<td>17h</td>
<td>1–2 cm</td>
<td>Trappes</td>
<td>Montclar</td>
</tr>
<tr>
<td>Castelnau - Rivière – Basse (65)</td>
<td>29 April 2012</td>
<td>18h</td>
<td>1.5 cm</td>
<td>Momuy</td>
<td>Toulouse</td>
</tr>
<tr>
<td>Baume-les-Dames (25)</td>
<td>20 mai 2012</td>
<td>13h</td>
<td>5–6 cm</td>
<td>Montancy</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Different dates and episodes of hail in France.

5. Conclusion

This paper has present an intercomparative study between the polarimetric variables and classification of hydrometeor types seen by pairs of Météo France radars in the south of France.

Such a comparison can provide important information about the state of radars and the algorithms of treatment and analysis. More advanced research should be done for the localization of a common volume (like a common RHI volume). The results presented here show a good correlation between radars even with different bands.

For the study of hail, membership functions should be revisited to better distinguish between large rain and hail. Even with perfect MBF, large common interval between MBF remains which show the limit of discrimination of polarimetric variables!

The method of validation hail measurements is planned to study in Météo France to extend the hail type to three types: small hail (diameter < 5 mm), medium hail (diameter between 5 – 20 mm) and large hail (diameter > 20 mm). This study should enrich our algorithm and, with real time production, enhance the prevention of the risks due to medium and large hail.

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References


