P11.150 **QUANTITATIVE PRECIPITATION ESTIMATION (QPE) IN THE FRENCH ALPS WITH A DENSE NETWORK OF POLARIMETRIC X-BAND RADARS**

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1. INTRODUCTION

The French Southern Alps is a region characterised by heavy rain and flash flood events. However, in such complex terrain the weather radar measurement error is increased significantly because of partial beam blockage, measurements made in the bright band or in snow, etc. Météo France, together with several other partners, is involved in a project called RHYTMME (Risques Hydro-météorologiques en Territoires de Montagnes et Méditerranéens) to establish a platform service for a better management of hydrometeorological hazards in this region.

The RHYTMME Project aims to deploy a dense network deployment of 4 polarimetric X-band radars over the period 2010 – 2013. The project also provides high-quality networked products (including QPE mosaics), that are integrated into automatic hydrometeorological warning systems. At present, two X-band radars are installed (in Mont Vial and Mont Maurel) and the radar production platform is running since June 2011. The raw data is concentrated in real-time in Toulouse and available for either real-time or off-line processing.

This paper presents the current status of the processing chain and discusses the preliminary results of the evaluation of various QPE algorithms. It is structured as follows: Section 2 provides an overview of the current RHYTMME radar data Processing chain, Section 3 discusses the adaptation of a polarimetric processing chain to X-band, Section 4 describes the QPE processing chain used in the evaluation, Section 5 summarizes the different QPE algorithms tested and section 6 analyses the preliminary results obtained. Finally, conclusions are discussed in section 7.

2. THE RHYTMME RADAR DATA PROCESSING CHAIN

Fig. 1 shows the flow diagram of the RHYTMME radar data processing chain. The polarimetric variables collected by the radars are horizontal reflectivity (Z_H), differential reflectivity (Z_{DR}), co-polar correlation coefficient (ρ_{HV}), and differential phase shift (Φ_{DP}) in polar coordinates. The radial range resolution is 300 m for Mont Vial and 240 m for Mont Maurel, while the azimuthal resolution is 0.5° for both radars. Mont Maurel also provides the standard deviation of the reflectivity from pulse to pulse (σ_Z) at 1 km^2 resolution. In addition, both radars provide mean Doppler velocity (v_D) and Doppler spectral width (σ_V). All this data is stored in a server and is available for off-line processing.

Since the radars in the network are heterogeneous, the first step in the processing is, if necessary, a pre-treatment of the data to make it in a uniform format so that it can be ingested into a polarimetric processing chain. The second step is the processing of the raw X-band polarimetric variables, which has been adapted from an in-house developed S- and C-band radar processing chain. The next step is to combine the processed polarimetric information available on PPIs to generate the best surface estimation of the 1 km², 5' rainfall accumulation using several polarimetric rain rate estimation algorithms.

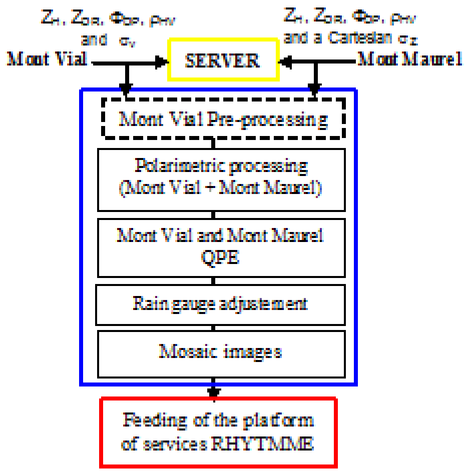

Fig. 1 The flow diagram of the RHYTMME radar data processing chain.

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3. THE POLARIMETRIC PROCESSING CHAIN

The modules of this processing chain are described in detail by Boumahmoud et al. (2010). Fig. 2 shows the flow diagram of the chain. The inputs of the dual-polarization chain are the polarimetric fields of Z_H, Z_{DR}, Φ_{DP}, ρ_{HV} in polar coordinates and a Cartesian field of σ_Z. It performs successively the following operations: calibration of Z_H and Z_{DR}, partial beam blockage correction using static propagation maps, non meteorological echo identification, ρ_{HV}-based bright band identification, Φ_{DP} offset removal and filtering, K_{DP} estimation, attenuation correction, hydrometeor classification and the computation of daily monitoring indicators (Bias curves for Z_H and Z_{DR}, offset curves for Φ_{DP}, average ρ_{HV} in rain, etc.)

Since the echo type classification and the attenuation correction are strongly dependent upon the radar frequency, these modules have been adapted to the X-band.

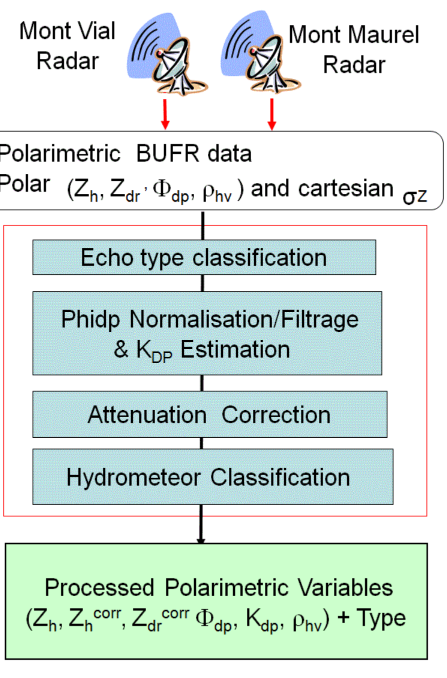


Fig.2 Flow diagram of the Dual polar chain

The echo type classification is performed in two steps: a pre-classification in ground clutter, clear air and precipitation and the classification of different types of precipitation.

Gourley et al. (2007) developed the pre-classification algorithms at C-band implemented in the polarimetric chain. The scheme is based on a fuzzy logic algorithm with the particularity that the membership functions are obtained by empirical observations and objectively weighted according to the level of trust of each dataset for a particular radar site. It was observed that three parameters were the best discriminators between the different categories, ρ_{HV}, the texture of Z_{DR} and σ_Z.

The first step in the adaptation of the algorithm to X-band has been therefore to empirically obtain the membership functions for these 3 parameters. Since Mont Vial does not provide the Cartesian field of σ_Z, we decided to test other discriminating parameters and the texture of Φ_{DP} and the texture of Z_H gave satisfactory results. The correct identification of ground clutter is very important in polarimetric radars. Misidentified clutter echoes can lead to aberrant values of the precipitation field for an entire ray due to the resultant wrong attenuation correction. On the other hand, the identification of precipitation as clutter leads to gaps in the rain field, which is a serious issue in areas that already suffer heavily from clutter.

The hydrometeor classification is also performed using fuzzy logic. If the use of fuzzy logic precipitation classification at S and C band can be considered relatively mature the same cannot be said at X band due to the relatively recent interest of the community for such frequency band. Meteo France is currently developing and evaluating the performance of an new algorithm (Al-sakka et al. 2011).

The attenuation correction, at this stage, is performed using a simple static empirical linear relationship between the path-integrated attenuation (and differential attenuation) and ΦDP. Both the specific attenuation and the specific differential attenuation are considered proportional to Φ_{DP} with a constant of proportionality (γ_H for the specific attenuation and γ_{DP} for the specific differential attenuation respectively) that is frequency dependent (Ryzhkov & Zrnic 1995). The value of γ_H was experimentally estimated using the Mont Vial radar data from scatter plots of measured Z_H versus Φ_{DP} to be 0.28. The value of γ_{DP} was deduced from ratios of γ_H/γ_{DP} appeared in literature (Bringi & Chandrasekar, 2001) and Snyder et al. (2010). We chose $\gamma_{DP} = 0.04$.

The polarimetric chain outputs are Z_{DR} and Z_H (with and without attenuation correction), ρ_{HV}, offset corrected and filtered (using a running median filter of about 6 km) Φ_{DP}, estimated K_{DP}, texture of Z_{DR}, the estimated path-integrated attenuation and differential attenuation, σ_Z and the echo type classification in polar coordinates. The corrected Z_H, the echo type and the Path Integrated Attenuation (PIA) are also provided, in Cartesian coordinates.

4. THE QPE PROCESSING CHAIN

A polarimetric QPE processing chain, designed for evaluation purposes, that obtains hourly precipitation accumulation estimation from single tilts has been implemented (Figueras et al., 2011). Its flow diagram is shown in Fig. 3.

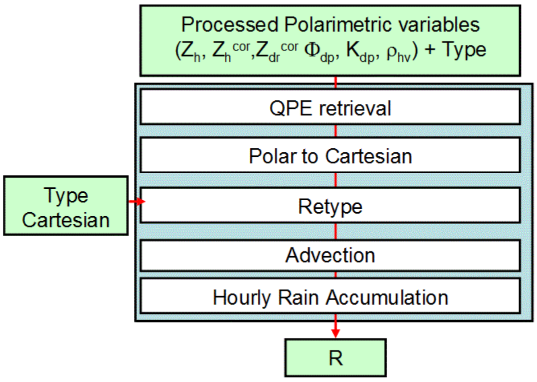


Fig.3 Flow diagram of the QPE processing

The inputs of the algorithm evaluation are the outputs of the polarimetric pre-processing chain. The first step is to estimate the instantaneous rainfall rate in areas classified as precipitation using one of the implemented algorithms (see section 5). The outputs of the algorithm are then transformed from polar to Cartesian coordinates using the Cressman Analysis. At this point the data is re-evaluated according to the echo type. Pixels classified as noise, single polarization (low SNR), sea clutter and clear air are re-assigned from missing value to 0 mm/h rainfall rate. To compensate for the advection between measurements a temporal interpolation is performed using an advection field calculated a priori from the evolution of the previous reflectivity measurements. The interpolated rainfall rate field is added and thus the 5 minute precipitation accumulation is obtained. It follows the addition of the 12 5 minute precipitation accumulation fields to obtained the hourly rainfall accumulation. The hourly rainfall accumulation can then be compared with the hourly rainfall accumulation obtained by the high density network of rain gauges operated by Météo France.

This comparison is done on a collocated pixel basis and the maximum distance from the radar system evaluated is 60 km. Only one elevation angle is used in the evaluation. The quality of the algorithms is evaluated based on the normalized bias between the rain gauge and the radar retrieved rainfall accumulation (NB) defined as:

$$NB = \frac{\langle R \rangle}{\langle G \rangle} - 1$$

and the correlation (corr):

$$corr = \frac{\sum_{\forall i} \left(G_i - \langle G \rangle\right)\left(R_i - \langle R \rangle\right)}{\sqrt{\sum_{\forall i} \left(G_i - \langle G \rangle\right)^2} \sqrt{\sum_{\forall i} \left(R_i - \langle R \rangle\right)^2}}$$

5. TESTED POLARIMETRIC QPE ALGORITHMS

At this stage 2 families of algorithms have been implemented: 1) simple Z-R relations with and without attenuation correction based on Φ_{dp}, 2) algorithms based on the relation between rainfall rate (R) and K_{DP}. In addition, a synthetic algorithm has been implemented combining R-K_{DP} and Z-R relations <u>with attenuation correction</u>. It is based on a threshold on K_{DP} (0.5º/km, approximately 10 mm/h). Below the threshold level Z-R relations are used and above it R-K_{DP} relations are used instead.

To summarize, we have tested 8 algorithms:

- Two different Z-R relations with and without attenuation correction (Marshall-Palmer and the relation used by the American WSR-88D radars, i.e. 200 $R^{1.6}$ and $300R^{1.4}$)

- Two R-K_{DP} relations of the form $R=a(K_{DP}/f)^b$ (From Bringi and Chandrasekar 2001): One for the Beard-Chuang equilibrium shape model (a=129, b=0.85) (Beard and Chuang, 1987) and another corresponding to the Brandes equilibrium shape model (a=132, b=0.791) Brandes et al. (2002), with f=9.375 GHz.

- Four synthetic algorithms Z-K_{DP} :

- Z-K_{DP1} : Marshall-Palmer (Att. corr.MP) and Beard et Chuang.

- Z-K_{DP2} : Marshall-Palmer (Att. corr. MP) and Brandes et al.

- Z-K_{DP3} : Fulton et al. (Att. corr WSR-88D) and Beard et Chuang.

- Z-K_{DP4} : Fulton et al. (Att. corr. WSR-88D) and Brandes et al.

6. PRELIMINARY RESULTS

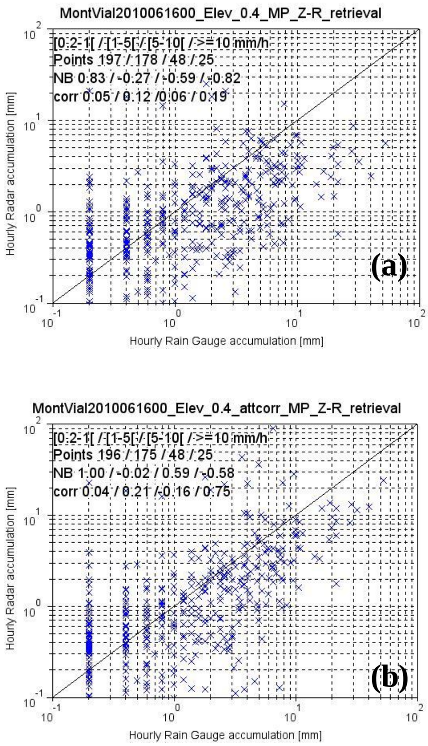
Presented here are preliminary results obtained from an event occurred the 16th June 2010 in Mont Vial. All the results are stratified according to 4 ranges on the rain gauge hourly accumulations: [0.2, 1[, [1, 5[, [5, 10[and >10 mm/h. Notice that for small intervals the correlation does not provide meaningful results.

Figures 4 and 5 summarizes the results obtained by Marshall-Palmer and the relation used by the American WSR-88D radars (without attenuation correction, with attenuation correction and with attenuation correction and partial beam blockage correction). It can be observed that:

- Without attenuation correction, Marshall-Palmer scores are equivalent to the WSR-88D scores.
- The attenuation correction significantly improves the correlation between rain gauge and radar retrieved measurements, particularly at higher precipitation rates. There is also an improvement of the bias.
- The benefit of the partial beam blockage correction is self evident, since there is a remarkable improvement of both the correlation and the bias.

Figure 6 summarizes the results obtained by R-K_{DP} relation (Beard and Chuang) and synthetic algorithms Z-K_{DP1} and Z-K_{DP3} while Figure 7 summarizes the results obtained by R-K_{DP} relation (Brandes et al.) and synthetic algorithms Z-K_{DP2} and Z-K_{DP4}. They show that:

- In general terms the R-K_{DP} algorithms show an improved correlation with respect to the other tested algorithms, particularly at higher precipitation rates (above 10 mm/h).
- The evaluation of the results of a synthetic Z-K_{DP} algorithm shows that the combination of Attenuation corrected Marshall-Palmer and Brandes et al. are the best both in terms of correlation and bias.



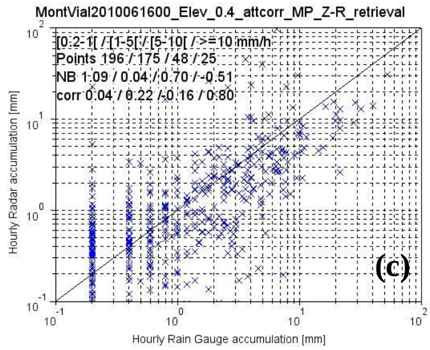


Fig.4 QPE results : (a) MP,(b) Att. corr. MP and (c) Att. corr. MP with PBB correction

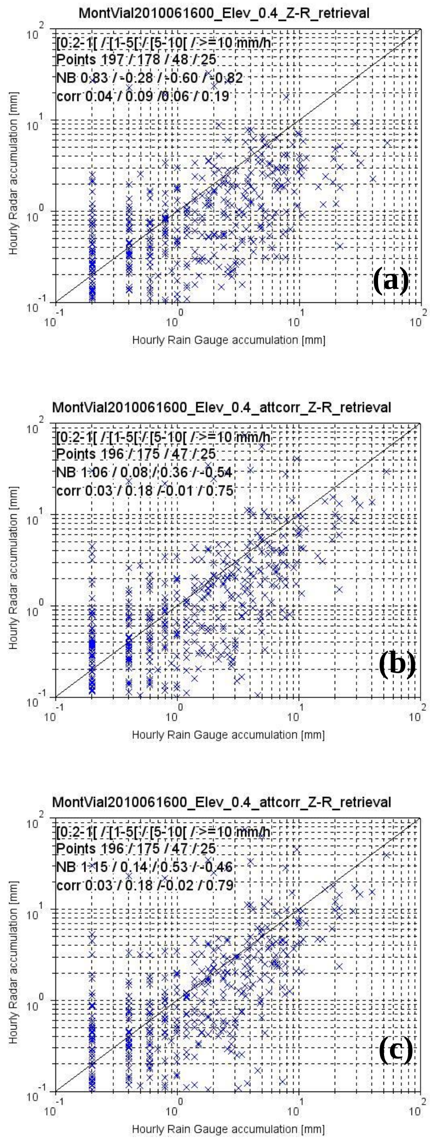


Fig.5 QPE results : (a) WSR-88D, (b) Att. corr. WSR-88D and (c) Att. corr. WSR-88D with PBB correction

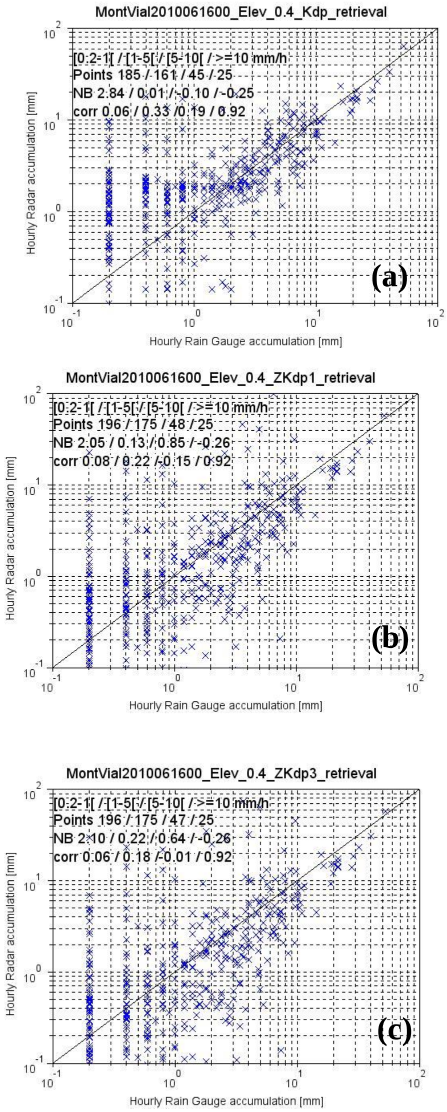
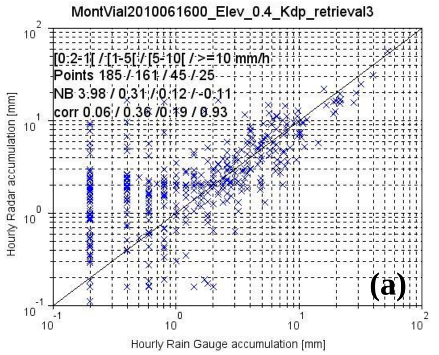


Fig.6 QPE results : (a) Beard and Chuang relation , (b) synthetic algorithm Z-K_{DP1} and (c) Z-K_{DP3}



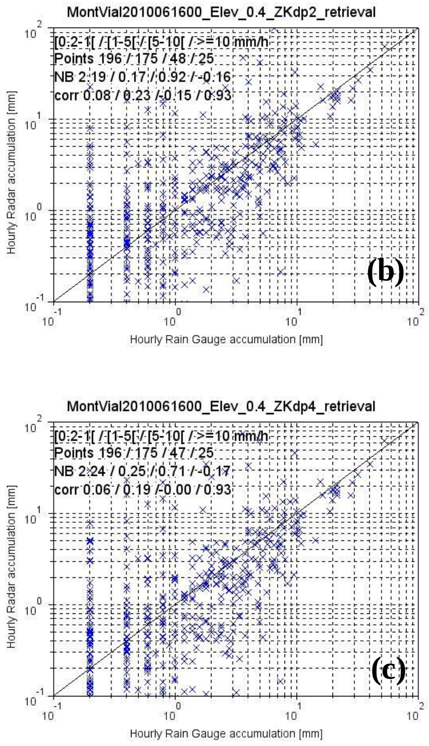


Fig.7 QPE results : (a) Brandes et al. relation , (b) synthetic algorithm Z-K_{DP2} and (c) Z-K_{DP4}

7. Conclusion

This paper has presented the current status of development of a polarimetric radar network data processing chain to provide accurate QPE to decision makers in a flooding-prone mountainous region.

We as well summarize the results of several Pol-QPE algorithms that have been preliminary tested, which are based on simple Z-R relationships and on K_{DP}. K_{DP} has shown to be a very good candidate because it is insensitive to calibration errors and partial beam blocking. A synthetic Z-K_{DP} algorithm, which combines R-K_{DP} relations for intense precipitation and Z-R relations corrected for attenuation in the weak rain, has been tested and the one which shows the best score is Z-K_{DP2} (combination of Attenuation corrected Marshall-Palmer and Brandes et al.).

The next step will be to enhance the evaluation including more events and testing other polarimetric precipitation estimation algorithms, such as the integrated ZZDR technique by Illingworth & Thompson (2005), the variational approach (Hogan, 2007) and ZPHI (Testud et al. 2000).

Once the optimal algorithm is determined, the implementation of intelligent compositing rules between X-band radars, allowing for a mitigation of attenuation effects and optimal exploitation of the network will be studied. Maps of minimum detectable signal will also be produced and used in the compositing rules in order to mitigate situations of severe attenuation/extinction leading to complete misses of precipitation detection by one particular radar.

Finally, the fact that, among the two already installed radars, one has a radome and the other one does not opens perspectives in the quantitative evaluation of wet radome attenuation on polarimetric measurements.

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